ARAB REPUBLIC OF EGYPT

MINISTRY OF ELECTRICITY AND RENEWABLE ENERGY

EGYPTIAN ELECTRICITY HOLDING COMPANY

EGYPTIAN ELECTRICITY TRANSMISSION COMPANY (EETC)

INTEGRATION OF WIND POWER IN THE EGYPTIAN POWER SYSTEM AND ESTABLISHMENT OF WIND INTEGRATION CODE – PHASE 1

Financed by African Development Bank (AfDB)

Project No: P-EG-FE0-004

Consultant: Grontmij A/S as Lead Consultant in association with Energinet.dk, SEAS-NVE, Ea Energy Analyses and Saleh & Hegab.

FINAL REPORT

June 2016

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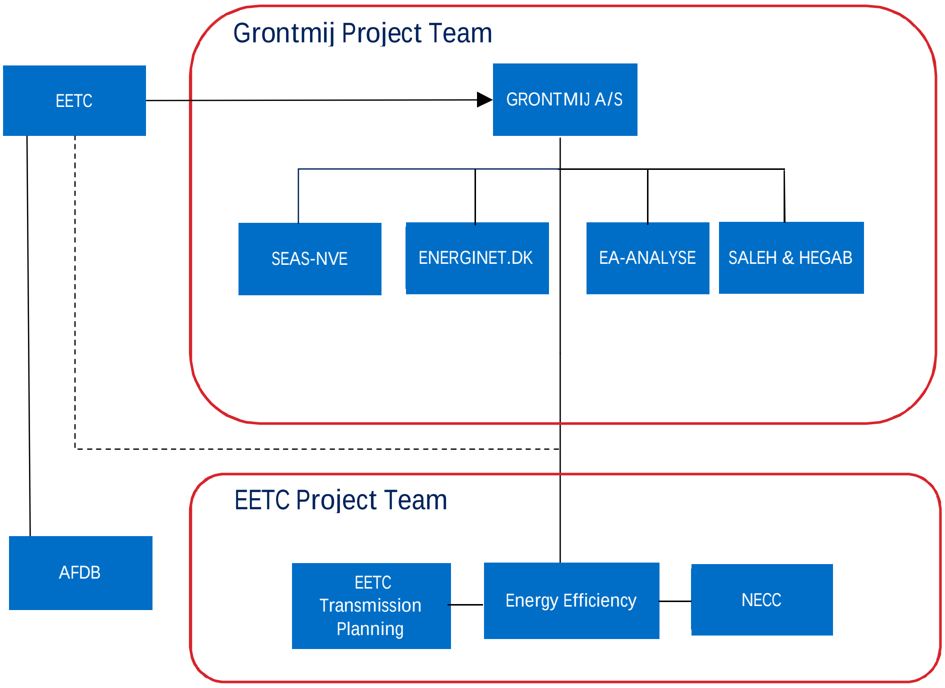
- Grontmij A/S is Europe's largest engineering consultancy company with 14.500 consultants. Grontmij A/S has high expertise with project development and owners engineering of large-scale wind power farms in Egypt and renewable energy project developments.
- Energinet.dk is the Danish National Transmission System Operator with 25 % wind power in their transmission grid system. Energinet.dk has specialist expertise in developing of national grid codes and control of the power system network with high level of wind penetration.
- SEAS-NVE is the Danish Regional Transmission System Operator with deep expertise in PSS/E modelling and power system analysis of integration of renewable energy.
- Ea Energy Analyses is a specialist Danish energy consultancy firm with deep expertise in energy modelling of the power system, dispatch strategies and economic energy analysis.
- Saleh & Hegab is an Egyptian engineering company with expertise in the local electrical engineering and local substation infrastructure projects.



The EETC Project Team consists of the EETC Transmission System Studies Department, the Energy Efficiency Department and the NECC Dispatch Centre.

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ACRONYMS AND ABBREVIATIONS

Acronym / abbreviation	Meaning
AfDB	African Development Bank
cap	Capacity
Ceq	Capacitance equivalent
DK	Denmark
EAPP	East African Power Pool
EEHC	Egyptian Electricity Holding Company
EETC	Egyptian Electricity Transmission Company
FLHs	Full load hours
GW	Giga Watt
Hz	Hertz
IEC	International Electrotechnical Commission
kV	Kilo volt
kW	Kilo watt
ms	mili seconds
MVA	Mega volt ampere
Mvar	Mega volt ampere reactive
MW	Mega watt
MWh	Mega watt hour
Nat.	Natural
OH	Overhead line
P	Active power
pu.	Per unit
Q	Reactive
R	Resistance
Req	Resistance equivalent
Sec	Seconds
TOR	Terms of reference
uF	Micro farad
VOW	Value of wind
WF	Wind farm
X	Reactance
Xeq	Reactance equivalent

0 Executive summary

The overall objective of the project was defined to study the grid impact of integrating 7200 MW wind power up to year 2030 into the Egyptian power system and to provide planning and operational recommendations for the successful integration of the wind power.

The study has been split into two phases due to grant limitation. Jointly with EETC it was decided to divide the project into a Phase 1 and Phase 2. This report concerns Phase 1, which specifically focuses on the wind power integration and solar PV power integration up to year 2018. Phase 1 focuses on integrating 3942 MW of wind power and 2000 MW of PV solar power into the Egyptian power system up to year 2018. The 3942 MW of wind power is located in the El-Zayt and Gulf of Suez Region of Egypt and the 2000 MW of PV solar power is located in the BenBan Region of Egypt.

This report is a system impact study based on 4 scenarios and international best practices for integration of large amount of renewable energy in the Egyptian Transmission System.
The study leads to:

- a detailed review of the existing PSS/E Data Files
- a detailed wind turbine and solar PV grid modelling
- a method for aggregating the wind power and solar PV for the Egyptian power system
- wind power and Solar PV integration simulation into the Egyptian power system and its implications on the Egyptian power system planning.
- an assessment of reinforcement of the transmission grid system
- a dynamic transient stability analysis

This system study is therefore a vital key contribution to Egypt's ambitious future wind power and solar PV plans and it formulates the technical requirements and recommendations to ensure the safety and stability of the power system and next step recommendations for Phase 2. This approach is also consistent with the Egyptian Government's strategy for diversification of energy supply, reducing dependence on fossil fuels, and increasing the use of clean renewable energies.

It is important to understand that a system study is carried out in order to analyse the whole transmission grid system in Egypt. Where a grid impact study will focus on the analysis performed by the developer of the wind farm/solar PV plant to verify the fulfilment of the EETC grid code.

A grid impact study will focus on analysing:

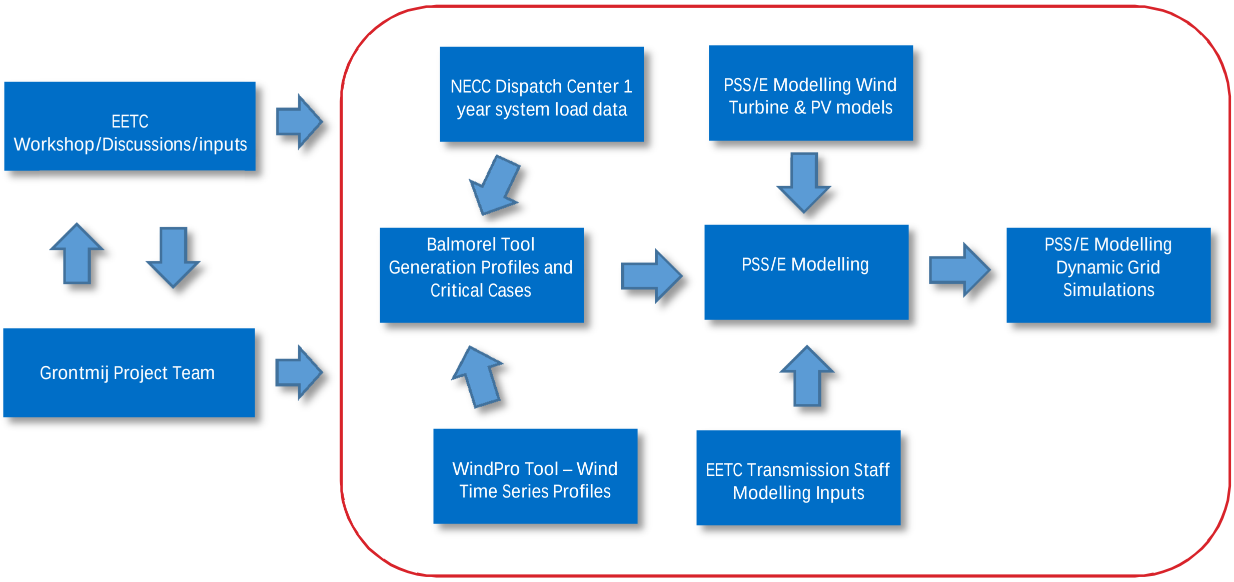
- The internal collection grid in relation to optimizing the medium voltage cabling, load flow data of the transformers/cables, voltage levels and, short-circuit calculations.
- Harmonic study to verify that the harmonics fulfil the requirements in the wind integration grid code
- Load flow study to verify the active power, reactive power, PQ capability according to the requirements in grid code.
- Dynamic study to verify the aggregated model of the wind farm/solar PV plant and verify the fault-ride through capabilities according to the requirements in the grid code.

Phase 2 will be defined from the outcomes and conclusions of Phase 1 and will focus on power system protection, operational requirements, control strategies, wind and solar PV forecasting systems and modification of the existing wind and solar PV power grid codes.

With Grontmij A/S support and participation, EETC has completed Phase 1 of this study and the results were released at a presentation workshop on 21st June 2016.

Methodology Approach

The key element to the methodology approach was to work hand-in-hand with EETC and furthermore to increase the EETC technical knowledge in wind power integration and grid modelling specifically for the Egyptian Power System.



The Key Assumptions of the Study

1. Existing PSS/E Data files for year 2015 and year 2018 received from EETC in October 2015.
2. Use of PSS/E software tool for both static and dynamic modelling and grid simulations.
3. Use of Balmorel tool for assessment of generation profiles and wind curtailment due to bird migration.
4. Integration of 3942 MW of wind power up to year 2018 in the regions of El-Zayt and Gulf of Suez.
5. Integration of 2000 MW of Solar PV up to year 2018 in the region of Benban.
6. 1 year system load data year 2014 from EETC Dispatch Centre.
7. Implementation of static and dynamic wind turbine models in the existing EETC PSS/E file for year 2015 and year 2018.
8. Implementation of static and dynamic PV solar models in the existing EETC PSS/E file for year 2015 and year 2018.
9. Aggregation of specific wind farm projects in PSS/E according to wind generation plan up to year 2018, based on Grontmij experience from NREA wind farm projects.
10. Calculated cable lengths for each wind farm in the aggregated models.
11. Aggregation of PV solar farm projects in PSS/E according to solar PV generation plan up to year 2018, based on international experience.
12. Wind speed time-series for the Gulf of Suez and in Zafarana generated through met masts in Egypt and through meso-scale models.
13. Generation patterns for year 2015 and year 2018 comprising of maximum demand/full wind generation and minimum demand/full wind generation.
14. Generation pattern for year 2015 and year 2018 comprising of maximum demand/no wind generation and minimum demand/no wind generation.
15. The generation patterns for year 2015 and year 2018 represents 4 scenarios.

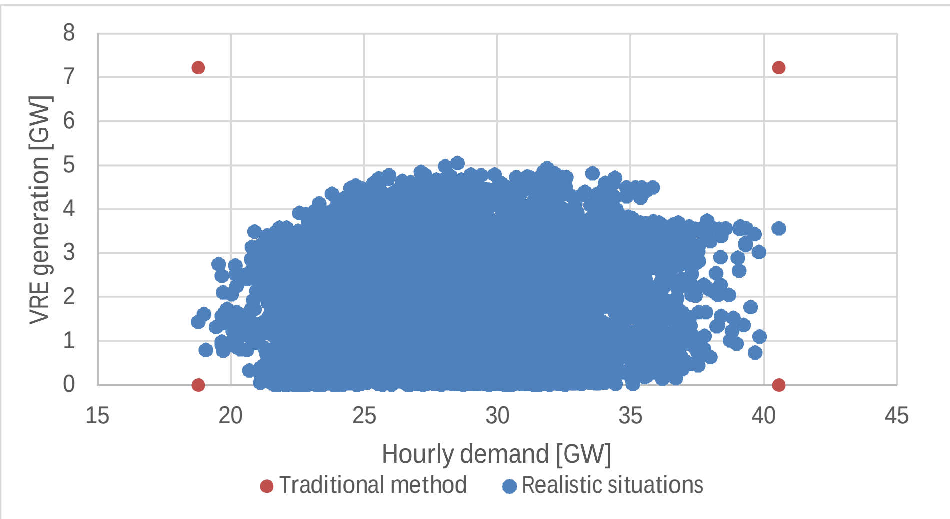
1. The generation patterns are used as input data for the PSS/E model study for detailed of grid stability analysis.
2. The dynamic transient stability simulations are conducted for the 4 scenarios with 9 defined cases for each scenario.

<u>The Key Focus for Balmorel Energy Modelling</u>

The Egyptian power system has been modelled using the Balmorel model. The model optimise the dispatch by minimising the total costs of supplying electricity. The procedure takes into account the marginal costs of the individual power plants (fuel price divided by efficiency) as well as start/stop costs and restrictions on the transport between zones. The electricity system is modelled as consisting of 7 zones: Cairo, North Upper Egypt, South Upper Egypt, West Delta, Middle Delta, Alexandria and Canal.

The Balmorel model has developed data table generation profiles for year 2015 and year 2018 with wind power and solar power, generated through the EETC hourly system load data for year 2014. The Balmorel generation data profiles for year 2015 and year 2018 represents “extreme situations” generated with max/min. demand with full wind generation meaning all wind farms are generating at full capacity, and no wind power generation, respectively, when all wind farms are shut down. The Balmorel model generation data is then used as input data for the dynamic PSS/E model study, for analysis the grid stability in extreme situations.

The extreme situations are defined in 4 scenarios. The red dots indicate the four max/min scenarios. The blue dots indicate all the hourly combinations of demand and variable renewable generation in 2018. This represents the selection criteria for the 4 scenarios.



<u>Generation patterns for the 4 scenarios:</u>

Scenario I: • Maximum demand • Maximum wind and solar generation	Scenario 2: • Minimum demand • Maximum wind and solar generation
Scenario 3: • Maximum demand • No wind or solar generation	Scenario 4: • Minimum demand • No wind or solar generation

The Key Focus for Load Flow Analysis Simulation:

- Identifying the existing bottlenecks that may affect the grid system in year 2015 PSS/E file with and without wind power according to defined scenarios mentioned below.
- Identifying the expected bottlenecks in the grid system in year 2018 PSS/E file with and without Solar PV and Wind Power according to defined scenarios mentioned below.
- Recommendations to overcome the identified bottlenecks and recommendations to reinforcement of the existing grid system year 2015 and future grid system year 2018.

Comparison table scenarios for analysis simulation:

Scenario 1	Scenario 2	Scenario 3	Scenario 4
Maximum Demand and Maximum PV Solar and Wind Power	Minimum Demand and Maximum PV Solar and Wind Power	Maximum Demand and No PV Solar and Wind Power	Minimum demand and No PV Solar and Wind Power
Identification of existing bottlenecks in year 2015 - PSS/E Simulations	Identification of existing bottlenecks in year 2015 - PSS/E Simulations	Identification of existing bottlenecks in year 2015 - PSS/E Simulations	Identification of existing bottlenecks in year 2015 - PSS/E Simulations
Identification of expected bottlenecks in year 2018 - PSS/E Simulations	Identification of expected bottlenecks in year 2018 - PSS/E Simulations	Identification of expected bottlenecks in year 2018 - PSS/E Simulations	Identification of expected bottlenecks in year 2018 - PSS/E Simulations
Recommendations to overcome bottlenecks - Reinforcement of grid system	Recommendations to overcome bottlenecks - Reinforcement of grid system	Recommendations to overcome bottlenecks - Reinforcement of grid system	Recommendations to overcome bottlenecks - Reinforcement of grid system

The Key Focus for Dynamic Transient Analysis Simulation:

For each scenario, 9 dynamic simulation analysis cases are investigated in a comparison table.

Scenario 1	Scenario 2	Scenario 3	Scenario 4
Maximum Demand and Maximum PV Solar and Wind Power	Minimum Demand and Maximum PV Solar and Wind Power	Maximum Demand and No PV Solar and Wind Power	Minimum demand and No PV Solar and Wind Power
9 Dynamic Transient Simulation Cases in PSS/E Simulations	9 Dynamic Transient Simulation Cases in PSS/E Simulations	9 Dynamic Transient Simulation Cases in PSS/E Simulations	9 Dynamic Transient Simulation Cases in PSS/E Simulations
Response and Behavior Graphs in PSS/E Simulations.	Response and Behavior Graphs in PSS/E Simulations.	Response and Behavior Graphs in PSS/E Simulations.	Response and Behavior Graphs in PSS/E Simulations.
Recommendations to Overcome Stability Issues	Recommendations to Overcome Stability Issues	Recommendations to Overcome Stability Issues	Recommendations to Overcome Stability Issues

The dynamic transient stability simulations are conducted for the 4 scenarios with the following 9 defined cases for each scenario.

Cases 1 – 5 are chosen in order to analyse the 500 kV circuit which has considerable power flow on the South and North transmission. The applied two faults are in accordance with the technical requirements from EETC. The 10 seconds are selected in order to have a stabilized period to see the next fault.

- Case 1- Tripping Kurimat500-Samalut500 circuit after 100ms fault after 10 second trip Cairo500- Samalut500 Circuit.
- Case 2- Tripping the first Assut500-Samalut500 circuit after 100ms fault then after 10 second trip the secondary circuit.
- Case 3- Tripping the first Assut500-N.Hamadi500 circuit after 100ms fault then after 10 second trip the secondary circuit.
- Case 4- Tripping the first N.Hamadi500-High Dam500 circuit after 100ms fault then after 10 second trip the secondary circuit.
- Case 5- Tripping Nobaria500-Cairo500 circuit after 100ms fault then after 10 second trip the secondary circuit.

Cases 6 – 7 are chosen in order to analyse the 220 KV circuit with considerable power flow from renewable energy. The applied two faults are in accordance with the technical requirements from EETC.

- Case 6 Year 2018 - Tripping line 4 Samalut-881 FIT circuit after 100ms fault

- Case 6 Year 2015 - Tripping Zafarana 220kV line –PETROLP220 circuit after 100 ms fault then after 10 second trip the secondary circuit.

- Case 7 Year 2018 - Tripping line 635 El Zayt-998 Zafarana 100ms fault. Both lines one at 1 sec one at 11 seconds
- Case 7 Year 2015 – Tripping 220 kV line Zafarana – RasGhareb after 100 ms fault then after 10 second trip the secondary circuit.

  Case 8 is chosen in order to analyse the 500 KV circuit with considerable power flow from renewable energy. The applied two faults are in accordance with the technical requirements from EETC.

- Case 8 Year 2018 - Tripping line 5420 Benban- Naghamadi 2 after 100 ms fault then after 10 second trip the secondary circuit.
- Case 8 Year 2015 – Tripping 200 MW El-Zayt Wind farm

  Case 9 is chosen in order to analyse the tripping of 500MW at Benban as the maximum amount of renewable to be lost and to analyse if the power system is designed to lose a high amount of generation.

- Case 9 Year 2018 - Power change, disconnect 500 MW at Benban at 1 second 400164-400234 power generators increment 10

The Key-Conclusions and Recommendations of the Study are:

1. The EETC PSS/E Data files for year 2015 and year 2018 have successfully been analysed and the Load Flow Model and Dynamic Model is after modifications running with no simulation errors and the initial conditions are acceptable. Each power plant in the PSS/E data files have been aligned with the power plant information from the EEHC Annual Report in order to identify each power plant in the PSS/E-file and update any new power plants. The dynamic data of the model have been analysed according to general design rules and international standard parameters. In a mutual effort between the Consultant and the EETC support staff from the Studies Sector, the PSS/E files have been clarified and adjusted.

2. In the PSS/E Data File year 2015 and year 2018 received from EETC, several busbars at the 220 kV level were outside the normal voltage range of 0,9 – 1.05 pu. due to lack of reactive power in the Egyptian Power System and therefore the existing generators are running at their highest capability. To support the voltage and to reduce the MVar requirements on the generators and to run the cases in PSS/E, capacitance were included at specific locations as outlined in detail in the study from the PSS/E Simulations.

3. The review of the PSS/E data files concludes that it is required that EETC sets up a verification process of the steady state electrical simulation model and is provided with capacity training in verification/validation. On the 7th and 8th of December 2015 the Consultant conducted a training workshop in introduction to verification and validation process. After completion of the workshop, EETC acknowledged the importance of this topic and to further develop their technical skills in this field.

4. An economic model of the Egyptian Power System has been modelled using the Balmorel model tool. This model has generated the critical generation patterns for year 2015 and year 2018. The generation patterns represent 4 scenarios generated with max/min. demand with full wind generation meaning all wind farms are generating at full capacity, and no wind power generation, respectively, when all wind farms are shut down. These generation patterns are used as input data for the PSS/E model study, for detailed analyses of grid stability in extreme situations. The model has optimised the dispatch by minimising the total costs of supplying electricity. The procedure takes into account the marginal costs of the individual power plants (fuel price divided by efficiency) as well as start/stop costs and restrictions on the transport between zones. The electricity system is modelled as consisting of 7 zones: Cairo, North Upper Egypt, South Upper Egypt, West Delta, Middle Delta, Alexandria and Canal. This division is based on the Egyptian generation companies, where Hydro power generation is included in Upper Egypt. The value of the generated electricity from wind power is assessed together with the need for forced curtailment of wind power. In order to assess the impact of increased amounts of wind power in the Egyptian power system, sensitivity analyses were performed in which the wind power capacity was gradually expanded. In a sensitivity analysis, 2500 MW is added per simulation (1250 MW in the Suez Gulf, and 1250 MW on the Nile banks) until a total of 25,000 MW is added to the existing capacity. The Balmorel model shows that it is profitable to include up to 15.000 MW wind power capacity in the Egyptian Power System.

5. Aggregated wind farm models and Solar PV models have succesfully been created and implemented in the PSS/E Files for year 2015 and year 2018. Furthermore, SVC models have successfully been implemented in the PSS/E data file for year 2018 in order to support the grid stability. The EETC Support Staff from the Studies Sector and NECC Staff have been trained in PSS/E modelling and creating aggregated models for simulations. The detailed calculation, descriptions and parameter overviews with cable length summaries are attached in Annex 1.

6. The Load Flow Analysis in PSS/E has identified the following bottlenecks in the Egyptian Power System for year 2015 and for the 4 defined scenarios. Printshots of the PSS/E Simulation Load Flow are presented in the Report. The transmission lines marked in red are overloaded and needs to be reinforced.

Lines loaded more than 70%	Year 2015 - Line loading - 100 % - 90 % - 80 % - 70%							
Node	Names	Voltage / kV	Rating	Base case Existing Egyptian Power System	Scenario 1 Maximum Demand and Maximum Wind and Solar PV	Scenario 2 Minimum Demand and Maximum Wind and Solar PV	Scenario 3 Maximum Demand and No Wind and Solar PV	Scenario 4 Minimum Demand and No Wind and Solar PV
563-593	DOMIAT-S - PROBLEN	220	305	253	253	276		271
5-130	C.500 - NOB-500	500	1559					1248
328-542	N-BAHTEE - CAIRO-N	220	381	297		306	281	296
329-521	TEB_GEN - WADI-H	220	362	324				
336-561	W-DOM-PS - GAMALIA	220	570	422				
350-518	TORA - CAIRO-S	220	457	333				
374-5360	C-EAST - HELIOP2	220	133	96	104		111	
450-509	HARAM - C.500	220	381	381	375	267	339	274
451-509	GIZA - C.500	220	381	365	355		320	
501-502	NAG-H - GERGA	220	457		282		282	
512-3370	HADABA - OCTOBRGEN2	220	419	312				
561-636	GAMALIA - A-KBEER	220	305	229	243			
515-528	KURAIMAT - CAIRO-E	220	305	321		242		257
558-563	TRUST - DOMIAT-S	220	305	235	234	259		254
522-523	N-TEBB - TEBBIN	220	457		410			
523-40050	TEBBIN - DUMM 33&	220	457	326				
527-40053	BASATEEN - DUMM 36&	220	267	225	190		230	
527-40055	BASATEEN - DUMM 38&	220	267	225	190		230	
528-530	CAIRO-E - SKR-KOR	220	343		250			
531-533	SUEZ-S - SUEZ-500	220	438		324		367	
531-99995	SUEZ-S -	220	190		193		235	
538-539	STAD - METRO	220	381	268	274		276	
540-541	SABTIA - SHOB_KH	220	305	233	238		239	
541-543	SHOB_KH - CAIRO-N	220	381		272		274	
542-700	CAIRO-N - SABTIA	220	286	213	210		211	
583-2432	A-KIR - ABIS 2	220	194		171		140	
583-40030	A-KIR - DUMM 13&	220	194		164		141	
595-40058	C.N_GEN1 - DUMM 41&	220	229	208	182	164	194	178
595-40059	C.N_GEN1 - DUMM 42&	220	229	208	182	164	194	178

Lines loaded more than 70%	Year 2015 - Line loading - 100 % - 90 % - 80 % - 70%							
Node	Names	Voltage / kV	Rating	Base case Existing Egyptian Power System	Scenario 1 Maximum Demand and Maximum Wind and Solar PV	Scenario 2 Minimum Demand and Maximum Wind and Solar PV	Scenario 3 Maximum Demand and No Wind and Solar PV	Scenario 4 Minimum Demand and No Wind and Solar PV
634-40051	ECTSADIA - DUMM 34&	220	247		190			
700-701	SABTIA - N-SABTIA	220	305	285	282		283	
704-40050	- DUMM 33&		457	328				
5820-40030	SMOUHA2 - DUMM 13&	220	194		165		142	
6001-6008	N.ASSYUT - ASMNT 1	132	68	49			49	

7. The Load Flow Analysis in PSS/E has identified the following future bottlenecks in the Egyptian Power System for year 2018 and for the 4 scenarios. Printshots of the PSS/E Simulation Load Flow are presented in the Report. The transmission lines marked in red are overloaded and needs to be reinforced.

Lines loaded more than 70%	Year 2018 - Line loading - 100 % - 90 % - 80 % - 70%							
Node	Names	Voltage / kV	Rating	Base case Existing Egyptian Power System	Scenario 1 Maximum Demand and Maximum Wind and Solar PV	Scenario 2 Minimum Demand and Maximum Wind and Solar PV	Scenario 3 Maximum Demand and No Wind and Solar PV	Scenario 4 Minimum Demand and No Wind and Solar PV
46-40044	MOTAMDIA - DUMM 27&	220	419	404	384		360	
46-40045	MOTAMDIA - DUMM 28&	220	419	404	384		360	
118-554	NOBARIA - MENOUF	220	457		382		365	
626-40044	CAIRO-W - DUMM 27&	220	419	403	384		359	
626-40045	CAIRO-W - DUMM 28&	220	419	403	384		359	
240-556	K_ZIAT - TANTA	220	457	358	390		354	
247-251	ASHMOAN - N GIZA	220	450	424	559	384	430	
247-553	ASHMOAN - KALUBIA	220	457		472		397	
329-522	TEB_GEN - N-TEBB	220	362		259			
336-561	W-DOM-PS - GAMALIA	220	572	406	523			
348-513	OCTBR-220 - 6-OCT	220	457		475		403	
374-5360	C-EAST - HELIOP2	220	133		462		258	
450-40041	HARAM - DUMM 24&	220	457	441				
40040-40041	DUMM 23& - DUMM 24&	220	457	440				
522-523	N-TEBB - TEBBIN	220	457		431			

Lines loaded more than 70%	Year 2018 - Line loading - 100 % - 90 % - 80 % - 70%							
Node	Names	Voltage / kV	Rating	Base case Existing Egyptian Power System	Scenario 1 Maximum Demand and Maximum Wind and Solar PV	Scenario 2 Minimum Demand and Maximum Wind and Solar PV	Scenario 3 Maximum Demand and No Wind and Solar PV	Scenario 4 Minimum Demand and No Wind and Solar PV
451-40035	GIZA - DUMM 18&	220	457	385				
40034-40035	DUMM 17& - DUMM 18&	220	457	384				
518-40040	CAIRO-S - DUMM 23&	220	381	439				
501-502	NAG-H - GERGA	220	457		297		239	
508-40094	SELWA - ESNA	220	457		328			
511-553	BASSOS - KALUBIA	220	457		356		335	
511-40042	BASSOS - DUMM 25&	220	248		236		216	
511-40043	BASSOS - DUMM 26&	220	248		236		216	
512-518	HADABA - CAIRO-S	220	457		320			
554-40042	MENOUF - DUMM 25&	220	248		237		216	
554-40043	MENOUF - DUMM 26&	220	248		237		216	
512-797	HADABA - MAHSORA-ZONE	220	457		404			
513-740	6-OCT - ELGAMAL	220	457		344			
515-904	KURAIMAT - DUM-MNSR-KUR	220	305	319	532	459	373	408
515-9041	KURAIMAT - DUM MNSR KUR	220	305	319	532	459	373	408
785-890	HELWAN-SOUTH - ZAHRAA-MAADI	500	1732		1237			
904-905	DUM-MNSR-KUR - ZAH-MDNTNASR	220	362	323	532	459	373	408
518-40034	CAIRO-S - DUMM 17&	220	381	384				
524-625	PTROL-PL – ZAFRANA	220	438		540	525		
524-634	PTROL-PL – ECTSADIA	220	438		328	336		
526-891	KATAMIA - ZAHRAA-MAADI	220	457		321			
527-2931	BASATEEN - DUMBS-NRGS	220	268		214			
527-2941	BASATEEN - DUMBS-NRGS	220	268		214			
528-905	CAIRO-E - ZAH-MDNTNASR	220	362	255	467	430	313	376
533-5330	SUEZ-500 – DUMMY	220	229		184			
533-5331	SUEZ-500 – DUMMY	220	229		184			
538-539	STAD - METRO	220	381	327	293		292	
539-541	METRO - SHOB_KH	220	381	349	312		311	
540-541	SABTIA - SHOB_KH	220	305	231				

Lines loaded more than 70%	Year 2018 - Line loading - 100 % - 90 % - 80 % - 70%							
Node	Names	Voltage / kV	Rating	Base case Existing Egyptian Power System	Scenario 1 Maximum Demand and Maximum Wind and Solar PV	Scenario 2 Minimum Demand and Maximum Wind and Solar PV	Scenario 3 Maximum Demand and No Wind and Solar PV	Scenario 4 Minimum Demand and No Wind and Solar PV
541-543	SHOB_KH - CAIRO-N	220	381	274				
542-700	CAIRO-N - SABTIA	220	286	252	227		215	
542-3280	CAIRO-N - NBAH2	220	381	333				
545-546	N.ASHER - ASHER	220	438		476			
546-749	ASHER - BADR220	220	457		350			
547-548	ABU-SULT – MANAIF	220	229	170	210			
549-558	PORTSAID – TRUST	220	438		415			
549-593	PORTSAID – PROBLEN	220	438		458			
549-40027	PORTSAID - DUMM 10&	220	324		256			
549-40029	PORTSAID - DUMM 12&	220	324		256			
552-811	BAHTEEM - BASOUS2	220	457		379			
553-756	KALUBIA - BANHA-EAST	220	305		250		253	
554-1180	MENOUF - NOBARIA2	220	457		382		365	
555-5840	TAHRIR-B - ETAY-B2	220	229				188	
558-563	TRUST - DOMIAT-S	220	305		461		223	234
561-636	GAMALIA - A-KBEER	220	305		348			
563-593	DOMIAT-S - PROBLEN	220	305		491		240	249
565-598	K-SHEKH - SIDI-SAL	220	305		257			
569-587	K-DAWAR - ABIS	220	190	168			204	
583-2432	A-KIR - ABIS 2	220	194	170	171		153	
583-40030	A-KIR - DUMM 13&	220	194	168	166		151	
587-61400	ABIS - SUIF2	220	305				267	
5820-40030	SMOUHA2 - DUMM 13&	220	194	169	167		152	
592-613	A-EGP-CO - SP.STEEL	220	381	295	309		289	
595-811	C.N_GEN1 - BASOUS2	220	381					370
610-7874	RIVA - N-ASSIUT-GEN	220	457	467			351	
613-621	SP.STEEL - AL-EZZ	220	381		272			
625-635	ZAFRANA - ZAFRANA2	220	438		358	344		
635-998	ZAFRANA2 - RAS GHAREB	220	457			327		
700-701	SABTIA - N-SABTIA	220	305	339	306		290	
905-9041	ZAH-MDNTNASR - DUM MNSR KUR	220	362	323	532	459	373	408

Lines loaded more than 70%	Year 2018 - Line loading - 100 % - 90 % - 80 % - 70%							
Node	Names	Voltage / kV	Rating	Base case Existing Egyptian Power System	Scenario 1 Maximum Demand and Maximum Wind and Solar PV	Scenario 2 Minimum Demand and Maximum Wind and Solar PV	Scenario 3 Maximum Demand and No Wind and Solar PV	Scenario 4 Minimum Demand and No Wind and Solar PV
2501-2505	ASWAN - KOMOMBO	132	137		98			
2510-2517	NAG-HAMD - SOHAG	132	80		58			
2511-2514	NAG-HAMD - QUENA	132	114	82				
2517-6011	SOHAG - ASSYUT STEAM	132	68	52				
6001-6008	N.ASSYUT - ASMNT 1	132	68	78	67		68	
6002-6005	SAMALUT - MENIA	132	68	57			51	
6008-6011	ASMNT 1 - ASSYUT STEAM	132	68	90	74		74	
6009-6011	ASMNT 2 - ASSYUT STEAM	132	68	88	73		73	
6882-6894	S3 220 - S1	220	457		410	424		

8. The Dynamic Transient Stability Analysis for scenario 1 and scenario 2 has identified grid stability issues in case 4 and case 6 and recommendations as outlined in the below table. Please refer to the PSS/E simulations graphs for each case in the dynamic analysis chapter in the report.

Scenario 1

Maximum Demand and Maximum PV Solar and Wind Power

Year 2015:

Grid stability issue on the High Dam to Nag Hamadi 500 kV line.

Year 2018:

Grid stability issue on the High Dam to Nag Hamadi 500 kV line.

Grid stability issue on the Samalut 500kV line to Ras Ghareb 500 kV, FIT 2000 MW Wind Farms.

Response and Behaviour Graphs for Grid Stability Issues:

Year 2015:

Case 4 - PSS/E simulation,

Tripping the first N.Hamadi500-High Dam500 circuit after 100ms fault then after 10 second tripping the other

Year 2018:

Case 4 and 6 - PSS/E simulation:

Tripping line 4 Samalut-881 FIT circuit after 100ms fault

Recommendations to Overcome Grid Stability Issues:

year 2015:

Reinforcement of the 500 kV line High-Dam Nag Hamadi

Install a SVC in Nag Hamadi

year 2018:

Reinforcement of the 500 kV line High-Dam Nag Hamadi

Reinforcement of the line FIT-RAS ghareb.

Install SVC at Nag Hamadi, Assuit and Hurgharda

Scenario 2

Minimum Demand and Maximum PV Solar and Wind Power

Year 2015:

Grid stability issue on the High Dam to Nag Hamadi 500 kV line.

Year 2018:

Grid stability issue on the Samalut 500kV line to Ras Ghareb 500 kV, FIT 2000 MW Wind Farms.

Response and Behaviour Graphs for Grid Stability Issues:

Year 2015:

Case 4 - PSS/E simulation,

Tripping the first N.Hamadi500-High Dam500 circuit after 100ms fault then after 10 second tripping the other

Year 2018:

Case 6 - PSS/E simulation:

Tripping line 4 Samalut-881 FIT circuit after 100ms fault

Recommendations to Overcome Grid Stability Issues:

year 2015:

Reinforcement of the 500 kV line High-Dam Nag Hamadi

Install a SVC in Nag Hamadi

year 2018:

Reinforcement of the 500 kV line FIT-RAS ghareb

Install SVC in Assuit

Install SVC in Hurgharda

9. The Dynamic Transient Stability Analysis for scenario 3 and scenario 4 has identified grid stability issues on case 4 only and mitigation recommendations as outlined in the below table. Please refer to the PSS/E simulations graphs for each case in the dynamic analysis chapter in the report.

Scenario 3 Maximum Demand and No PV Solar and Wind Power	Scenario 4 Minimum Demand and No PV Solar and Wind Power
Year 2015: Grid stability issue on the High Dam to Nag Hamadi 500 kV line. Year 2018: Grid stability issue on the High Dam to Nag Hamadi 500 kV line.	Year 2015: No Issues Year 2018: No issues
Response and Behaviour Graphs for Grid Stability Issues: Year 2015: Case 4 - PSS/E simulation, Tripping the first N.Hamadi500-High Dam500 circuit after 100ms fault then after 10 second tripping the other Year 2018: Case 4 - PSS/E simulation: Tripping the first N.Hamadi500-High Dam500 circuit after 100ms fault then after 10 second tripping the other	Response and Behaviour Graphs for Grid Stability Issues: Year 2015: No Issues Year 2018: No Issues
Recommendations to Overcome Grid Stability Issues: year 2015: Reinforcement of the 500 kV line High-Dam Nag Hamadi Install a SVC in Nag Hamadi year 2018: Install SVC in Assuit Install SVC in Hurgharda	Recommendations to Overcome Grid Stability Issues: Year 2015: No Issues Year 2018: No Issues

The Key Outcome of the Study:

The analysis indicates that 750 MW wind power in the base case 2015 can be integrated into the grid system with the reinforcement of the transmission system on the following transmission line.

- 220 kV line SUEZ-S to SK-KOR

The analysis for year 2018 indicates that 3940 MW wind power and 2000 MW of Solar PV can be integrated into the system with reinforcement of the transmission system on the following transmission lines:

<u>500 kV level</u>

- 500 kV line High-Dam Nag Hamadi
- 500 kV line FIT-RAS Ghareb

<u>220 kV level</u>

- 220 kV line ASHMOAN - N GIZA
- 220 kV line ASHMOAN – KALUBIA
- 220 kV line OCTBR-220 - 6-OCT
- 220 kV line C-EAST - HELIOP2
- 220 kV line CAIRO-E - ZAH-MDNTNASR
- 220 kV line N.ASHER - ASHER
- 220 kV line PORTSAID - PROBLEN
- 220 kV line TRUST - DOMIAT-S – PROBLEN
- 220 kV line K-DAWAR – ABIS
- 220 kV line SELWA-ESNA
- 220 kV line A-DAM-WAD.NOKR
- 220 kV line A-DAM-BENBAN

Above 3942 MW and 2000 MW of Solar PV will require additional reinforcement of the transmission system, subject to the site location of the wind and solar power.

The stable dynamic transient stability simulation for year 2018 shows that in order to compensate for the variation in load and reactive losses three SVC is suggested at the following locations:

- Naga Hamadi: 600MVAr
- Asyut: 600MVar
- Hurghada: 300MVAr

For year 2018, above 3942 MW, it is important to focus on the frequency control and MVAr control in order to avoid violations of reliability and operating code requirements. The technical requirements shall be grouped as follows for the wind turbine and solar PV requirements:

- Control of reactive power
  - This includes requirements to contribute to voltage control on the network in normal operation but also during faults, the typical requirements can be given as constant reactive power Q, constant PF and voltage control.
  - The behaviour during faults

- Control of active power
  - This includes to lower the production during constrains in the power system, but also to minimize impacts on large foreseen events causing suddenly changes of all renewables as the huricans, Dawn, sunset, solar elicpes etc.
  - The behaviour during faults
  - Facilitate auxiliary services as secondary reserve and others
  - Frequency support outside a specified deadband

Above 2000 MW Solar PV might pose technical and reliability concerns for EETC due to the location of Solar PV at BenBan and the load on the existing 500kV system. The BenBan location of solar PV impose problems for the power system control, since the 500kV lines between High dam and Cairo is increased in load and thereby decrease the damping between the conventional power plants in Cairo and High Sam. Therefore, further extension of Solar PV should take place in areas, such that the 500 kV circuit in North-South is not further loaded.

The requirements for low voltage ride through shall secure that wind power and Solar PV maintain voltage support during the failure and controlled production immediately after failures. This again should reflect the demands for the duration of clearing the failures from the power system.

The Solar PV Plants equipped with inverters have similar control behaviors to the Type 4 wind turbines, and therefore it is foreseen that Solar PV can comply with grid code requirements. However for type 1 and type 2 wind turbines, the requirements in the grid code is not expected to be fulfilled even though some developers will suggest STATCOM to be installed together with the wind farms.

The wind power and Solar PV will introduce a larger power flow and variation on the power flow in the Egyptian grid system, which will increase the focus on keeping the voltage/MVAr in balance. The next steps for establishing a validation/verification process of the Egyptian grid system, updating the existing grid codes for wind/PV and furthermore introducing forecasting systems in power system operation/planning is very essential.

An important bird migration route of soaring birds passes through the Gulf of Suez. The impacts of bird migration in this region are modelled by decreasing the wind power output by 0%, 25%, 50%, 75% or 100% (partial shut-down of the wind farm) during the potential flight hours of the birds. These hours are identified between 9 a.m. and 7 p.m. during 3 months in spring (starting 17th of February) and 3 months in fall (from 18th of August). The shut downs are randomized ensuring a total decrease in annual generation of 8%.

Grontmij A/S experience on working with NREA on the Gabel-El-Zayt Wind Farm for the spring season 2016, has shown that the establishment of the shut-down on demand modality is well functioning and minimizing the shut-down of wind turbines.

The running reserve for year 2015 and year 2018 is as following:

	Running reserve / MW	2015	2018
No wind power, no Solar PV	Base case	6502	15515
Maximum Wind Power and Maximum Solar PV	Maximum demand	4507	6031
	Minimum demand	4056	7248
No Wind Power and No Solar PV	Maximum demand	4657	6702
	Minimum demand	4600	4681

The wind farms and Solar PV plants are configured so that the maximum amount to be disconnected during a failure is 500 MW.

Way forward

The need for establishing a validation and verification process of the Egyptian Power System steady state electrical simulation model and capacity training in verification/validation is necessary through a separate study.

The main steps for establishing this, shall include:

1. Form a dedicated project team with the NECC dispatch centre, with the objective of defining the recommendable verification process for the steady state electrical simulation model for the existing Egyptian power system and gathering required measurements for training..

2. Training of EETC staff at Energinet.dk in Denmark for 2 weeks. The training will focus on step by step knowledge transfer to EETC team on how to implement the verification process on the steady state electrical simulation model for Egypt and capacity training, hands-on experience with verification/validation state estimators and simulation tool kits.

3. During the training EETC will be trained to operate their State Estimator and Simulator Toolkit for Egypt.

4. Preparing a project roadmap by gathering the outcomes from the workshop in Egypt and training in Denmark and formulate a detailed verification process action plan and report it to EETC and NECC.

5. This report shall outline:
   i. the work packages required for performing the tasks for the verification process of the steady state electrical simulation model.
   ii. agreed role for Consultant and EETC/NECC staff,
   iii. proposed milestones for the defined work packages
   iv. proposed meeting schedule for follow up in Cairo combined with interim reporting and regular follow-up via teleconference.

6. EETC shall in Cairo provide the required EETC staff resources to operate their state estimator and simulator toolkit.

7. Performing workshop in Cairo with the EETC and NECC staff to start the implementation as agreed in action plan.

8. Performing workshop in corporation with EETC/NECC to analyse the results from the work packages and propose actions to updated PSS/E file from Phase 1 study, for the EETC staff to correct identified deviations between the steady state simulation model and actual measurements.

9. Follow up on the EETC procedure in accordance with agreed work plan and technical assistance with the action plan.

The 2nd phase is expected to cover:

- Analysing the requirements for power system protection, operation and control strategies as per the ToR of the project.

- Modifying the existing Wind Integration Grid Code and the PV Code.

- Developing suggestions on how to integrate wind forecasting system in the power system operation and planning in Egypt (to be reviewed).

- Training workshops for EETC staff in power system protection, operation and control.

1 Introduction to Study

1.1 Background of Study

The Government of the Arab Republic of Egypt has received a grant from the African Development Bank (AfDB) towards the cost of studying the integration of wind power in the Egyptian power system and establishment of wind integration grid code for Egypt.

The Egyptian Government is promoting renewable energy sources for power generation, in particular solar and wind power. Egypt has a significant potential with one of the world's best wind resources, so the focus on renewable energy is a sustainable way to meet the rising demand.

Electricity in Egypt is generated mainly from thermal and hydropower stations. However, the percentage of hydro power energy generated is gradually reducing due to the fact that all major hydropower sites have already been developed and new generation plants being built are mainly gas fired. Thermal generation is based on combined cycle and steam plant technologies. Combined cycle plants offer higher thermal efficiency but steam plants are more versatile in terms of fuel use and thus most suited to deal with changes in the system base load. With a growing electricity demand in Egypt, the power supply capacity needs to be expanded, raising certain issues about: (a) the volume and the cost of natural gas that would be available to the power sector; (b) the realistic potentials, costs, and time-line of other (hydro, solar, wind, nuclear) energy options; and (c) the manner in which the corresponding huge investments would be financed.

In response to the above concerns the Ministry of Electricity and Energy pursues a power development strategy that aims at: (i) increased use of efficient fossil-fuel generation technologies (CCGT and supercritical steam boilers) ;(ii) large scale development of Egypt's renewable resources with the goal of having 20% of its generated energy in the form of renewable; and (iii) stepping up efforts for more efficient consumption of electricity. The target for renewable energy is expected to be met largely by scaling-up of wind power as solar is still very costly and the hydro potential is largely utilized. The share of wind power is expected to reach 12 percent, while the remaining 8 percent would come from hydro and solar. This translates into a wind power capacity of about 7,200 MW by nearly 2022.

International experience suggests that a high penetration level of wind power into the power system can have an impact on the power system operation and in particular when the wind power is geographically concentrated.

This study will contribute with the important issues of system grid stability based on various scenarios, analysis and the international best experiences. The study will lead to a clear understanding of wind turbine grid modelling, wind power & solar PV integration into the Egyptian Power System and its implications on the Egyptian power system planning, control and operation and the transmission system network, furthermore the addition of the establishment of updated wind integration grid code. This study is therefore a vital key contribution to Egypt's ambitious future wind power and solar PV plans and it formulates the technical requirements to ensure the safety and stability of the power system. It is also consistent with the Government's strategy for diversification of energy supply, reducing dependence on fossil fuels, and increasing the use of clean renewable energies. The main outcomes and objective of the study is outlined in the next sections.

1.2 The Objective of Phase 1 Study

The objective of the project was defined to study the grid impact of integrating 7200 MW wind power up to year 2030 into the Egyptian power system and to provide planning and operational recommendations for the successful integration of the wind power.

Jointly with EETC it was decided to divide the project into a Phase 1 and Phase 2. This report concerns Phase 1, which specifically focuses on the wind power integration and solar PV power integration up to year 2018. Phase 1 focuses on integrating 3942 MW of wind power and 2000 MW of PV solar power into the Egyptian power system up to year 2018. The 3942 MW of wind power is located in the El-Zayt and Gulf of Suez Region of Egypt and the 2000 MW of PV solar power is located in the BenBan Region of Egypt.

Phase 2 will focus on power system protection, operational requirements, control strategies, wind forecasting systems and modification of the existing wind power grid codes. Phase 2 will be defined from the outcomes and conclusions of Phase 1.

Figure 1-1 and Table 1-1 illustrates the current and upcoming development of wind power projects in the El-Zayt and Gulf of Suez region, which will be studied in the project. Furthermore, 2000 MW of PV solar power in Benban will be studied in the project.

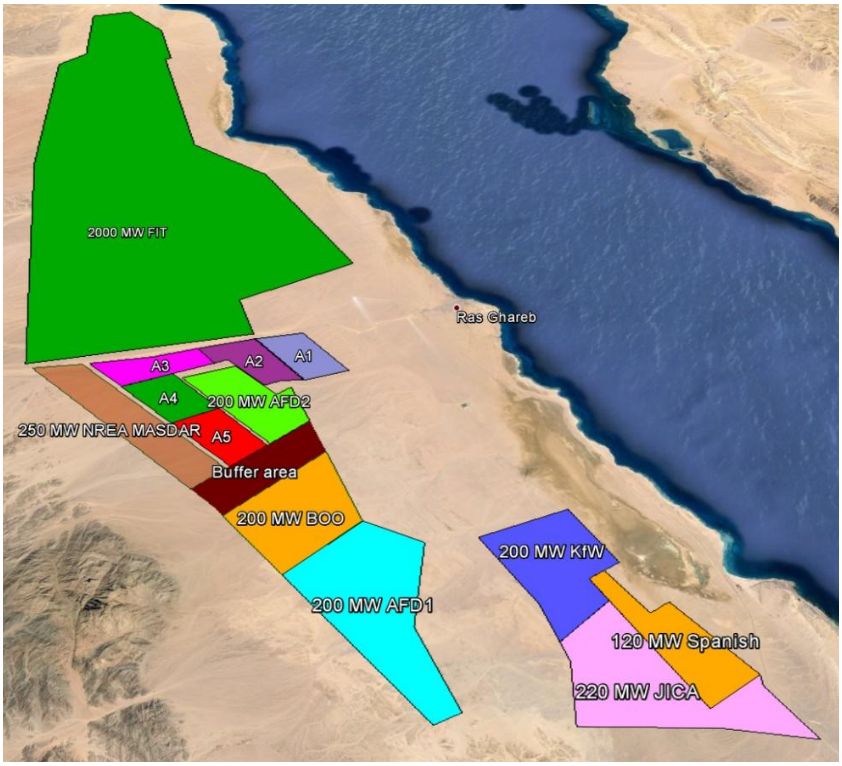


Figure 1-1: Wind power project overview in El-Zayt and Gulf of Suez region.

Year / Project	Project	Total MW
Hurghada	Hurghada	5,4
Zafarana	Zafarana	546,6
Gabel-EL-Zayt	KFW	200
2016	Spanish	120
2017	JICA	220
2017	FIT	2000
2017	BOO	200
2017	Masdar	250
2018	AFD1	200
2019	AFD2	200
	Total Wind	3942
Solar PV Benban projects	Total Solar PV	2000

Table 1-1: Specific project overview of current and future wind farm and solar PV developments in Egypt up to year 2018/2019.

1.3 Methodology Overview of Phase 1

Figure 1-2 illustrates the methodology overview of Phase 1. The key element to the methodology approach is to work hand-in-hand with EETC and furthermore to increase their technical knowledge in wind power integration and grid modelling specifically for the Egyptian Power System.

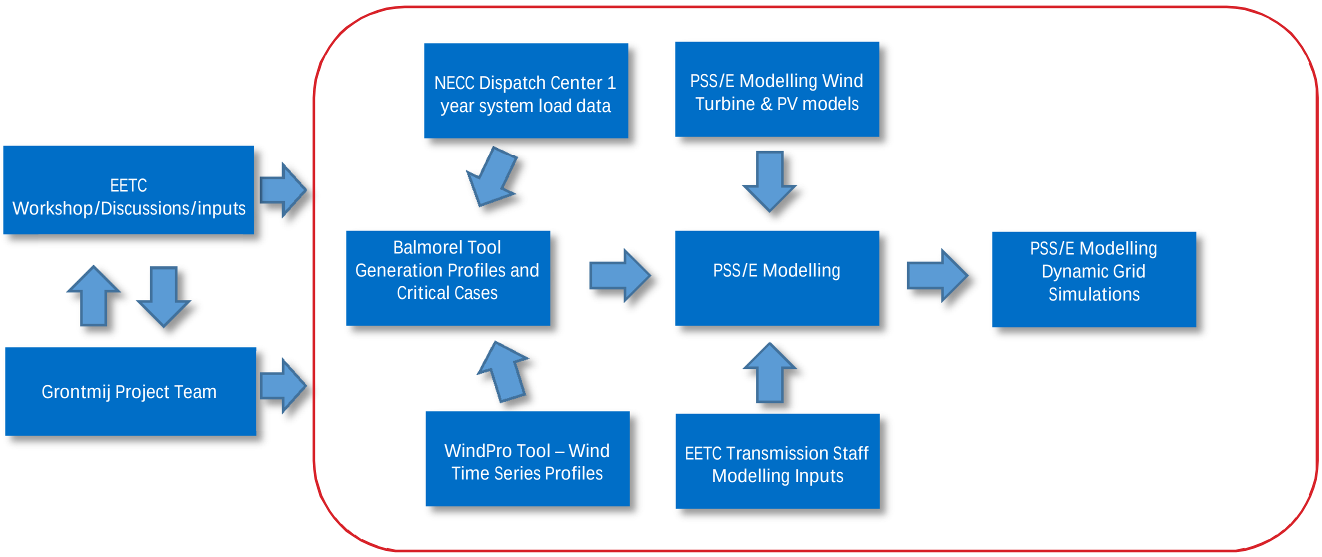


Figure 1-2: Flow chart of methodology overview for Phase 1

1.4 Main Key Assumptions for Phase 1

Below is listed the main key assumptions of the study for Phase 1.

3. Use of PSS/E software tool for dynamic modelling and grid simulations.
4. Use of Balmorel tool for assessment of generation profiles and wind curtailment due to bird migration.
5. Integration of 3942 MW of wind power up to year 2018 in the regions of El-Zayt and Gulf of Suez.
6. Integration of 2000 MW of Solar PV up to year 2018 in the region of Benban.
7. 1 year system load data year 2014 from EETC Dispatch Centre.
8. Implementation of static and dynamic wind turbine models in the existing EETC PSS/E file for year 2015 and year 2018.
9. Implementation of static and dynamic PV solar models in the existing EETC PSS/E file for year 2015 and year 2018.
10. Aggregation of specific wind farm projects in PSS/E according to wind generation plan up to year 2018.
11. Calculated cable lengths for each wind farm in the aggregated models.
12. Aggregation of PV solar farm projects in PSS/E according to solar PV generation plan up to year 2018.
13. Wind speed time-series for the Nile, the Gulf of Suez and in Zafarana generated through met masts in Egypt and through meso-scale models.
14. Generation patterns for year 2015 and year 2018 comprising of maximum demand/full wind generation and minimum demand/full wind generation.
15. Generation pattern for year 2015 and year 2018 comprising of maximum demand/no wind generation and minimum demand/no wind generation.
16. The generation patterns for year 2015 and year 2018 represents 4 scenarios.
17. The generation patterns are used as input data for the PSS/E model study for detailed of grid stability in extreme situations.
18. The dynamic transient stability simulations are conducted for the 4 scenarios with 9 defined cases for each scenario.

1.5 Main Key Technical Outcome of the Study

The Key Focus for Load Flow Analysis Simulation:

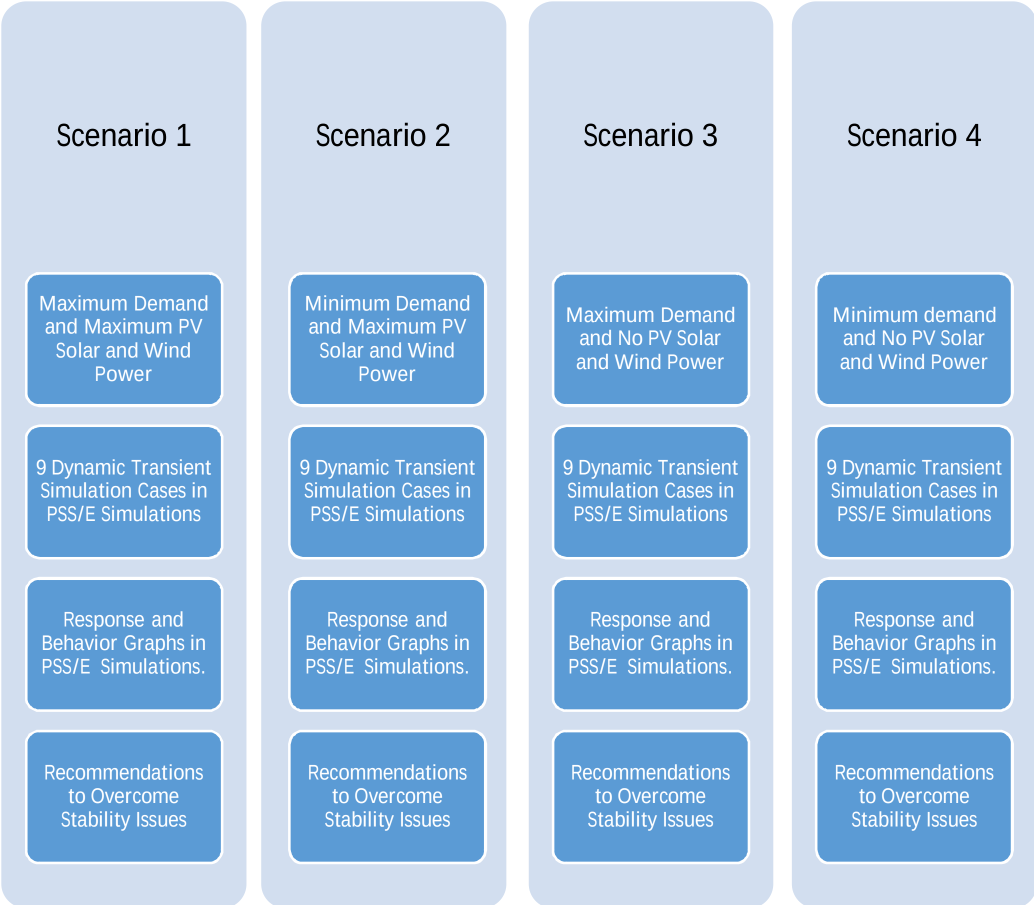
- Identifying the existing bottlenecks that may affect the grid system in year 2015 PSS/E file with and without wind power according to defined scenarios mentioned below.
- Identifying the expected bottlenecks in the grid system in year 2018 PSS/E file with and without Solar PV and Wind Power according to defined scenarios mentioned below.
- Recommendations to overcome the identified bottlenecks and recommendations to reinforcement of the existing grid system year 2015 and future grid system year 2018

Comparison table scenarios for analysis simulation.

Scenario 1	Scenario 2	Scenario 3	Scenario 4
Maximum Demand and Maximum PV Solar and Wind Power	Minimum Demand and Maximum PV Solar and Wind Power	Maximum Demand and No PV Solar and Wind Power	Minimum demand and No PV Solar and Wind Power
Identification of existing bottlenecks in year 2015 - PSS/E Simulations	Identification of existing bottlenecks in year 2015 - PSS/E Simulations	Identification of existing bottlenecks in year 2015 - PSS/E Simulations	Identification of existing bottlenecks in year 2015 - PSS/E Simulations
Identification of expected bottlenecks in year 2018 - PSS/E Simulations	Identification of expected bottlenecks in year 2018 - PSS/E Simulations	Identification of expected bottlenecks in year 2018 - PSS/E Simulations	Identification of expected bottlenecks in year 2018 - PSS/E Simulations
Recommendations to overcome bottlenecks - Reinforcement of grid system	Recommendations to overcome bottlenecks - Reinforcement of grid system	Recommendations to overcome bottlenecks - Reinforcement of grid system	Recommendations to overcome bottlenecks - Reinforcement of grid system

The Key Focus for Dynamic Transient Analysis Simulation:

For each scenario, 9 simulation analysis cases are investigated in a comparison table.



<u>9 Dynamic Transient Simulation Cases:</u>

- Tripping Kurimat500-Samalut500 circuit after 100ms fault after 10 second trip Cairo500- Samalut500 Circuit.
- Tripping the first Assut500-Samalut500 circuit after 100ms fault then after 10 second tripping the other one.
- Tripping the first Assut500-N.Hamadi500 circuit after 100ms fault then after 10 second tripping the other one.
- Tripping the first N.Hamadi500-High Dam500 circuit after 100ms fault then after 10 second tripping the other.
- Tripping Nobaria500-Cairo500 circuit after 100ms fault
- Tripping line 4 Samalut-881 FIT circuit after 100ms fault
- Tripping line 635 El Zayt-998 Zafarana 100ms fault. Both lines one at 1 sec one at 11 seconds
- Tripping line 5420 Benban- Naghamadi 2
- Power change, disconnection of 500 MW at Benban at 1 second 400164-400234 power generators increment 10, where applicable

1.6 Training Workshop Summary

During the project period 3 training workshops with 9 trainings sessions have been conducted. Reference is made to Annex 1 for training presentation and materials.

The objective of the training workshops are to provide the EETC project team with specific project relevant training in PSS/E modelling, grid stability analysis and knowledge transfer about dynamic wind turbine models for the upcoming wind farms in Egypt and PV solar modelling in PSS/E. Furthermore, the training sessions provides high skilled knowledge transfer on how to perform the verification and validation process of a power system.

Training Workshop 1: 2nd to 5th of February 2015:

Training sessions:

1. Planning and Operating: Transmission Infrastructure.
2. Introduction to PSS/E Modelling and system simulation.

Training Workshop 2: 6th to 9th of July 2015:

Training sessions:

3. Review and validation of existing PSS/E model of the Egyptian Power system.
4. Setup of PSS/E model for future scenarios and behaviour of existing windfarms in the model.
5. Challenges in integration of wind power and possible solutions.
6. Simulating wind power curtailment and the value of wind power in Egypt.

Training Workshop 3: 7th to 9th of December 2015:

Training sessions:

7. Introduction to verification and validation process part 1.
8. Introduction to verification and validation process part 2.
9. PSS/E modelling and system simulation.

1.7 Worldwide Experiences in Wind and Solar Integration, Lessons Learned from China

In planning for largescale wind development in Egypt it can be useful to review and reflect on the experiences of other countries that have integrated large amounts of wind energy. As the world leader in installed wind capacity, China is a relevant market to focus on.

1.7.1 Development in installed capacity and generation

At the start of the millennium, China's installed wind capacity was rather insignificant, with wind pioneers such as Denmark having over 5 times the installed capacity. However, this would change dramatically soon thereafter, as China's annual capacity additions grew rapidly from 2005 onwards. (see figure below).

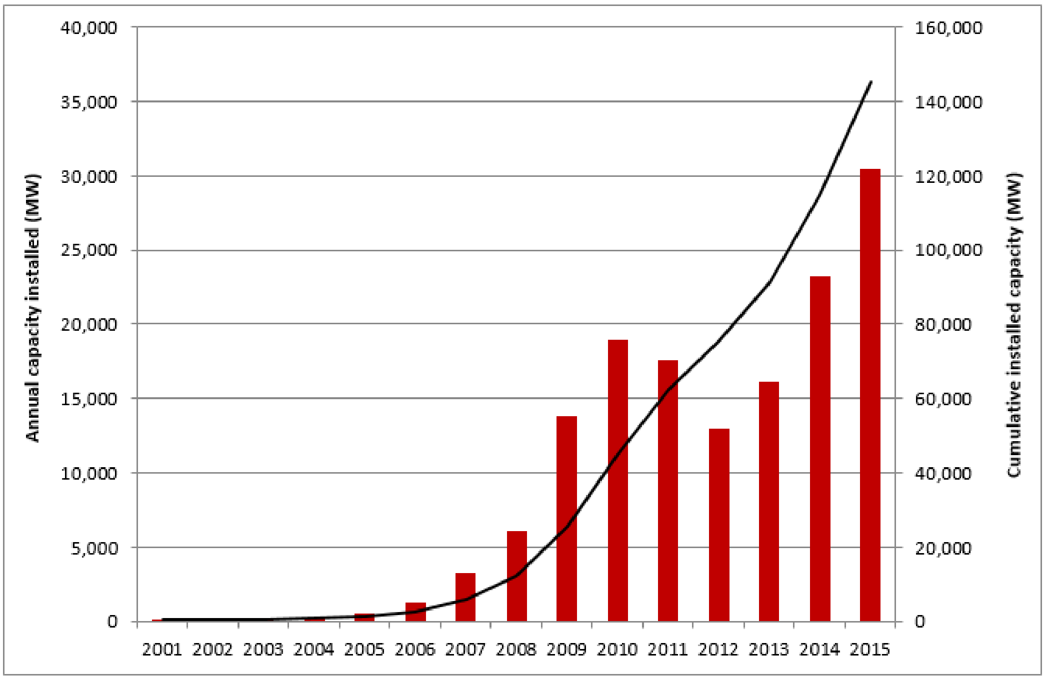


Figure 1-3: Chinese annual installed wind capacity in MW (red bars and left axis), and cumulative installed wind capacity in MW (black line and right axis). Data: GWEC.

According to the Global Wind Energy Council (GWEC), during the period from 2010 to 2015 China averaged nearly 20 GW of additional wind capacity each year, bringing its total installed capacity to over 145 GW by the end of 2015. To put this figure into perspective, this is roughly the same as the total installed capacity of all of Europe (GWEC, 2016). According to GWEC, over 30 GW were installed in 2015, which can in part be explained by the fact that there was an end of year deadline to complete projects by, as projects completed after December 31st will receive a reduced feed-in tariff (roughly CNY 0.02/kWh or $0.003/kWh lower than previously) (Yang, 2015).

To put the above wind capacity figures into context, the below figure displays the development of the overall electricity generation capacity in China according to fuel type.

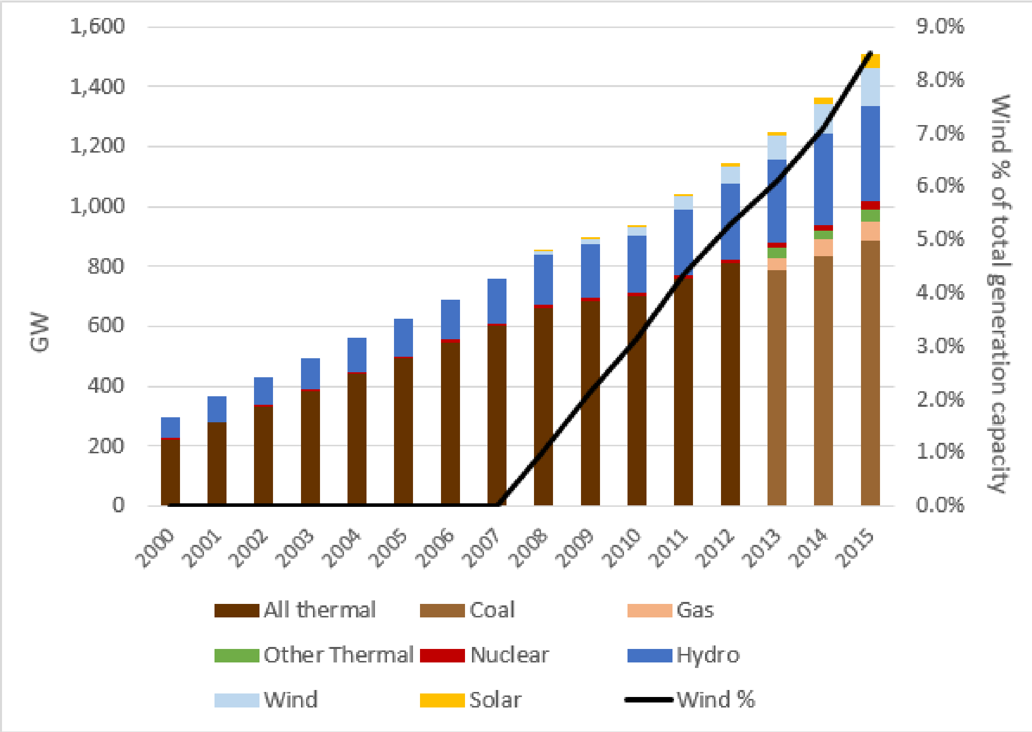


Figure 1-4: Development in Chinese electricity generation capacity by fuel in GW (columns and left axis), and wind's share of total Chinse generation capacity (black line and right axis) For some years data was not available, so linear interpolations between known years were undertaken. Please note that prior to 2013, all thermal sources are merged into one category. Sources: List of National Statistics Bulletin Power Industry, National Bureau of Statistics, and AEA Energy and Economic Database and State Grid Corporation of China.

The figure highlights the fact that coal is still the backbone of Chinese electricity generation, but wind has seen its share grow significantly in recent years, and by 2015 it accounted for over 8.5% of Chinese generation capacity.

That coal is still the dominant fuel in electricity generation is also highlighted in the following figure, which displays the development in total electricity production by fuel. What is also apparent though, is the slowing down in electricity demand growth, and the gradual decline in the share of electricity production from coal, which is being replaced by natural gas, wind and other renewables.

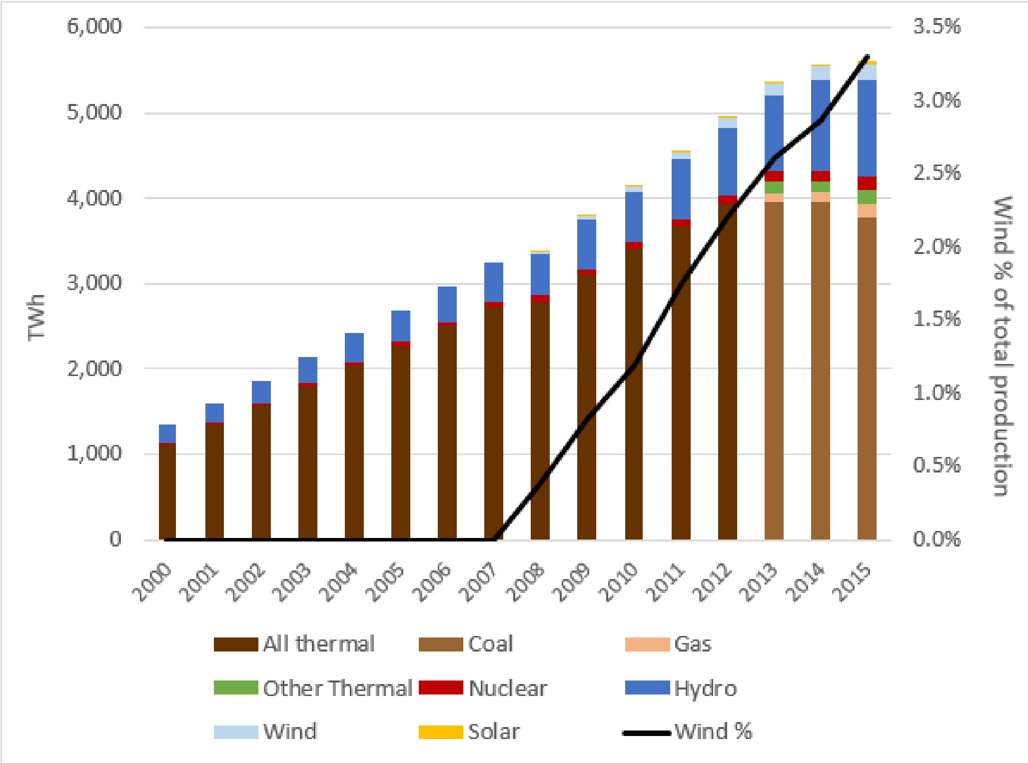


Figure 1-5: Development in Chinese electricity generation by fuel in TWh (columns and left axis), and wind's share of total Chinse generation (black line and right axis). For some years data was not available, so linear interpolations between known years were undertaken. Please note that prior to 2013, all thermal sources are merged into one category. Sources: List of National Statistics Bulletin Power Industry, National Bureau of Statistics, and AEA Energy and Economic Database and State Grid Corporation of China.

1.7.2 Policy and regulatory framework overview

The extremely large growth in wind capacity in China was brought about via a series of policies and regulations passed by the central government. This evolution can be largely divided into 5 phases (IRENA, 2012):

- Demonstration phase and joint venture establishment (1986-2000)
- Early commercialisation and tariff establishment (2001-2005)
- Renewable Energy Law (2005-2007)
- Wind Power bases and FITs (2008-2014)
- 13th 5-year plan and power market reforms (2015 to present)

Demonstration phase (1986-2000)

The early stages of China's wind development were characterised by a few domestic R&D projects, and demonstration projects such as the wind farm built in Rongcheng, Shandong province in 1986 (Pengfei, 2005). Early commercialisation was reliant on government funding and assistance from foreign governments, which both donated wind turbines, and provided loans. An early example was the Dabancheng wind farm in Xinjiang, which received 2 wind turbines from Denmark in 1986, and with a $3.2 million donation from the Danish government, purchased 13 more Danish turbines in 1989. (Qi, 2010). In fact, the predecessor of GoldWind, now the largest Chinese turbine producer, was the Xinjiang Wind Energy Company, which was formed to operate Dabancheng wind farm. These imported turbines (150 to 250 kW) were larger and involved more advanced technology than domestic R&D at the time (ca. 55 kW level), thus granting Chinese engineers access to more sophisticated wind energy technologies and the ability to reverse engineer. Firms such as GoldWind, which had strong R&D departments, began to work with foreign firms and enter into licensing agreements, thus allowing them to quickly develop their own technology capability, and by 1999 they were producing turbines in the 600 kW class (Dai, Zhou, Xia, Ding, & Xue, 2014).

An important policy passed in 1994 was the regulation on grid-connecting operation in wind farms, which established that the national utility should facilitate the connection of wind farms to the nearest grid point, and all the electricity generated by wind farms should be purchased, thus providing investors with more security (IRENA, 2012).

Early commercialisation phase (2001-2005)

The 10th Five-Year Plan (2001-2005) saw the Chinese government introduce legislation that required a minimum portion of electricity supplied via renewables. As a result, renewable energy development was largely carried out by the Big Five state owned utility companies in response to government regulation which called for the inclusion of at least 2% non-hydro renewable sources in their generation *capacity* by 2015. Due to the fact that the legislation was based on a capacity requirement, and not a target for the generated power, it has been theorised that the utility companies in practice regarded the obligation as a tax on coal, and paid little attention to optimising the investments. As a result, many low cost wind farms with a high capacity, but little incentive to optimise production were established. These wind farms therefore utilised cheaper, low quality domestically produced turbines. (DEM et al., 2010)

In 2003, the National Development & Reform Commission (NDRC) issued the Wind Power Concession programme, a market-based system where projects were awarded to developers according to competitive bidding rounds. This programme incorporated a ‘local content’ provision, setting a a mandatory minimum localisation rate for newly installed wind turbines of at least 50% in 2003, and 70% after 2004. Tariffs for concession projects were determined by the concession bidding rounds, while government approved tariffs were utilised for projects less than 50 MW (IRENA, 2012).

A number of domestic wind turbine manufactures entered into joint-venture projects, for example: GoldWind and the German firm Vensys, Zhejiang Windey and Baoding Tianwei with Garrad Hassan, and Shanghai Electric, CSIC Haizhuang, United Power and Guangdong Mingyang all collaborated with Aerodyn. Meanwhile, in order to protect their intellectual property, Vestas and GE did not set up joint-ventures, but instead built their own factories in China. From 2003 to 2007, five rounds of concession projects were carried out, with a cumulative total installed capacity of 3,350 MW. As a result, the NDRC goal of developing a domestic wind power industry based on locally produced, less expensive, technology was quite successful. (Dai, Zhou, Xia, Ding, & Xue, 2014).

Renewable Energy Law Phase (2005-2007)

The first Renewable Energy Law entered into force in 2006, and it was the first time that it was explicitly stated in law that grid companies should prioritise renewable energy over other sources of power (IRENA, 2012).

In 2007, the NDRC released the Medium and Long-Term Development Plan for Renewable Energy in China. This required power companies with installed capacity greater than five GW to have at least three percent of their total capacity in the form of non-hydro renewable energy by 2010, with this growing to eight percent by 2020. This lead to a surge in wind investment, which reflected the fact that wind power was less costly to install and operate than solar and biomass alternatives. (Howell, Noellert, Hume, & Wolff, 2010).

Meanwhile, the government maintained the 70% local content requirement until 2009, at which point the government indicated that it was no longer deemed necessary, as all Chinese turbines met the requirements, and foreign manufactures had now established local factories that also met the requirements. Sceptics have indicated that the NDRC may have instead removed the requirement because it could jeopardise Chinese ambitions to produce turbines for export, both because standards and requirements in export countries were at a higher level than those prevailing in China at the time, and due to the fact the government wanted to avoid foreign discrimination against Chinese export. Alternatively, the NDRC may have abolished the localisation requirement in a move to increase competition and consolidate the sector. At the time, significant amounts of investment capital were tied up in projects that occupied valuable wind resources with below-standard turbines. These turbines were often supplied by manufacturers that had no experience, and no long-term plans for maintenance, and as result would likely be out of business when it came time to replace worn out components. (DEM et al., 2010).

Wind power bases phase (2008-2014)

One of the most important drivers in the large growth in installed capacity was the Wind Base Programme, which started in 2008. The programme involved seven selected areas, each of which were to develop more than 10 GW of wind capacity, with the initial plan calling for a total capacity target of 138 GW by 2020. Locations for the bases were determined by the National Energy Administration according to the areas with the best wind resources. (IRENA, 2012).

In July of 2009, the National Development and Reform Commission published the 'Notice on Wind Power on the Pricing Policy'. It divided the country into four categories of wind power resource areas according to wind resources and construction conditions, and set feed-in tariffs accordingly, i.e. lower tariffs in regions with good wind conditions, and higher tariffs where conditions are less favourable. Class I areas (the dark orange in the figure below) received 0.51 RMB/kWh, Class II areas (the medium orange) received 0.54 RMB/kWh, Class III areas (the yellow) received 0.58 RMB/kWh, while Class IV areas (the remaining light yellow) received 0.61 RMB/kWh. (DEM et al., 2010).

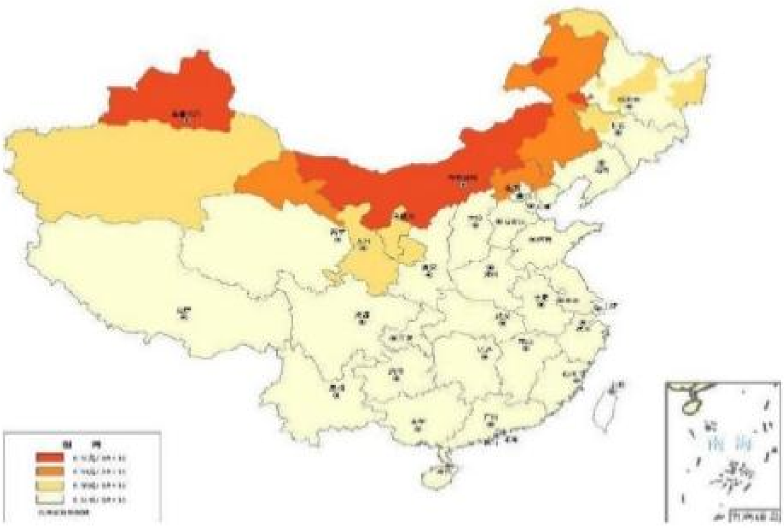


Figure 1-6: Feed-in tariff wind resource areas in China (DEM et al., 2010)

13th 5-year plan and power market reforms phase (2015 to present)

The 13th 5-year plan (2016-2020) has seen China adopt targets for non-fossil generation of 15% in 2020 and 20% in 2030. Carbon emissions are planned to peak in 2030, and relative to 2005 levels, CO_2 emissions intensity are to be reduced by 60%-65% by 2030. Total installed wind power has already exceeded 100 GW, and is planned to exceed 220-250 GW during the 13th five-year plan period.

Pricing reforms are also promoted in the period of 13th five-year plan, and during March of 2015, the State Council (SC) released document #9 on power market reform, which provides direction to all authorities, power companies, and institutes indicating that power market liberalisation shall be realised. This builds on an early announcement on October 15th 2014, when a new policy issued jointly by Communist Party of China Central Committee (CPCCC) and SC stated that regulation on electricity pricing will be reduced to a minimum level before 2020. It stated that a market combining residual regulatory operations and market-driven operations will be a unique characteristic of the electricity market of China in the next few years. Moreover, in this new round of market and pricing reform, the central government of China has delegated most of the power to the local provincial governments. Provincial governments are then to test different mechanisms based on local situations.

As was indicated previously, the feed-in tariffs for onshore wind will be reduced in 2016, and again in 2018. For projects commissioned after January 1st, 2016, rates will be cut by 0.02 RMB/kWh for Classes I, II and II, while the Class IV areas (currently the highest, at 0.61 RMB/kWh) will be cut by 0.01 RMB/kWh. For projects commissioned after January 1st, 2018, rates for the first three classes will be cut by an additional 0.03 RMB/kWh, while Class IV will be cut by an additional 0.02 RMB/kWh (CEE News, 2016). The resulting rates are displayed in the table below.

Resource class	Wind feed-in tariff (RMB//kWh)			
	2015	2016	2017	2018
I	0.49	0.47	0.47	0.44
II	0.52	0.50	0.50	0.47
III	0.56	0.54	0.54	0.51
IV	0.61	0.60	0.60	0.58

1.7.3 Results of policy and regulatory framework

There are a number of consequences that can be directly attributed to the policy and regulatory framework implemented by the central government, some more positive than others. Two of the most predominant will be discussed below.

Development of home market

From the very beginning, the Chinese central government has relied on the domestic market in order to develop a Chinese wind manufacturing industry. This is notable because it is in contrast to the Chinese solar industry, which initially relied primarily on exports for its development. As was described above, China was initially far behind in R&D capabilities, but as described in a 2014 paper, “Chinese firms forged ahead by importing production lines, gaining technological licenses through acquisition, and purchasing intellectual property. China’s strong manufacturing base, low labour costs and extensive investment in the industry resulted in Chinese wind energy technology taking a different path from that of its EU counterparts”. (Dai, Zhou, Xia, Ding, & Xue, 2014).

This extensive investment was driven by regulation as well, as large electricity producers were required to have a certain % of their generation capacity from renewables, which lead to large numbers of sometimes low quality domestic turbines being erected. While the local content requirements were abolished in 2009, it is apparent from the figure below that the Chinese government was successful in promoting the development of a domestic wind industry. According to statistics from the China Wind Energy Association (CWEA) the 3 large international wind turbine producers Vestas, GE and Gamesa, only accounted for 0.42 GW of installed capacity in 2014, while the top 10 domestic producers accounted for over 80% of total Chinese installations.

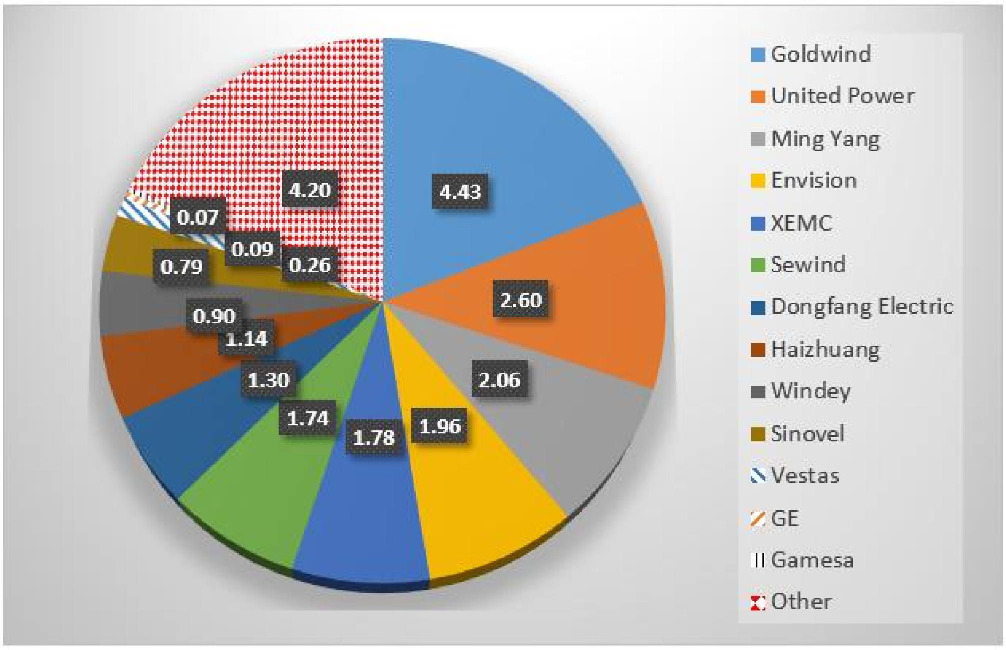


Figure 1-7: Chinese installed capacity in 2014 by supplier (GW). Striped sections represent the three largest international manufactures, while the red dotted section represents all the remaining smaller producers. (Wind Power Monthly, 2015)

Concentration of RE development far from load areas

Another result of the centralised planning is that the vast majority of wind production is located quite far away from major load centres, with the majority of wind development occurring in what is often referred to as the Three Norths Region. These areas have the best wind resources and include Northeast China, the northern part of North China as well as Northwest China.

The concentration of wind production in these relatively sparsely populated areas is complicated by the fact that these regions all have significant heat seasons, the result of which is that coal-fired combined heat and power units are not able to reduce their electricity production enough to allow the integration of all the wind power when it is both cold and windy.

In addition, the long distances from load centres has required the establishment of ultra-high voltage transmission lines, which are capital intensive and also involve transmission losses given the long transport distances.

1.7.4 Challenges

Becoming the world leader in installed wind capacity over such a short time period is an impressive feat, however China is also facing a number of challenges today that it must address going forward.

Curtailment

Chinese wind power development has been very rapid in recent years, and in many provinces measures have not been taken in time to ensure that the developed wind farms can actually feed all their wind energy into the grid. In the so-called 'three norths', established wind farms are frequently curtailed. Wind curtailment is the most pressing and challenging wind related issue in China today, as extremely high curtailment levels are found throughout the country, particularly in the North. Wind curtailment rates for the first quarter of 2016 supplied by the NEA are displayed in the figure below.

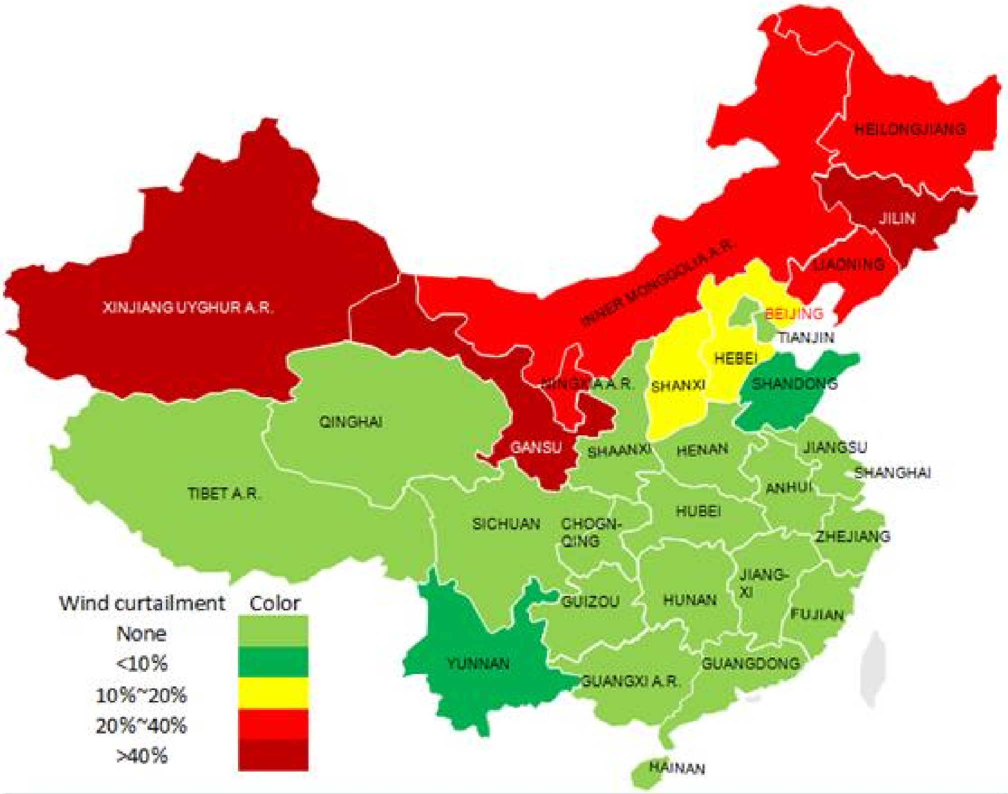


Figure 1-8: Curtailment rates in China for the first quarter of 2016 based on NEA data (Azure, 2016)

The curtailment rates in the norther portion of above figure are astounding, with notable highs being reached in Jilin (53%), Xinjiang (49%), Gansu (48%), and Ningxia (35%). (Azure, 2016). What is particularly problematic with the high curtailment rates in the North, is that in the Northern provinces of China, the heating season is characterised by significant coal consumption with associated emissions. Coal is used for heating in individual heat stoves, district heating heat-only boilers and CHP units. Heat stoves are particularly inefficient and emission-intensive and therefore in many places they are being replaced by expansion of district heating systems. Local heat-only boilers in the district heating systems have varying quality but are generally not state-of-the-art. For this reason, it is further relevant to find ways to displace their coal consumption with other heat supply options. It is relevant to consider solutions which simultaneously address the challenge of increasing curtailment and improve the overall environmental efficiency of the supply-chain for heating.

Curtailment challenges the business cases of wind power developers and leads to wasted opportunities to reduce the consumption of coal and associated emissions including CO_2, NOx, SO_2 and harmful particle emissions. This creates an unfortunate barrier towards future developments of renewable energy and therefore creative solutions are, and should be, actively pursued to mitigate the issue.

Expansion of transmission networks in step with wind expansion

Another challenge that also contributes to the above curtailment issue, is ensuring that transmission network expansion is undertaken in step with wind expansion. There are numerous examples throughout China of situations where curtailment must be undertaken due to bottlenecks in the transmission grid. In order to avoid this, a high degree of coordination between wind park development and transmission network development should be prioritised.

Electricity market reform

Another challenge that the central government is beginning to address, is electricity market reform. Reforms are needed in order to:

- promote flexibility in the system (i.e. provide incentives for thermal plants to run at lower minimum loads, increase ramp rates, etc.)
- abolish guaranteed full load hour agreements
- encourage investment and utilisation of electricity storage options
- utilise transmission capacity more flexibly
- provide incentives to improve and utilise wind and solar forecasts more effectively
- improve and coordinate system dispatch
- provide incentives to place new RE generation in 'system friendly' areas

All of the above reforms will also assist in addressing the curtailment predicament.

Financing of RE production

While the overall share of electricity production from renewables is still rather small (less than 4%), it is growing rapidly, and this will therefore increase the costs of financing RE production. This is particularly a problem in China, which has large reserves of inexpensive coal at its disposal. The central government has already begun to address this issue in part by undertaking the FIT reductions highlighted above, but reducing curtailment rates, and potentially funding RE through CO_2 pricing could be an option going forward.

1.7.5 Lessons learned and key takeaways

Some of the key takeaways from the Chinese wind development include:

- Long-term and stable wind and energy policies provide strong incentives for both domestic and foreign firms to invest in wind technology.

- Flexibility is key. Dispatchers must see and have control of flexible resources and/or markets must be designed to deliver and promote system flexibility.

- Avoid generation deployment hotspots.

- The correct incentives must be place, for example incentives for generators to reduce minimum generation loads, increase ramp rates, invest in and utilise storage efficiently, etc.

- Transmission must be utilised as flexibly as possible, and from an overall system perspective. In addition, a high degree of coordination between wind development and transmission network development should be prioritised.

- The utilisation and development of state of the art forecasting technology for RE production should be prioritised.

- Grid codes must ensure wind turbines/farms meet a number of technical requirements, i.e. fault ride through capabilities and reactive power consumption requirements.

As Egypt expands its wind production, it is worth stating that traditional means of operating and planning a power systems work fine until a certain percentage of variable renewable energy production is achieved. At that point, the paradigm for markets, dispatching, planning, forecasting, etc., must change. China is an example of what happens if this is not recognised and addressed at an early stage. This has led to an overdevelopment of both conventional and variable renewable energy, resulting in stranded costs, massive curtailment of RE production, and roughly 200 GW of coal capacity currently being built, despite the fact that is unlikely required. This is by no means a suggestion that largescale wind development should not be undertaken in Egypt. On the contrary, countries such as Denmark have shown that much higher levels of wind integration can be achieved with very little curtailment. What the case of China does suggest however, is that the above issues should be taken into consideration early in the process, and it highlights the importance of long-term planning with a focus on flexibility and the proper incentives.

1.8 Worldwide Experiences in Wind and Solar Integration, Lessons Learned from USA/California

During the period of 1985 to 1998 no really technical requirements were established for handling wind integration – now technical requirements on frequency and voltage range disconnection, reactive power control capability, low voltage ride through capability, power quality aspects as harmonics, rapid voltage fluctuations, high wind ramp down, electrical simulation modelling, compliance tests etc. In basic terms it was more or less the "Wild West" scenario on wind power.

In the period mentioned the focus were more on Production Tax Credits (PTC) (financial) than on obstacles for delivering optimal active and reactive power services to the electrical power system. Optimal wind positions were even taken into account when designing and establishing the large scale wind power plants in California. If there were no cash impact of the bad performance, no one cares about the missing performance and even the stability impact on the power grid system.

After experience with severe stability impact on the power grid system a row of minimum requirements for connection to the power grid system in form of the standard series - IEEE 1547 (Standard for Interconnecting Distributed Resources with Electric Power Systems) which is a standard of the Institute of Electrical and Electronics Engineers meant to provide a set of criteria and requirements for the interconnection of distributed generation resources into the power grid. The requirements were founded in the period of 1998 – 2005.

The standard series consists of the following individual standards:

- IEEE 1547.1, published in 2005, further describes the testing of the interconnection in order to determine whether or not it conforms to standards.
- IEEE 1547.2, published in 2008, provides a technical background on the standard.
- IEEE 1547.3, published in 2007, details techniques for monitoring of distributed systems.
- IEEE 1547.4, published in 2011, is a guide for the design, operation, and integration of conforming systems.
- IEEE 1547.5, is designed for distributed sources larger than 10 MVA
- IEEE 1547.6, published in 2011, describes practices for secondary network interconnections.
- IEEE 1547.7, published in 2013, provides distribution impact studies for distributed resource interconnection.

Based on the established requirements the current situation for wind integration is were well managed and the operation of wind power plants is more aligned with the global best practice including application of ancillary services from wind power plants on equal basis as for other kind of generation units.

Nowadays solar power plants create a lot of complexity in system operation of renewable energy sources. Based on the fact that it's much more complex to predict clouds than wind, the forecasting procedure adds a lot of challenges to the operation of renewables.

Further reading of Integration of Renewable Resources in California can be obtained in the report from California Independent System Operator (CAISO), November 2007 named as "Transmission and operating issues and recommendations for integrating renewable resources on the California ISO-controlled Grid". An updated version of the challenges of renewable integration in California can be found in the Olivine report from 2014 – "Distributed Energy Resources Integration

Summarizing the Challenges and Barriers", by Robert W. Anderson, Spence Gerber, and Elizabeth Reid, January 24, 2014.

The experience on integration of renewables in California of today is that a huge amount of renewables requires a kind of storage – hydro power, pump storage, batteries, and conversion into gasses etc. a lot of activities on storage are evolving in California as well as in other areas of the globe.

More details about the Californian power system can be found via the following web site link: http://www.caiso.com/Pages/default.aspx

1.9 Power System Analysis with Large Amount of Wind Power

Traditionally only large central synchronous generators were used to generate power. However, wind power and photovoltaic is now becoming an increasingly important source of energy. During the last decades, wind power and PV capacity has increased and the costs of harnessing wind energy and PV have been continually decreasing. At the end of 2015 the total installed capacity of wind power in Europe was approximately 141 GW (15,6 percent) of the total installed power capacity, which is enough to supply 11,4 percent of the electricity demand, with 12.8 GW installed 2015 and on PV the total installed power capacity was 96 GW with 8 GW installed 2015.

1.9.1 Power system stability

Historically power systems, including their generation, were run by monopolies, but since the late 1990s governments across the world have worked at deregulating electricity markets on the assumption that competition will result in their more efficient operation. As more electrical power has been generated and consumed, the expansion of the electricity grid to transport this electricity from producers to consumers has progressed relatively slowly, because of the large costs involved. As a result of this the transmission system is being operated at its limits, and in ways for which it was not designed. Interconnections which were once built to help improve reliability levels are now used for energy trading[1].

Increasing the transfer of power along transmission lines stresses the power system. Once the system is stressed, many undesirable phenomena arise, and these can cause damage to different parts of the system. In order to keep the system operating securely, limits must be placed on power transfers.

[1] The Dynamic Impact of Large Wind Farms on Power System Stability, PhD Thesis, Katherine Elkington

One limit placed on transfers relates to heating. This is the thermal limit, which establishes the maximum electrical current that a transmission line or electrical facility can conduct over a specified time period before it sustains permanent damage by overheating, or before it violates public safety requirements.
Limits on power transfer are also required to keep the power system stable. If the system becomes unstable, then the security of the supply of electricity can be compromised. Power system stability can be classified into three categories:

1. Rotor angle stability refers to the ability of synchronous machines in an interconnected power system to remain in synchronism after being subjected to a disturbance. Instability may result in the form of increasing angular swings of some generators, leading to their loss of synchronism with other generators. Even sustained oscillations that are damped slowly may result in faulty tripping of protection equipment, and undesirable strain on the turbine shafts in power plants. Rotor angle stability can be divided into two types.

- Small-signal rotor angle stability which refers to the ability of the power system to maintain synchronism under small disturbances. These disturbances are small in the sense that linearisation of system equations can be performed to analyse system performance. This type of stability depends on the initial operating state of the system.

- Transient stability, which is concerned with the ability of the power system to maintain synchronism when subjected to a severe disturbance.

2. Frequency stability refers to the ability of a power system to maintain steady frequency following a severe system upset which results in a significant imbalance between generation and load. If there is an excess of load, kinetic energy from generators is used to supply the loads, which causes the generators to decelerate and the system frequency to decrease. Similarly if there is a load deficit, kinetic energy will build up in the generators, causing the frequency to increase.

3. Voltage stability refers to the ability of a power system to maintain acceptable voltages at all nodes in the system. A voltage collapse typically occurs when not enough reactive power is being produced to energise the power system components, and is often a slow process. A possible outcome of voltage instability is loss of load in an area, or tripping of transmission lines and other elements by their protective systems, leading to cascading outages.

To determine whether or not the system is secure, the N-1 criterion is often applied. This criterion was introduced after the 1965 Northeast USA blackout. The N-1 criterion, in its simplest form, says that the system should be able to withstand the loss of any component, for example, line, transformer or generator, without jeopardising the operation of the system. It is widely used in power system operation today all over the world. By examining contingencies arising from the loss of one component, and evaluating the resulting stability, power system security can be tested.

Transfers may be limited because of rotor angle stability. The oscillations occurring between large groups of machines, called inter-area oscillations, are most likely to occur when ties between the areas are weak or heavily loaded. By determining an acceptable level of power oscillation damping, transfer limits can be set. They can also be set by reference to the clearing capabilities of protection equipment. Higher transfers usually lead to shorter critical clearing times and, if breakers are not able to activate quickly enough after a fault, parts of the power system may lose synchronism.

Increasing transfers may also pose a problem for frequency stability. If transfers are increased, it is usually because there are loads in another area which need to be supplied. Supplying the extra loads reduces reserves, and the system may not be able to accommodate the loss of the largest generating unit without an unacceptable reduction in frequency. It is not a large transfer in itself which causes a problem for frequency, but the fact that large imbalances can arise when production is lost.

Large transfers also require large amounts of reactive power. As transfers become larger, voltages decrease along transmission lines. If there is a lack of reactive power at the receiving end of a line, then the system can lose voltage stability. By setting limits for acceptable voltages, a transfer limit can be determined.

1.9.2 Compensation Methods

Reactive Power Compensation Methods
Reactive power compensation is needed in order to manage reactive power, to regulate the power factor of the system and to improve the performance of the AC system. Reactive power (VARs) is required to maintain the voltage, which is consumed by transformers, transmission lines and consumers. The restriction on reactive compensation is that it shall be generated/consumed in close vicinity to the area where it is needed.

Power Generators
To use the existing power generators reactive capability is a common way to compensated, and is also to be considered as the primary source of voltage support, some of the drawbacks especially with Renewable where the transmission in the system will increase, is that the generator is not always in the area where the reactive support is required. Also due to the generation from remote power generators, the power generator to generate reactive support is not in operation (most generators have a minimum generation capacity), since the power is generated from renewables. Also to keep a power plant running in order to supply reactive power is quite expensive.

To use the reactive power capability of the renewables shunt be utilized, but these devices can't control the voltage at consumers which are often far away.

Shunt compensation
The device connected in parallel with transmission line is called the shunt compensator. Shunt connected Reactors used to limit the overvoltage while the shunt connected Capacitors are used to maintain the voltage levels by compensate reactive power to the transmission system. The main advantage is low cost and flexibility of installation and operation. Disadvantage is that reactive output is proportional to square of the voltage. They should preferable be installed at the distribution levels when compensating loads and on transmission levels when compensation transmission losses.

Series compensation
When a device is connected in series with the transmission line it is called series compensation. Both capacitive and inductive modes of operation exists. The advantage to use series compensation to compensated reactive losses on the transmission lines, is that the devices is current dependent, thereby only few switching operations is require, the device is self regulating. Some of the drawbacks is that series compensation can increase Sub synchronous Resonances by changing the resonances of the system. The device series capacitors or Thyristor Controlled Seires Capacitors TCSC. With the TCSC the power osculation in the system can be actively damped. All equipment is place on HV potential.

Synchronous condenser
The Synchronous condenser SC is a machine introduced to supply MVAR to the system. The Synchronous condenser is used typical where the system needs reactive power support but also short circuit power. The SC is not as fast as a SVC. This could be in weak systems with connection of conventional thyristor base High voltage DC transmissons. HVDC

Static VAR compensators (SVC)
SVC is a thyristor controlled electrical device build with Capacitors and reactive for providing reactive support to transmission networks. The SVC is fast acting within 2-3 periods 30-60ms and able to control the voltage, both by limiting the voltage and supporting the voltage dynamically, and thereby to increase the transmission capacity on existing lines and to damp power swing. The disadvantage is the this device is more expensive than shuntbanks.

Is the requirements faster reactive support, the static compensator STATCOM is to be considered. The STATCOM uses a Voltage source inverter of either IGTB (transistors) or GTO (Gate Turn of Thyritors) and is able to react less than 1 period 20ms and does also not require the same amount of space as the SVC. The STATCOM is more expensive than the SVC.

VSC HVDC or HVDC can be used to transmit large amount of reactive power across large distances and thereby minimize the stress on the existing transmission lines.

2 Assumptions and Approach of the Study

2.1 Introduction

In this section the assumptions and approach for the study is outlined and it is the basis for the analysis of this study. EETC and the Consultant has cooperated hand-in-hand in order to have the most relevant and sufficient data for the study, which is presented in the following sections.

2.2 Power System and Energy Model Tool

The wind turbine/solar PV modelling and grid simulations are conducted in the Power System Simulator for Engineering software package PSS/E™ version 33.5.

The analyses to potential curtailment of wind power and the creation of realistic generation profiles for the study is based on the energy model Balmorel. The Balmorel model computes optimal dispatch of generation for all hours of the year and based on this, several critical cases in the power system are selected. These dispatch snapshots are to be used for implementation in the PSS/E model, where a further analysis of the grid stability is performed. Balmorel is an open source model[2].

2.3 EETC PSS/E Data File

EETC has provided the Consultant with an existing file of the Egyptian Power System in PSS/E for year 2015 and year 2018.

The Consultant has together with the dedicated EETC staff from Transmission Planning Department and Energy Efficiency Department, checked and updated any mismatch or error in the existing files. The Consultant has prepared the dynamic models and the aggregated models for the wind farms and solar PV farms, which the Consultant has implemented in the existing PSS/E files.

2.4 EETC Generation Capacity for year 2015 and 2018

The capacity for each main generation unit for year 2015 and year 2018 is listed Table 2-1.

Location	Plant name	Type	Cap. 2015 [MW]	Cap. 2018 [MW]
South Upper Egypt	High Dam	(H)	2,340	2,340
	Aswan Dam I	(H)	329	329
	Aswan Dam II	(H)	268	268
	Esna	(H)	90	90
	New Naga Hamadi	(H)	64	72
	Benban	(S)	0	2,000
North Upper Egypt	Cairo West	(ST)	0	650

[2] See this link for examples of use of the model: ea-energianalyse.dk/themes/modelling_of_energy_systems_balmorel.html
See: www.balmorel.com for further information.

	Walidia	(ST)	630	1,280
	Kuriemat	(CC)	1,254	1,254
	Kuriemat 1	(CC)	750	750
	Kuriemat 2	(ST)	500	500
	Assiut	(GT)	143	1,575
	Assiut New	(ST)	1,053	500
	GERGA	(ST)	53	0
	MALAWI	(ST)	53	0
	GALEB	(ST)	53	0
	SAMALOT	(ST)	53	0
	Bani Seuif	(CC)	0	4,200
	Kuriemat Solar / Thermal	(S/CC)	140	140
	Nile Wind	(W)	0	0
	Kuriemat PV	(S)	0	20
Canal	Zafarana(Wind)	(W)	547	547
	Hurghada wind	(W)	5	37
	Gabel El Zayt	(W)	200	540
	Suez gulf wind	(W)	0	0
	Suez gulf wind AFD	(W)	0	200
	FIT	(W)	0	2,000
	Masder	(W)	0	250
	BOO	(W)	0	200
	Auction	(ST)	0	0
	Ataka	(ST)	1,730	1,950
	Abu Sultan	(ST)	600	600
	Shabab	(GT)	590	840
	New Gas Shabab	(GT)	1,000	1,000
	Port Said(4)	(GT)	54	154
	Arish	(ST)	60	60
	Oyoun Mousa	(ST)	640	660
	Sharm El-Sheikh(5)	(GT)	425	478
	Hurghada	(GT)	300	443
	Suez Gulf (BOOT)	(ST)	682	736
	PortSaid East(BOOT)	(ST)	932	986
	El-Ain Al-Sokhna	(ST)	1,300	1,300
	GULF GTZ	(ST)	650	650
Cairo	Shoubra El-Kheima	(ST)	1,260	1,260
	Cairo West Ext(1)	(ST)	1,608	1,360
	Cairo South I	(CC)	600	585
	Cairo South II	(CC)	175	175
	Cairo North	(CC)	1,500	1,570
	Cairo East	(GT)	52	52
	El-Tebeen	(ST)	700	700

	Wadi Hof	(GT)	99	99
	6 October	(GT)	1,200	1,515
	Giza North	(CC)	2,250	2,340
	Basateen	(GT)	52	52
	HELIOPOLIS	(GT)	52	52
	Helwan South	(ST)	0	1,910
	New Cairo	(ST)	0	2,800
Middle Delta	Damietta	(CC)	1,125	1,125
	New Gas Damietta	(GT)	500	500
	Damietta West(3)	(GT)	1,000	3,750
	Talkha	(ST)	382	382
	Talkha 210	(ST)	420	420
	Talkha 750	(CC)	750	750
	Banha powerplnat	(CC)	750	750
	El-Atf	(ST)	750	750
West Delta	Nubaria 1,2	(ST)	1,500	1,500
	Nubaria 3	(CC)	750	750
	Mahmoudia	CC)	608	384
	Mahmoudia 2	(GT)	200	510
	Kafr El-Dawar	(ST)	440	460
	Damanhour Ext	(ST)	366	366
	Damanhour (Old)	(ST)	195	195
	Damanhour	(CC)	150	150
	Sidi Krir 3,4 (BOOT)	(CC)	0	630
	West-Borolus	(CC)	0	2,835
	BINS	(ST)	0	750
Alexandria	El-Seiuf	(GT)	165	1,170
	Abu Kir	(ST)	915	915
	New Abu Kir(6)	(ST)	1,230	1,230
	Sidi Krir 1.2	(CC)	1,322	1,322
	Sidi Krir	(ST)	750	750
	Matrouh	(ST)	60	60

Table 2-1: Detailed overview of type and generation capacity installed in year 2015 and year 2018. (CC: Combined cycle gas turbine, ST: steam turbine, GT: gas turbine, S: solar, W: wind, H: hydro)

2.5 EETC Wind Power Generation Plan year 2015

A detailed overview is presented with the current wind power generation connected to the Egyptian grid system and wind farms under construction to connected to the grid system before year 2018.

P. short	Project	Connection	Wind turbine	Generator	Size/kW	No. of turbines	Total/MW
ZAF1	Zafarana 1	Zafarana new	Nordex	Type 1	600	50	30
ZAF2	Zafarana 2	Zafarana	Nordex	Type 1	600	55	33
ZAF3	Zafarana 3	Zafarana new	VESTAS	Type 2	660	46	30.36
ZAF4	Zafarana 4	Zafarana	Nordex	Type 1	660	71	46.86
ZAF5	Zafarana 5	Zafarana	Gamesa	Type 3	850	100	85
ZAF6	Zafarana 6	Zafarana	Gamesa	Type 3	850	94	79.9
ZAF7	Zafarana 7	Zafarana	Gamesa	Type 3	850	142	120.7
ZAF8	Zafarana 8	Zafarana new	Gamesa	Type 3	850	142	120.7
	Hurghada	Hurghada		Type 1			5.4
Zayt1	KfW/EIB Gabel El Zayt	Gabel-El Zayt substation	Gamesa	Type 3	2000	100	200
Wind farms under construction							
Zayt2	JICA Gabel El-Zayt	Gabel-El Zayt substation	Gamesa	Type 3	2000	110	220
Zayt3	Spanish Gabel El Zayt	Gabel-El Zayt substation	Gamesa	Type 3	2000	60	120

Table 2-2: Detailed overview of current wind power connected to the grid system and modelled in PSS/E file for year 2015.

2.6 EETC Wind Power and Solar PV Generation Plan year 2018

A detailed overview is presented with the current wind power generation connected to the Egyptian grid system and future solar PV and wind farms expected to be connected to the grid system by year 2018.

P. short	Project	Connection	Wind turbine	Generator	Size/kW	No. of turbines/PV	Total/MW
ZAF1	Zafarana 1	Zafarana new	Nordex	Type 1	600	50	30
ZAF2	Zafarana 2	Zafarana	Nordex	Type 1	600	55	33
ZAF3	Zafarana 3	Zafarana new	VESTAS	Type 2	660	46	30,36
ZAF4	Zafarana 4	Zafarana	VESTAS	Type 2	660	71	46,86
ZAF5	Zafarana 5	Zafarana	Gamesa	Type 3	850	100	85
ZAF6	Zafarana 6	Zafarana	Gamesa	Type 3	850	94	79,9
ZAF7	Zafarana 7	Zafarana	Gamesa	Type 3	850	142	120,7
ZAF8	Zafarana 8	Zafarana new	Gamesa	Type 3	850	142	120,7

HurT1	Hurghada	Hurghada		Type1			5,4
Zayt1	KfW/EIB Gabel El Zayt	Gabel-El Zayt substation	Gamesa	Type 3	2000	100	200
Zayt2	JICA Gabel El-Zayt	Gabel-El Zayt substation	Gamesa	Type 3	2000	110	220
Zayt3	Spanish Gabel El Zayt	Gabel-El Zayt substation	Gamesa	Type 3	2000	60	120
AFD1	AFD1(KFW)	Suez Gulf (RAS Ghareb)	Generic	Type 3	2000	100	200
AFD2	AFD2	Suez Gulf (RAS Ghareb)	Generic	Type 3	2000	100	200
BOO	BOO	Suez Gulf (RAS Ghareb)	Generic	Type 3	2000	100	200
MAS	Masdar	Suez Gulf (RAS Ghareb)	Generic	Type 3	2000	125	250
FIT1	FIT	Suez Gulf (RAS Ghareb)	Generic	Type 3	2000	250	500
FIT2	FIT	Suez Gulf (RAS Ghareb)	Generic	Type 3	2000	250	500
FIT3	FIT	Suez Gulf (RAS Ghareb)	Generic	Type 3	2000	250	500
FIT4	FIT	Suez Gulf (RAS Ghareb)	Generic	Type 3	2000	250	500
Benban1	Benban	Benban	Generic	PV	2000	250	500
Benban2	Benban	Benban	Generic	PV	2000	250	500
Benban3	Benban	Benban	Generic	PV	2000	250	500
Benban4	Benban	Benban	Generic	PV	2000	250	500

Table 2-3: Detailed overview of the current wind power connected to the grid system and future expected solar PV and wind farms to be connected to the grid system by 2018.

2.7 Wind profiles for the study

Wind speed time-series for the Nile, the Gulf of Suez and in Zafarana are modelled and generated through wind data measurements from met masts in Egypt and through meso-scale models. The full load hours for the respective areas are 2530, 3945 and 3265. The wind power along the Nile is located in the North Upper Egypt region, whereas the Gulf of Suez and Zafarana are situated in Canal.

In Table 2-4 and Figure 2-1 details are presented with met mast data and meso-scale simulation graph of the wind speed in the areas.

Wind data site	Mast to use	Easting (UTM-84)	Northing (UTM-84)	Z	From	To	Months	Umean	in height
Zafarana	Zaf.7	463930	3227176	18	jan-08	dec -09	23	8,1	47,5
ElZayt-North	North_ 1	483766	3128438	337	sep-13	sep -14	12	8,1	80
ElZayt-South	M2	500686	3112586	231	feb-13	feb-14	12	10,4	80
Nile west	M1	240137	3166072	140	feb-12	nov -13	21	7,8	81,5

Table 2-4: Details of wind met mast data used for the inputs to the study.

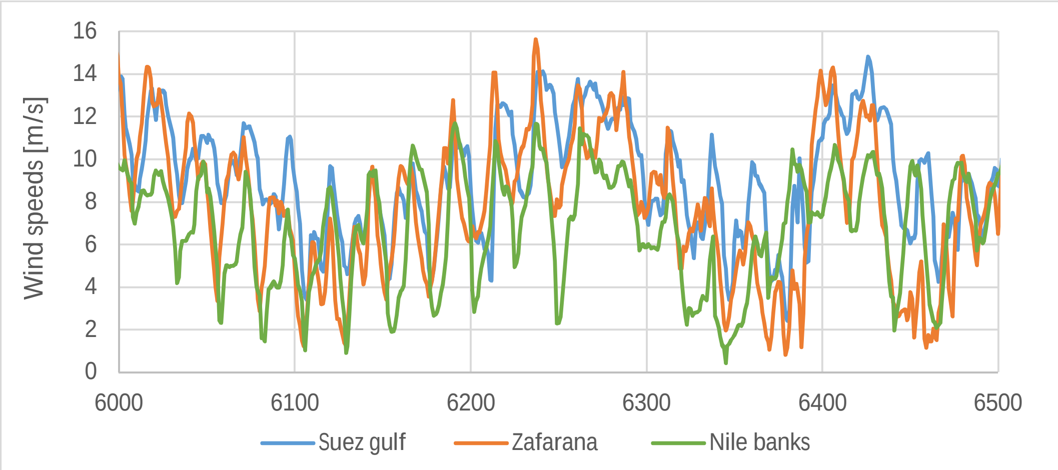


Figure 2-1: Wind Speed data in Egypt (Hours 6000-6500)

3 Economic Model of Egyptian Electricity System

3.1 Introduction

With introduction of large amount of wind and solar generation many new generation patterns will develop. In addition to the well-known variation in demand (day/night, weekdays/weekends, winter/summer) the weather dependent variation from wind and solar will generate need for change in practical operation of the Egyptian grid.

Two tasks will be developed in this chapter:

- Study of the operational impact in various scenarios with increasing wind power capacity in the Egyptian system. The value of the generated electricity from wind power will be described together with the need for forced curtailment of wind power (Section 3.3).
- Critical generation patterns will be developed for 2015 and 2018. These generation patterns will then be used as input data for the PSS/E model study, for detailed analyses of voltage and grid stability in these extreme situations (Section 3.4).

This chapter presents the development of data table generation profiles for year 2015 and year 2018 with wind power and solar power, generated through the EETC hourly system load data for year 2014. The Balmorel generation data profiles for year 2015 and year 2018 represents "extreme situations" generated with max/min. demand with full wind generation meaning all wind farms are generating at full capacity, and no wind power generation, respectively, when all wind farms are shut down. The Balmorel model generation data will then be used as input data for the dynamic PSS/E model study, for analysis the grid stability in these extreme situations.

3.2 Egyptian Power Model Setup in Balmorel

The Egyptian power system has been modelled using the Balmorel model. The model optimise the dispatch by minimising the total costs of supplying electricity. The procedure takes into account the marginal costs of the individual power plants (fuel price divided by efficiency) as well as start/stop costs and restrictions on the transport between zones.

The electricity system is modelled as consisting of 7 zones: Cairo, North Upper Egypt, South Upper Egypt, West Delta, Middle Delta, Alexandria and Canal (Figure 3-1: Regions defined in the Balmorel Model). This division is based on the Egyptian generation companies, where Hydro power generation is included in Upper Egypt.

The transmission grid is simplified and represented by 11/13 lines (2015/2018) between the zones as shown in Table 3-3 and Figure 3-6. The actual transmission system has 326 busbars (31 at 132 kV, 268 at 220 kV, 1 at 400 kV, 26 at 500 kV).

Figure 3-1: Regions defined in the Balmorel Model

Unit commitment limitations were added to the generation units to represent a more realistic dispatch. Constraints as start-up costs, minimum up and down time, ramp-up rates and fixed fuel use are included. The unit commitment parameters differ per fuel and technology type, see Table 3-1. The Egyptian electricity system was modelled for 52 weeks in 2015 and 2018 with hourly resolution. Fuel prices are shown in

Fuel-/Technology	Start-up costs	Min. gen.	Fixed fuel use	Min. down	Min. up	Ramp up	Ramp down
Units	[$/MW]	[% of total capacity]	[% of fuel use at full cap]	[Hours]	[Hours]	[% of full cap/hour]	[% of full cap/hour]
Nat. gas – CC	194,1	0,46	0,2	3,15	2,63	2,5	1,97
Nat. gas – GT	97,9	0,34	0,17	0,64	0,62	7,33	8,07
Nat. gas – ST	210,7	0,14	0,08	4,0	3,5	0,9	0,9
Coal	353,6	0,37	0,1	5,0	3,2	0,8	1,2
Nuclear	530,3	0,5	0,0	0,0	0,0	1,2	1,2
Fuel oil	205	0,32	0,08	4,0	2,2	0,7	0,9
Light oil	61,6	0,23	0,19	0,0	0,0	9,1	12,1
Water	0,0	0,38	0,0	0,0	0,0	14,6	37,7

Table 3-1: UC parameters

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USD/GJ	Coal	Natural gas	Fuel oil	Light oil
2015	5.12	9.78	18.46	22.71
2018	5.23	10.55	18.69	23.05

Table 3-2: Fuel prices

3.2.1 Electricity demand

For the electricity demand, projections from the EEHC (Egyptian Electricity Holding Company) up to the year 2026 are used.

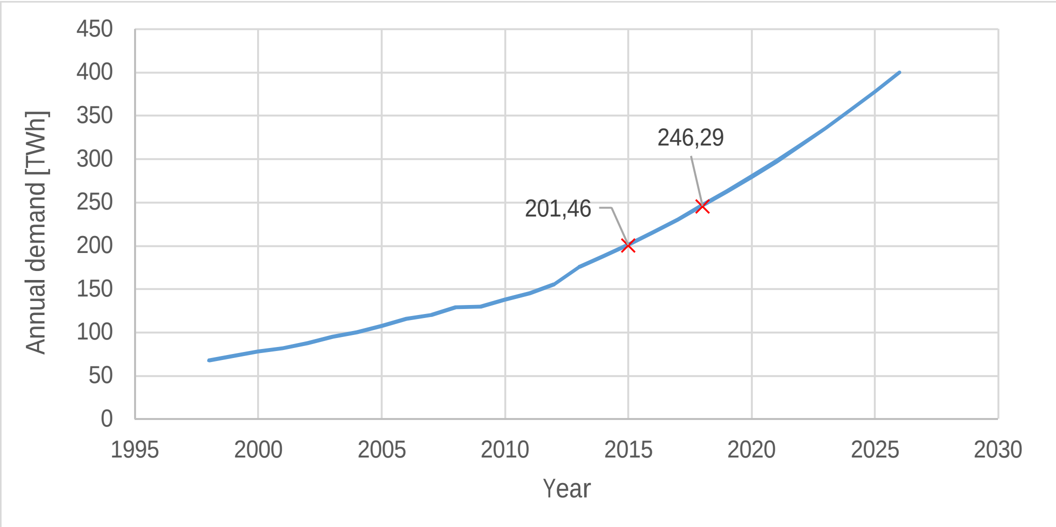


Figure 3-2: Projected Egyptian annual electricity demand in TWh - red marks: year 2015, 2018

Shares per region are obtained from aggregated EETC values for 2015, and kept constant for 2018.

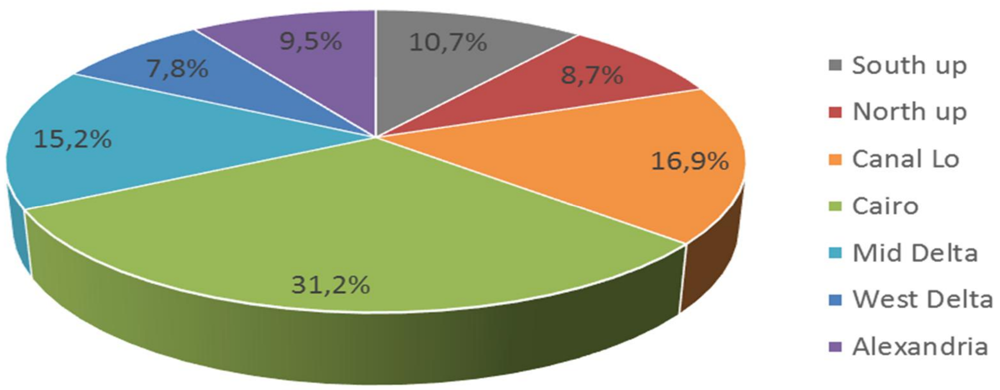


Figure 3-3: Share of total demand per region

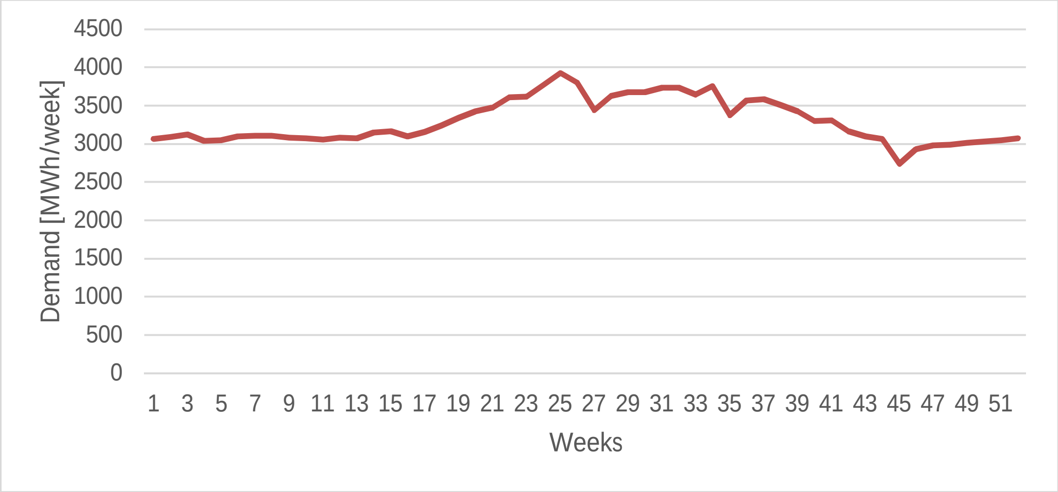


Figure 3-4: Seasonal variation in demand

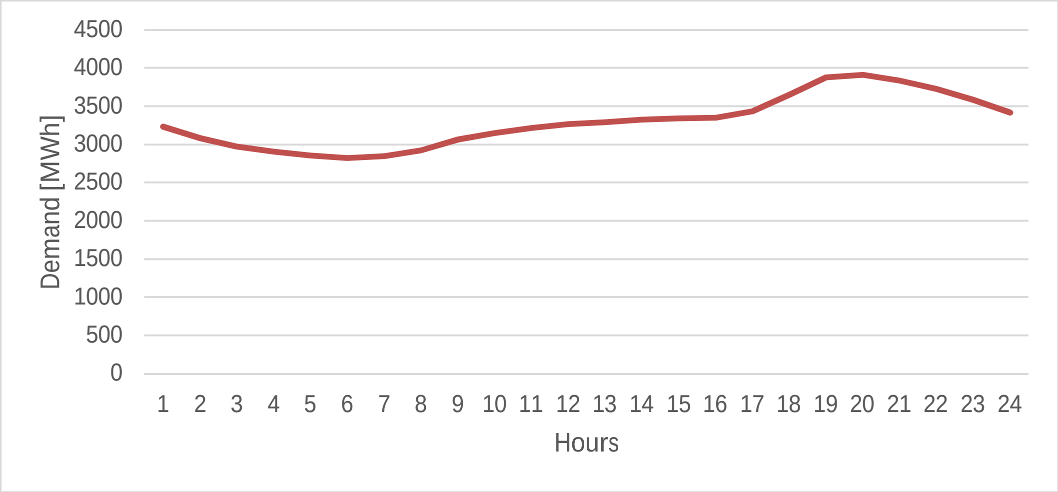


Figure 3-5: Average daily demand profile

3.2.2 Generation

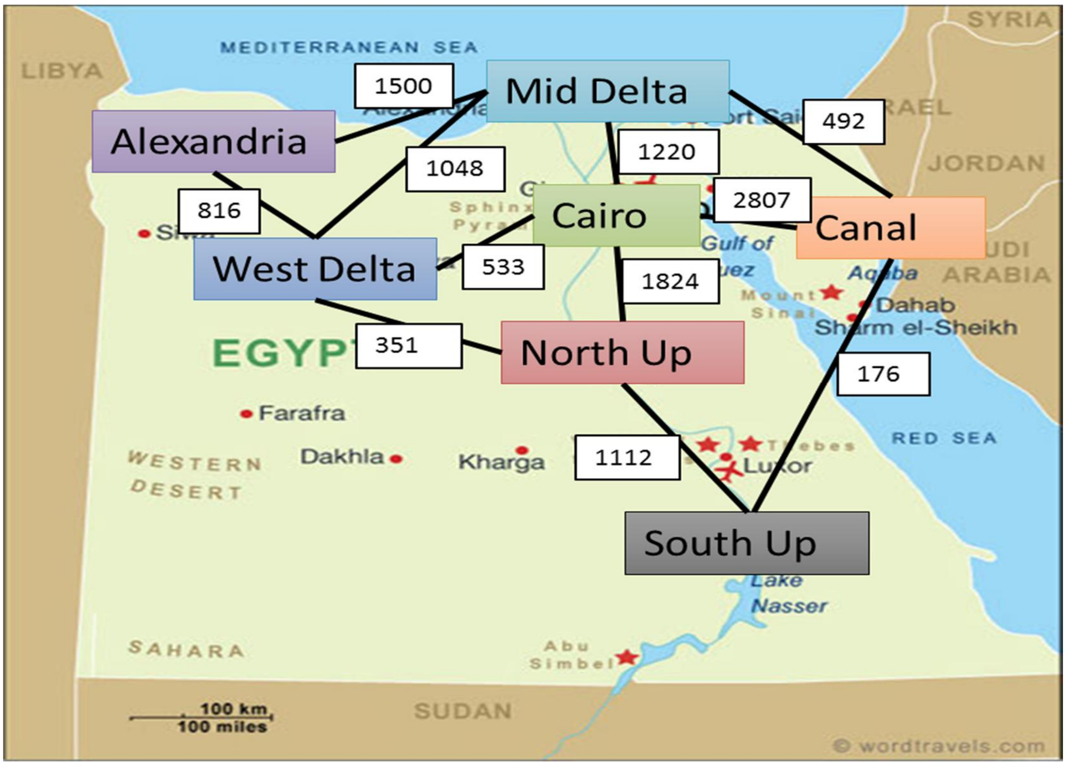
The generation input data is based on input obtained from the EETC (Egyptian Electricity Transmission Company). The list of generators and their capacities were shown in chapter 2.

3.2.3 Transmission

Transmission capacities are based on input obtained from the EETC, the seven transmission zones used by the EETC are aggregated to fit the five Balmorel regions. The transmission capacities between the regions are shown in Table 3-3 and Figure 3-6.

	2015	1	2	3	4	5	6	7
1	SOUTH UP	-	1112	176				
2	NORTH UP	1112	-		1824		351	
3	CANAL	176		-	2807	492		
4	CAIRO		1824	2807	-	1220	533	
5	MID. DELTA			492	1220	-	1048	1500
6	WEST DELTA		351		533	1048	-	816
7	ALEXANDRIA					1500	816	-
	2018	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1	SOUTH UP	-	3495	457	1882			
2	NORTH UP	3495	-	2304	7269		1473	
3	CANAL	457	2304	-	7009	1567		
4	CAIRO	1882	7269	7009	-	5951	3817	
5	MID. DELTA			1567	5951	-	9202	1386
6	WEST DELTA		1473		3817	9202	-	9267
7	ALEXANDRIA					1386	9267	-

Table 3-3: Typical, maximum transfer capacity between the zones.



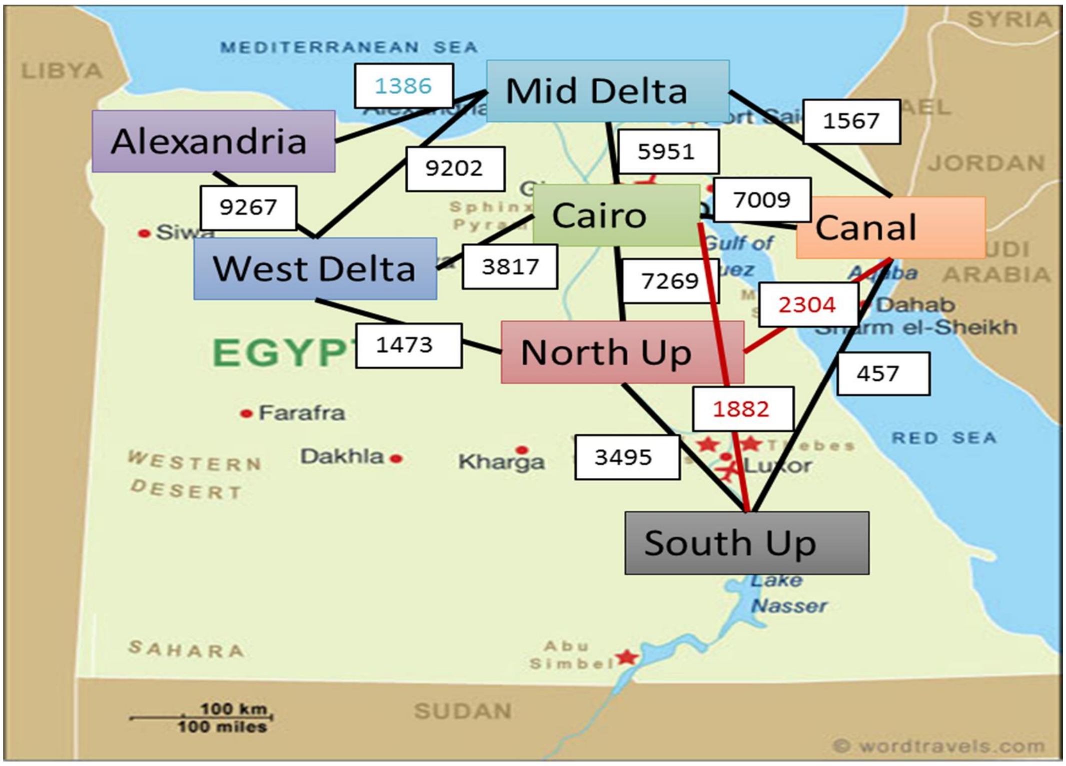


Figure 3-6: Balmorel transmission capacities (MW) between the regions. 2015 (up) and 2018 (down).

3.2.4 Wind profiles

Wind farms on the banks of the Nile, in the Gulf of Suez and in Zafarana are modelled with wind speed time-series provided by EMD International AS. A standard power curve is used to obtain the power output values. The full load hours (FLHs) for the respective areas are 2530, 3945 and 3265. The wind power along the Nile is located in the Upper Egypt region, whereas the Gulf of Suez and Zafarana are situated in Canal.

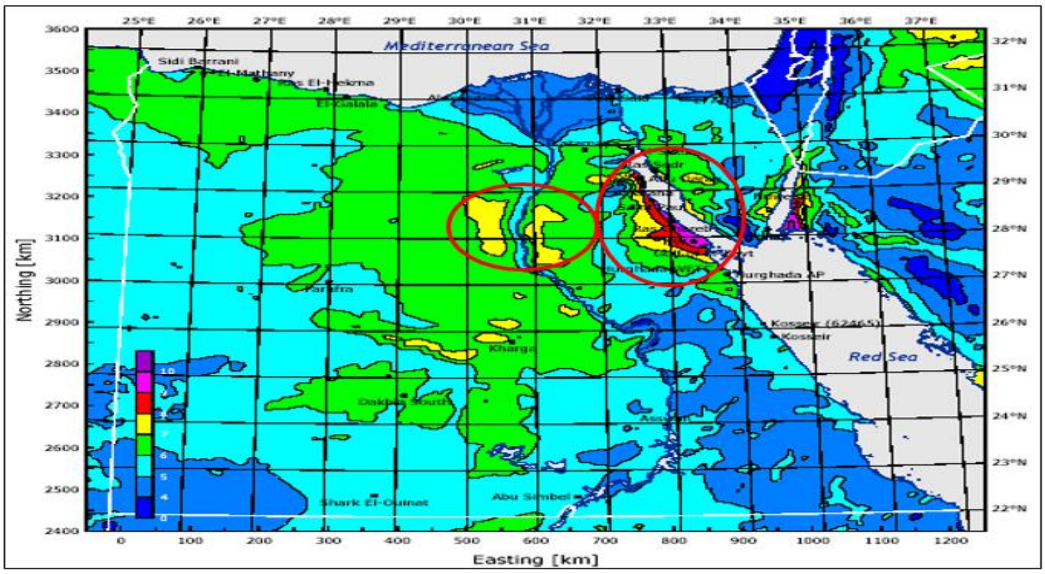


Figure 3-7: Wind speed atlas of Egypt

3.2.5 Bird migration route and wind power curtailment

An important bird migration route of soaring birds passes through the Gulf of Suez, located in Canal (Figure 3-8). The impacts of bird migration in this region are modelled by decreasing the wind power output by 0%, 25%, 50%, 75% or 100% (partial shut-down of the wind farm) during the potential flight hours of the birds. These hours are identified between 9 a.m. and 7 p.m. during 3 months in spring (starting 17th of February) and 3 months in fall (from 18th of August). The shut downs are randomized ensuring a total decrease in annual generation of 8%. Figure 3-9 shows 96 exemplary hours during fall season.

Figure 3-8: Bird migration routes

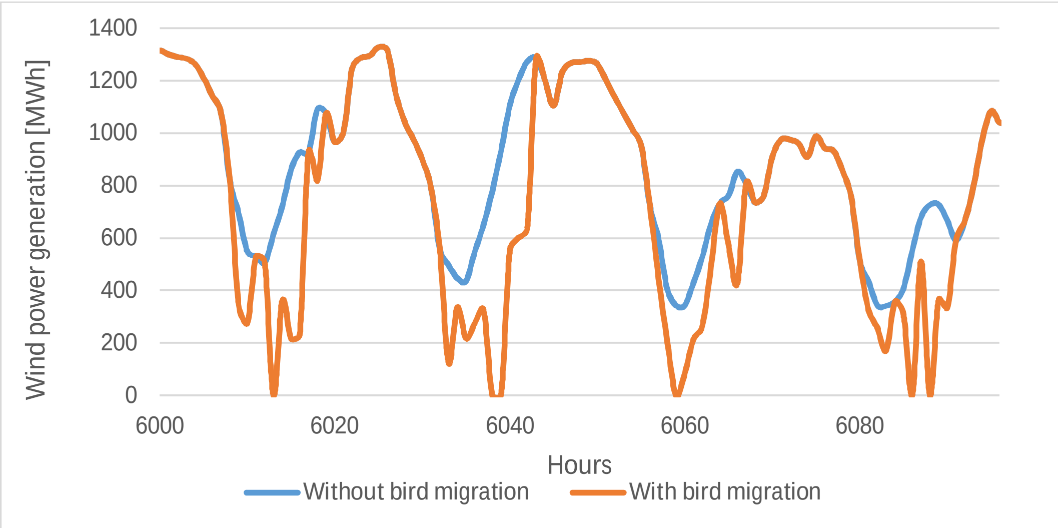


Figure 3-9: Wind power generation for 96 hours modelled with and without bird migration. Selected hours.

3.2.6 Recommended data improvements

The data used for this study are considered to be relevant and general of high quality. The data about generation capacity (all types of generation) are detailed and accurate. The wind profiles are generated to this project and are of high quality.

However, some data can be further improved to increase the overall accuracy. The electricity demand profiles (hourly values) for each of the seven zones should be updated. Currently the national demand profile are scaled to represent each of the seven zones. In reality the profiles will be different – reflecting the different representation of end-users in the zones (e.g. the share of households and industry).

The values used to describe the dynamic properties of the generators (ramp rates, start/stop costs, minimum generation levels) are based on standard values found in literature. These values should be reviewed and adapted to actual generators. E.g. it can be expected that old and new generators has different values.

Finally it is recommend to update demand prognosis and fuel prices, as these are central parameters and are likely to change over time.

3.3 Value of wind power and potential curtailment

In order to assess the impact of increased amounts of wind power in the Egyptian power system, sensitivity analyses were performed in which wind power capacity was gradually added to the power system in 2015. In a sensitivity analysis, 2500 MW is added per simulation (1250 MW in the Suez Gulf, and 1250 MW on the Nile banks) until a total of 25,000 MW is added to the existing capacity.

The last section looks at the economic impact of shut-downs due to bird migration that are not taken into account in the sensitivity analysis.

In Figure 3-10 the effect of increased wind power capacity on various monetary variables is shown. The value of wind (VOW), being the marginal short-term price weighted according to wind production, is initially equal to the overall marginal price and the prices in the regions with wind power (Canal and North Upper Egypt). The wind power production thus does not have a large impact on the marginal prices. This is beneficial for the wind power producers. The impact of the wind power production on the VOW is initially low, but gradually the VOW decreases with increasing wind capacity to a point where it drops beneath the average marginal prices. The overall impact on both the marginal price and the VOW at 7000 MW added wind power remains relatively low. For the Egyptian power system to experience serious drops in marginal price and VOW, much larger shares of wind power need to be added. Figure 3-10 illustrates that at about 15 GW of added wind power capacity, the drop in the marginal prices of Canal and North Upper Egypt and in the VOW becomes substantial. The impact in Upper-Egypt is lower compared to East-Delta, due to its lower wind production (lower FLHs) and the balancing capacity of the hydro generation (the High Aswan dam).

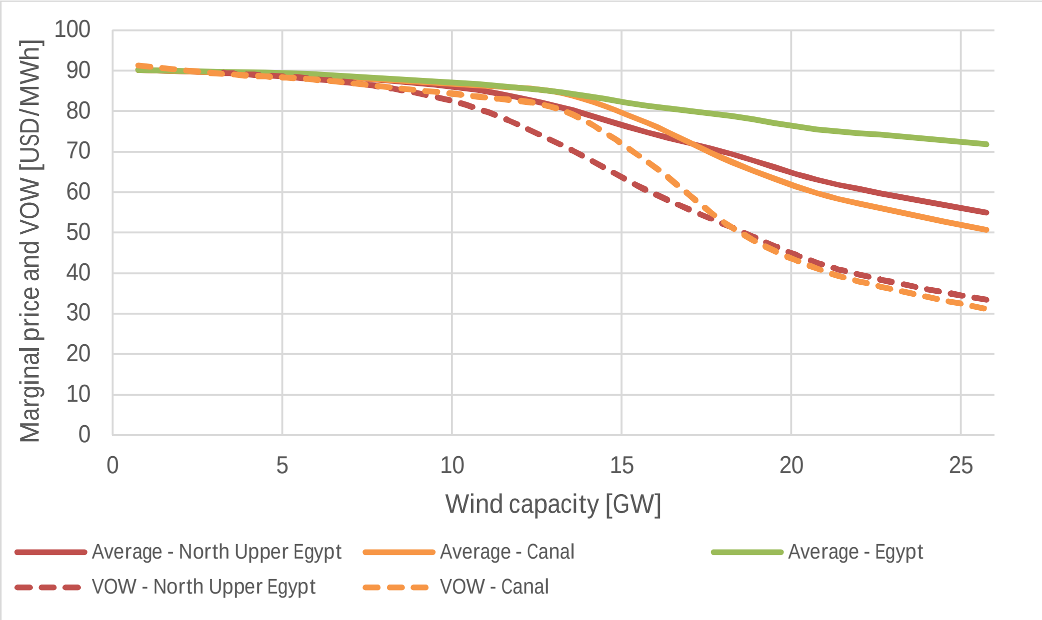


Figure 3-10: Value of wind and marginal price versus larger amounts of wind capacity

Figure 3-11 explains the large drop in prices. At a value of about 15 GW additional wind power capacity, small amounts of wind curtailment start occurring. The difference between the simulations with and without unit commitment is very small (values below 0.3 percentage point). This indicates that the share of curtailment due to dynamic properties is negligible. It is therefore concluded that most of the curtailment seen is caused by transmission constraints. Congestion in the transmission lines connecting the wind power areas with major consumption regions, results in the isolation of these regions. A consequence is that most of the wind power is consumed in the region where it is produced, with low marginal prices (and VOW) as a consequence.

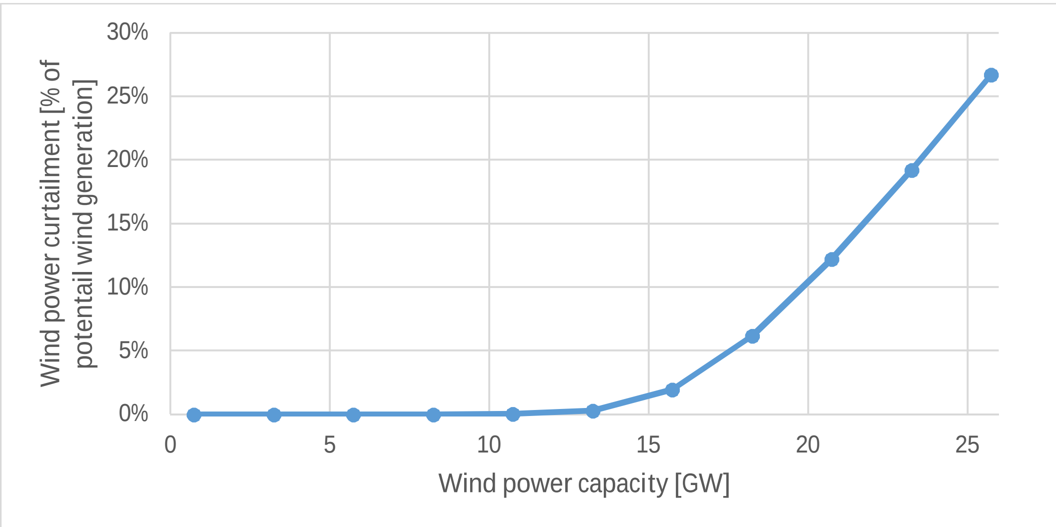


Figure 3-11: Wind curtailment versus larger amounts of wind capacity

The duration curves in Figure 3-12 and Figure 3-13 show that especially the lower end of the marginal prices are decreased drastically, both for the overall and the Canal marginal price. In Canal, marginal prices close to zero are encountered for high amounts added wind capacity.

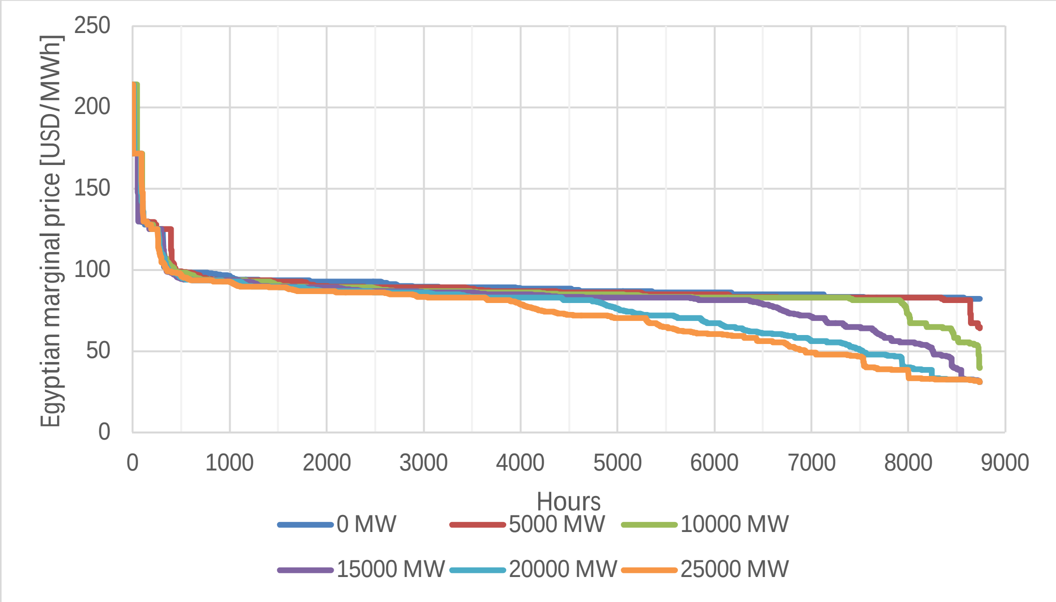


Figure 3-12: Overall Egyptian marginal price duration curve for several cases of added wind

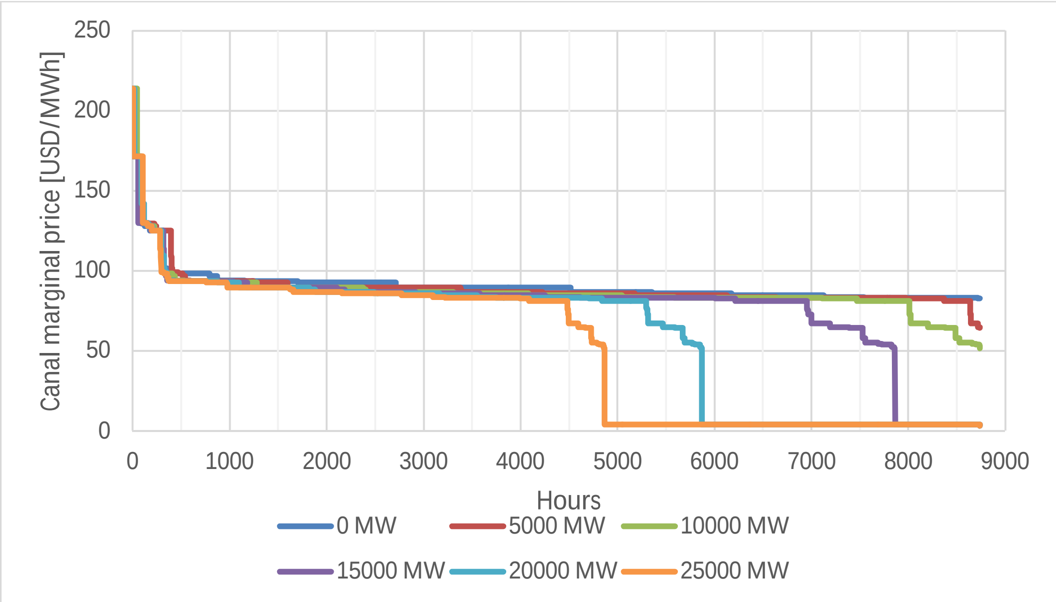


Figure 3-13: Canal marginal price duration curve for several cases of added wind

Figure 3-14 shows the capacity factor (net annual transmission divided by the capacity and the number of hours in the year) of some of the transmission lines between Balmorel regions. As expected, transmission out of regions with wind power generation increases. The capacity factors for the lines Canal to Cairo and North Upper Egypt to Cairo show higher capacity factors with increased wind power capacity, converging to about 46% and 56% respectively. The percentage of hours at which the transmission lines are used at full capacity are shown for those two lines in Figure 3-15. Regions that were originally supplying a large share of electricity, as Mid Delta and West Delta, transmit less power when more wind power is installed and Cairo imports power from Canal and North Upper Egypt.

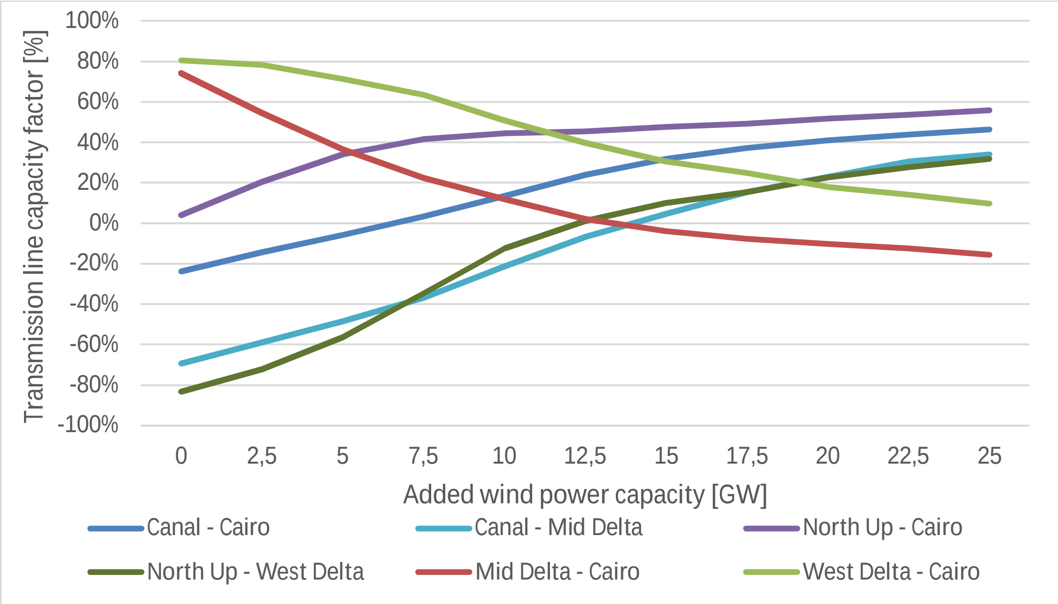


Figure 3-14: Transmission line capacity factor versus larger amounts of wind capacity

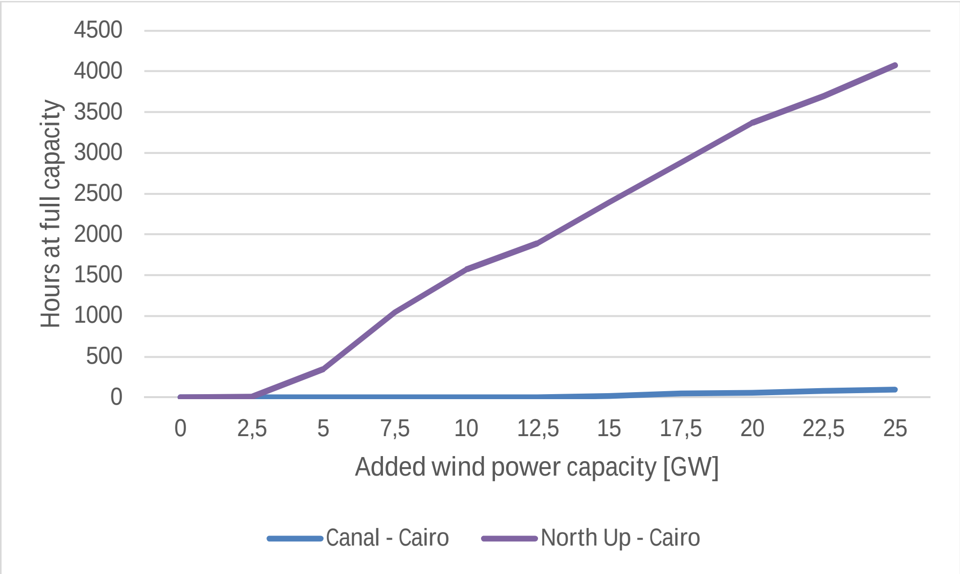


Figure 3-15: Full transmission capacity versus wind power capacity

The total system costs decrease with extra wind power generation as seen in Figure 3-16. The decrease is mainly in the fuel cost component. Capital costs related to the wind turbines are indicated in stripes. The graph indicates it is profitable to include more wind power capacity (until 15 GW wind).

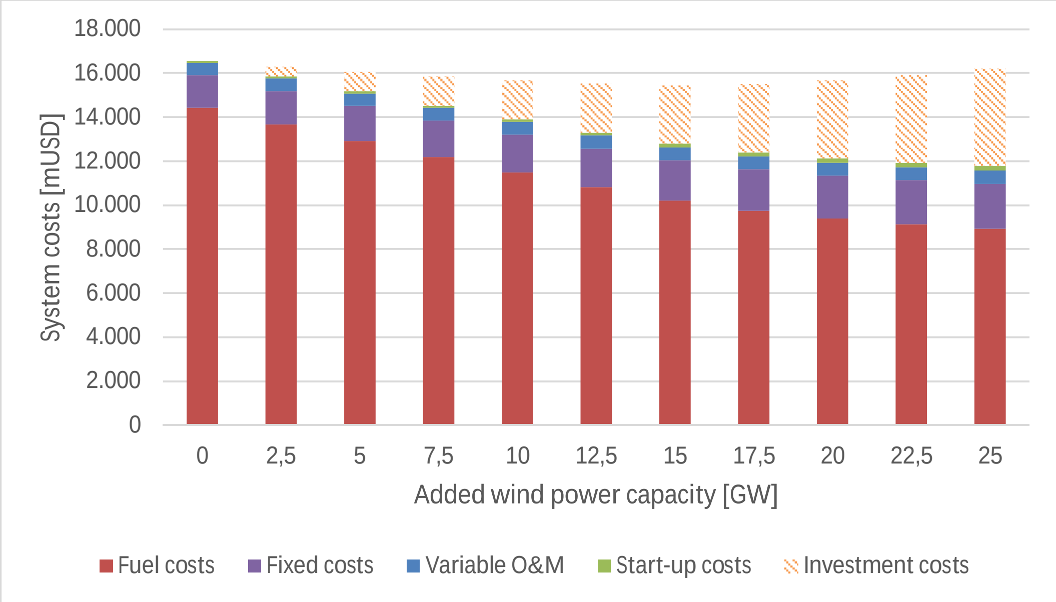


Figure 3-16: System costs for several cases of added wind

For the power plants in the Canal region, the impact on the income due to the bird migration shut-downs is shown in Figure 3-17. Four farms are modelled in the Canal region, the existing Zafarana wind farm (547 MW), Hurghada and Gabel El Zayt and the farm with additional wind the Suez Gulf. The three latter have the same wind profile and are thus grouped and labelled "Suez Gulf" in Figure 3-17.The bird migration initially has a negative impact on the income of both Zafarana and the Suez Gulf farms. The loss grows as more capacity is installed. At 15 GW extra capacity, the moment when wind power curtailment starts to occur, the impact of bird migration decreases as the VOW decreases.

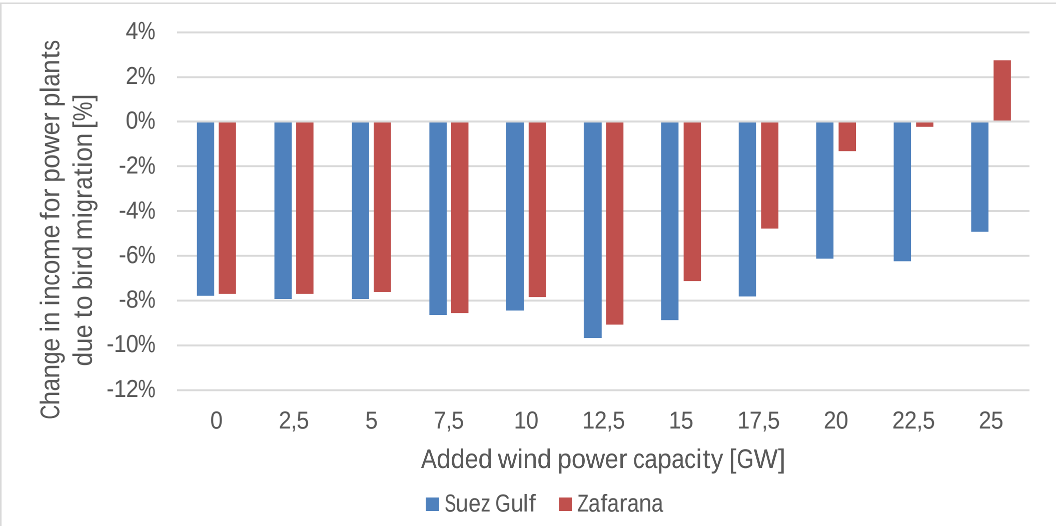


Figure 3-17: Change in income of power plants due to bird migration shut-downs for larger amounts of wind capacity

Figure 3-18 explains the smaller and eventually even positive impact, on the Zafarana wind farm at very large added wind capacities in Figure 3-17. As the wind farms in the Suez Gulf are the main force to drive prices down, its bird shut-downs are accompanied by higher marginal prices in East-Delta, resulting in a higher VOW for the Zafarana wind farm.

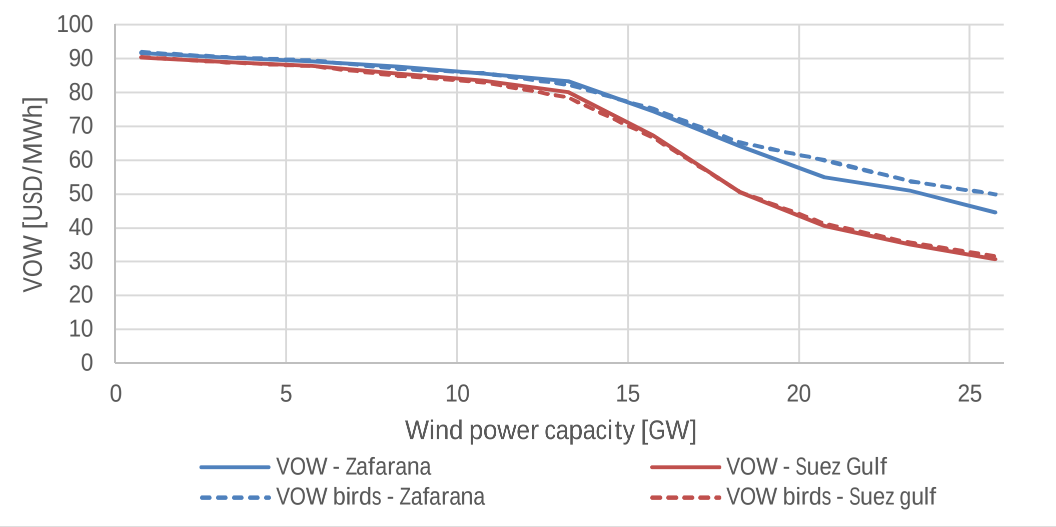


Figure 3-18: VOW for the two wind farms in East Delta, with and without bird migration shut-downs

Finally, Figure 3-19 shows the impact on the system costs of bird migration. With little wind capacity in the system, the impact on the total system costs is negligible. Even at high wind capacities the changes in system costs remain under 4%. The main cost component is fuel costs. When less wind with zero fuel cost is available, costlier fuels need to be used.

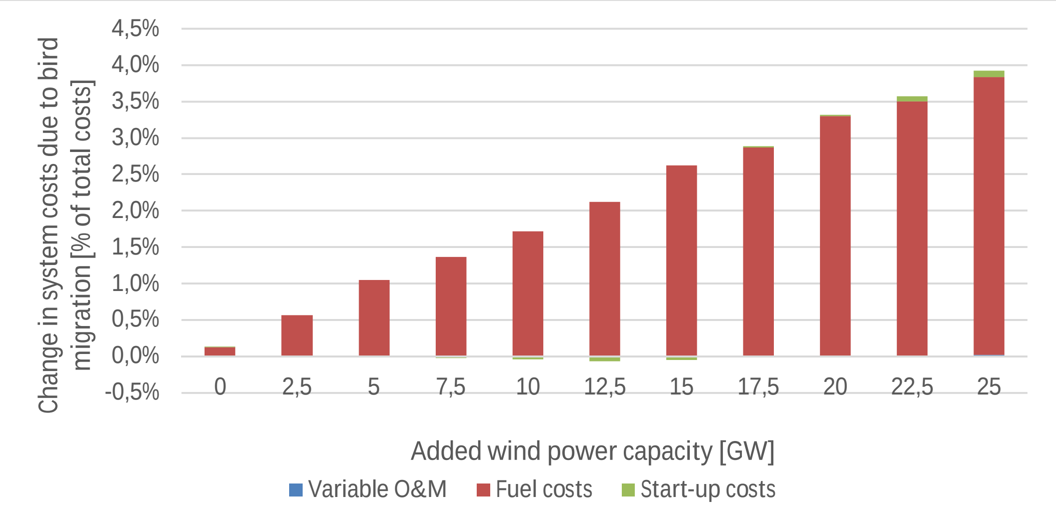


Figure 3-19: Impact of the bird migration shut-downs on the system costs for several cases of added wind capacity

3.4 Generation patterns for year 2015 and 2018

A number of generation patterns are developed. A generation pattern is a set of generation values for each individual generator. The generation patterns is used as input for the PSS/E model, for checking power flow, voltage and grid stability. Two different methods are applied:

- **Traditional method:** Four situations defined as minimum and maximum demand combined with minimum and maximum generation from wind and solar.
- **Critical cases from a list of realistic situations:** From the simulation 8760 hourly values exist and a specific hours can be found by defining a criteria, e.g. the hour with the highest flow in the transmission system.

In all cases Balmorel is used to obtain a generation pattern that represent optimal dispatch (least cost dispatch).

Note that the traditional method may create situations that are unlikely to occur in real life, e.g. maximum demand and maximum generation from wind and solar is unlikely to happen at the same time, because peak demand typically is in early evening – while maximum solar generation take place mid-day.

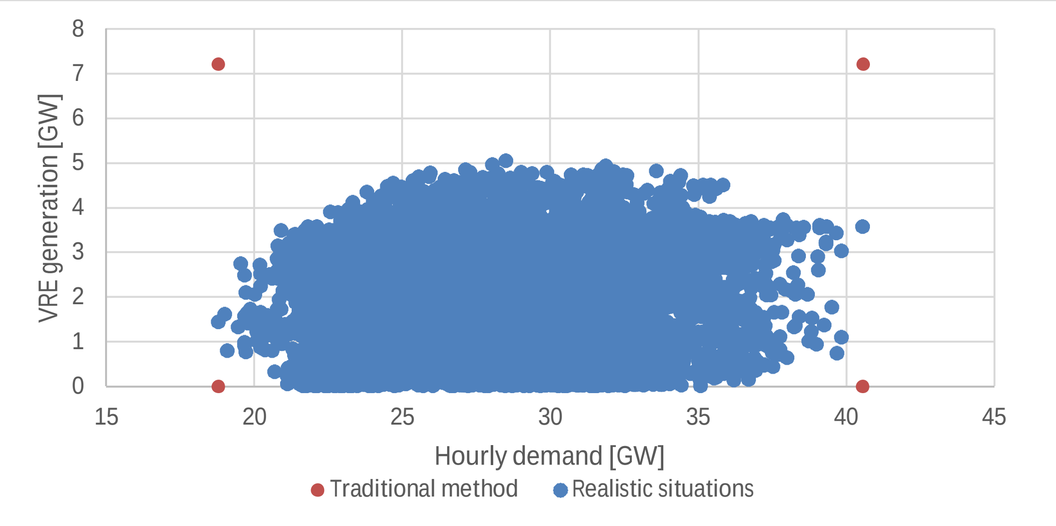


Figure 3-20: Different demand/generation situations. The red dots indicate the four max/min cases. The blue dots indicate all the hourly combinations of demand and variable renewable generation (VRE, wind and solar) in 2018

Pattern I: • Maximum demand • Maximum wind and solar generation	Pattern II: • Minimum demand • Maximum wind and solar generation
Pattern III: • Maximum demand • No wind or solar generation	Pattern IV: • Minimum demand • No wind or solar generation

Table 3-4: The four traditional generation patterns

The four generation patterns of the traditional method for year 2015 and 2018 are shown in below tables:

		Cap. 2015 [MW]	Balmorel generation full wind and solar 2015 [MW]		Balmorel generation no wind and solar 2015 [MW]	
			I: Max demand	II: Min Demand	III: Max demand	IV: Min Demand
South Upper Egypt	High Dam	2,340	2,340	889	2,340	889
	Aswan Dam I	329	306	146	306	146
	Aswan Dam II	268	266	163	266	163
	Esna	90	46	44	46	44
	New Naga Hamadi	64	3	2	3	2
North Upper Egypt	Walidia	630	0	0	0	0
	Kuriemat	1,254	1,129	176	1,129	654
	Kuriemat 1	750	675	675	675	675
	Kuriemat 2	500	450	450	450	450
	Assiut	143	0	0	0	0
	Assiut New	1,053	0	0	0	0
	GERGA	53	48	7	48	7
	MALAWI	53	48	7	48	7
	GALEB	53	48	7	48	7
	SAMALOT	53	48	7	48	7
	Kuriemat Solar / Thermal	140	140	140	0	0
Canal	Zafarana(Wind)	547	547	547	0	0
	Hurghada wind	5	5	5	0	0
	Gabel El Zayt	200	200	200	0	0
	Ataka	1,730	1,500	0	1,500	0
	Abu Sultan	600	150	0	450	0
	Shabab	590	503	0	531	0
	New Gas Shabab	1,000	875	0	875	0
	Port Said(4)	54	48	0	48	0
	Arish	60	54	0	33	0
	Oyoun Mousa	640	576	90	576	90
	Sharm El-Sheikh(5)	425	180	0	369	0
	Hurghada	300	264	0	264	0
	Suez Gulf (BOOT)	682	614	0	614	0
	PortSaid East(BOOT)	932	682	0	682	48
	El-Ain Al-Sokhna	1,300	1,080	151	1,080	151
	GULF GTZ	650	585	68	585	68
Cairo	Shoubra El-Kheima	1,260	945	0	945	0

	Cairo West Ext(1)	1,608	1,447	185	1,447	185
	Cairo South I	600	510	0	510	0
	Cairo South II	175	158	0	158	0
	Cairo North	1,500	1,350	1,350	1,350	1,350
	Cairo East	52	47	0	47	0
	El-Tebeen	700	0	0	0	0
	Wadi Hof	99	89	0	89	0
	6 October	1,200	1,050	1,050	1,050	1,050
	Giza North	2,250	2,000	2,000	2,000	2,000
	Basateen	52	47	0	47	0
	HELIOPOLIS	52	47	0	47	0
Middle Delta	Damietta	1,125	1,013	1,013	1,013	1,013
	New Gas Damietta	500	450	0	450	0
	Damietta West(3)	1,000	875	875	875	875
	Talkha	382	344	4	344	0
	Talkha 210	420	210	0	210	0
	Talkha 750	750	675	0	675	0
	Banha powerplnat	750	675	675	675	675
	El-Atf	750	675	675	675	675
West Delta	Nubaria 1,2	1,500	1,350	1,350	1,350	1,350
	Nubaria 3	750	675	675	675	675
	Mahmoudia	608	547	0	547	0
	Mahmoudia 2	200	150	150	150	150
	Kafr El-Dawar	440	0	0	330	0
	Damanhour Ext	366	300	0	300	0
	Damanhour (Old)	195	0	0	65	0
	Damanhour	150	125	125	125	125
Alexandria	El-Seiuf	165	132	0	132	0
	Abu Kir	915	824	105	824	105
	New Abu Kir(6)	1,230	1,107	91	1,107	91
	Sidi Krir 1.2	1,322	1,190	542	1,190	912
	Sidi Krir	750	675	675	675	675
	Matrouh	60	0	0	0	0
Total		**41,362**	**33,087**	**15,313**	**33,087**	**15,313**

Table 3-5: Balmorel generation data tables for the four generation patterns of the traditional method in the year 2015

		Cap. 2018 [MW]	Balmorel generation full wind and solar 2018 [MW]		Balmorel generation no wind and solar 2018 [MW]	
			I: Max demand	II: Min Demand	III: Max demand	IV: Min Demand
South Upper Egypt	High Dam	2,340	2,340	889	2,340	889
	Aswan Dam I	329	306	146	306	146
	Aswan Dam II	268	266	163	266	163
	Esna	90	46	44	46	44
	New Naga Hamadi	72	3	2	3	2
	Benban	2,000	2,000	2,000	0	0
North Upper Egypt	Cairo West	650	400	0	400	0
	Walidia	1,280	0	0	0	0
	Kuriemat	1,254	1,129	88	1,129	88
	Kuriemat 1	750	675	345	675	675
	Kuriemat 2	500	450	230	450	450
	Assiut	1,575	0	0	0	0
	Assiut New	500	0	0	0	0
	Bani Seuif	4,200	3,780	3,476	3,780	3,780
	Kuriemat Solar / Thermal	140	140	140	0	0
	Nile Wind	0	0	0	0	0
	Kuriemat PV	20	20	20	0	0
Canal	Zafarana(Wind)	547	547	547	0	0
	Hurghada wind	37	37	37	0	0
	Gabel El Zayt	540	540	540	0	0
	Suez gulf wind AFD	200	200	200	0	0
	FIT	2,000	2,000	2,000	0	0
	Masder	250	250	250	0	0
	BOO	200	200	200	0	0
	Ataka	1,950	0	0	0	0
	Abu Sultan	600	0	0	0	0
	Shabab	840	0	0	737	0
	New Gas Shabab	1,000	0	0	875	0
	Port Said(4)	154	0	0	139	0
	Arish	60	0	0	0	0
	Oyoun Mousa	660	594	0	594	0
	Sharm El-Sheikh(5)	478	0	0	411	0
	Hurghada	443	0	0	384	0
	Suez Gulf (BOOT)	736	0	0	0	0
	PortSaid East(BOOT)	986	0	0	682	0
	El-Ain Al-Sokhna	1,300	1,080	0	1,080	0

	GULF GTZ	650	489	0	489	0
Cairo	Shoubra El-Kheima	1,260	0	0	0	0
	Cairo West Ext(1)	1,360	990	46	990	46
	Cairo South I	585	0	0	510	0
	Cairo South II	175	0	0	0	0
	Cairo North	1,570	1,413	690	1,413	1,413
	Cairo East	52	0	0	47	0
	El-Tebeen	700	0	0	0	0
	Wadi Hof	99	0	0	67	0
	6 October	1,515	1,350	276	1,350	276
	Giza North	2,340	2,106	2,106	2,106	2,106
	Basateen	52	47	0	47	0
	HELIOPOLIS	52	47	0	47	0
	Helwan South	1,910	1,719	0	1,719	0
	New Cairo	2,800	0	0	0	0
Middle Delta	Damietta	1,125	1,013	425	1,013	838
	New Gas Damietta	500	120	0	450	0
	Damietta West(3)	3,750	3,375	0	3,375	0
	Talkha	382	0	0	0	0
	Talkha 210	420	0	0	0	0
	Talkha 750	750	0	0	500	0
	Banha powerplnat	750	675	345	675	675
	El-Atf	750	675	345	675	675
West Delta	Nubaria 1,2	1,500	1,350	575	1,350	1,250
	Nubaria 3	750	675	345	675	675
	Mahmoudia	384	0	0	200	0
	Mahmoudia 2	510	450	207	450	450
	Kafr El-Dawar	460	0	0	0	0
	Damanhour Ext	366	0	0	0	0
	Damanhour (Old)	195	0	0	0	0
	Damanhour	150	125	0	125	0
	Sidi Krir 3,4 (BOOT)	630	341	48	341	48
	West-Borolus	2,835	2,548	1,172	2,548	2,548
	BINS	750	675	345	675	675
Alexandria	El-Seiuf	1,170	0	0	1,053	0
	Abu Kir	915	750	0	750	0
	New Abu Kir(6)	1,230	650	0	650	0
	Sidi Krir 1.2	1,322	1,190	134	1,190	134
	Sidi Krir	750	675	345	675	675
	Matrouh	60	0	0	0	0
Total		**66,473**	**40,450**	**18,721**	**40,450**	**18,721**

Table 3-6: Balmorel generation data tables for the four generation patterns of the traditional method in the year 2018

The results are summarized in

	Time	2015	2018
Minimum demand	Week 45 Wednesday Hour 07	15,313 MWh	18,721 MWh
Maximum demand	Week 25 Monday Hour 20	33,087 MWh	40,450 MWh

Table 3-7

	Time	2015	2018
Minimum demand	Week 45 Wednesday Hour 07	15,313 MWh	18,721 MWh
Maximum demand	Week 25 Monday Hour 20	33,087 MWh	40,450 MWh

Table 3-7: Maximum and minimum demand (traditional method).

As these cases represent the most extreme instances, a number of alternative cases are simulated using wind speed time series, in which the grid is stressed.

- A+B: Highest/Lowest residual demand (demand – wind/solar generation)
- C+D: Highest/Lowest transmission in the entire grid (flow on all lines are summed)
- E+F: Highest/Lowest transmission in lines to Cairo (flow on lines to Cairo are summed)

These generation patterns are found simply by searching all the hours of the simulated year (2015 and 2018). Each pattern represent the optimal dispatch for the selected hour. The generation patterns for these cases are shown in Table 3-9 and Table 3-10.

	2015		2018	
	Time	Key numbers (MW)	Time	Key numbers (MW)
Pattern A: Highest residual demand	Week 25 Monday Hour 20	Demand = 33,087 Wind = 712 Solar = 0 Residual = 32,375	Week 26 Tuesday Hour 20	Demand = 39,570 Wind = 743 Solar = 0 Residual = 38,827
Pattern B: Lowest residual demand	Week 45 Wednesday Hour 07	Demand = 15,313 Wind = 177 Solar = 5 Residual = 15,136	Week 45 Tuesday Hour 09	Demand = 19,488 Wind = 1,841 Solar = 908 Residual = 17,648
Pattern C: Highest total transmission	Week 06 Friday Hour 07	Demand = 18,025 Wind = 59 Solar = 1 Residual = 17,966	Week 45 Thursday Hour 11	Demand = 36,888 Wind = 929 Solar = 0 Residual = 38,959
	Week 45	Demand = 24,206	Week 23	Demand = 21,443

Pattern D: Lowest total transmission	Sunday Hour 18	Wind = 337 Solar = 0 Residual = 23,869	Wednesday Hour 20	Wind = 94 Solar = 1,113 Residual = 21,348
Pattern E: Highest transmission to Cairo	Week 25 Monday Hour 20	Demand = 33,087 Wind = 712 Solar = 0 Residual = 32,375	Week 30 Tuesday Hour 15	Demand = 31,167 Wind = 2,113 Solar = 1,064 Residual = 29,054
Pattern F: Lowest transmission to Cairo	Week 16 Thursday Hour 01	Demand = 21,445 Wind = 696 Solar = 0 Residual = 20,759	Week 45 Thursday Hour 06	Demand = 19,654 Wind = 777 Solar = 0 Residual = 18,877

Table 3-8: Key numbers for the critical cases from a list of realistic situation.

			Balmorel generation wind time series 2015 [MW]					
		Cap. 2015 [MW]	A: Max res. demand	B: Min res. demand	C: Max trans	D: Min trans	E: Max trans to Cairo	F: Min trans to Cairo
South Upper Egypt	High Dam	2,340	2,340	889	889	2,167	2,340	889
	Aswan Dam I	329	306	146	152	146	306	205
	Aswan Dam II	268	266	163	165	163	266	217
	Esna	90	46	44	62	44	46	77
	New Naga Hamadi	64	3	2	2	2	3	4
North Upper Egypt	Walidia	630	0	0	0	0	0	0
	Kuriemat	1,254	1,129	519	1,129	1,129	1,129	1,129
	Kuriemat 1	750	675	675	675	675	675	675
	Kuriemat 2	500	450	450	450	450	450	450
	Assiut	143	0	0	0	0	0	0
	Assiut New	1,053	0	0	0	0	0	0
	GERGA	53	48	7	48	48	48	48
	MALAWI	53	48	7	48	48	48	48
	GALEB	53	48	7	48	48	48	48
	SAMALOT	53	48	7	48	48	48	48
	Kuriemat Solar / Thermal	140	0	5	1	0	0	0
Canal	Zafarana(Wind)	547	518	97	24	262	518	505
	Hurghada wind	5	5	2	1	2	5	5
	Gabel El Zayt	200	189	78	34	73	189	186
	Ataka	1,730	1,500	0	0	0	1,500	0
	Abu Sultan	600	150	0	0	0	150	0
	Shabab	590	531	0	0	0	531	0
	New Gas Shabab	1,000	875	0	0	375	875	0
	Port Said(4)	54	48	0	0	0	48	0

	Arish	60	33	0	0	0	33	0
	Oyoun Mousa	640	576	90	90	576	576	576
	Sharm El-Sheikh(5)	425	375	0	0	0	375	0
	Hurghada	300	264	0	0	0	264	0
	Suez Gulf (BOOT)	682	614	0	48	341	614	48
	PortSaid East(BOOT)	932	682	0	95	682	682	95
	El-Ain Al-Sokhna	1,300	1,080	151	151	1,080	1,080	1,080
	GULF GTZ	650	585	68	91	489	585	585
Cairo	Shoubra El-Kheima	1,260	945	0	132	0	945	88
	Cairo West Ext(1)	1,608	1,447	185	1,206	1,320	1,447	1,320
	Cairo South I	600	510	0	0	0	510	510
	Cairo South II	175	158	0	0	0	158	0
	Cairo North	1,500	1,350	1,350	1,350	1,350	1,350	1,350
	Cairo East	52	47	0	0	26	47	0
	El-Tebeen	700	0	0	0	0	0	0
	Wadi Hof	99	67	0	0	0	67	0
	6 October	1,200	1,050	1,050	1,050	1,050	1,050	1,050
	Giza North	2,250	2,000	2,000	2,000	2,000	2,000	2,000
	Basateen	52	47	0	26	47	47	26
	HELIOPOLIS	52	47	0	26	47	47	26
Middle Delta	Damietta	1,125	1,013	1,013	1,013	1,013	1,013	1,013
	New Gas Damietta	500	450	0	0	375	450	0
	Damietta West(3)	1,000	875	875	875	875	875	875
	Talkha	382	344	7	46	344	344	46
	Talkha 210	420	210	0	0	0	210	0
	Talkha 750	750	675	0	250	0	675	500
	Banha powerplnat	750	675	675	675	675	675	675
	El-Atf	750	675	675	675	675	675	675
West Delta	Nubaria 1,2	1,500	1,350	1,350	1,350	1,350	1,350	1,350
	Nubaria 3	750	675	675	675	675	675	675
	Mahmoudia	608	547	0	0	0	547	0
	Mahmoudia 2	200	150	150	150	150	150	150
	Kafr El-Dawar	440	0	0	0	0	0	0
	Damanhour Ext	366	300	0	0	0	300	0
	Damanhour (Old)	195	0	0	0	0	0	0
	Damanhour	150	125	125	125	125	125	125
Alexandria	El-Seiuf	165	132	0	0	0	132	0
	Abu Kir	915	824	105	105	750	824	129
	New Abu Kir(6)	1,230	1,107	91	182	650	1,107	91
	Sidi Krir 1.2	1,322	1,190	905	1,190	1,190	1,190	1,190
	Sidi Krir	750	675	675	675	675	675	675
	Matrouh	60	0	0	0	0	0	0
Total		**41,362**	**33,087**	**15,313**	**18,025**	**24,206**	**33,087**	**21,455**

Table 3-9: Balmorel data generation table using wind speed and solar time series, year 2015.

			Balmorel generation wind time series 2018 [MW]					
		Cap. 2018 [MW]	A: Max res. demand	B: Min res. demand	C: Max trans	D: Min trans	E: Max trans to Cairo	F: Min trans to Cairo
South Upper Egypt	High Dam	2,340	2,340	889	2,340	889	889	889
	Aswan Dam I	329	306	146	306	146	301	146
	Aswan Dam II	268	266	163	266	163	264	163
	Esna	90	46	44	46	44	36	44
	New Naga Hamadi	72	3	2	3	2	2	2
	Benban	2,000	0	841	0	1,031	986	0
North Upper Egypt	Cairo West	650	400	0	400	0	56	0
	Walidia	1,280	0	0	0	0	0	0
	Kuriemat	1,254	1,129	88	627	88	1,129	88
	Kuriemat 1	750	675	675	675	675	675	675
	Kuriemat 2	500	450	230	450	450	450	450
	Assiut	1,575	0	0	0	0	0	0
	Assiut New	500	0	0	0	0	0	0
	Bani Seuif	4,200	3,780	3,780	3,780	3,780	3,780	3,780
	Kuriemat Solar / Thermal	140	0	58	0	71	68	0
	Nile Wind	0	0	0	0	0	0	0
	Kuriemat PV	20	0	8	0	10	10	0
Canal	Zafarana(Wind)	547	185	332	36	47	325	58
	Hurghada wind	37	6	17	10	1	20	8
	Gabel El Zayt	540	93	253	149	8	299	120
	Suez gulf wind AFD	200	35	94	55	3	111	45
	FIT	2,000	346	935	553	29	1,108	446
	Masder	250	43	117	69	4	138	56
	BOO	200	35	94	55	3	111	45
	Ataka	1,950	0	0	0	0	0	0
	Abu Sultan	600	0	0	0	0	0	0
	Shabab	840	737	0	737	0	0	0
	New Gas Shabab	1,000	875	0	875	0	0	0
	Port Said(4)	154	120	0	120	0	0	0
	Arish	60	0	0	0	0	0	0
	Oyoun Mousa	660	594	0	594	0	90	0
	Sharm El-Sheikh(5)	478	0	0	0	0	0	0
	Hurghada	443	0	0	0	0	0	0
	Suez Gulf (BOOT)	736	341	0	0	0	0	0
	PortSaid East(BOOT)	986	682	0	0	0	0	0
	El-Ain Al-Sokhna	1,300	1,080	0	1,080	0	151	0

	GULF GTZ	650	489	23	489	23	456	23
Cairo	Shoubra El-Kheima	1,260	0	0	0	0	0	0
	Cairo West Ext(1)	1,360	990	46	990	46	990	46
	Cairo South I	585	510	0	0	0	0	0
	Cairo South II	175	0	0	0	0	0	0
	Cairo North	1,570	1,413	1,377	1,413	1,413	1,413	1,413
	Cairo East	52	47	0	47	0	0	0
	El-Tebeen	700	0	0	0	0	0	0
	Wadi Hof	99	0	0	0	0	0	0
	6 October	1,515	1,350	276	1,350	1,350	1,350	621
	Giza North	2,340	2,106	2,106	2,106	2,106	2,106	2,106
	Basateen	52	47	0	47	0	0	0
	HELIOPOLIS	52	47	0	47	0	0	0
	Helwan South	1,910	1,719	0	1,719	0	210	0
	New Cairo	2,800	0	0	0	0	0	0
Middle Delta	Damietta	1,125	1,013	425	1,013	924	1,013	627
	New Gas Damietta	500	375	0	375	0	0	0
	Damietta West(3)	3,750	3,375	0	3,375	332	3,375	0
	Talkha	382	0	0	0	0	0	0
	Talkha 210	420	0	0	0	0	0	0
	Talkha 750	750	500	0	250	0	0	0
	Banha powerplnat	750	675	675	675	675	675	675
	El-Atf	750	675	345	675	675	675	675
West Delta	Nubaria 1,2	1,500	1,350	575	1,350	1,250	1,350	1,250
	Nubaria 3	750	675	345	675	675	675	675
	Mahmoudia	384	50	0	0	0	0	0
	Mahmoudia 2	510	450	450	450	450	450	450
	Kafr El-Dawar	460	0	0	0	0	0	0
	Damanhour Ext	366	0	0	0	0	0	0
	Damanhour (Old)	195	0	0	0	0	0	0
	Damanhour	150	125	0	125	0	0	0
	Sidi Krir 3,4 (BOOT)	630	341	48	341	48	341	48
	West-Borolus	2,835	2,548	2,548	2,548	2,548	2,548	2,548
	BINS	750	675	675	675	675	675	675
Alexandria	El-Seiuf	1,170	194	0	461	0	0	0
	Abu Kir	915	750	0	600	0	0	0
	New Abu Kir(6)	1,230	650	0	0	0	0	0
	Sidi Krir 1.2	1,322	1,190	134	1,190	134	1,190	134
	Sidi Krir	750	675	675	675	675	675	675
	Matrouh	60	0	0	0	0	0	0
Total		**66,473**	**39,570**	**19,488**	**36,888**	**21,443**	**31,167**	**19,654**

Table 3-10: Balmorel data generation table using wind speed and solar time series, year 2018

4 Modification of existing PSS/E static and dynamic models with detailed wind farm and Solar PV modelling

4.1 Introduction

This chapter presents the detailed aggregated parameters for wind turbine models, and solar PV models implemented for this the study. The Consultant has implemented all the static and dynamic models for the specific wind power and PV solar power projects into the existing EETC PSS/E data file.

The detailed calculation with cable length summary for the Zafarana wind farms, Gabel-El-Zayt Wind farm and Solar PV in BenBan are attached in Annex 1.

4.2 Aggregation Calculation Example

Compared to conventional power stations, wind power plants consist of a large number of generators of small size. Therefore, representing every wind generator individually increases the calculation time of dynamic simulations considerably. Therefore, model aggregation techniques is be applied for dynamic power system analysis and system studies of large wind farms, where aggregated wind farm models present the electrical wind-farm response by one equivalent generator model.

For the study, the wind farm and PV solar collector system is modelled as single-machine equivalent models as shown in

Figure 4-1 and regardless of size or configuration, single generator equivalent is sufficient for grid system studies. In the cases where there are two or more types of WTGs in the wind farm, or the main wind farm transformers are three winding transformers the model shown in Figure 4-2 is used and when the plant contains feeders with very dissimilar impedance, representing the plant with two equivalent generators. This representation has been shown to be sufficient for bulk-level dynamic simulations.

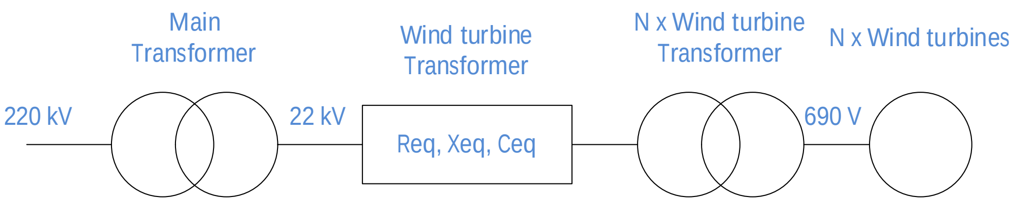


Figure 4-1: The aggregated model for two winding transformers

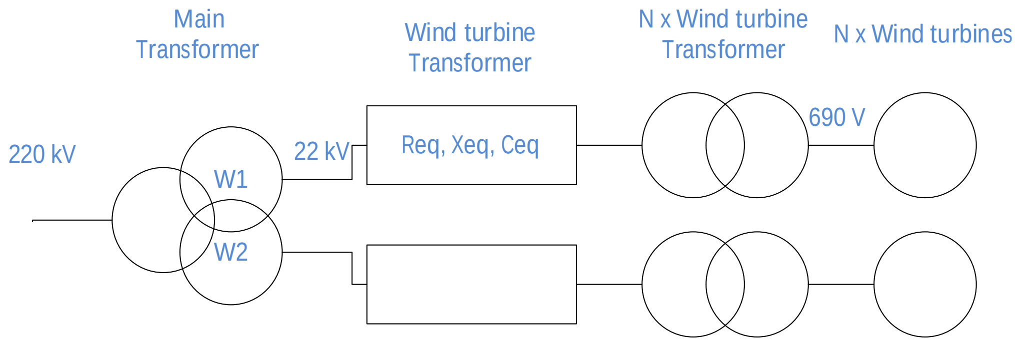


Figure 4-2: The aggregated model for three winding transformers

The detailed calculation with cable length summary for the Zafarana wind farms, Gabel-El-Zayt Wind farm and Solar PV in BenBan are attached in Annex 1.

Below is illustrated an example of the 200 MW El-Zayt Wind Farm aggregation parameters.

Park summary		
ITC Voltage	22	kV
Frequency	50	Hz
Export Voltage	220	kV
Turbines	100	
Turbine power	2,00	MW
Installed power	200,0	MW
Power factor	0,950	
ITC grid		
Slack	1%	
number of cables	168	
	cable length	route length
	0,0 km	0,0 km
501Al22Al	**73,1 km**	71,9 km
630Al22Al	6,8 km	6,4 km
500Al22Al	12,8 km	11,7 km
185Al22Al	4,0 km	3,6 km
Total	96,7 km	93,6 km

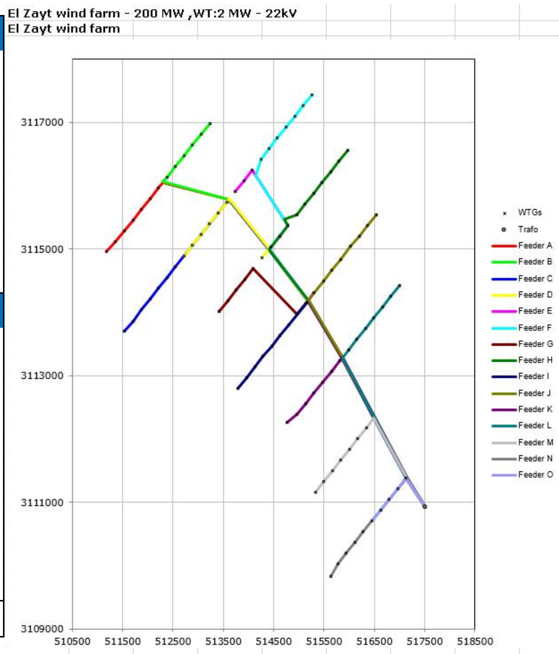


Table 4-1: Layouts of El Zayt wind farm with connection to transformer and substation

	Case	Transformer	Project 1, Feeder		Power / MW
El Zayt	101	No.1 (125MVA) W1	ELZ1: C8,C10,C12	ELZTR1W1	42
El Zayt	102	No.1 (125MVA) W2	ELZ1: C1,C2,C5,C6	ELZTR1W2	54
El Zayt	103	No.2 (125MVA) W1	ELZ1: C3,C4,C7,C14	ELZTR2W1	52
El Zayt	104	No.2 (125MVA) W2	ELZ1: C9,C11,C13,C15	ELZTR2W2	52

Table 4-2: Case details of the Gabel-El-Zayt wind farm projects

Aggregated model parameters ITC cable grid	Case 101	Case 102	Case 103	Case 104
Voltage/kV	22	22	22	22
Number of turbines	21	27	26	26
Power/MW	42	54	52	52
Current Ieq/kA	1,102	1,417	1,365	1,365
Ploss ITC cables	0,30	0,55	0,44	0,24
Qgen ITC cables	1,50	2,91	2,12	1,20
Qind ITC cables	0,41	0,73	0,60	0,33
Req / Ohm	0,004	0,007	0,005	0,003
Xeq / Ohm	0,005	0,009	0,007	0,004
Ceq / uF	10	19	14	8

Table 4-3: Aggregated model parameters for the wind farm projects in Gabel-El-Zayt area

4.3 Static and Dynamic Wind Farm and Solar PV PSS/E Models

The static and dynamic models implemented by the Consultant in the existing EETC PSS/E file is listed below. These projects has created as aggregated models.

P. short	Project	Connection	Wind turbine	Generator	Size/kW	No. of turbines/PV	Total/MW
ZAF1	Zafarana 1	Zafarana new	Nordex	Type 1	600	50	30
ZAF2	Zafarana 2	Zafarana	Nordex	Type 1	600	55	33
ZAF3	Zafarana 3	Zafarana new	VESTAS	Type 2	660	46	30,36
ZAF4	Zafarana 4	Zafarana	VESTAS	Type 2	660	71	46,86
ZAF5	Zafarana 5	Zafarana	Gamesa	Type 3	850	100	85
ZAF6	Zafarana 6	Zafarana	Gamesa	Type 3	850	94	79,9
ZAF7	Zafarana 7	Zafarana	Gamesa	Type 3	850	142	120,7
ZAF8	Zafarana 8	Zafarana new	Gamesa	Type 3	850	142	120,7
HurT1	Hurghada	Hurghada		Type1			5,4
Zayt1	KfW/EIB Gabel El Zayt	Gabel-El Zayt substation	Gamesa	Type 3	2000	100	200
Zayt2	JICA Gabel El-Zayt	Gabel-El Zayt substation	Gamesa	Type 3	2000	110	220
Zayt3	Spanish Gabel El Zayt	Gabel-El Zayt substation	Gamesa	Type 3	2000	60	120
AFD1	AFD1(KFW)	Suez Gulf (RAS Ghareb)	Generic	Type 3	2000	100	200
AFD2	AFD2	Suez Gulf (RAS Ghareb)	Generic	Type 3	2000	100	200
BOO	BOO	Suez Gulf (RAS Ghareb)	Generic	Type 3	2000	100	200
MAS	Masdar	Suez Gulf (RAS Ghareb)	Generic	Type 3	2000	125	250

FIT1	FIT	Suez Gulf (RAS Ghareb)	Generic	Type 3	2000	250	500
FIT2	FIT	Suez Gulf (RAS Ghareb)	Generic	Type 3	2000	250	500
FIT3	FIT	Suez Gulf (RAS Ghareb)	Generic	Type 3	2000	250	500
FIT4	FIT	Suez Gulf (RAS Ghareb)	Generic	Type 3	2000	250	500
Benban1	Benban	Benban	Generic	PV	2000	250	500
Benban2	Benban	Benban	Generic	PV	2000	250	500
Benban3	Benban	Benban	Generic	PV	2000	250	500
Benban4	Benban	Benban	Generic	PV	2000	250	500

Table 4-4: Installed wind farms and Solar PV in PSS/E file

4.4 Aggregation of Wind Farm and Solar PV Models

4.4.1 Aggregated model values of wind farms in year 2015

The values of the data used in the aggregated models for each wind farm and the connection to the main transformers:

	Case	Transformer	Power / MW	Req / Ohm	Xeq / Ohm	Ceq / uF	#WT
Zafarana	09	No.1 (75MVA)	12	0,001	0,001	1,3	20
Zafarana	10	No.1 (75MVA)	21,8	0,001	0,002	3,1	33
Zafarana	11	No.2 (75MVA)	21	0,001	0,002	2,7	35
Zafarana	12	No.2 (75MVA)	25,1	0,002	0,003	3,5	38
Zafarana	13	No.3 (125MVA) W1	49,3	0,011	0,023	17,5	58
Zafarana	14	No.3 (125MVA) W2	55,3	0,006	0,013	14,3	65
Zafarana	15	No.4 (125MVA) W1	47,6	0,011	0,020	14,4	56
Zafarana	16	No.4 (125MVA) W2	53,6	0,008	0,014	15,3	63
Zafarana	17	No.5 (125MVA) W1	47,6	0,006	0,007	16,1	56
Zafarana	18	No.5 (125MVA) W2	32,3	0,005	0,006	14,3	38
Zafarana	19	New St No.1 (125MVA) W1	19,8	0,002	0,003	3,2	33
Zafarana	20	New St No.1 (125MVA) W1	19,1	0,001	0,001	2,7	29
Zafarana	21	New St No.1 (125MVA) W1	10,2	0,002	0,003	3,9	12
Zafarana	22	New St No.1 (125MVA) W2	45,9	0,006	0,012	11,3	54
Zafarana	23	New St No.2 (125MVA) W1	10,2	0,001	0,001	1,2	17
Zafarana	24	New St No.2 (125MVA) W1	11,2	0,001	0,001	1,5	17
Zafarana	25	New St No.2 (125MVA) W1	22,1	0,003	0,008	7,9	26
Zafarana	26	New St No.2 (125MVA) W2	42,5	0,005	0,008	9,8	50

	Case	Transformer	Power / MW	Req / Ohm	Xeq / Ohm	Ceq / uF	#WT
Hurghada	51	No.1 (7MVA)	5,4	0,001	0,000	0,0	1
El Zayt	101	No.1 (125MVA) W1	42	0,004	0,005	9,9	21
El Zayt	102	No.1 (125MVA) W2	54	0,007	0,009	19,1	27
El Zayt	103	No.2 (125MVA) W1	52	0,005	0,007	14,0	26
El Zayt	104	No.2 (125MVA) W2	52	0,003	0,004	7,9	26
El Zayt	105	No.3 (125MVA) W1	56	0,005	0,007	13,2	28
El Zayt	106	No.3 (125MVA) W2	54	0,007	0,009	19,1	27
El Zayt	107	No.4 (125MVA) W1	56	0,006	0,008	15,0	28
El Zayt	108	No.4 (125MVA) W2	54	0,003	0,004	8,2	27
El Zayt	109	No.5 (150MVA) W1	60	0,005	0,007	14,1	30
El Zayt	110	No.5 (150MVA) W2	60	0,007	0,010	21,2	30

Table 4-5: Aggregated model values for wind farms in year 2015

4.4.2 Aggregated models for wind farms in year 2018

The additional aggregated wind turbines added to the model for 2018 are shown in the table below.

	Case	Transformer	Power / MW	Req / Ohm	Xeq / Ohm	Ceq / uF	#WT
AFD	115	No.1 (150MVA) W1	50	0,006	0,009	16,6	25
AFD	116	No.1 (150MVA) W2	50	0,006	0,009	16,6	25
AFD	117	No.2 (150MVA) W1	50	0,006	0,009	16,6	25
AFD	118	No.2 (150MVA) W2	50	0,006	0,009	16,6	25
AFD	119	No.1 (150MVA) W1	50	0,006	0,009	16,6	25
AFD	120	No.1 (150MVA) W2	50	0,006	0,009	16,6	25
AFD	121	No.2 (150MVA) W1	50	0,006	0,009	16,6	25
AFD	122	No.2 (150MVA) W2	50	0,006	0,009	16,6	25
BOO	123	No.1 (150MVA) W1	50	0,006	0,009	16,6	25
BOO	124	No.1 (150MVA) W2	50	0,006	0,009	16,6	25
BOO	125	No.2 (150MVA) W1	50	0,006	0,009	16,6	25
BOO	126	No.2 (150MVA) W2	50	0,006	0,009	16,6	25
MAS	127	No.1 (150MVA) W1	62	0,006	0,009	16,6	31
MAS	128	No.1 (150MVA) W2	63	0,004	0,005	9,6	32
MAS	129	No.2 (150MVA) W1	62	0,006	0,009	16,6	31
MAS	130	No.2 (150MVA) W2	63	0,004	0,005	9,6	32

	Case	Transformer	Power / MW	Req / Ohm	Xeq / Ohm	Ceq / uF	#WT
FIT	131	No.1 (150MVA) W1	62	0,006	0,009	16,6	31
FIT	132	No.1 (150MVA) W2	63	0,004	0,005	9,6	32
FIT	133	No.2 (150MVA) W1	62	0,006	0,009	16,6	31
FIT	134	No.2 (150MVA) W2	63	0,004	0,005	9,6	32
FIT	135	No.3 (150MVA) W1	62	0,006	0,009	16,6	31
FIT	136	No.3 (150MVA) W2	63	0,004	0,005	9,6	32
FIT	137	No.4 (150MVA) W1	62	0,006	0,009	16,6	31
FIT	138	No.4 (150MVA) W2	63	0,004	0,005	9,6	32
FIT	139	No.1 (150MVA) W1	62	0,006	0,009	16,6	31
FIT	140	No.1 (150MVA) W2	63	0,004	0,005	9,6	32
FIT	141	No.2 (150MVA) W1	62	0,006	0,009	16,6	31
FIT	142	No.2 (150MVA) W2	63	0,004	0,005	9,6	32
FIT	143	No.3 (150MVA) W1	62	0,006	0,009	16,6	31
FIT	144	No.3 (150MVA) W2	63	0,004	0,005	9,6	32
FIT	145	No.4 (150MVA) W1	62	0,006	0,009	16,6	31
FIT	146	No.4 (150MVA) W2	63	0,004	0,005	9,6	32
FIT	147	No.1 (150MVA) W1	62	0,006	0,009	16,6	31
FIT	148	No.1 (150MVA) W2	63	0,004	0,005	9,6	32
FIT	149	No.2 (150MVA) W1	62	0,006	0,009	16,6	31
FIT	150	No.2 (150MVA) W2	63	0,004	0,005	9,6	32
FIT	151	No.3 (150MVA) W1	62	0,006	0,009	16,6	31
FIT	152	No.3 (150MVA) W2	63	0,004	0,005	9,6	32
FIT	153	No.4 (150MVA) W1	62	0,006	0,009	16,6	31
FIT	154	No.4 (150MVA) W2	63	0,004	0,005	9,6	32
FIT	155	No.1 (150MVA) W1	62	0,006	0,009	16,6	31
FIT	156	No.1 (150MVA) W2	63	0,004	0,005	9,6	32
FIT	157	No.2 (150MVA) W1	62	0,006	0,009	16,6	31
FIT	158	No.2 (150MVA) W2	63	0,004	0,005	9,6	32
FIT	159	No.3 (150MVA) W1	62	0,006	0,009	16,6	31
FIT	160	No.3 (150MVA) W2	63	0,004	0,005	9,6	32
FIT	161	No.4 (150MVA) W1	62	0,006	0,009	16,6	31

	Case	Transformer	Power / MW	Req / Ohm	Xeq / Ohm	Ceq / uF	#WT
FIT	162	No.4 (150MVA) W2	63	0,004	0,005	9,6	32

Table 4-6: Aggregated model values for wind farms in year 2018

4.4.3 Aggregated models for Solar PV farms in year 2018

The additional aggregated solar PV farms added to the model for 2018 are shown in the table below.

	Case	Transformer	Power / MW	Req / Ohm	Xeq / Ohm	Ceq / uF	#WT
Benban	163	No.1 (150MVA) W1	62	0,006	0,009	16,6	31
Benban	164	No.1 (150MVA) W2	63	0,004	0,005	9,6	32
Benban	165	No.2 (150MVA) W1	62	0,006	0,009	16,6	31
Benban	166	No.2 (150MVA) W2	63	0,004	0,005	9,6	32
Benban	167	No.3 (150MVA) W1	62	0,006	0,009	16,6	31
Benban	168	No.3 (150MVA) W2	63	0,004	0,005	9,6	32
Benban	169	No.4 (150MVA) W1	62	0,006	0,009	16,6	31
Benban	170	No.4 (150MVA) W2	63	0,004	0,005	9,6	32
Benban	171	No.1 (150MVA) W1	62	0,006	0,009	16,6	31
Benban	172	No.1 (150MVA) W2	63	0,004	0,005	9,6	32
Benban	173	No.2 (150MVA) W1	62	0,006	0,009	16,6	31
Benban	174	No.2 (150MVA) W2	63	0,004	0,005	9,6	32
Benban	175	No.3 (150MVA) W1	62	0,006	0,009	16,6	31
Benban	176	No.3 (150MVA) W2	63	0,004	0,005	9,6	32
Benban	177	No.4 (150MVA) W1	62	0,006	0,009	16,6	31
Benban	178	No.4 (150MVA) W2	63	0,004	0,005	9,6	32
Benban	179	No.1 (150MVA) W1	62	0,006	0,009	16,6	31
Benban	180	No.1 (150MVA) W2	63	0,004	0,005	9,6	32
Benban	181	No.2 (150MVA) W1	62	0,006	0,009	16,6	31
Benban	182	No.2 (150MVA) W2	63	0,004	0,005	9,6	32
Benban	183	No.3 (150MVA) W1	62	0,006	0,009	16,6	31
Benban	184	No.3 (150MVA) W2	63	0,004	0,005	9,6	32
Benban	185	No.4 (150MVA) W1	62	0,006	0,009	16,6	31
Benban	186	No.4 (150MVA) W2	63	0,004	0,005	9,6	32

Benban	187	No.1 (150MVA) W1	62	0,006	0,009	16,6	31
Benban	188	No.1 (150MVA) W2	63	0,004	0,005	9,6	32
Benban	189	No.2 (150MVA) W1	62	0,006	0,009	16,6	31
Benban	190	No.2 (150MVA) W2	63	0,004	0,005	9,6	32
Benban	191	No.3 (150MVA) W1	62	0,006	0,009	16,6	31
Benban	192	No.3 (150MVA) W2	63	0,004	0,005	9,6	32
Benban	193	No.4 (150MVA) W1	62	0,006	0,009	16,6	31
Benban	194	No.4 (150MVA) W2	63	0,004	0,005	9,6	32

Table 4-7: Aggregated model values for Solar PV farms in year 2018

5 Load Flow Analysis of Egyptian Transmission System

5.1 Introduction

The chapter presents the Load Flow Analysis of the Egyptian Transmission System with specific focus on analysing the 4 defined scenarios. The chapter is structured with following items:

- Identifying the existing bottlenecks grid system in year 2015 PSS/E file with and without Solar PV and Wind Power according to defined scenarios.
- Identifying the expected bottlenecks in the grid system in year 2018 PSS/E file with and without Solar PV and Wind Power according to defined scenarios.
- Recommendations to overcome the identified bottlenecks and recommendations to reinforcement of the existing grid system year 2015 and future grid system year 2018

The PSS/E load flow simulation data and contingency analysis data is attached in Annex 1.

The objective of the load flow calculations are to determine the flows on the transmission lines, transformers and voltage on the power system buses. The calculations is essential in the planning and design of the interconnection of the wind farms to the system, to ensure that existing equipment is operated within its capabilities and that the generated power can be transmitted successfully to the loads without overloading and voltage problems. The calculations are performed for the base case and contingency conditions where on or more power system elements are out of service. The system performance is compared to operating limits and criteria.

5.2 Bottlenecks in the transmission system year 2015

5.2.1 Line MVA Limit Violations Load Flow 2015

The Load Flow Analysis in PSS/E has identified the following bottlenecks in the Egyptian Power System for year 2015 and for the 4 defined scenarios. The transmission lines marked in red are overloaded and needs to be reinforced.

Please refer to Annex 1 for detailed PSS/E data simulations.

Lines loaded more than 70%	Year 2015 - Line loading - 100 % - 90 % - 80 % - 70%							
Node	Names	Voltage / kV	Rating	Base case Existing Egyptian Power System	Scenario 1 Maximum Demand and Maximum Wind and Solar PV	Scenario 2 Minimum Demand and Maximum Wind and Solar PV	Scenario 3 Maximum Demand and No Wind and Solar PV	Scenario 4 Minimum Demand and No Wind and Solar PV
563-593	DOMIAT-S - PROBLEN	220	305	253	253	276		271
5-130	C.500 - NOB-500	500	1559					1248
328-542	N-BAHTEE - CAIRO-N	220	381	297		306	281	296

Lines loaded more than 70%	Year 2015 - Line loading - 100 % - 90 % - 80 % - 70%							
Node	Names	Voltage / kV	Rating	Base case Existing Egyptian Power System	Scenario 1 Maximum Demand and Maximum Wind and Solar PV	Scenario 2 Minimum Demand and Maximum Wind and Solar PV	Scenario 3 Maximum Demand and No Wind and Solar PV	Scenario 4 Minimum Demand and No Wind and Solar PV
329-521	TEB_GEN - WADI-H	220	362	324				
336-561	W-DOM-PS - GAMALIA	220	570	422				
350-518	TORA - CAIRO-S	220	457	333				
374-5360	C-EAST - HELIOP2	220	133	96	104		111	
450-509	HARAM - C.500	220	381	381	375	267	339	274
451-509	GIZA - C.500	220	381	365	355		320	
501-502	NAG-H - GERGA	220	457		282		282	
512-3370	HADABA - OCTOBRGEN2	220	419	312				
561-636	GAMALIA - A-KBEER	220	305	229	243			
515-528	KURAIMAT - CAIRO-E	220	305	321		242		257
558-563	TRUST - DOMIAT-S	220	305	235	234	259		254
522-523	N-TEBB - TEBBIN	220	457		410			
523-40050	TEBBIN - DUMM 33&	220	457	326				
527-40053	BASATEEN - DUMM 36&	220	267	225	190		230	
527-40055	BASATEEN - DUMM 38&	220	267	225	190		230	
528-530	CAIRO-E - SKR-KOR	220	343		250			
531-533	SUEZ-S - SUEZ-500	220	438		324		367	
531-99995	SUEZ-S -	220	190		193		235	
538-539	STAD - METRO	220	381	268	274		276	
540-541	SABTIA - SHOB_KH	220	305	233	238		239	
541-543	SHOB_KH - CAIRO-N	220	381		272		274	
542-700	CAIRO-N - SABTIA	220	286	213	210		211	
583-2432	A-KIR - ABIS 2	220	194		171		140	
583-40030	A-KIR - DUMM 13&	220	194		164		141	
595-40058	C.N_GEN1 - DUMM 41&	220	229	208	182	164	194	178
595-40059	C.N_GEN1 - DUMM 42&	220	229	208	182	164	194	178
634-40051	ECTSADIA - DUMM 34&	220	247		190			
700-701	SABTIA - N-SABTIA	220	305	285	282		283	
704-40050	- DUMM 33&		457	328				
5820-40030	SMOUHA2 - DUMM 13&	220	194		165		142	
6001-6008	N.ASSYUT - ASMNT 1	132	68	49			49	

5.2.2 Line MVA Limit Violations Load Flow 2015 – Snapsnots from PSS/E Simulation

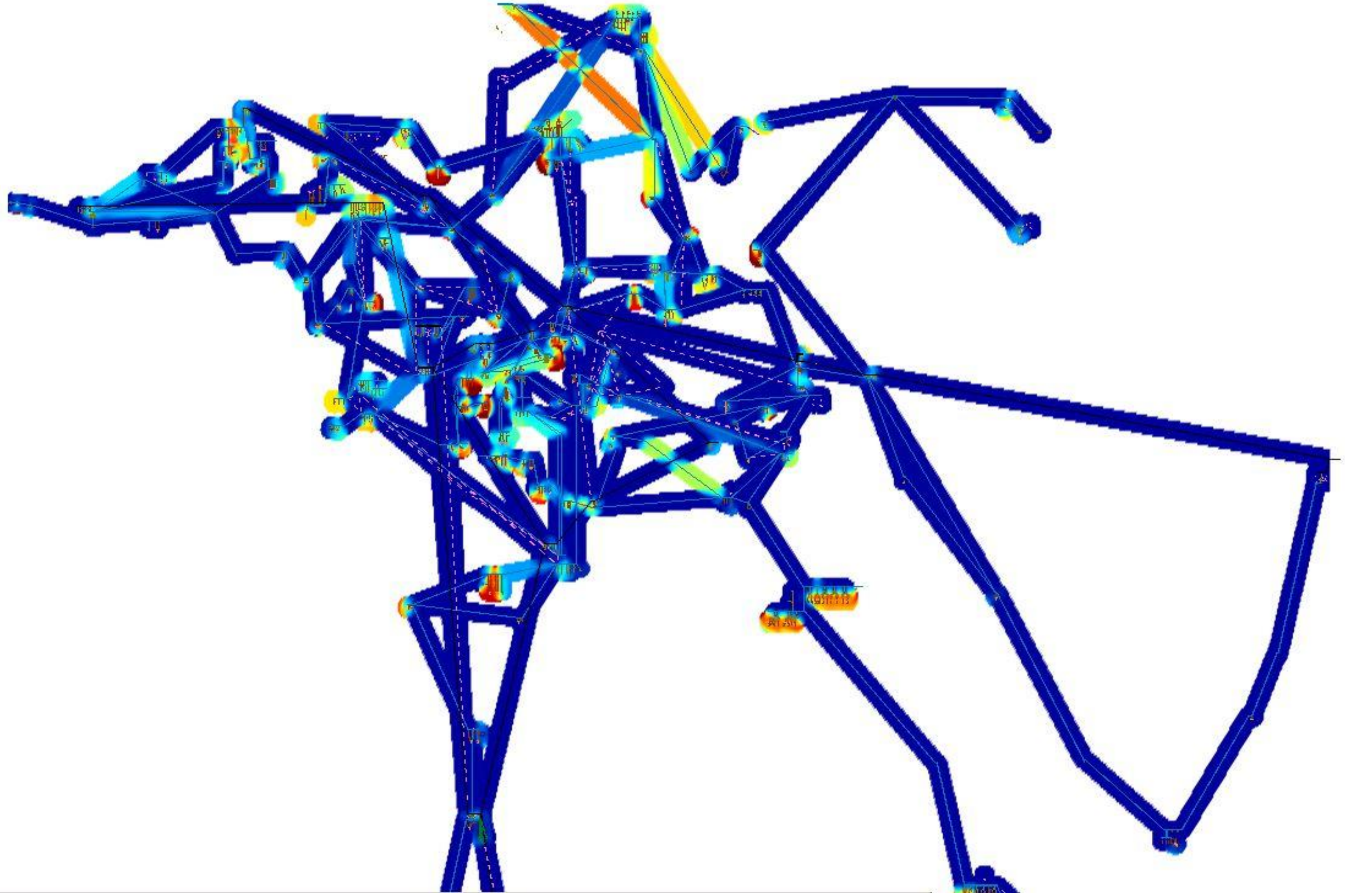


Figure 5-1: PSS/E Load Flow Snapsnot Scenario 1, North Egypt: Maximum Demand, Maximum Wind Power and PV Solar Power.

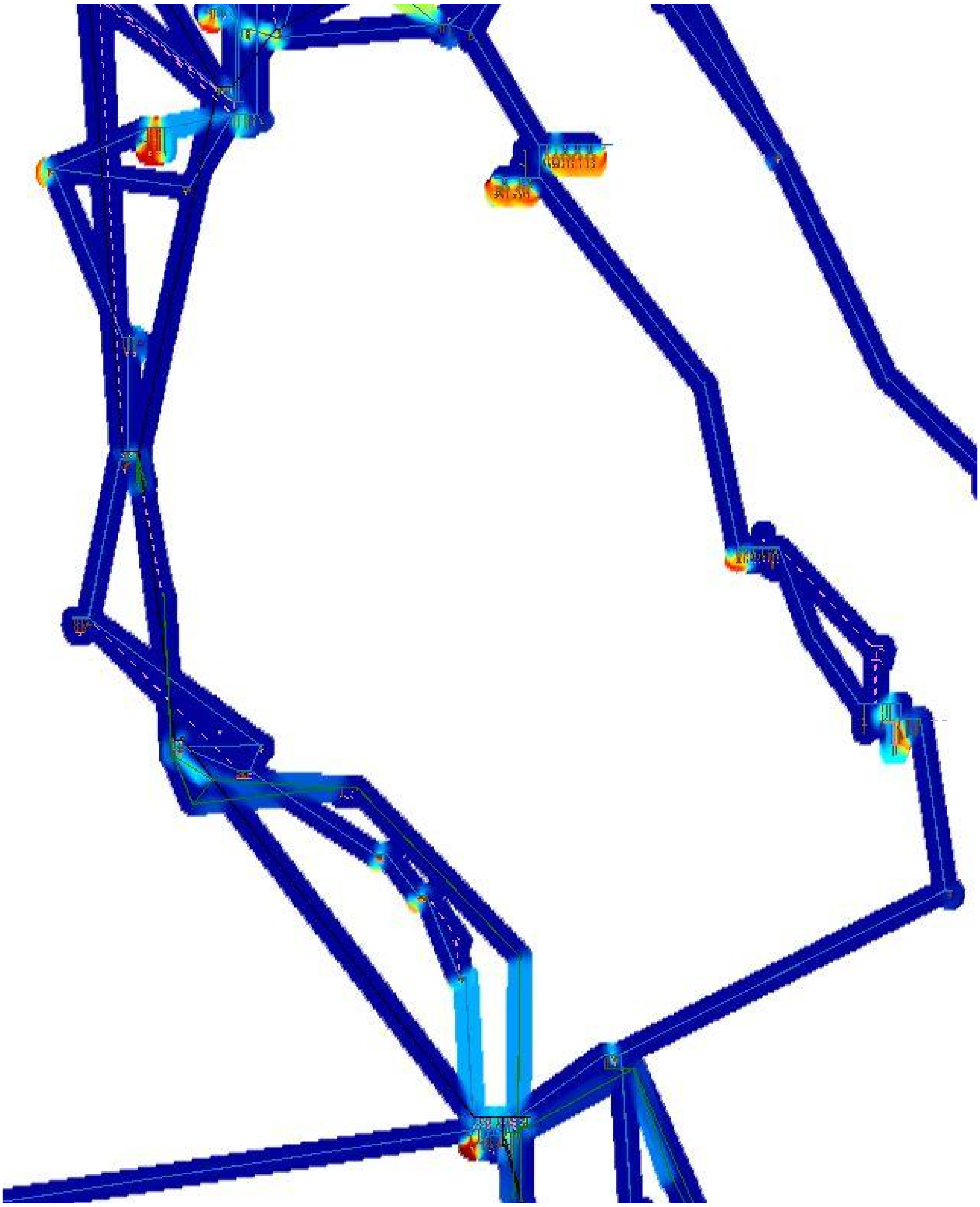


Figure 5-2: PSS/E Load Flow Snapsnot Scenario 1, Egypt Middle 1: Maximum Demand, Maximum Wind Power and PV Solar Power.

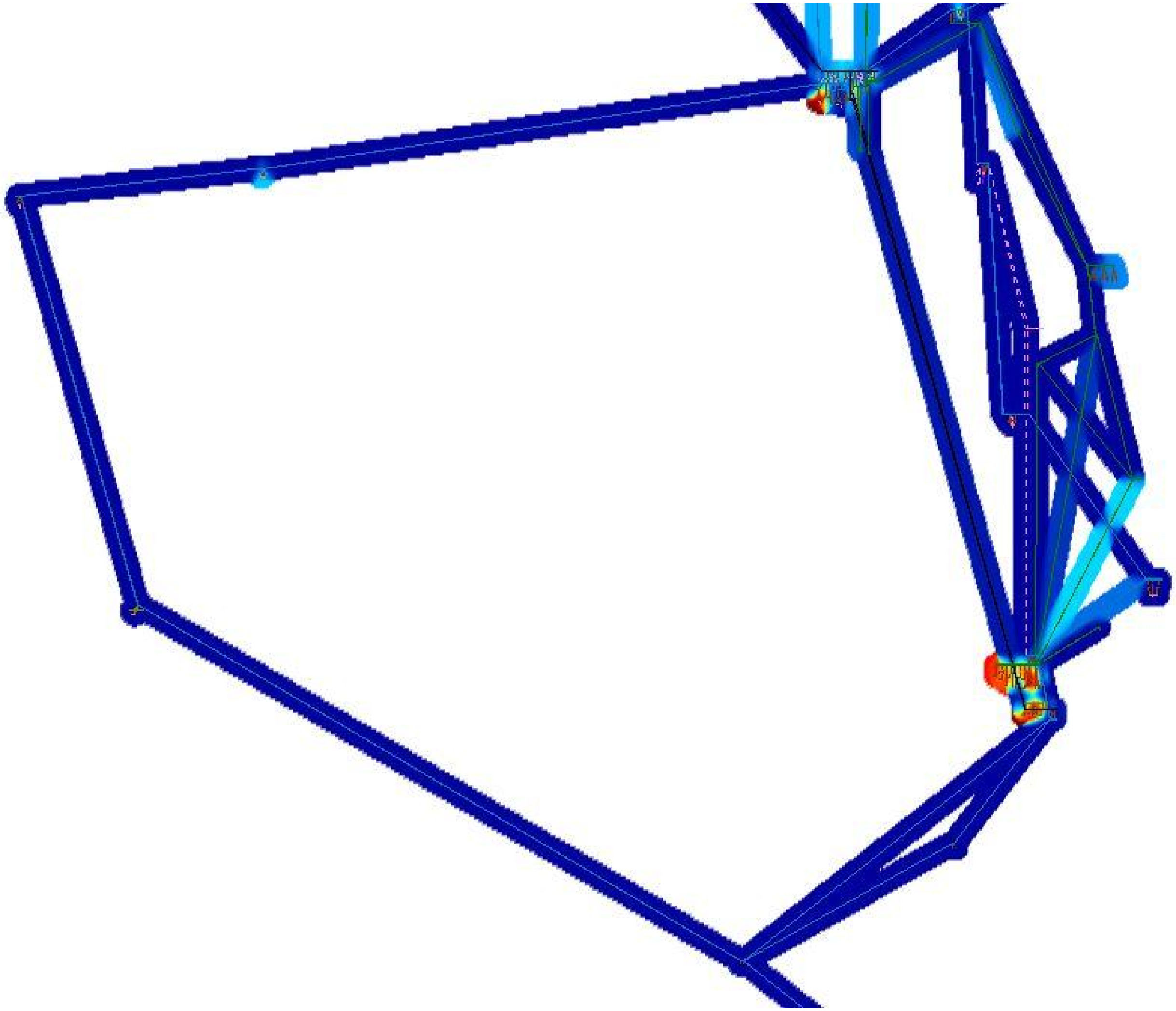


Figure 5-3: PSS/E Load Flow Snapsnot Scenario 1, South Egypt: Maximum Demand, Maximum Wind Power and PV Solar Power.

5.3 Future bottlenecks in the transmission system year 2018

5.3.1 Line MVA Limit Violations Load Flow 2018

The Load Flow Analysis in PSS/E has identified the following future bottlenecks in the Egyptian Power System for year 2018 and for the 4 scenarios. The transmission lines marked in red are overloaded and needs to be reinforced.

Please refer to Annex 1 for detailed PSS/E data simulations and contingency anaysis.

Lines loaded more than 70%	Year 2018 - Line loading - 100 % - 90 % - 80 % - 70%							
Node	Names	Voltage / kV	Rating	Base case Existing Egyptian Power System	Scenario 1 Maximum Demand and Maximum Wind and Solar PV	Scenario 2 Minimum Demand and Maximum Wind and Solar PV	Scenario 3 Maximum Demand and No Wind and Solar PV	Scenario 4 Minimum Demand and No Wind and Solar PV
46-40044	MOTAMDIA - DUMM 27&	220	419	404	384		360	
46-40045	MOTAMDIA - DUMM 28&	220	419	404	384		360	
118-554	NOBARIA - MENOUF	220	457		382		365	
626-40044	CAIRO-W - DUMM 27&	220	419	403	384		359	
626-40045	CAIRO-W - DUMM 28&	220	419	403	384		359	
240-556	K_ZIAT - TANTA	220	457	358	390		354	
247-251	ASHMOAN - N GIZA	220	450	424	559	384	430	
247-553	ASHMOAN - KALUBIA	220	457		472		397	
329-522	TEB_GEN - N-TEBB	220	362		259			
336-561	W-DOM-PS - GAMALIA	220	572	406	523			
348-513	OCTBR-220 - 6-OCT	220	457		475		403	
374-5360	C-EAST - HELIOP2	220	133		462		258	
450-40041	HARAM - DUMM 24&	220	457	441				
40040-40041	DUMM 23& - DUMM 24&	220	457	440				
522-523	N-TEBB - TEBBIN	220	457		431			
451-40035	GIZA - DUMM 18&	220	457	385				
40034-40035	DUMM 17& - DUMM 18&	220	457	384				
518-40040	CAIRO-S - DUMM 23&	220	381	439				
501-502	NAG-H - GERGA	220	457		297		239	
508-40094	SELWA - ESNA	220	457		328			
511-553	BASSOS - KALUBIA	220	457		356		335	
511-40042	BASSOS - DUMM 25&	220	248		236		216	
511-40043	BASSOS - DUMM 26&	220	248		236		216	
512-518	HADABA - CAIRO-S	220	457		320			

Lines loaded more than 70%	Year 2018 - Line loading - 100 % - 90 % - 80 % - 70%							
Node	Names	Voltage / kV	Rating	Base case Existing Egyptian Power System	Scenario 1 Maximum Demand and Maximum Wind and Solar PV	Scenario 2 Minimum Demand and Maximum Wind and Solar PV	Scenario 3 Maximum Demand and No Wind and Solar PV	Scenario 4 Minimum Demand and No Wind and Solar PV
554-40042	MENOUF - DUMM 25&	220	248		237		216	
554-40043	MENOUF - DUMM 26&	220	248		237		216	
512-797	HADABA - MAHSORA-ZONE	220	457		404			
513-740	6-OCT - ELGAMAL	220	457		344			
515-904	KURAIMAT - DUM-MNSR-KUR	220	305	319	532	459	373	408
515-9041	KURAIMAT - DUM MNSR KUR	220	305	319	532	459	373	408
785-890	HELWAN-SOUTH - ZAHRAA-MAADI	500	1732		1237			
904-905	DUM-MNSR-KUR - ZAH-MDNTNASR	220	362	323	532	459	373	408
518-40034	CAIRO-S - DUMM 17&	220	381	384				
524-625	PTROL-PL – ZAFRANA	220	438		540	525		
524-634	PTROL-PL – ECTSADIA	220	438		328	336		
526-891	KATAMIA - ZAHRAA-MAADI	220	457		321			
527-2931	BASATEEN - DUMBS-NRGS	220	268		214			
527-2941	BASATEEN - DUMBS-NRGS	220	268		214			
528-905	CAIRO-E - ZAH-MDNTNASR	220	362	255	467	430	313	376
533-5330	SUEZ-500 – DUMMY	220	229		184			
533-5331	SUEZ-500 – DUMMY	220	229		184			
538-539	STAD - METRO	220	381	327	293		292	
539-541	METRO - SHOB_KH	220	381	349	312		311	
540-541	SABTIA - SHOB_KH	220	305	231				
541-543	SHOB_KH - CAIRO-N	220	381	274				
542-700	CAIRO-N - SABTIA	220	286	252	227		215	
542-3280	CAIRO-N - NBAH2	220	381	333				
545-546	N.ASHER - ASHER	220	438		476			
546-749	ASHER - BADR220	220	457		350			
547-548	ABU-SULT – MANAIF	220	229	170	210			
549-558	PORTSAID – TRUST	220	438		415			
549-593	PORTSAID – PROBLEN	220	438		458			
549-40027	PORTSAID - DUMM 10&	220	324		256			
549-40029	PORTSAID - DUMM 12&	220	324		256			

Lines loaded more than 70%	Year 2018 - Line loading - 100 % - 90 % - 80 % - 70%							
Node	Names	Voltage / kV	Rating	Base case Existing Egyptian Power System	Scenario 1 Maximum Demand and Maximum Wind and Solar PV	Scenario 2 Minimum Demand and Maximum Wind and Solar PV	Scenario 3 Maximum Demand and No Wind and Solar PV	Scenario 4 Minimum Demand and No Wind and Solar PV
552-811	BAHTEEM - BASOUS2	220	457		379			
553-756	KALUBIA - BANHA-EAST	220	305		250		253	
554-1180	MENOUF - NOBARIA2	220	457		382		365	
555-5840	TAHRIR-B - ETAY-B2	220	229				188	
558-563	TRUST - DOMIAT-S	220	305		461		223	234
561-636	GAMALIA - A-KBEER	220	305		348			
563-593	DOMIAT-S - PROBLEN	220	305		491		240	249
565-598	K-SHEKH - SIDI-SAL	220	305		257			
569-587	K-DAWAR - ABIS	220	190	168			204	
583-2432	A-KIR - ABIS 2	220	194	170	171		153	
583-40030	A-KIR - DUMM 13&	220	194	168	166		151	
587-61400	ABIS - SUIF2	220	305				267	
5820-40030	SMOUHA2 - DUMM 13&	220	194	169	167		152	
592-613	A-EGP-CO - SP.STEEL	220	381	295	309		289	
595-811	C.N_GEN1 - BASOUS2	220	381					370
610-7874	RIVA - N-ASSIUT-GEN	220	457	467			351	
613-621	SP.STEEL - AL-EZZ	220	381		272			
625-635	ZAFRANA - ZAFRANA2	220	438		358	344		
635-998	ZAFRANA2 - RAS GHAREB	220	457			327		
700-701	SABTIA - N-SABTIA	220	305	339	306		290	
905-9041	ZAH-MDNTNASR - DUM MNSR KUR	220	362	323	532	459	373	408
2501-2505	ASWAN - KOMOMBO	132	137		98			
2510-2517	NAG-HAMD - SOHAG	132	80		58			
2511-2514	NAG-HAMD - QUENA	132	114	82				
2517-6011	SOHAG - ASSYUT STEAM	132	68	52				
6001-6008	N.ASSYUT - ASMNT 1	132	68	78	67		68	
6002-6005	SAMALUT - MENIA	132	68	57			51	
6008-6011	ASMNT 1 - ASSYUT STEAM	132	68	90	74		74	
6009-6011	ASMNT 2 - ASSYUT STEAM	132	68	88	73		73	
6882-6894	S3 220 - S1	220	457		410	424		

5.3.2 Line MVA Limit Violations Load Flow 2018 – Snapsnots from PSS/E Simulation

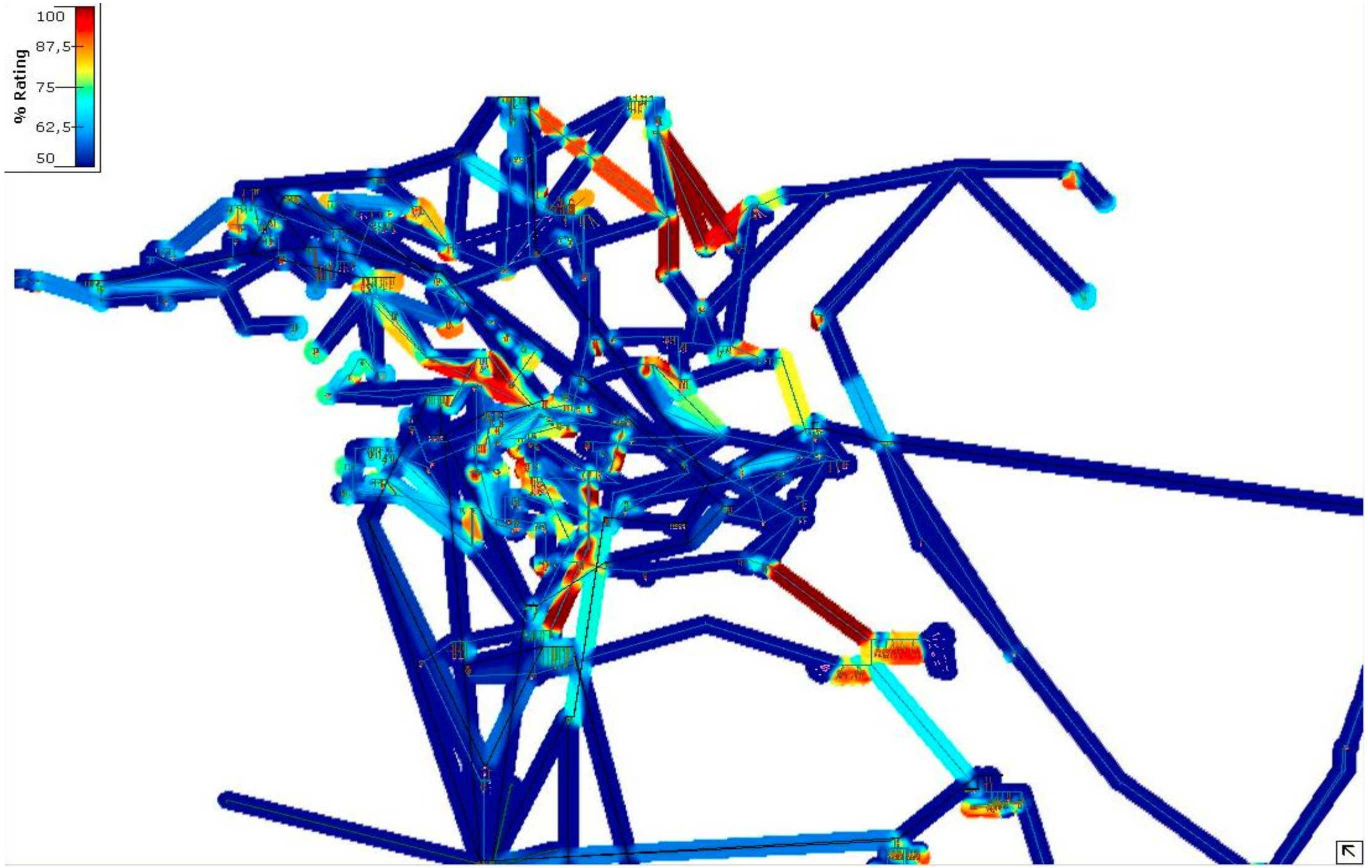


Figure 5-4: PSS/E Load Flow Snapsnot Scenario 1, North Egypt: Maximum Demand, Maximum Wind Power and PV Solar Power.

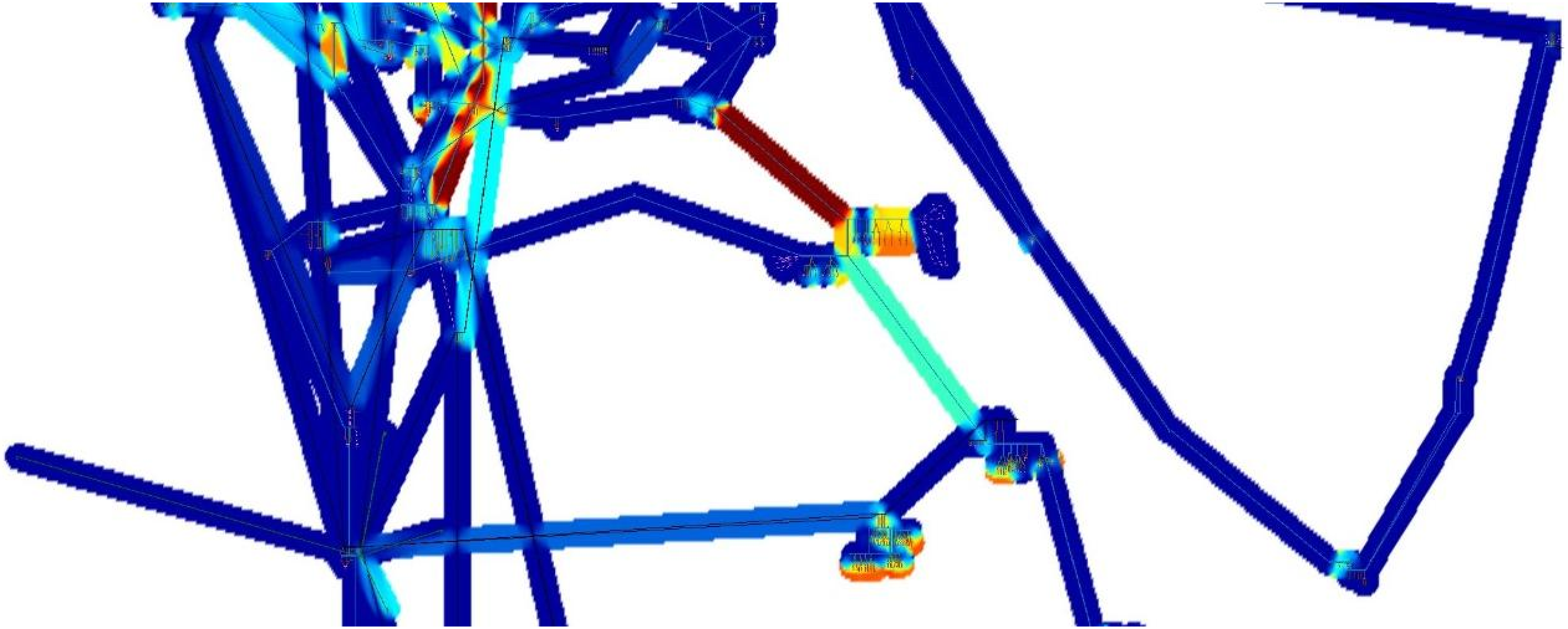


Figure 5-5: PSS/E Load Flow Snapsnot Scenario 1, Egypt Middle 1: Maximum Demand, Maximum Wind Power and PV Solar Power.

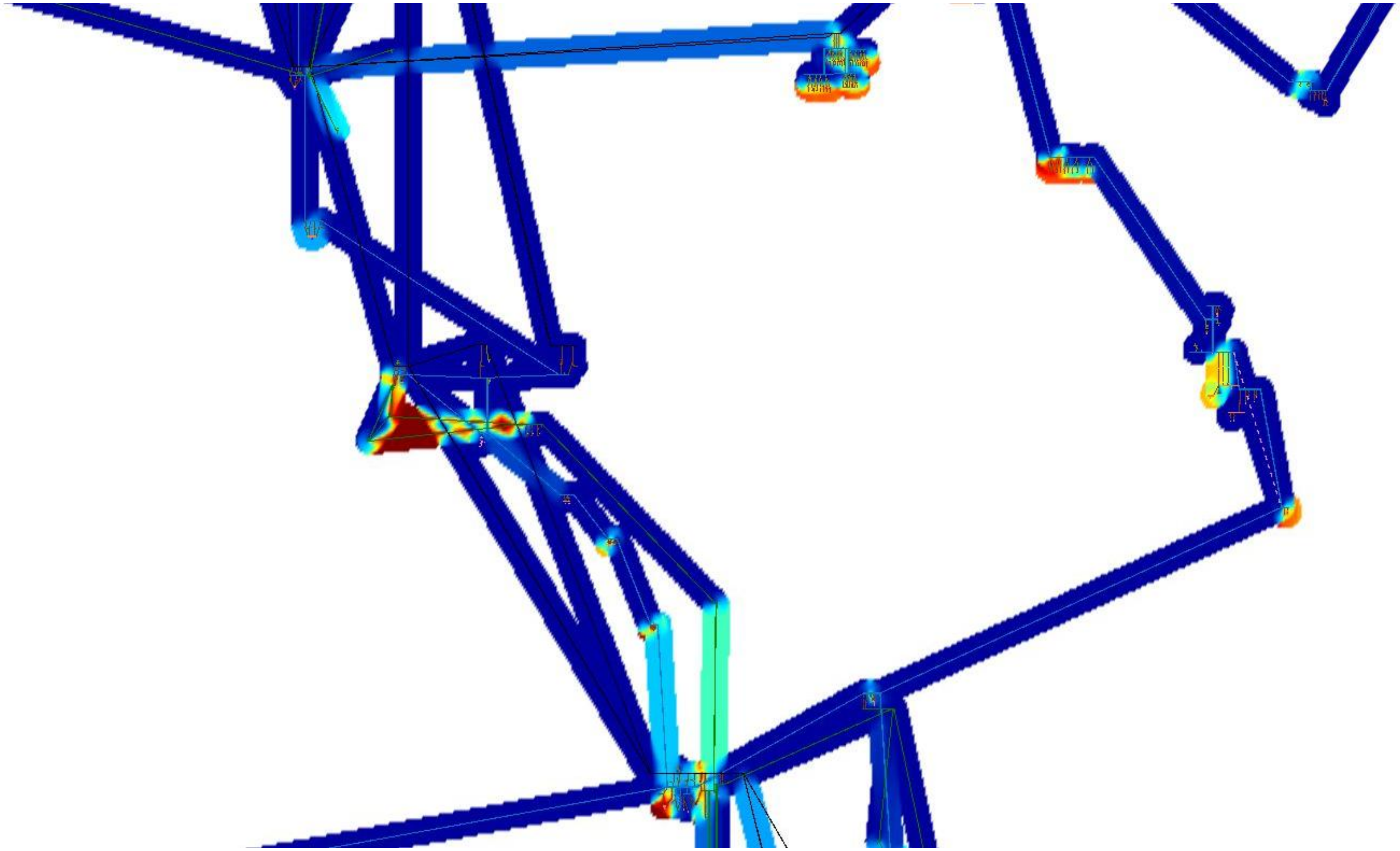


Figure 5-6: PSS/E Load Flow Snapsnot Scenario 1, Egypt Middle 2: Maximum Demand, Maximum Wind Power and PV Solar Power.

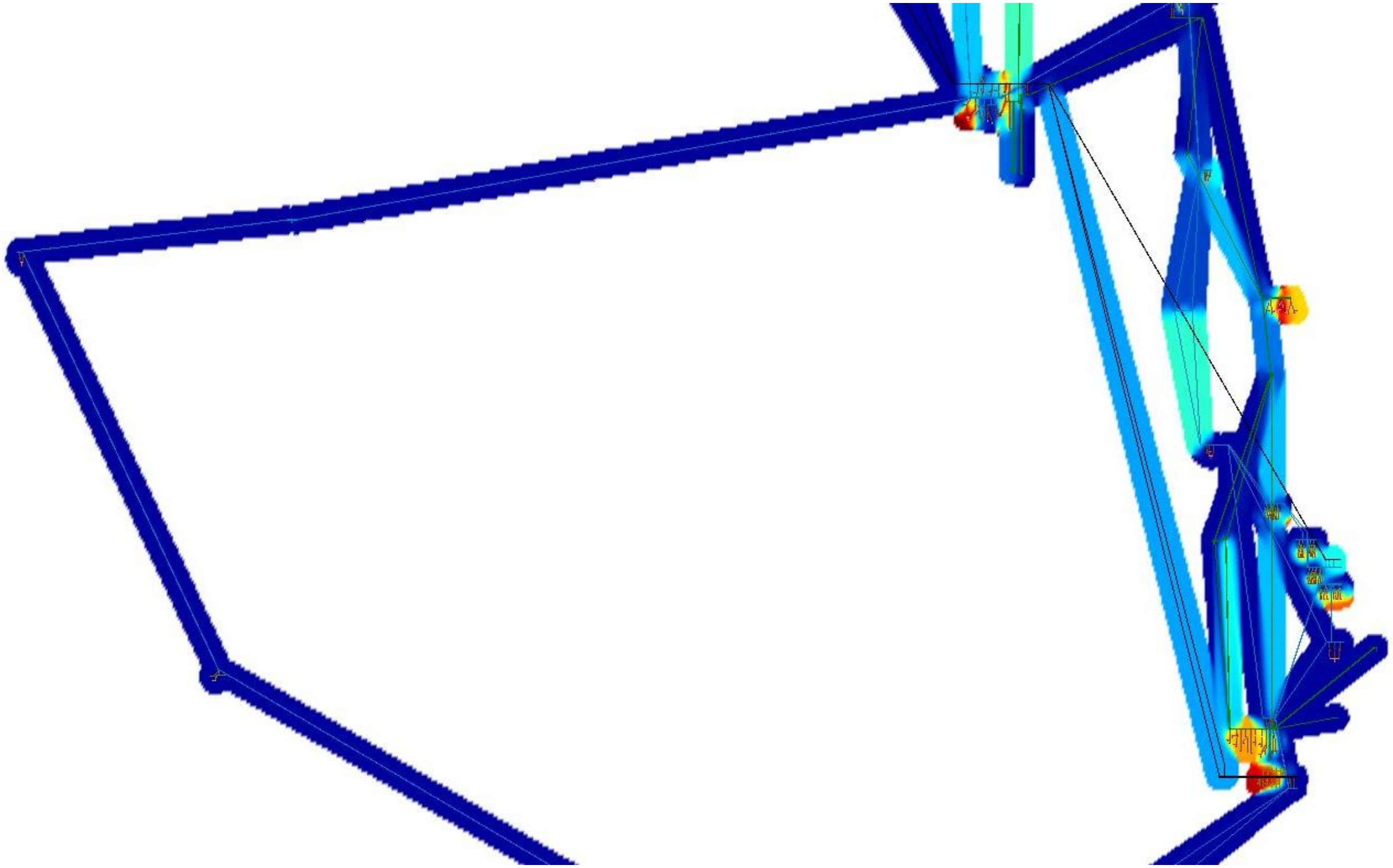


Figure 5-7: PSS/E Load Flow Snapsnot Scenario 1, South Egypt: Maximum Demand, Maximum Wind Power and PV Solar Power.

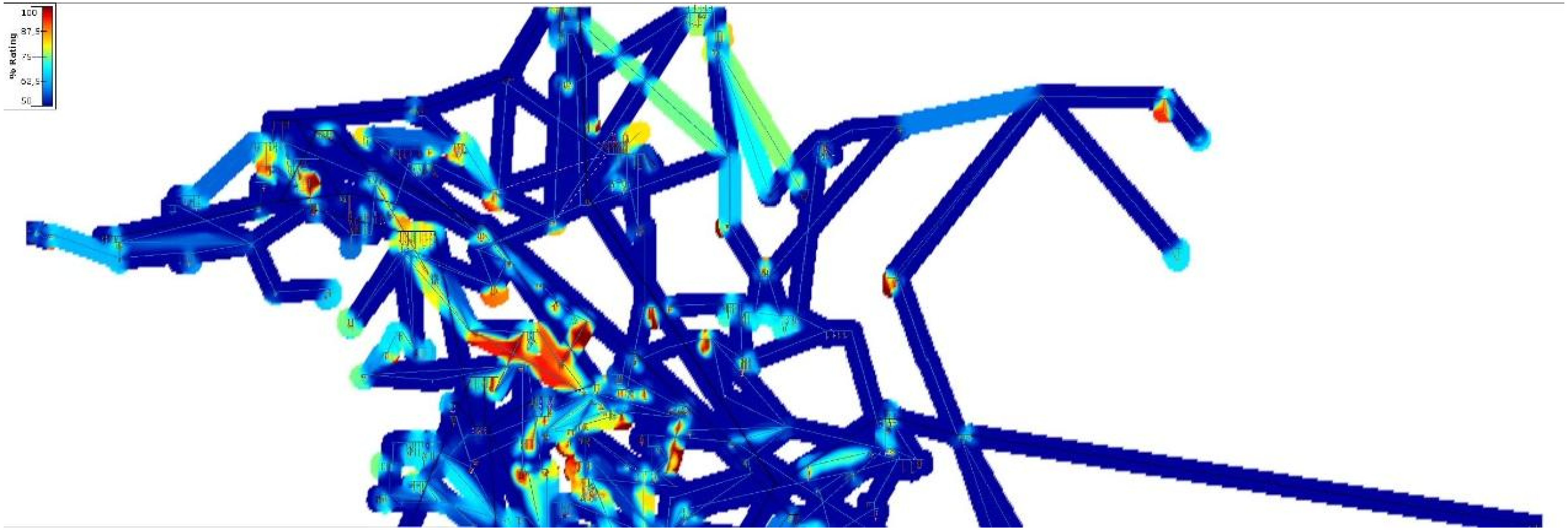


Figure 5-8: PSS/E Load Flow Snapsnot Scenario 2, North Egypt: Maximum Demand, No Wind Power and PV Solar Power.

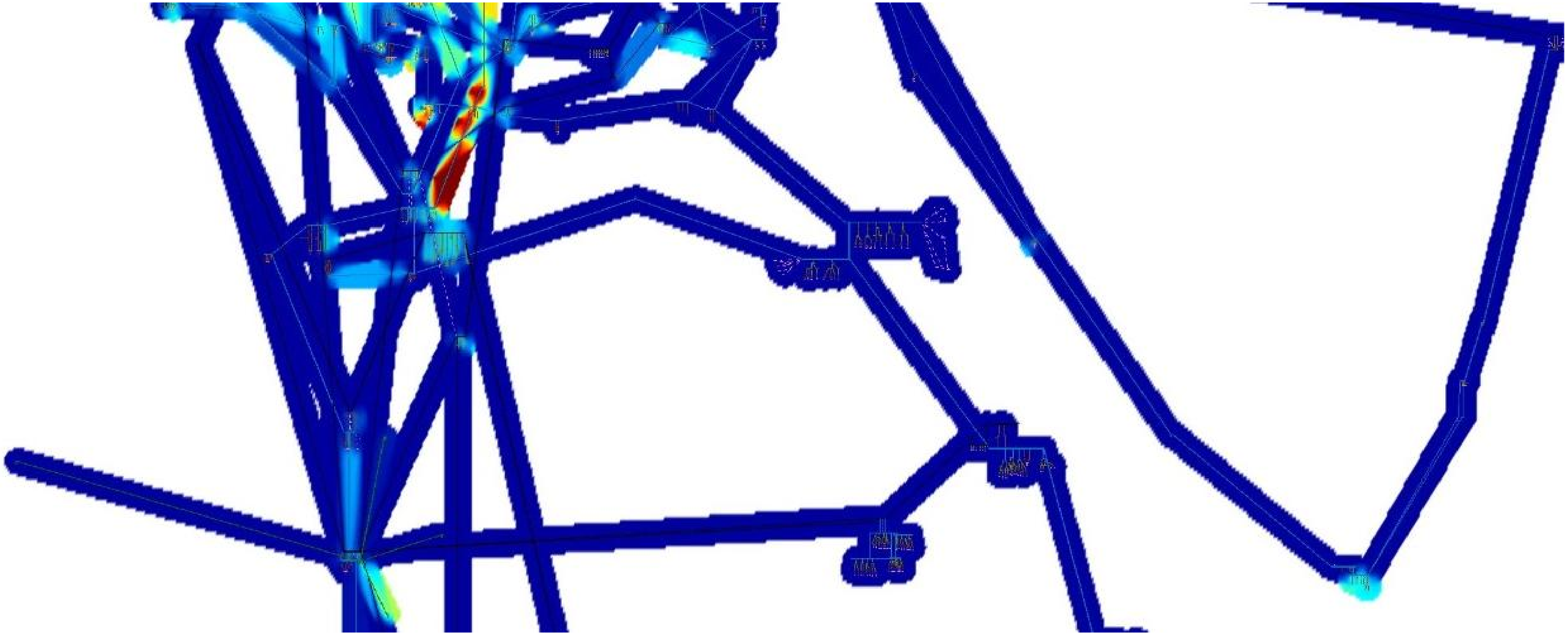


Figure 5-9: PSS/E Load Flow Snapsnot Scenario 2, Egypt Middle 1: Maximum Demand, No Wind Power and PV Solar Power.

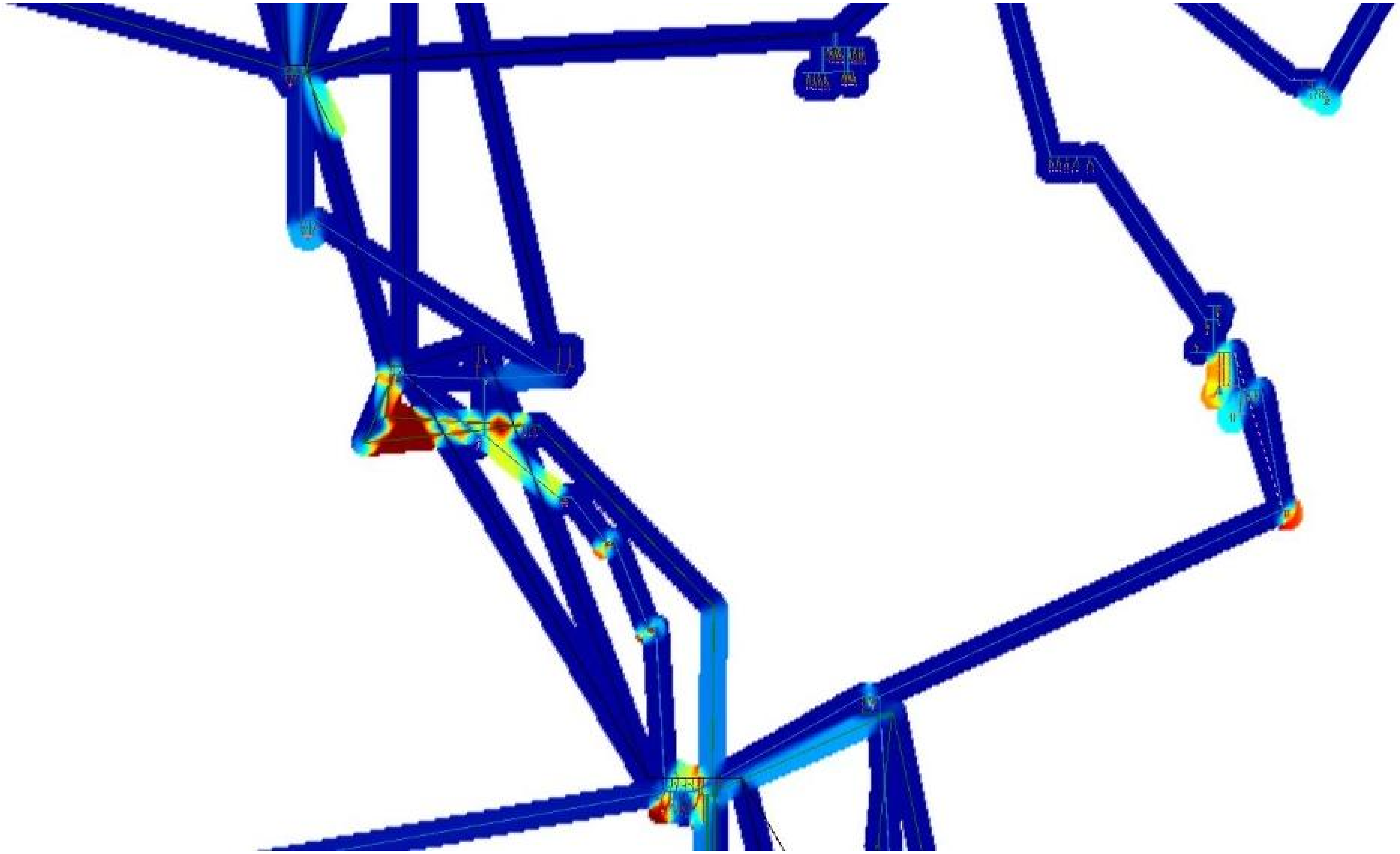


Figure 5-10: PSS/E Load Flow Snapsnot Scenario 2, Egypt Middle 2: Maximum Demand, No Wind Power and PV Solar Power.

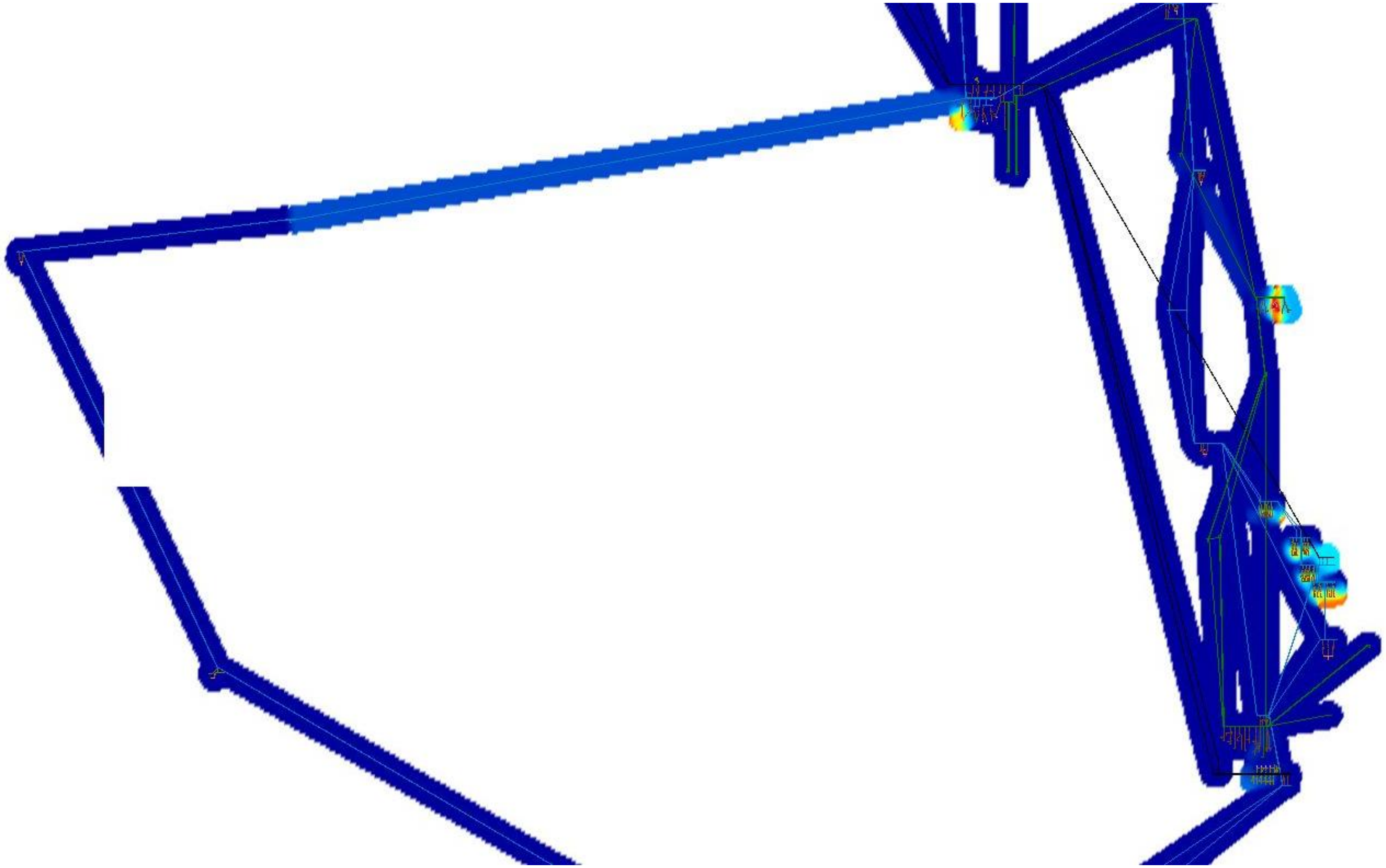


Figure 5-11: PSS/E Load Flow Snapsnot Scenario 2, South Egypt: Maximum Demand, No Wind Power and PV Solar Power.

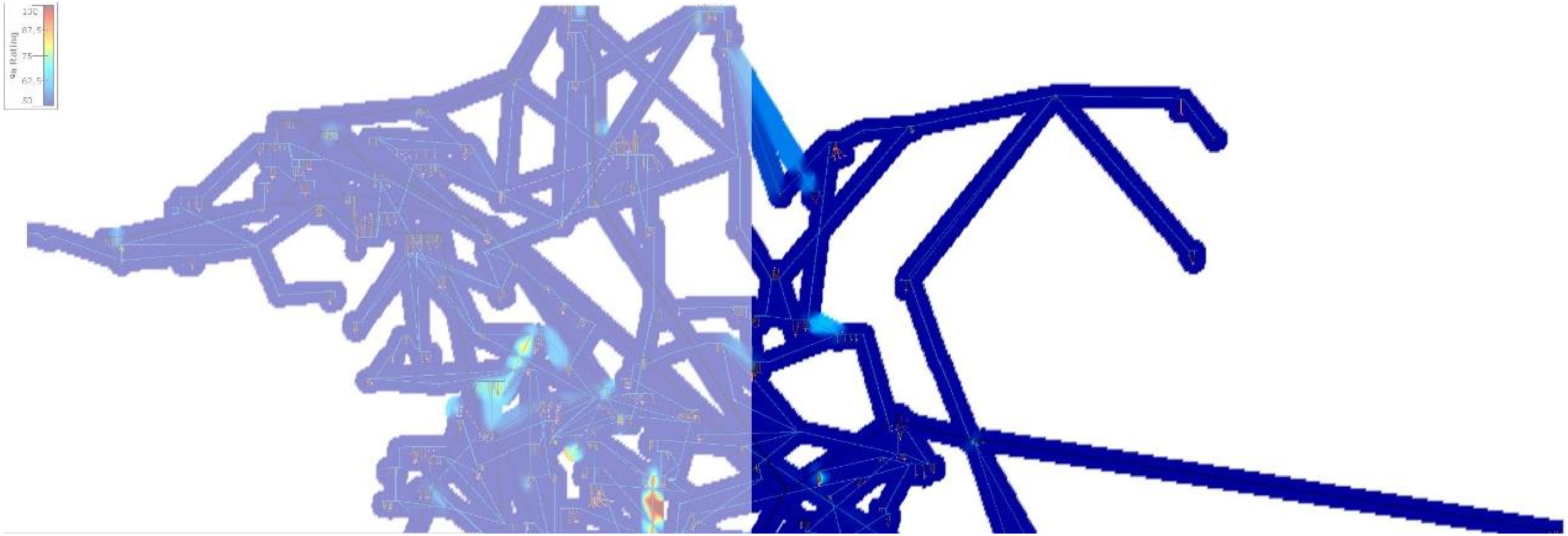


Figure 5-12: PSS/E Load Flow Snapsnot Scenario 3, North Egypt: Minimum Demand, Maximum Wind Power and PV Solar Power.

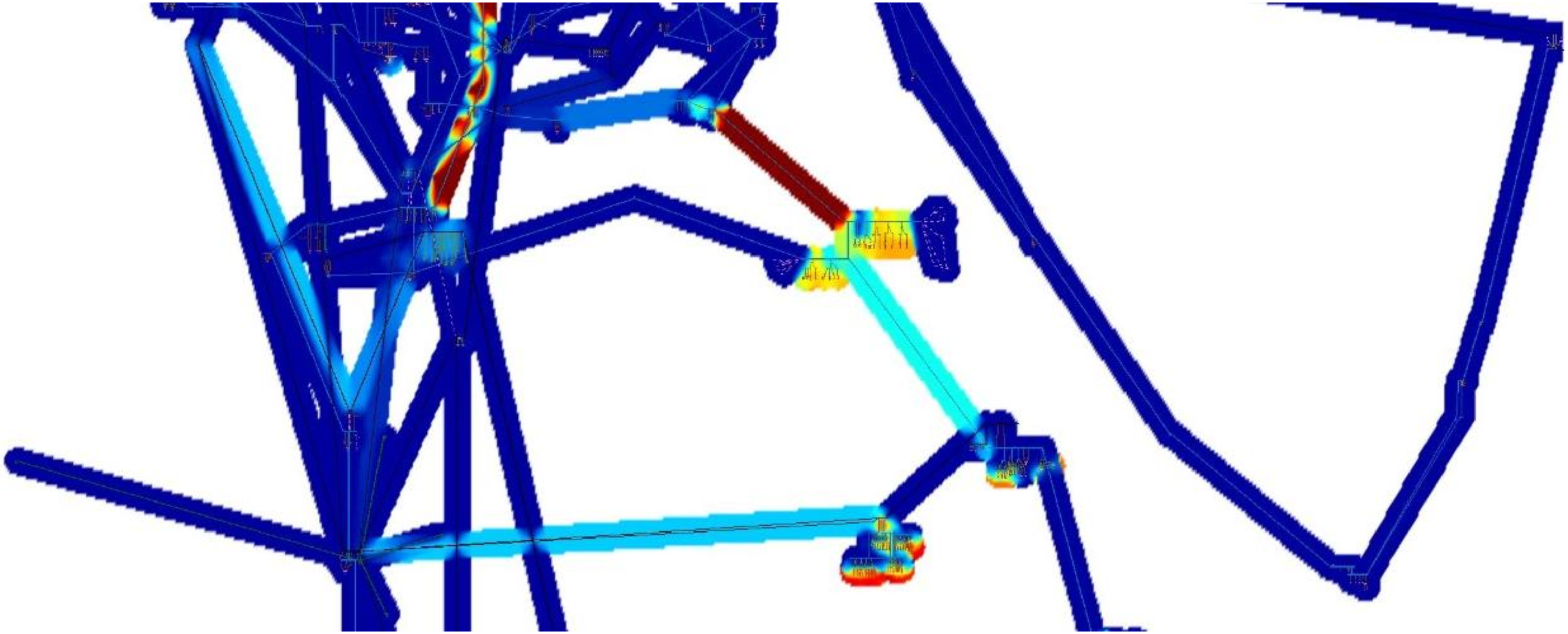


Figure 5-13: PSS/E Load Flow Snapsnot Scenario 3, Egypt Middle 1: Minimum Demand, Maximum Wind Power and PV Solar Power.

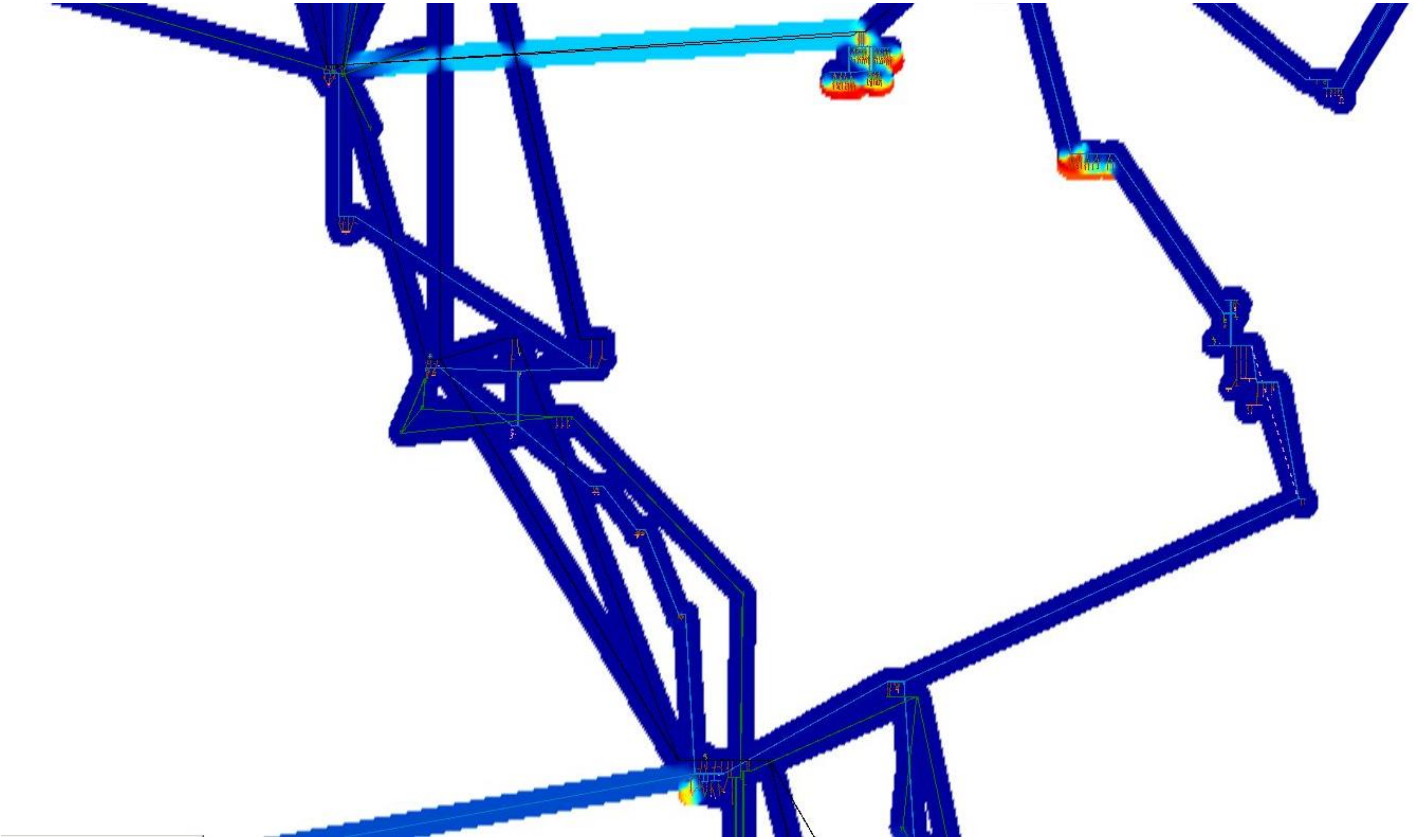


Figure 5-14: PSS/E Load Flow Snapsnot Scenario 3, Egypt Middle 2: Minimum Demand, Maximum Wind Power and PV Solar Power.

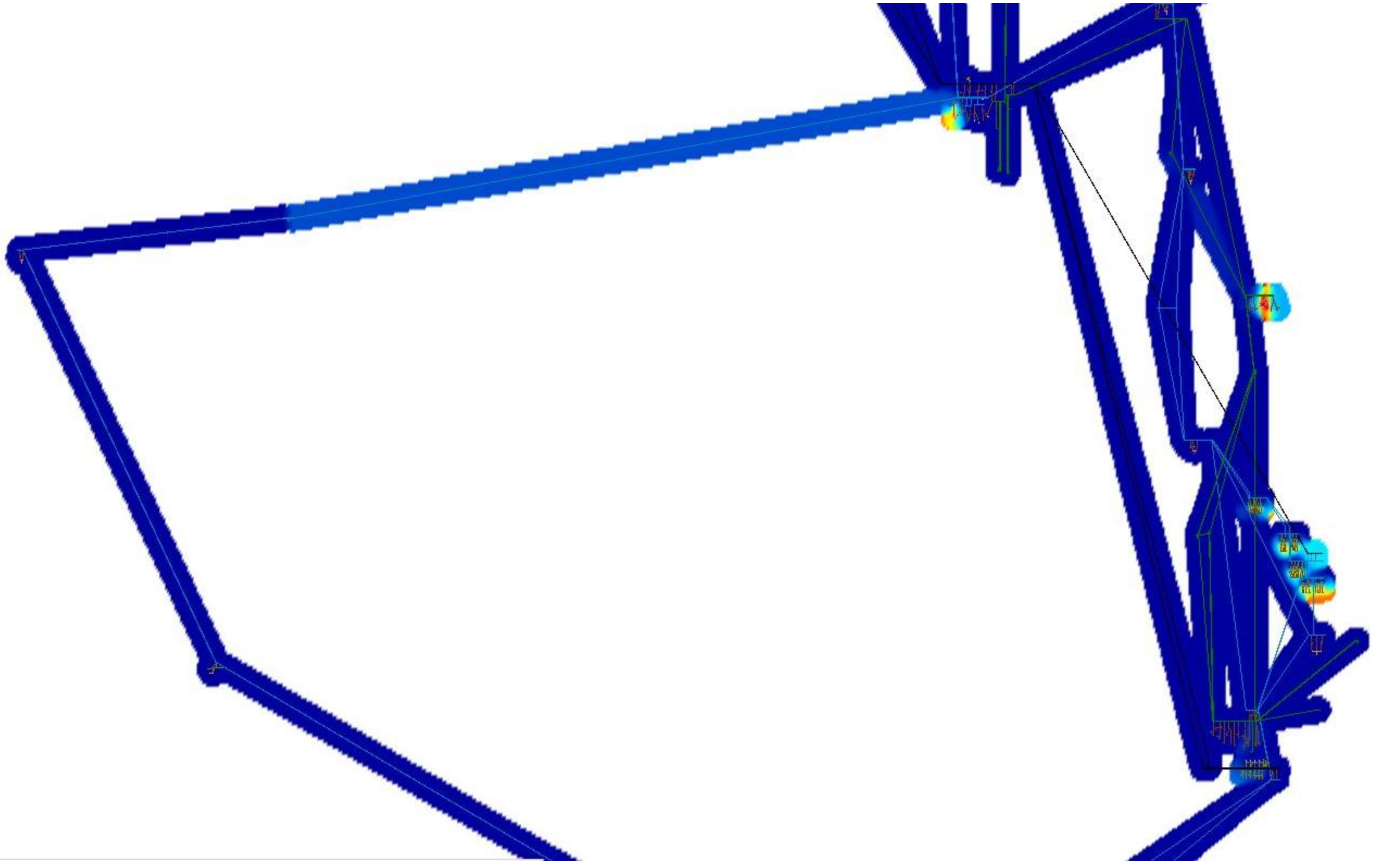


Figure 5-15: PSS/E Load Flow Snapsnot Scenario 3, South Egypt: Minimum Demand, Maximum Wind Power and PV Solar Power

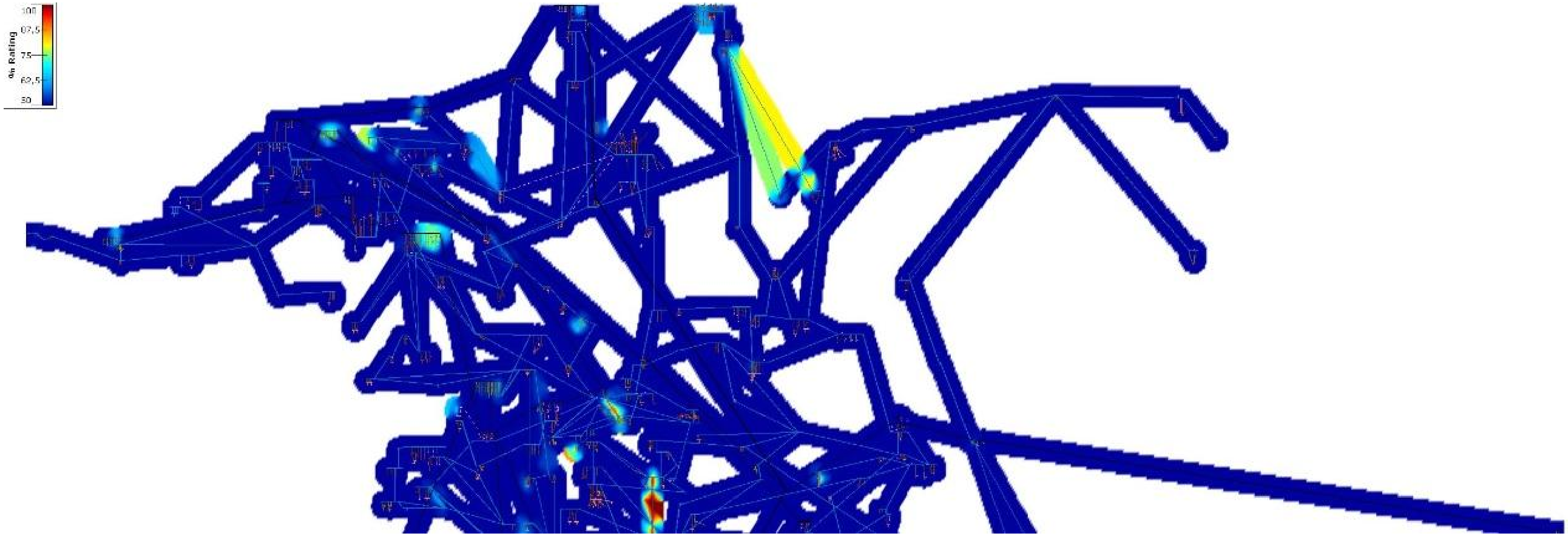


Figure 5-16: PSS/E Load Flow Snapsnot Scenario 4, North Egypt: Minimum Demand, No Wind Power and PV Solar Power.

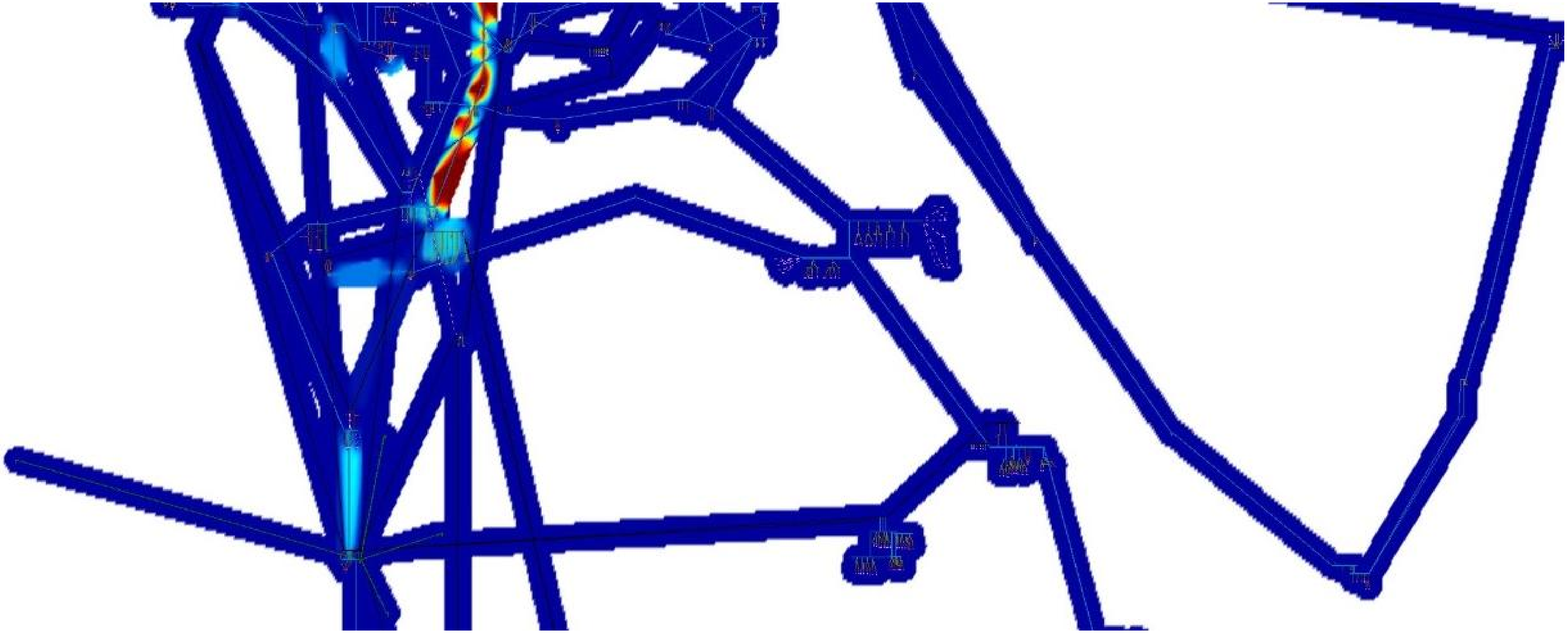


Figure 5-17: PSS/E Load Flow Snapsnot Scenario 4, Egypt Middle 1: Minimum Demand, No Wind Power and PV Solar Power.

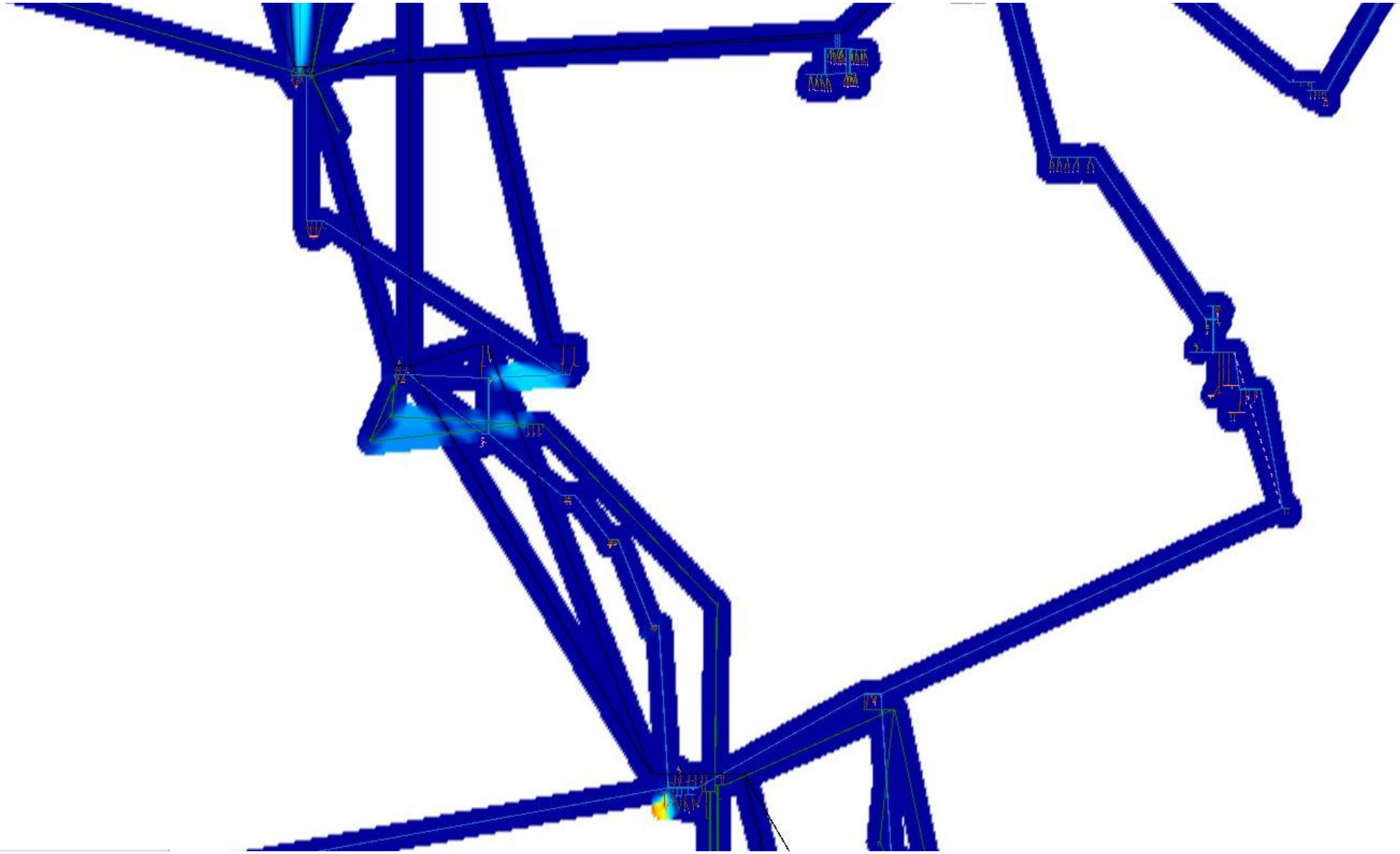


Figure 5-18: PSS/E Load Flow Snapsnot Scenario 4, Egypt Middle 2: Minimum Demand, No Wind Power and PV Solar Power.

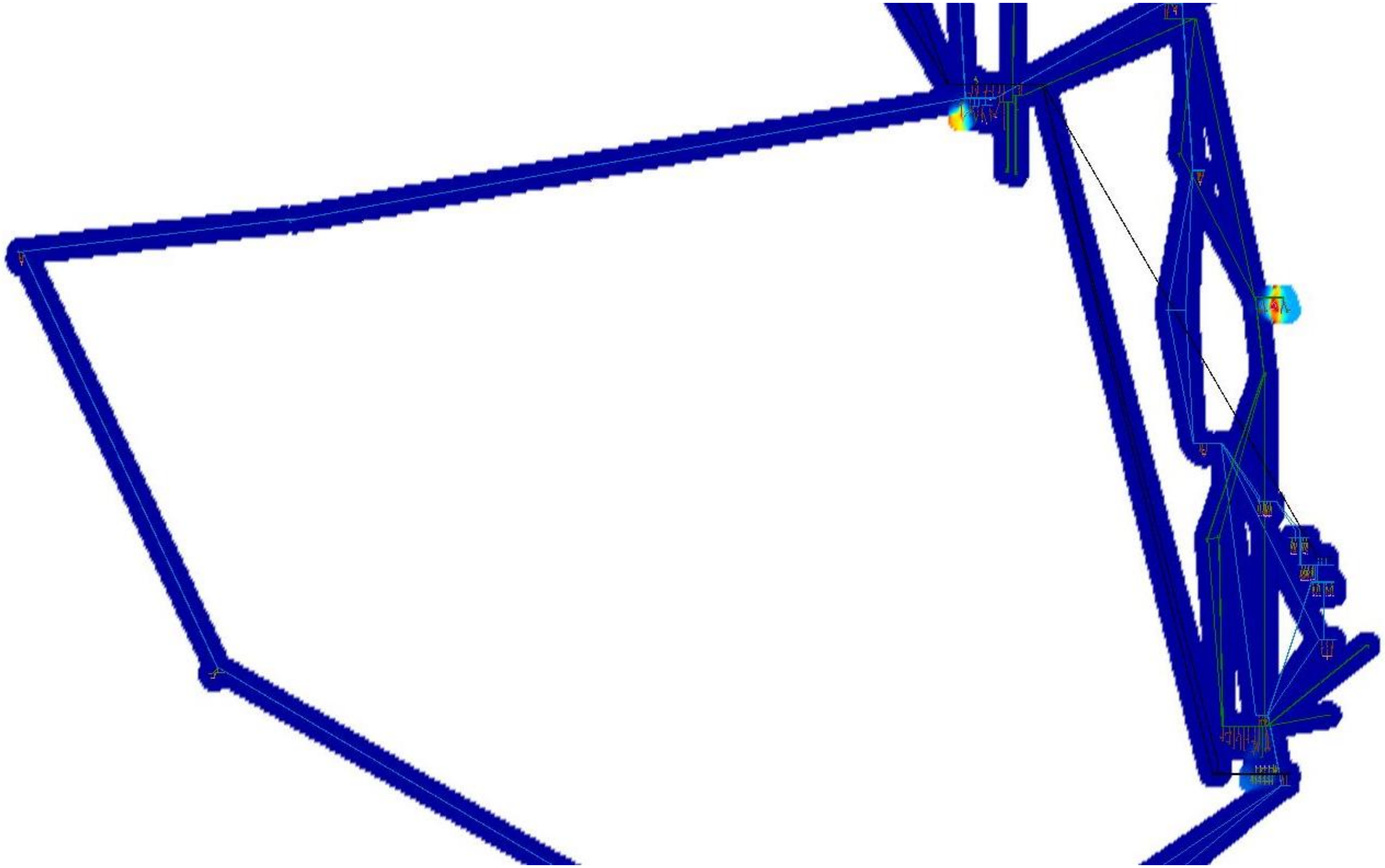


Figure 5-19: PSS/E Load Flow Snapsnot Scenario 4, South Egypt: Minimum Demand, No Wind Power and PV Solar Power

5.3.3 Voltage violations base case 2018

Figure 5-20: Voltage Violation base case 2018

5.3.4 Voltage violations Scenario 1-4

Figure 5-21: Voltage Violation Scenario 1, 2018: Maximum Demand, Maximum Wind Power and PV Solar Power.

Figure 5-22: Voltage Violation Scenario 2, 2018: Maximum Demand, No Wind Power and PV Solar Power.

Figure 5-23: Voltage Violation Scenario 3, 2018: Minimum Demand, Maximum Wind Power and PV Solar Power.

Figure 5-24: Voltage Violation Scenario 4, 2018: Minimum Demand, No Wind Power and PV Solar Power

5.4 Recommendations to overcome bottlenecks 2015

From the Load Flow Analysis for year 2015 it is necessary to reinforce the following transmission lines in the grid system in order to transmit the generated power successfully without overloading problems

.

The table below illustrates the specific lines for each scenario to be reinforced.

2015		Voltage level	Reinforcement	Base case	Scenario 1 Maximum Demand and Maximum Wind and Solar PV	Scenario 2 Maximum Demand and No Wind and Solar PV	Scenario 3 Minimum Demand and Maximum Wind and Solar PV	Scenario 4 Minimum Demand and No Wind and Solar PV
450-509	HARAM - C.500	220	Dobbelt circuit	X				
515-528	KURAIMAT - CAIRO-E	220	Dobbelt circuit	X				
531-99995-530	SUEZ-S - SK-KOR	220	Dobbelt circuit		X		X	
Contingency Analysis								
586-609	A-DAM-WAD.NOKR	220	Single circuit	X	X		X	

From the Load Flow Analysis for year 2015 it is several busbars at the 220 kV level were outside the normal voltage range of 0,9 – 1.05 pu. due to lack of reactive power in the Egyptian Power System and therefore the existing generators are running at their highest capability. To support the voltage and to reduce the MVar requirements on the generators and to run the cases in PSS/E, capacitance were included at specific locations as outlined in below table.

The additional required capacitance in order to keep the voltage balance in the grid system for year 2015:

Bus number	Bus name	Base case year 2015	Scenario 1 Maximum Demand and Maximum Wind and Solar PV.	Scenario 2 Minimum Demand and Maximum Wind and Solar PV.	Scenario 3 Maximum Demand and No Wind and Solar PV.	Scenario 4 Minimum Demand and No Wind and Solar PV
2	NAG-H	-165	-165	-165	-165	-165
2	NAG-H	-165	-165	-165	-165	-165
2	NAG-H		300	300	300	300
3	ASSYUT		400	400	400	400
4	SAMALUT	-165	-165	-165	-165	-165
4	SAMALUT	-165	-165	-165	-165	-165
4	SAMALUT	-165	-165	-165	-165	-165
14	TABA400	-50	-50	-50	-50	-50
20	HD-REAC1	-165	-165	-165	-165	-165
21	HD-REAC2	-165	-165	-165	-165	-165
46	MOTAMDIA		300	300	300	300

Bus number	Bus name	Base case year 2015	Scenario 1 Maximum Demand and Maximum Wind and Solar PV.	Scenario 2 Minimum Demand and Maximum Wind and Solar PV.	Scenario 3 Maximum Demand and No Wind and Solar PV.	Scenario 4 Minimum Demand and No Wind and Solar PV
301	SHABAB		300	300	300	300
337	OCT-GEN220		300	300	300	300
350	TORA		300	300	300	300
351	OBOUR		300	300	300	300
451	GIZA		300	300	300	300
501	NAG-H		200	200	200	200
501	NAG-H			-100		-100
509	C.500	200	200	200	200	200
527	BASATEEN		300	300	300	300
528	CAIRO-E	400	400	400	400	400
545	N.ASHER		300	300	300	300
546	ASHER		300	300	300	300
550	ZAGAZIG		300	300	300	300
560	MANSORA	200	200	200	200	200
562	SHARKIA		300	300	300	300
565	K-SHEKH		300	300	300	300
578	MATROUH	-25	-25	-25	-25	-25
578	MATROUH	-25	-25	-25	-25	-25
604	KANTRA		200	200	200	200
610	RIVA		200	200	200	200
620	A.TARTOR			-100		-100
623	NWEBEA			-50		-50
624	SHERM			-100		-100
2504	IDFO		100	100	100	100
2505	KOMOMBO		100	100	100	100
2508	ISNA		50	50	50	50
6001	N.ASSYUT			-100		-100
8064	HURGAD		200	200	200	200
8885	BASATEEN GEN	5,4	5,4	5,4	5,4	5,4
8886	BASATEEN GEN	5,4	5,4	5,4	5,4	5,4
8887	BAS	5,4	5,4	5,4	5,4	5,4

Bus number	Bus name	Base case year 2015	Scenario 1 Maximum Demand and Maximum Wind and Solar PV.	Scenario 2 Minimum Demand and Maximum Wind and Solar PV.	Scenario 3 Maximum Demand and No Wind and Solar PV.	Scenario 4 Minimum Demand and No Wind and Solar PV
8888	BAS	5,4	5,4	5,4	5,4	5,4
8889	BAS	5,4	5,4	5,4	5,4	5,4
8890	BAS	5,4	5,4	5,4	5,4	5,4
8891	BAS	5,4	5,4	5,4	5,4	5,4
8892	BAS	5,4	5,4	5,4	5,4	5,4
8893	HELIOPOLIS G	5,4	5,4	5,4	5,4	5,4
8894	HELIOPOLIS G	5,4	5,4	5,4	5,4	5,4
8895	HELIOPOLIS	5,4	5,4	5,4	5,4	5,4
8896	HELIOPOLIS	5,4	5,4	5,4	5,4	5,4
8897	HELIOPOLIS	5,4	5,4	5,4	5,4	5,4
100021	ZAF1-WT1	14,6	14,6	14,6	14,6	14,6
100022	ZAF1-WT2	8	8	8	8	8
100024	ZAF1-WT1	13	13	13	13	13
100025	ZAF1-WT2	12,5	12,5	12,5	12,5	12,5
100026	ZAF1-WT3	3,5	3,5	3,5	3,5	3,5
100027	ZAF1-WT2	3,5	3,5	3,5	3,5	3,5
300004	WTZAFT1W1A		3,9	3,9	3,9	3,9
300012	WTZAFT1W1B		7,2	7,2	7,2	7,2
300024	WTZAFT2W1A		6,9	6,9	6,9	6,9
300032	WTZAFT2W1B		8,2	8,2	8,2	8,2
300104	WTZAFT1W1A		6,5	6,5	6,5	6,5
300112	WTZAFT1W1B		6,3	6,3	6,3	6,3
300144	WTZAFT2W1A		3,4	3,4	3,4	3,4
300152	WTZAFT2W1B		3,7	3,7	3,7	3,7
300204	WTHURT1A		1,8	1,8	1,8	1,8

5.5 Recommendations to overcome bottlenecks 2018

From the Load Flow Analysis for year 2018 it is necessary to reinforce the following transmission lines in the grid system in order to transmit the generated power successfully without overloading problems

.

The table below illustrates the specific lines for the base case and each scenario to be reinforced.

2018		Voltage level	Reinforcement	Base case	Scenario 1 Maximum Demand and Maximum Wind and Solar PV	Scenario 3 Maximum Demand and No Wind and Solar PV	Scenario 2 Minimum Demand and Maximum Wind and Solar PV	Scenario 4 Minimum Demand and No Wind and Solar PV
247-251	ASHMOAN - N GIZA	220	Double circuit		X			
247-553	ASHMOAN - KALUBIA	220	Double circuit		X			
348-513	OCTBR-220 - 6-OCT	220	Double circuit		X			
374-5360	C-EAST - HELIOP2	220	Double circuit		X	X		
518-40040-40041-450	CAIRO-S - HARAM	220	Double circuit	X				
515-904/9041-905	KURAIMAT - MDNTNASR	220	Double circuit	X	X	X	X	X
524-625	PTROL-PL - ZAFRANA	220	Double circuit			X	X	
518-40034	CAIRO-S - DUMM 17&	220	Double circuit	X				
528-905	CAIRO-E - ZAH-MDNTNASR	220	Double circuit		X		X	X
545-546	N.ASHER - ASHER	220	Double circuit		X			
549-593	PORTSAID - PROBLEN	220	Double circuit		X			
558-563-593	TRUST - DOMIAT-S - PROBLEN	220	Double circuit		X			
561-636	GAMALIA - A-KBEER	220	Double circuit		X			
569-587	K-DAWAR - ABIS	220	Double circuit			X		
610-7874	RIVA - N-ASSIUT-GEN	220	Double circuit	X				
700-701	SABTIA - N-SABTIA	220	Double circuit	X	X			
6001-6008	N.ASSYUT - ASMNT 1 - ASSYUT STEAM	132	Double circuit	X				
6008-6011	ASMNT 1 - ASSYUT STEAM	132	Double circuit	X	X	X		
6009-6011	ASMNT 2 - ASSYUT STEAM	132	Double circuit	X	X	X		
Contingency Analysis								
508-40094	SELWA-ESNA	220	Single circuit		X			
586-609	A-DAM-WAD.NOKR	220	Single circuit		X		X	

586-5410	A-DAM-BENBAN	220	Single circuit				X	

From the Load Flow Analysis for year 2015 it is several busbars at the 220 kV level were outside the normal voltage range of 0,9 – 1.05 pu. due to lack of reactive power in the Egyptian Power System and therefore the existing generators are running at their highest capability. To support the voltage and to reduce the MVar requirements on the generators and to run the cases in PSS/E, capacitance were included at specific locations as outlined in below table.

Furthermore in order to compensate for the variation in load and reactive losses three SVC is suggested at the following locations:

- Bus 2 Naga Hamadi: 600MVAr
- Bus 3 Asyut: 600MVar
- Bus 8064 Hurghada: 300MVAr

The additional required capacitance in order to keep the voltage balance in the grid system for year 2018 are the following:

Bus number	Bus name	Base case B-Shunt (MVar)	Scenario 1 Maximum Demand and Maximum Wind and Solar PV. B-Shunt (MVar)	Scenario 2 Minimum Demand and Maximum Wind and Solar PV. B-Shunt (MVar)	Scenario 3 Maximum Demand and No Wind and Solar PV. B-Shunt (MVar)	Scenario 4 Minimum Demand and No Wind and Solar PV B-Shunt (MVar)
2	NAG-H	-165	-165	-165	-165	-165
2	NAG-H	-165	-165	-165	-165	-165
2	NAG-H		200	200	200	200
2	NAG-H		300			
4	SAMALUT	-165	-165	-165	-165	-165
4	SAMALUT	-165	-165	-165	-165	-165
4	SAMALUT	-165	-165	-165	-165	-165
10	KURAIMAT		400	400	400	400
14	TABA400	-50	-50	-50	-50	-50
20	HD-REAC1	-165	-165	-165	-165	-165
21	HD-REAC2	-165	-165	-165	-165	-165
247	ASHMOAN		300	300	300	300
328	N-BAHTEE		400	400	400	400
351	OBOUR		400	400	400	400
374	C-EAST	100	100	100	100	100
374	C-EAST	100	100	100	100	100
374	C-EAST	100	100	100	100	100
374	C-EAST	100	100	100	100	100
410	MASED1		100	100	100	100
450	HARAM		400	400	400	400

Bus number	Bus name	Base case B-Shunt (MVar)	Scenario 1 Maximum Demand and Maximum Wind and Solar PV. B-Shunt (MVar)	Scenario 2 Minimum Demand and Maximum Wind and Solar PV. B-Shunt (MVar)	Scenario 3 Maximum Demand and No Wind and Solar PV. B-Shunt (MVar)	Scenario 4 Minimum Demand and No Wind and Solar PV B-Shunt (MVar)
501	NAG-H		600	600	600	600
502	GERGA		200			
504	ASSYUT		400	400	400	400
509	C.500	200	200	200	200	200
511	BASSOS		400	400	400	400
515	KURAIMAT					-400
524	PTROL-PL		300	300	300	300
524	PTROL-PL					-100
528	CAIRO-E	400	400	400	400	400
533	SUEZ-500		100	100	100	100
534	ATAKA		300	300	300	300
541	SHOB_KH		400	400	400	400
545	N.ASHER		400	400	400	400
547	ABU-SULT		400	400	400	400
549	PORTSAID		400	400	400	400
550	ZAGAZIG		400	400	400	400
553	KALUBIA		600	600	600	600
560	MANSORA	100	400	100	100	100
562	SHARKIA		400	400	400	400
578	MATROUH	-25	-25	-25	-25	-25
578	MATROUH	-25	-25	-25	-25	-25
578	MATROUH					-25
583	A-KIR		400	400	400	400
588	SALOUM		25			
589	BAGDAD		100	100	100	100
604	KANTRA		300	100	100	100
620	A.TARTOR					-50
624	SHERM		100	100	100	100
624	SHERM					-50
650	OYNAT					-50
760	BALAT					-50
815	KURIMAT					-100

Bus number	Bus name	Base case B-Shunt (MVar)	Scenario 1 Maximum Demand and Maximum Wind and Solar PV. B-Shunt (MVar)	Scenario 2 Minimum Demand and Maximum Wind and Solar PV. B-Shunt (MVar)	Scenario 3 Maximum Demand and No Wind and Solar PV. B-Shunt (MVar)	Scenario 4 Minimum Demand and No Wind and Solar PV B-Shunt (MVar)
998	RAS GHAREB				-400	-200
998	RAS GHAREB					-200
2504	IDFO		100	100	100	100
2508	ISNA		150	150	150	150
5500	ZAGAZIG2		200	200	200	200
5600	MANSORA2	100	100	100	100	100
6005	MENIA		50			
6006	C.MINA		50			
6012	MAGAGA		50			
6882	S3 220		400	400	400	400
6882	S3 220				-120	
8064	HURGAD		200	200	200	200
8887	BAS	5,4	5,4	5,4	5,4	5,4
8888	BAS	5,4	5,4	5,4	5,4	5,4
8889	BAS	5,4	5,4	5,4	5,4	5,4
8890	BAS	5,4	5,4	5,4	5,4	5,4
8891	BAS	5,4	5,4	5,4	5,4	5,4
100021	ZAF1-WT1	14,6				
100022	ZAF1-WT2	8				
100024	ZAF1-WT1	13				
100025	ZAF1-WT2	12,5				
100026	ZAF1-WT3	3,5				
100027	ZAF1-WT2	3,5				
300004	WTZAFT1W1A		3,9	3,9	3,9	3,9
300012	WTZAFT1W1B		7,2	7,2	7,2	7,2
300024	WTZAFT2W1A		6,9	6,9	6,9	6,9
300032	WTZAFT2W1B		8,2	8,2	8,2	8,2
300104	WTZAFT1W1A		6,5	6,5	6,5	6,5
300112	WTZAFT1W1B		6,3	6,3	6,3	6,3
300144	WTZAFT2W1A		3,4	3,4	3,4	3,4
300152	WTZAFT2W1B		3,7	3,7	3,7	3,7
300204	WTHURT1A		1,8	1,8	1,8	1,8

6 Wind Turbines Model Type 1 - 4 and Solar PV Models for the PSS/E Study

6.1 Introduction

This chapter gives an introduction to the theoretical wind turbine models and Solar PV models relevant for the PSS/E modelling. The EETC staff has during the training workshops gained theoretical and hands-on training in PSS/E modelling and received training materials and detailed academic studies. The following sections provides a brief overview for the reader to understand the background and models used for the PSS/E modelling.

6.2 Type 1 - 4 Wind Turbine Models for PSS/E

6.2.1 Introduction to Types of Wind Turbines

A wide variety of wind turbine technologies are in use today. Typical wind power plants consist of hundreds of turbines, usually all employing the same technology. These technologies vary in cost, complexity, efficiency of wind power extraction, and equipment used. The wind turbines is classified into four basic types. [3]

The wind turbines generic models for the study are developed according to IEC 61400-27.

- Type 1; Fixed speed induction generator
- Type 2; Variable-slip induction generator
- Type 3; Double-fed induction generator (DFIG)
- Type 4; Full scale converter generator

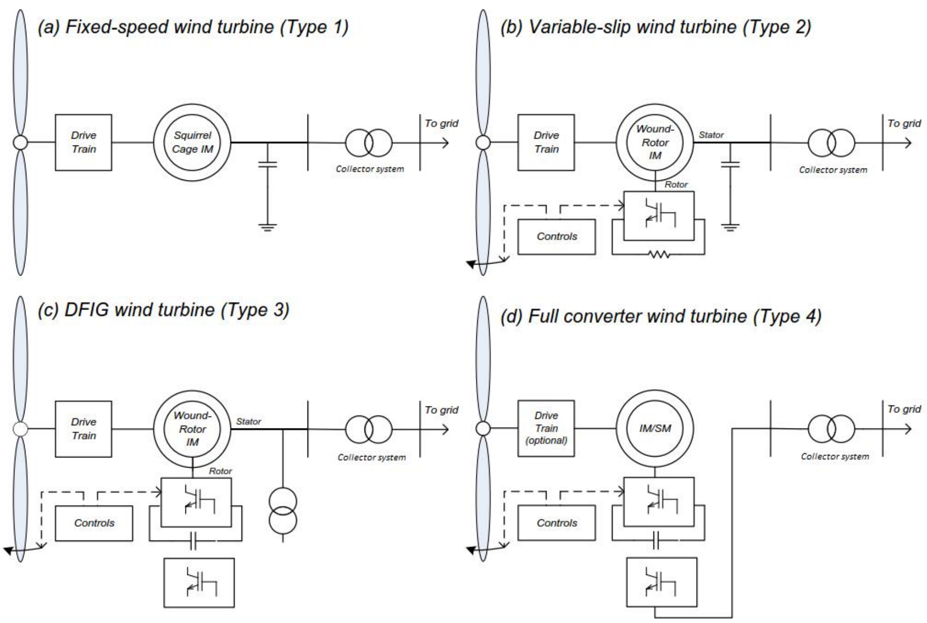


Figure 6-1: Dominant wind turbine technologies

[3] http://www.nrel.gov/docs/fy12osti/52780.pdf , p. 11-13

Fixed-speed, type 1, wind turbines are the most basic utility-scale wind turbines in operation. They operate with very little variation in turbine rotor speed, and employ squirrel-cage induction machines (IM) directly connected to the grid. Some of these turbines do not have blade-pitching capability. Although relatively robust and reliable, there are significant disadvantages of this technology, namely that energy capture from the wind is sub-optimal and reactive power compensation is required. Variable-speed wind turbines (the broad category into which the other three dominant technologies fall) are designed to operate at a wide range of rotor speeds. These turbines usually employ blade-pitching. Speed and power controls allow these turbines to extract more energy from a given wind regime than fixed-speed turbines can.

Variable-slip (VS), type 2, or dynamic rotor resistance (DRR) turbines control the resistance in the rotor circuit of the machine to allow a wide range of operating slip (speed) variation (up to 10%). However, power is lost as heat in the rotor resistance.

Doubly-fed induction generator (DFIG), type 3, turbines remedy this problem by employing a back-to-back AC/DC/AC converter in the rotor circuit to recover the slip power. Flux-vector control of rotor currents allows decoupled real and reactive power output, as well as maximized wind power extraction and lowering of mechanical stresses. Since the converter is only handling the power in the rotor circuit, it does not need to be rated at the machine's full output [4].

In full scale converter, type 4, turbines, a back-to-back AC/DC/AC converter is the only power flow path from the wind turbine to the grid. There is no direct connection to the grid. These turbines may employ synchronous or induction generators and offer independent real and reactive power control. In the full-converter turbine model described in this report, a permanent magnet alternator (PMA) machine with full converter is simulated. Block diagrams for the four models are shown in Figure 6-1. In the following sections the wind model types in PSS/E is described.

6.2.2 Type 1 Fixed speed induction generator in PSS/E

The type 1 wind turbine is represented by three generic models in PSSE.

- WT1G includes the induction generator dynamics
- WT12T includes the double mass shaft compliance model
- WT12A contains the pseudo governor model

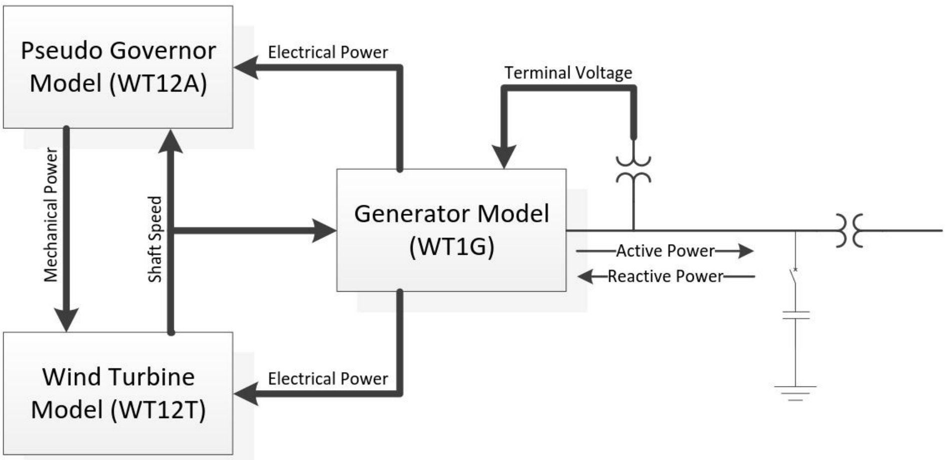


Figure 6-2: Type 1 wind turbine model connectivity diagram in PSS/E

[4] http://www.nrel.gov/docs/fy12osti/52780.pdf , p. 11-13

6.2.3 Type 2 Variable-slip induction generator PSS/E

The type 2 wind turbine is represented by four generic models in PSSE.

- WT2G includes the generator/converters model
- WT2E contains the electrical control model
- WT12T model includes the wind turbine model
- WT12A contains the pseudo governor model

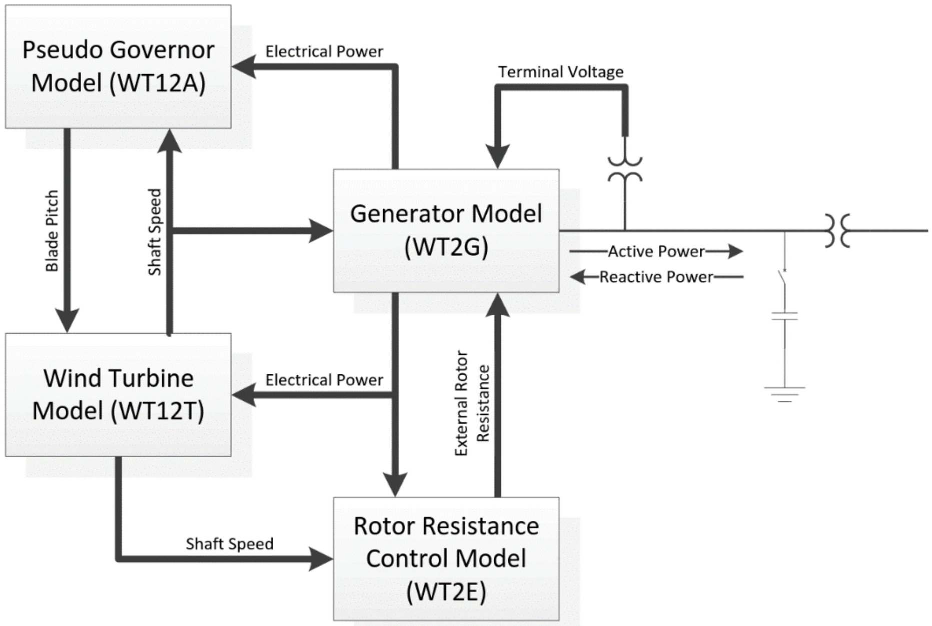


Figure 6-3: Type 2 wind turbine model connectivity diagram in PSS/E

6.2.4 Type 3 Double fed induction generator PSS/E

The type 3 wind turbine is represented by four generic models.

- WT3G1 includes the generator and converters dynamics
- WT3T1 includes the wind aerodynamic model and the single or double mass shaft compliance model.
- WT3P1 includes the pitch controller model.
- WT3E1 model contains the real and reactive control models

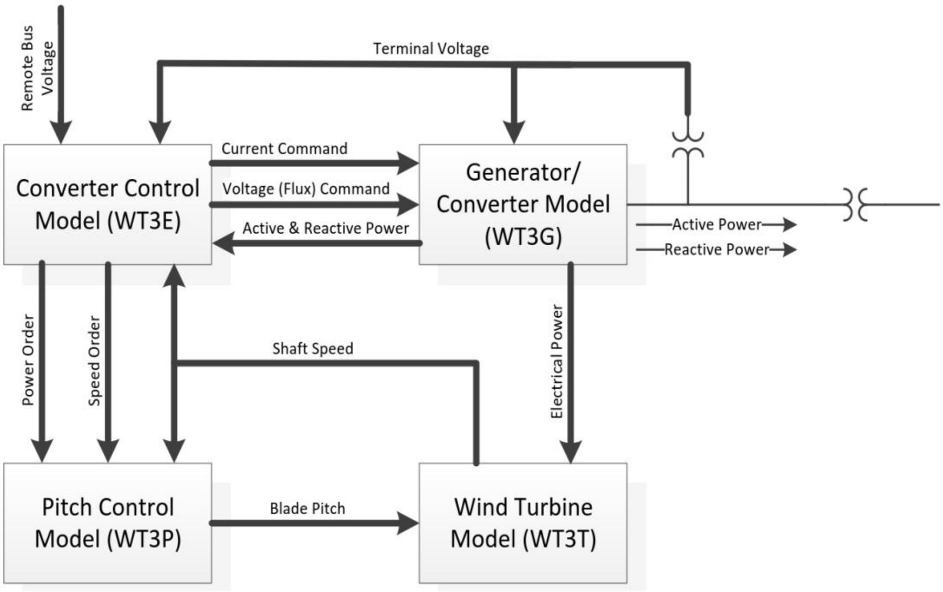


Figure 6-4: Type 3 wind turbine model connectivity diagram in PSS/E

6.2.5 Type 4 Full scale converter generator PSS/E

The type 4 wind turbine is represented by two generic models.

- WT4G includes the generator and converters dynamics
- WT4E contains the electrical control model for the type 4 wind generator.

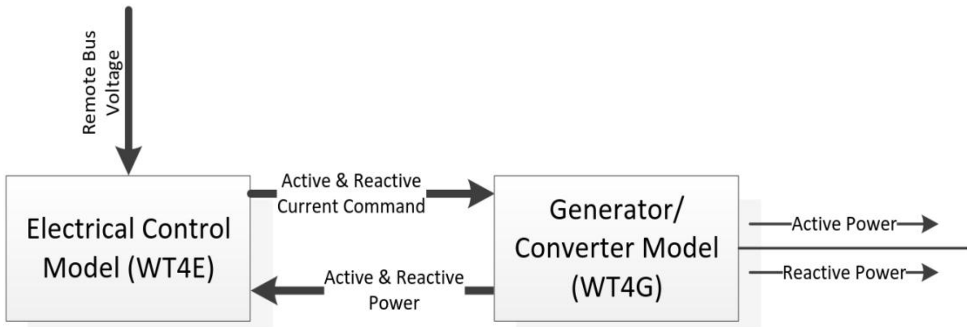


Figure 6-5: Type 4 wind turbine model connectivity diagram in PSS/E

6.3 Solar PV Models for PSS/E

6.3.1 Introduction to Solar PV

PV systems are highly modular and can be designed for a wide range of applications, from small residential systems to utility-scale, transmission-connected power plants. Typical residential systems are less than 10 kW and have a single inverter, while commercial systems can reach several MW and typically have multiple inverters. Power is injected into the grid at unity power factor. Residential and commercial systems are electrically separated from the transmission system by two transformer stages and equivalent line impedance.

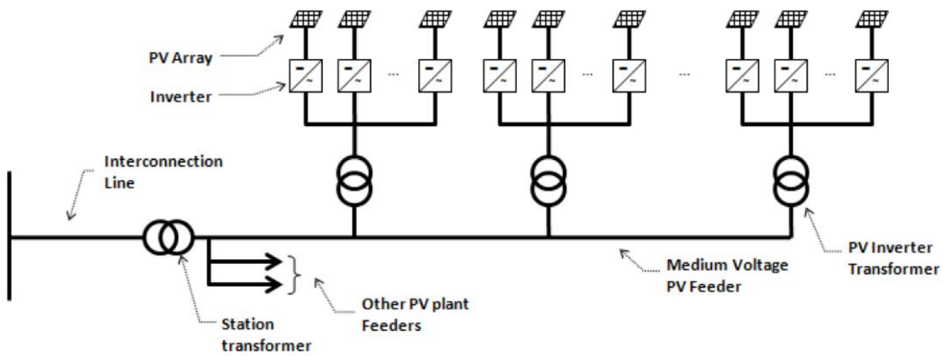


Figure 6-6: Generic large scale PV topology

Figure 6-6 shows the topology of a large PV power plant. Large PV plants typically have several medium voltage radial feeders. The PV inverters are connected to the feeders via step-up transformers, with several inverters sharing one step-up transformer. Some plants designs include capacitors or other reactive support systems that work in conjunction with the inverters to meet reactive power capability and control requirements at the point of interconnection.

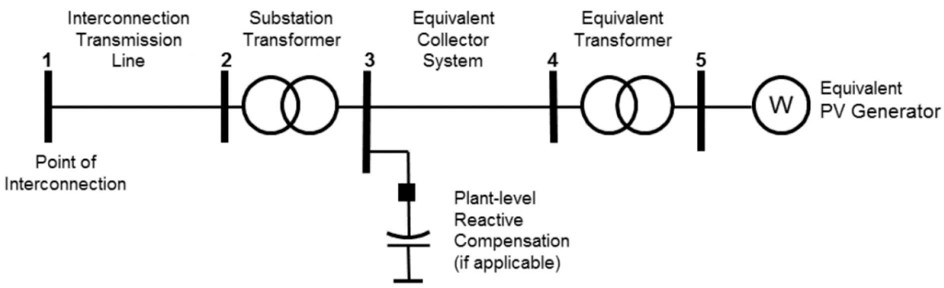


Figure 6-7: Aggregated PV topology

PV power plants must be represented by a simplified system consisting of one or more equivalent generators and unit transformers, equivalent collector system, substation transformer, and plant-level reactive support system, if present. For most PV plants, the single-generator equivalent model shown in Figure 6-7 is adequate for bulk-level power flow and dynamic simulations.

Energy storage is rarely installed in conjunction with grid-connected PV systems. Therefore, variations in irradiance are reflected into variations of PV plant output. In addition to the predictable seasonal and diurnal cycles, short-term irradiance variability also occurs as a result of cloud shadows moving across the PV array. Variability is a function of cloud characteristics (density, size, velocity, opacity, height) plant size and tracking method and physical separation between individual PV systems. Compared to irradiance measured at a single point, output variability of large PV plant or a collection of distributed PV systems varies much more slowly. A full discussion of variability is out of the scope of this study. Significant work has recently been done in this area.

6.3.2 Solar PV plant in PSS/E

The solar PV model in PSS/E is presented by 3 main models:

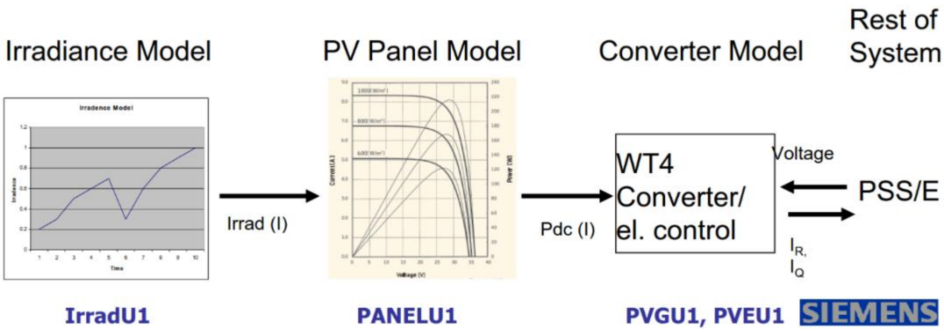


Figure 6-8: Overview of Solar PV Plant in PSS/E with 3 main models

<u>Irradiance model</u>

- Standard Model that allows user to vary the amount of solar irradiance
- User enteres up to 10 data points
- Initializes base on steady state P/Pmax
- For each time step outputs linearized irradiance level

<u>PV Panel Model</u>

- Standard Model for a PV panels I-V curve
- PV panel output varies with irradiance, temperature, terminal voltage
- User enter maximum Pdc for different irradiance levels
- For each timer step reads irradiance linearized power order

<u>Converter Model</u>

- Largely ignores dynamic from DC side
- Different reactive control modes: Voltage, PF and Q control
- Each times step, outputs linearized irradiance level

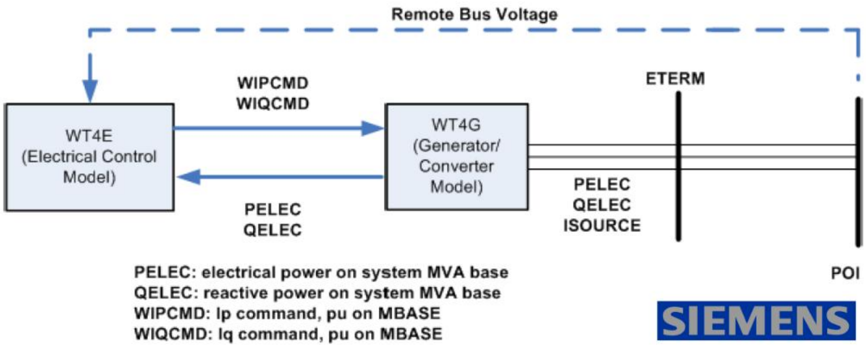


Figure 6-9: Solar PV Plant converter model - Type 4 wind turbine converter model, slightly modified

6.4 Overview of PSS/E models for wind turbine type and PV solar model.

Table 6-1 provides an overview of the PSS/E models for each type and PV.

Type 1	Type 2	Type 3	Type 4	PV
WT1G Generator Model	WT2G Generator Model	WT3G Generator/ Converter Model	WT4G Generator/ Converter Model	PVGU1 Generator
	WT2E Rotor resistance control Model	WT3E Electrical control	WT4E Electrical control	PVEU1 Electrical control
WT12T Two-Mass turbine model		WT3T Mechanical system model		PANELU1 PV Panel model
		WT3P Pitch control model		IrradU1 Irradiance model
WT12A Pseudo-Governor model				

Table 6-1: Overview of the PSS/E models for each of the four types and PV

Source: http://www.nrel.gov/docs/fy12osti/52780.pdf p. 11-13

7 Dynamic Analysis study

7.1 Introduction

This chapter presents the dynamic transient analysis study and analysis of eigenvalues.

The objective of the transient stability analysis is to calculate the system response from a defined set of disturbances with faults cleared by tripping of transmission lines. The response of the generators are checked to see that all machines remain in synchronism and damping of power system oscillations are acceptable.

The dynamic transient stability simulations are conducted for the 4 scenarios with the following 9 defined cases for each scenario.

Cases 1 – 5 are chosen in order to analyse the 500 kV circuit which has considerable power flow on the South and North transmission. The applied two faults are in accordance with the technical requirements from EETC.

- Case 1- Tripping Kurimat500-Samalut500 circuit after 100ms fault after 10 second trip Cairo500- Samalut500 Circuit.
- Case 2- Tripping the first Assut500-Samalut500 circuit after 100ms fault then after 10 second trip the secondary circuit.
- Case 3- Tripping the first Assut500-N.Hamadi500 circuit after 100ms fault then after 10 second trip the secondary circuit.
- Case 4- Tripping the first N.Hamadi500-High Dam500 circuit after 100ms fault then after 10 second trip the secondary circuit.
- Case 5- Tripping Nobaria500-Cairo500 circuit after 100ms fault then after 10 second trip the secondary circuit.

Cases 6 – 7 are chosen in order to analyse the 220 KV circuit with considerable power flow from renewable energy. The applied two faults are in accordance with the technical requirements from EETC.

- Case 6 Year 2018 - Tripping line 4 Samalut-881 FIT circuit after 100ms fault
- Case 6 Year 2015 - Tripping Zafarana 220kV line –PETROLP220 circuit after 100 ms fault then after 10 second trip the secondary circuit.

- Case 7 Year 2018 - Tripping line 635 El Zayt-998 Zafarana 100ms fault. Both lines one at 1 sec one at 11 seconds
- Case 7 Year 2015 – Tripping 220 kV line Zafarana – RasGhareb after 100 ms fault then after 10 second trip the secondary circuit.

Case 8 is chosen in order to analyse the 500 KV circuit with considerable power flow from renewable energy. The applied two faults are in accordance with the technical requirements from EETC.

- Case 8 Year 2018 - Tripping line 5420 Benban- Naghamadi 2 after 100 ms fault then after 10 second trip the secondary circuit.
- Case 8 Year 2015 – Tripping 200 MW El-Zayt Wind farm

Case 9 is chosen in order to analyse the tripping of 500MW at Benban as the maximum amount of renewable to be lost and to analyse if the power system is designed to lose a high amount of generation.

- Case 9 Year 2018 - Power change, disconnect 500 MW at Benban at 1 second 400164-400234 power generators increment 10

7.2 Transient Stability Analysis

Each scenario 1-4 for year 2015 and year 2018 has been simulated in PSS/E according to the 9 defined cases. All the response plots for each scenario and the PSS/E dynamic data simulation calculations are attached in Annex 2.

7.3 Summary of Transient Stability Analysis with Recommendations

Year 2015

Case number	Case event name	Result	Recommendation
Case 1	Tripping Kurimat500-Samalut500 circuit after 100ms fault after 10 second trip Cairo500- Samalut500 Circuit.	Scenario 1 – 4. The power system is stable with both circuits disconnected.	No issue
Case 2	Tripping the first Assut500-Samalut500 circuit after 100ms fault then after 10 second trip the secondary circuit.	Scenario 1 – 4. The power system is stable with both circuits disconnected.	No issue
Case 3	Tripping the first Assut500-N.Hamadi500 circuit after 100ms fault then after 10 second trip the secondary circuit.	Scenario 1 – 4. The power system is not stable with both the circuits disconnected. With one circuit disconnected the system is stable.	No issue
Case 4	Tripping the first N.Hamadi500-High Dam500 circuit after 100ms fault then after 10 second trip the secondary circuit.	Scenario 1 – 4. The power system is not stable with both the circuits disconnected. With one circuit disconnected the system is stable.	Reinforcement of the 500 kV line High-Dam Nag Hamadi Install a 600 MVAr SVC in Nag Hamadi
Case 5	Tripping Nobaria500-Cairo500 circuit after 100ms fault then after 10 second trip the secondary circuit.	Scenario 1 – 4. The power system is stable with one circuit disconnected	No issue
Case 6	Tripping Zafarana 220kV line – PETROLP220 circuit after 100 ms fault then after 10 second trip the secondary circuit.	Scenario 1 – 4. The power system is stable with both circuits disconnected	No issue

Case 7	Tripping 220 kV line Zafarana – RasGhareb after 100 ms fault then after 10 second trip the secondary circuit.	Scenario 1 – 4. The power system is stable with the both circuits disconnected	No issue
Case 8	Tripping 200 MW El-Zayt Wind farm	Scenario 1 – 4. The power system is stable with loss of the wind farm.	No issue

Year 2018

Case number	Case event name	Result	Recommendation
Case 1	Tripping Kurimat500-Samalut500 circuit after 100ms fault after 10 second trip Cairo500- Samalut500 Circuit.	Scenario 1 – 4. The power system is stable with both circuits disconnected.	No issues
Case 2	Tripping the first Assut500-Samalut500 circuit after 100ms fault then after 10 second trip the secondary circuit.	Scenario 1 – 4. The power system is stable with both circuits disconnected.	No issues
Case 3	Tripping the first Assut500-N.Hamadi500 circuit after 100ms fault then after 10 second trip the secondary circuit.	Scenario 1 – 4. The power system is stable with both circuits disconnected.	No issues
Case 4	Tripping the first N.Hamadi500-High Dam500 circuit after 100ms fault then after 10 second trip the secondary circuit.	Scenario 1: The power system is only stable with both the circuits connected. Scenario 2: The power system is stable with one circuit disconnected. Scenario 3 – 4. The power system is stable with both circuits disconnected.	Reinforcement of the 500 kV line High-Dam Nag Hamadi It is required to install a SVC at Nag Hamadi (600 MVar), Assuit (600 Mvar) and Hurghada (300 MVar) to keep the MVAr in balance and the grid stable.
Case 5	Tripping Nobaria500-Cairo500 circuit after 100ms fault then after 10 second trip the secondary circuit.	Scenario 1 – 4. The power system is stable with the circuit disconnected	No issue

Case 6	Tripping line 4 Samalut-881 FIT circuit after 100ms fault	Scenario 1 & 3. The power system is unstable with one circuit disconnected. Scenario 2 & 4. The power system is stable with both circuits disconnected.	Reinforcement of the line FIT-RAS Ghareb.
Case 7	Tripping line 635 El Zayt-998 Zafarana 100ms fault. Both lines one at 1 sec one at 11 seconds	Scenario 1 - 4. The power system is stable with both circuits disconnected	No issue
Case 8	Tripping line 5420 Benban- Naghamadi 2 after 100 ms fault then after 10 second trip the secondary circuit.	The power system is stable with both the circuits disconnected, without wind power At maximum demand and maximum wind power and solar PV, the system is very close to become instable.	It is required to install a SVC at Nag Hamadi (600 MVar), Assuit (600 Mvar) and Hurghada (300 MVar) to keep the MVAr in balance and the grid stable.
Case 9	Power change, disconnect 500 MW at Benban at 1 second 400164-400234 power generators increment 10	Scenario 1 - 4. The power system is stable with loosing 500 MW in BENBAN.	No issue

7.4 Analysis of Eigenvalues in the Complex Plane

The eigenvalues are analysed in PSS/E, through the modal analysis section in PSSPLT serves as an aide in the interpretation of dynamic simulation.

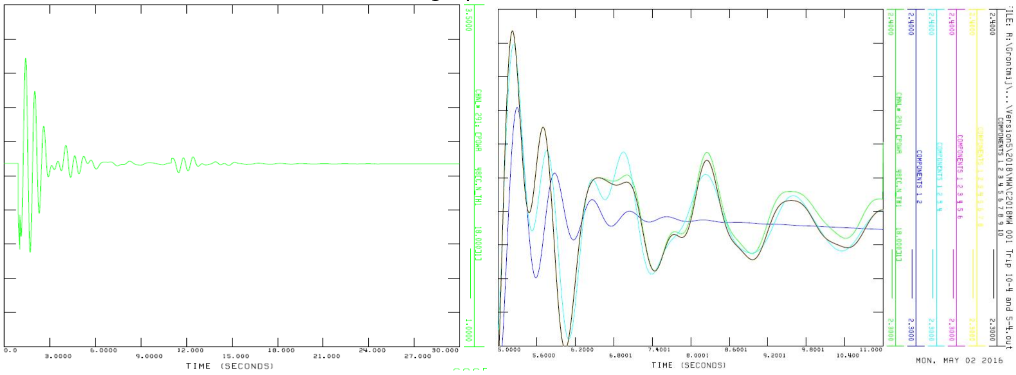
The eigenvalue study from PSS/E Simulation is attached in Annex 2.

The damped modes are characterized in terms of frequency and damping (i.e., their eigenvalues). Oscillation nodes and antinodes are determined by comparing the relative oscillation amplitudes and phases of representative units in the system. Similar analyses on bus voltages render the oscillations' electrical centers. These investigations provide the mode shape associated with each oscillation; or, in linear analysis terminology, the eigenvector associated with each eigenvalue.

$$\text{Output} = \sum\left(A_i \times e^{\sigma_i \times t}\right) + \sum\left(B_j \times e^{\sigma_j \times t} \times \cos(w_j \times t + \phi_j)\right)$$

The manual techniques of identifying eigenvalues have been automated in this modal analysis section of PSSPLT. The method is based on recursiveleast-square approximations.
The main idea behind modal decomposition is that any linear system response can be decomposed into a summation of terms like the following:

The method is demonstrated in below graph.

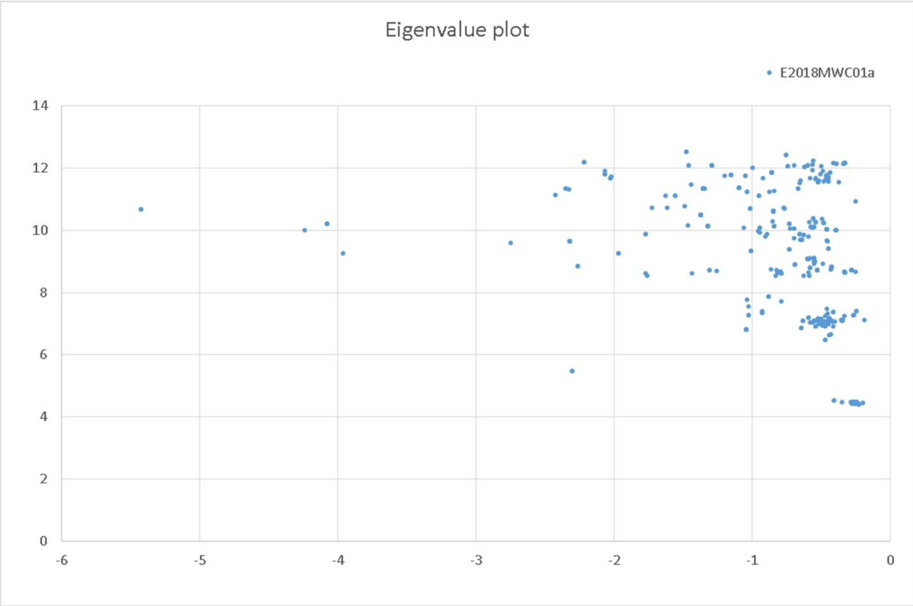


For the time 5-11 seconds the analysis is performed (to avoid) fast damped modes of no interest. The curve shows how the modal fitting emulate the signal in the investigated period

The modal component is given in the table below. Please refer to complete tables and eigen value analysis from PSS/E simulation in Annex 2.

MODAL COMPONENTS					
COMP.	EIGENVALUE		EIGENVECTOR		
NO	REAL	IMAGINARY	MAGNITUDE	ANGLE	REMARKS
1	-0.393384E-03	--	2.3401	--	TCNST:2542.045 SC.
2	-1.61278	10.7261	0.50178E-01	172.73	FREQ.: 1.707 HZ.
3	-0.893496	9.87955	0.34618E-01	-54.75	FREQ.: 1.572 HZ.
4	-0.252936	4.45147	0.26839E-01	-101.82	FREQ.: 0.708 HZ.
5	-0.596657	12.0882	0.15274E-01	-93.41	FREQ.: 1.924 HZ.
6	-0.442865	6.61841	0.10698E-01	172.79	FREQ.: 1.053 HZ.
7	-3.07953	18.2792	0.13206E-03	-52.22	FREQ.: 2.909 HZ.
8	-1.31819	23.0527	0.33112E-04	11.91	FREQ.: 3.669 HZ.
9	-3.24649	31.4828	0.82157E-05	-91.70	FREQ.: 5.011 HZ.
10	-2.13454	46.2613	0.59264E-05	-34.56	FREQ.: 7.363 HZ.

Below is illustrated the eigenvalues for maximum demand and maximum wind and solar PV for year 2018, case 1 at 5-11 seconds and 16-21 seconds.



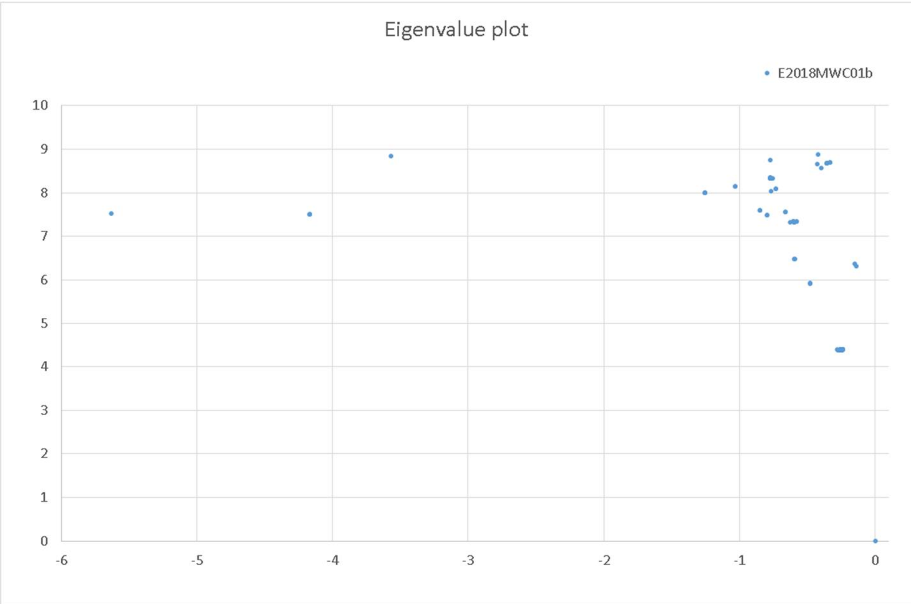


Figure 7-1: Eigenvalues for year 2018, maximum demand, maximum wind and solar PV case 1 at 5-11 seconds and 16-21 seconds

The following graph illustrates the generators participating in power swings at different frequency.

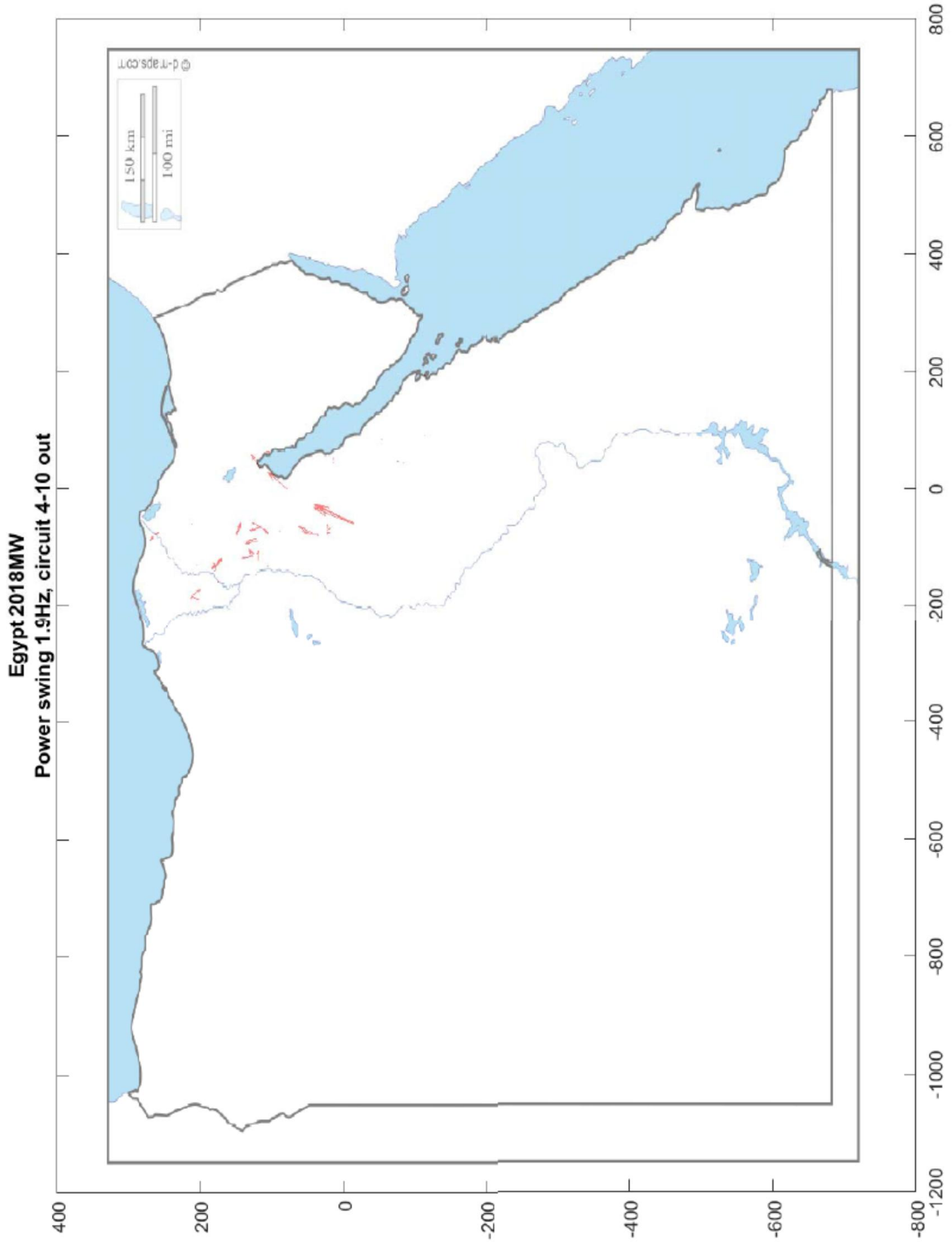


Figure 7-2: Generators participating in Power swings for the 2018MW case at 4-10 out and 1.9Hz

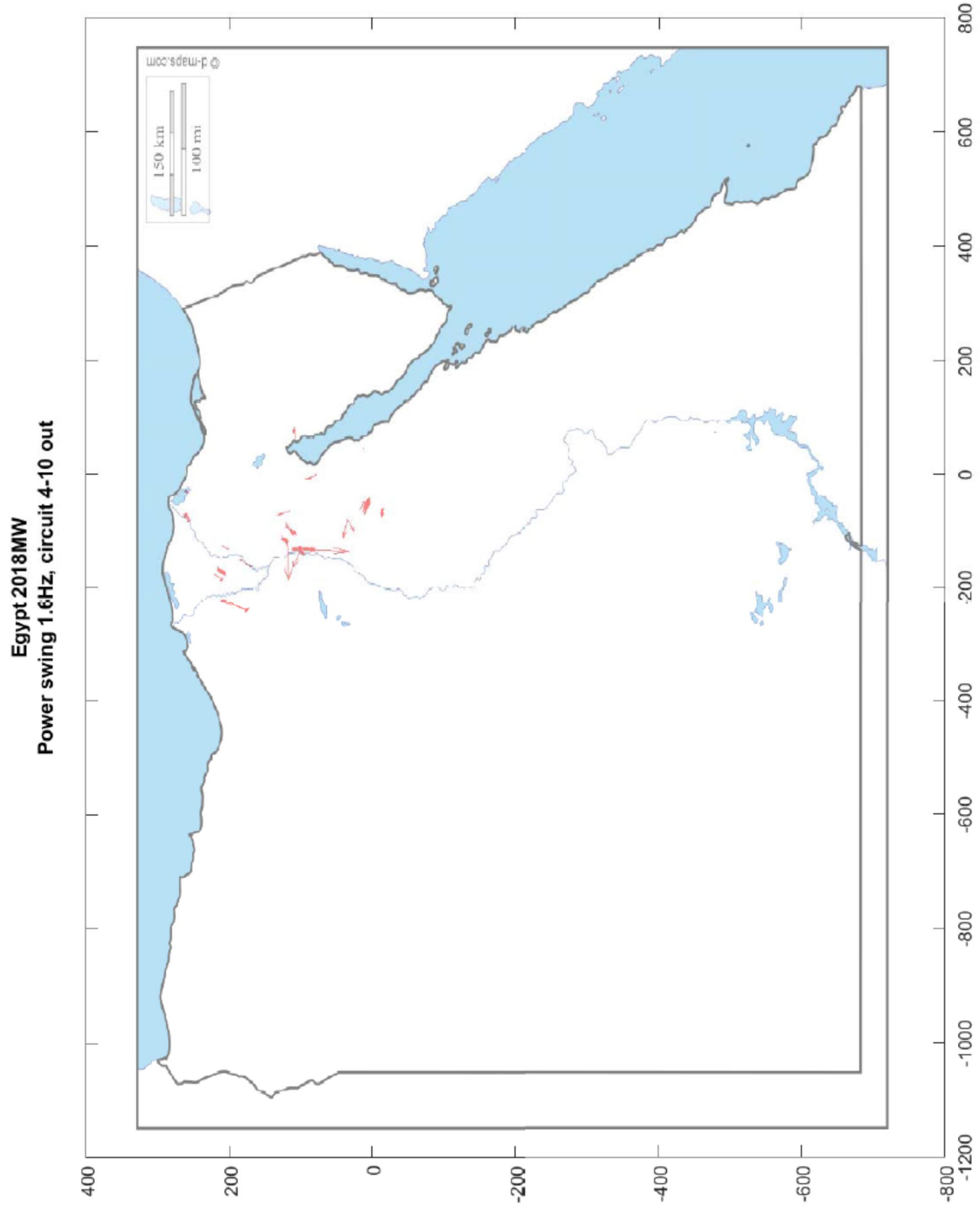


Figure 7-3: Generators participating in Power swings for the 2018MW case at 4-10 out and 1.6Hz

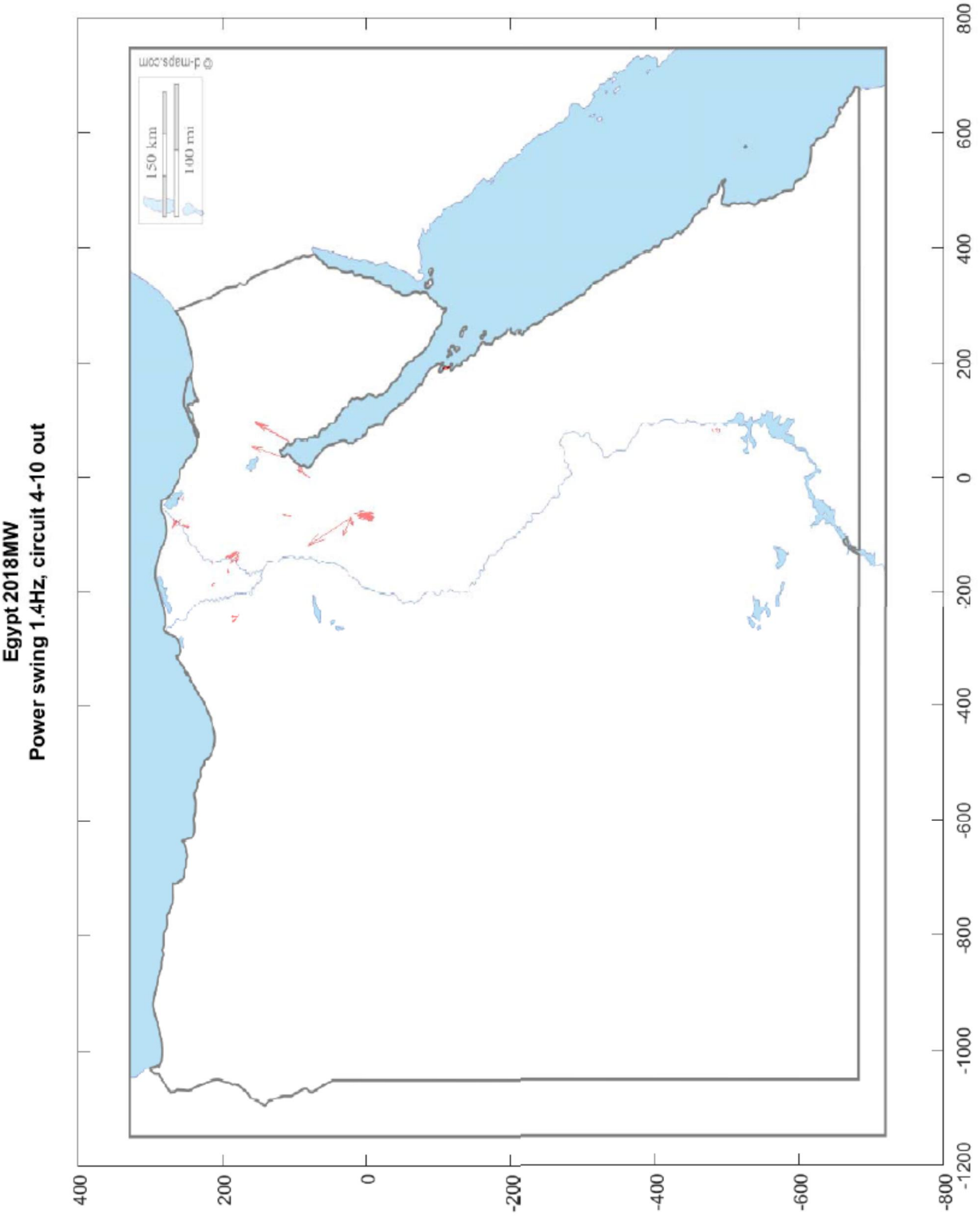


Figure 7-4: Generators participating in Power swings for the 2018MW case at 4-10 out and 1.4Hz

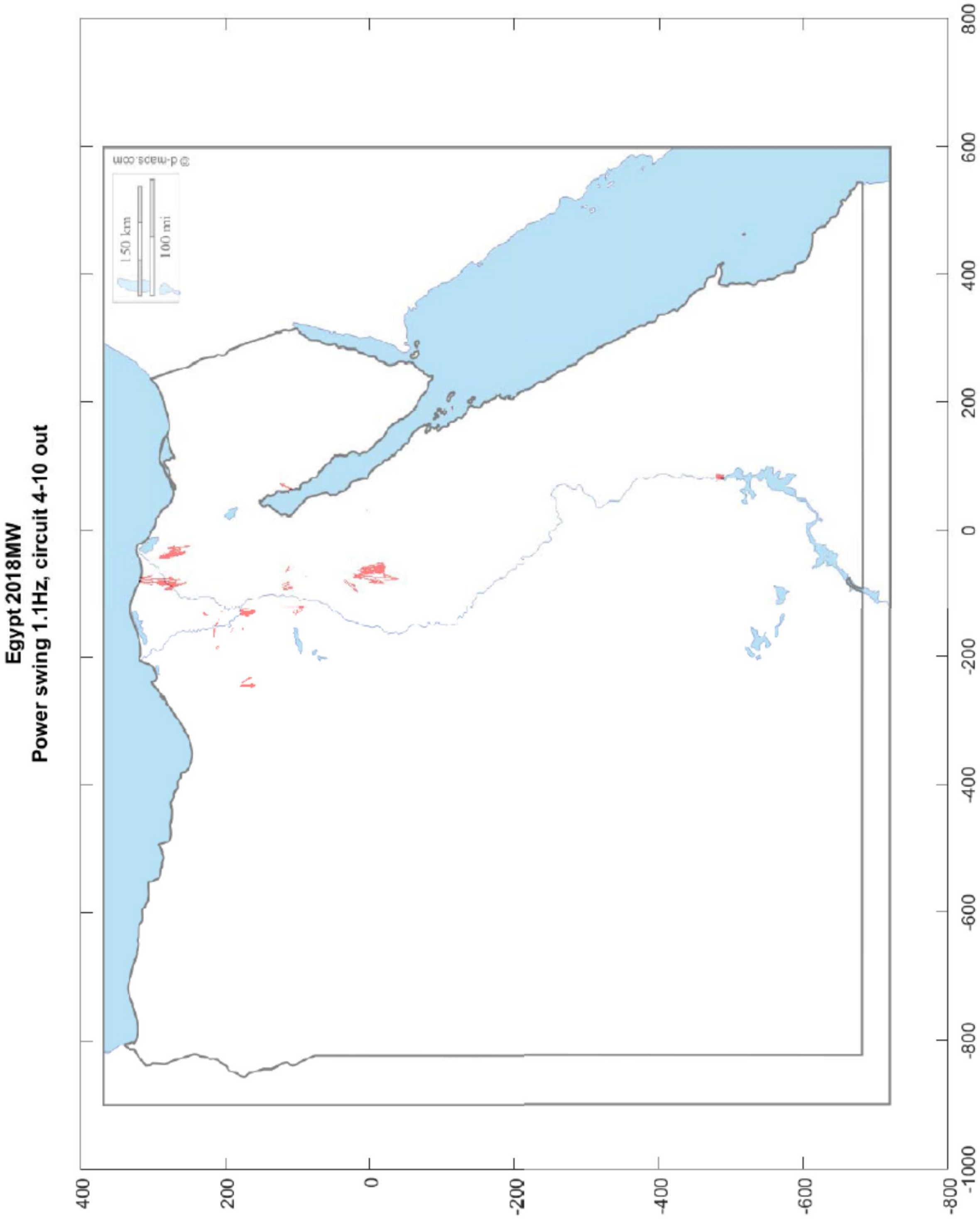


Figure 7-5: Generators participating in Power swings for the 2018MW case at 4-10 out and 1.1Hz

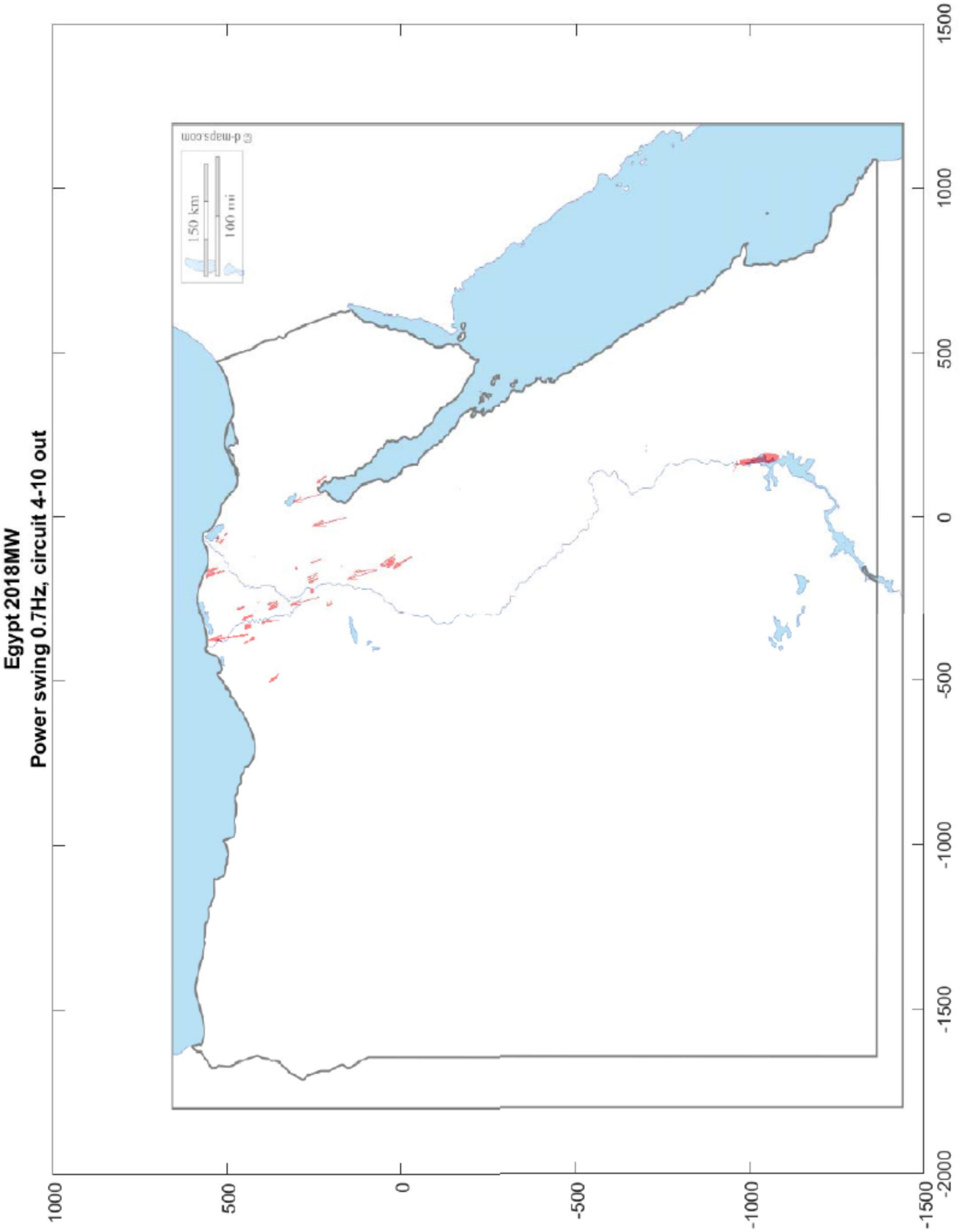


Figure 7-6: Generators participating in Power swings for the 2018MW case at 4-10 out and 0.7Hz

8 Conclusion and Recommendations

The Key-Conclusions and Recommendations of the Study are:

1. The EETC PSS/E Data files for year 2015 and year 2018 have successfully been analysed and the Load Flow Model and Dynamic Model is after modifications running with no simulation errors and the initial conditions are acceptable. Each power plant in the PSS/E data files have been aligned with the power plant information from the EEHC Annual Report in order to identify each power plant in the PSS/E-file and update any new power plants. The dynamic data of the model have been analysed according to general design rules and international standard parameters. In a mutual effort between the Consultant and the EETC support staff from the Studies Sector, the PSS/E files have been clarified and adjusted.

2. In the PSS/E Data File year 2015 and year 2018 received from EETC, several busbars at the 220 kV level were outside the normal voltage range of 0,9 – 1.05 pu. due to lack of reactive power in the Egyptian Power System and therefore the existing generators are running at their highest capability. To support the voltage and to reduce the MVar requirements on the generators and to run the cases in PSS/E, capacitance were included at specific locations as outlined in detail in the study from the PSS/E Simulations.

3. The review of the PSS/E data files concludes that it is required that EETC sets up a verification process of the steady state electrical simulation model and is provided with capacity training in verification/validation. On the 7th and 8th of December 2015 the Consultant conducted a training workshop in introduction to verification and validation process. After completion of the workshop, EETC acknowledged the importance of this topic and to further develop their technical skills in this field.

4. An economic model of the Egyptian Power System has been modelled using the Balmorel model tool. This model has generated the critical generation patterns for year 2015 and year 2018. The generation patterns represent 4 scenarios generated with max/min. demand with full wind generation meaning all wind farms are generating at full capacity, and no wind power generation, respectively, when all wind farms are shut down. These generation patterns are used as input data for the PSS/E model study, for detailed analyses of grid stability in extreme situations. The model has optimised the dispatch by minimising the total costs of supplying electricity. The procedure takes into account the marginal costs of the individual power plants (fuel price divided by efficiency) as well as start/stop costs and restrictions on the transport between zones. The electricity system is modelled as consisting of 7 zones: Cairo, North Upper Egypt, South Upper Egypt, West Delta, Middle Delta, Alexandria and Canal. This division is based on the Egyptian generation companies, where Hydro power generation is included in Upper Egypt. The value of the generated electricity from wind power is assessed together with the need for forced curtailment of wind power. In order to assess the impact of increased amounts of wind power in the Egyptian power system, sensitivity analyses were performed in which the wind power capacity was gradually expanded. In a sensitivity analysis, 2500 MW is added per simulation (1250 MW in the Suez Gulf, and 1250 MW on the Nile banks) until a total of 25,000 MW is added to the existing capacity. The Balmorel model shows that it is profitable to include up to 15.000 MW wind power capacity in the Egyptian Power System.

5. Aggregated wind farm models and Solar PV models have succesfully been created and implemented in the PSS/E Files for year 2015 and year 2018. Furthermore, SVC models have successfully been implemented in the PSS/E data file for year 2018 in order to support the grid stability. The EETC Support Staff from the Studies Sector and NECC Staff have been trained in PSS/E modelling and creating aggregated models for simulations. The detailed calculation, descriptions and parameter overviews with cable length summaries are attached in Annex 1.

6. The Load Flow Analysis in PSS/E has identified the following bottlenecks in the Egyptian Power System for year 2015 and for the 4 defined scenarios. Printshots of the PSS/E Simulation Load Flow are presented in the Report. The transmission lines marked in red are overloaded and needs to be reinforced.

Lines loaded more than 70%	Year 2015 - Line loading - 100 % - 90 % - 80 % - 70%							
Node	Names	Voltage / kV	Rating	Base case Existing Egyptian Power System	Scenario 1 Maximum Demand and Maximum Wind and Solar PV	Scenario 2 Minimum Demand and Maximum Wind and Solar PV	Scenario 3 Maximum Demand and No Wind and Solar PV	Scenario 4 Minimum Demand and No Wind and Solar PV
563-593	DOMIAT-S - PROBLEN	220	305	253	253	276		271
5-130	C.500 - NOB-500	500	1559					1248
328-542	N-BAHTEE - CAIRO-N	220	381	297		306	281	296
329-521	TEB_GEN - WADI-H	220	362	324				
336-561	W-DOM-PS - GAMALIA	220	570	422				
350-518	TORA - CAIRO-S	220	457	333				
374-5360	C-EAST - HELIOP2	220	133	96	104		111	
450-509	HARAM - C.500	220	381	381	375	267	339	274
451-509	GIZA - C.500	220	381	365	355		320	
501-502	NAG-H - GERGA	220	457		282		282	
512-3370	HADABA - OCTOBRGEN2	220	419	312				
561-636	GAMALIA - A-KBEER	220	305	229	243			
515-528	KURAIMAT - CAIRO-E	220	305	321		242		257
558-563	TRUST - DOMIAT-S	220	305	235	234	259		254
522-523	N-TEBB - TEBBIN	220	457		410			
523-40050	TEBBIN - DUMM 33&	220	457	326				
527-40053	BASATEEN - DUMM 36&	220	267	225	190		230	
527-40055	BASATEEN - DUMM 38&	220	267	225	190		230	
528-530	CAIRO-E - SKR-KOR	220	343		250			
531-533	SUEZ-S - SUEZ-500	220	438		324		367	
531-99995	SUEZ-S -	220	190		193		235	
538-539	STAD - METRO	220	381	268	274		276	
540-541	SABTIA - SHOB_KH	220	305	233	238		239	
541-543	SHOB_KH - CAIRO-N	220	381		272		274	
542-700	CAIRO-N - SABTIA	220	286	213	210		211	
583-2432	A-KIR - ABIS 2	220	194		171		140	
583-40030	A-KIR - DUMM 13&	220	194		164		141	
595-40058	C.N_GEN1 - DUMM 41&	220	229	208	182	164	194	178
595-40059	C.N_GEN1 - DUMM 42&	220	229	208	182	164	194	178
634-40051	ECTSADIA - DUMM 34&	220	247		190			

Lines loaded more than 70%	Year 2015 - Line loading - 100 % - 90 % - 80 % - 70%							
Node	Names	Voltage / kV	Rating	Base case Existing Egyptian Power System	Scenario 1 Maximum Demand and Maximum Wind and Solar PV	Scenario 2 Minimum Demand and Maximum Wind and Solar PV	Scenario 3 Maximum Demand and No Wind and Solar PV	Scenario 4 Minimum Demand and No Wind and Solar PV
700-701	SABTIA - N-SABTIA	220	305	285	282		283	
704-40050	- DUMM 33&		457	328				
5820-40030	SMOUHA2 - DUMM 13&	220	194		165		142	
6001-6008	N.ASSYUT - ASMNT 1	132	68	49			49	

7. The Load Flow Analysis in PSS/E has identified the following future bottlenecks in the Egyptian Power System for year 2018 and for the 4 scenarios. Printshots of the PSS/E Simulation Load Flow are presented in the Report. The transmission lines marked in red are overloaded and needs to be reinforced.

Lines loaded more than 70%	Year 2018 - Line loading - 100 % - 90 % - 80 % - 70%							
Node	Names	Voltage / kV	Rating	Base case Existing Egyptian Power System	Scenario 1 Maximum Demand and Maximum Wind and Solar PV	Scenario 2 Minimum Demand and Maximum Wind and Solar PV	Scenario 3 Maximum Demand and No Wind and Solar PV	Scenario 4 Minimum Demand and No Wind and Solar PV
46-40044	MOTAMDIA - DUMM 27&	220	419	404	384		360	
46-40045	MOTAMDIA - DUMM 28&	220	419	404	384		360	
118-554	NOBARIA - MENOUF	220	457		382		365	
626-40044	CAIRO-W - DUMM 27&	220	419	403	384		359	
626-40045	CAIRO-W - DUMM 28&	220	419	403	384		359	
240-556	K_ZIAT - TANTA	220	457	358	390		354	
247-251	ASHMOAN - N GIZA	220	450	424	559	384	430	
247-553	ASHMOAN - KALUBIA	220	457		472		397	
329-522	TEB_GEN - N-TEBB	220	362		259			
336-561	W-DOM-PS - GAMALIA	220	572	406	523			
348-513	OCTBR-220 - 6-OCT	220	457		475		403	
374-5360	C-EAST - HELIOP2	220	133		462		258	
450-40041	HARAM - DUMM 24&	220	457	441				
40040-40041	DUMM 23& - DUMM 24&	220	457	440				
522-523	N-TEBB - TEBBIN	220	457		431			
451-40035	GIZA - DUMM 18&	220	457	385				

Lines loaded more than 70%	Year 2018 - Line loading - 100 % - 90 % - 80 % - 70%							
Node	Names	Voltage / kV	Rating	Base case Existing Egyptian Power System	Scenario 1 Maximum Demand and Maximum Wind and Solar PV	Scenario 2 Minimum Demand and Maximum Wind and Solar PV	Scenario 3 Maximum Demand and No Wind and Solar PV	Scenario 4 Minimum Demand and No Wind and Solar PV
40034-40035	DUMM 17& - DUMM 18&	220	457	384				
518-40040	CAIRO-S - DUMM 23&	220	381	439				
501-502	NAG-H - GERGA	220	457		297		239	
508-40094	SELWA - ESNA	220	457		328			
511-553	BASSOS - KALUBIA	220	457		356		335	
511-40042	BASSOS - DUMM 25&	220	248		236		216	
511-40043	BASSOS - DUMM 26&	220	248		236		216	
512-518	HADABA - CAIRO-S	220	457		320			
554-40042	MENOUF - DUMM 25&	220	248		237		216	
554-40043	MENOUF - DUMM 26&	220	248		237		216	
512-797	HADABA - MAHSORA-ZONE	220	457		404			
513-740	6-OCT - ELGAMAL	220	457		344			
515-904	KURAIMAT - DUM-MNSR-KUR	220	305	319	532	459	373	408
515-9041	KURAIMAT - DUM MNSR KUR	220	305	319	532	459	373	408
785-890	HELWAN-SOUTH - ZAHRAA-MAADI	500	1732		1237			
904-905	DUM-MNSR-KUR - ZAH-MDNTNASR	220	362	323	532	459	373	408
518-40034	CAIRO-S - DUMM 17&	220	381	384				
524-625	PTROL-PL – ZAFRANA	220	438		540	525		
524-634	PTROL-PL – ECTSADIA	220	438		328	336		
526-891	KATAMIA - ZAHRAA-MAADI	220	457		321			
527-2931	BASATEEN - DUMBS-NRGS	220	268		214			
527-2941	BASATEEN - DUMBS-NRGS	220	268		214			
528-905	CAIRO-E - ZAH-MDNTNASR	220	362	255	467	430	313	376
533-5330	SUEZ-500 – DUMMY	220	229		184			
533-5331	SUEZ-500 – DUMMY	220	229		184			
538-539	STAD - METRO	220	381	327	293		292	
539-541	METRO - SHOB_KH	220	381	349	312		311	
540-541	SABTIA - SHOB_KH	220	305	231				
541-543	SHOB_KH - CAIRO-N	220	381	274				

Lines loaded more than 70%	Year 2018 - Line loading - 100 % - 90 % - 80 % - 70%							
Node	Names	Voltage / kV	Rating	Base case Existing Egyptian Power System	Scenario 1 Maximum Demand and Maximum Wind and Solar PV	Scenario 2 Minimum Demand and Maximum Wind and Solar PV	Scenario 3 Maximum Demand and No Wind and Solar PV	Scenario 4 Minimum Demand and No Wind and Solar PV
542-700	CAIRO-N - SABTIA	220	286	252	227		215	
542-3280	CAIRO-N - NBAH2	220	381	333				
545-546	N.ASHER - ASHER	220	438		476			
546-749	ASHER - BADR220	220	457		350			
547-548	ABU-SULT – MANAIF	220	229	170	210			
549-558	PORTSAID – TRUST	220	438		415			
549-593	PORTSAID – PROBLEN	220	438		458			
549-40027	PORTSAID - DUMM 10&	220	324		256			
549-40029	PORTSAID - DUMM 12&	220	324		256			
552-811	BAHTEEM - BASOUS2	220	457		379			
553-756	KALUBIA - BANHA-EAST	220	305		250		253	
554-1180	MENOUF - NOBARIA2	220	457		382		365	
555-5840	TAHRIR-B - ETAY-B2	220	229				188	
558-563	TRUST - DOMIAT-S	220	305		461		223	234
561-636	GAMALIA - A-KBEER	220	305		348			
563-593	DOMIAT-S - PROBLEN	220	305		491		240	249
565-598	K-SHEKH - SIDI-SAL	220	305		257			
569-587	K-DAWAR - ABIS	220	190	168			204	
583-2432	A-KIR - ABIS 2	220	194	170	171		153	
583-40030	A-KIR - DUMM 13&	220	194	168	166		151	
587-61400	ABIS - SUIF2	220	305				267	
5820-40030	SMOUHA2 - DUMM 13&	220	194	169	167		152	
592-613	A-EGP-CO - SP.STEEL	220	381	295	309		289	
595-811	C.N_GEN1 - BASOUS2	220	381					370
610-7874	RIVA - N-ASSIUT-GEN	220	457	467			351	
613-621	SP.STEEL - AL-EZZ	220	381		272			
625-635	ZAFRANA - ZAFRANA2	220	438		358	344		
635-998	ZAFRANA2 - RAS GHAREB	220	457			327		
700-701	SABTIA - N-SABTIA	220	305	339	306		290	
905-9041	ZAH-MDNTNASR - DUM MNSR KUR	220	362	323	532	459	373	408
2501-2505	ASWAN - KOMOMBO	132	137		98			

Lines loaded more than 70%	Year 2018 - Line loading - 100 % - 90 % - 80 % - 70%							
Node	Names	Voltage / kV	Rating	Base case Existing Egyptian Power System	Scenario 1 Maximum Demand and Maximum Wind and Solar PV	Scenario 2 Minimum Demand and Maximum Wind and Solar PV	Scenario 3 Maximum Demand and No Wind and Solar PV	Scenario 4 Minimum Demand and No Wind and Solar PV
2510-2517	NAG-HAMD - SOHAG	132	80		58			
2511-2514	NAG-HAMD - QUENA	132	114	82				
2517-6011	SOHAG - ASSYUT STEAM	132	68	52				
6001-6008	N.ASSYUT - ASMNT 1	132	68	78	67		68	
6002-6005	SAMALUT - MENIA	132	68	57			51	
6008-6011	ASMNT 1 - ASSYUT STEAM	132	68	90	74		74	
6009-6011	ASMNT 2 - ASSYUT STEAM	132	68	88	73		73	
6882-6894	S3 220 - S1	220	457		410	424		

8. The Dynamic Transient Stability Analysis for scenario 1 and scenario 2 has identified grid stability issues in case 4 and case 6 and recommendations as outlined in the below table. Please refer to the PSS/E simulations graphs for each case in the dynamic analysis chapter in the report.

Scenario 1 Maximum Demand and Maximum PV Solar and Wind Power	Scenario 2 Minimum Demand and Maximum PV Solar and Wind Power
Year 2015: Grid stability issue on the High Dam to Nag Hamadi 500 kV line. Year 2018: Grid stability issue on the High Dam to Nag Hamadi 500 kV line. Grid stability issue on the Samalut 500kV line to Ras Ghareb 500 kV, FIT 2000 MW Wind Farms.	Year 2015: Grid stability issue on the High Dam to Nag Hamadi 500 kV line. Year 2018: Grid stability issue on the Samalut 500kV line to Ras Ghareb 500 kV, FIT 2000 MW Wind Farms.
Response and Behaviour Graphs for Grid Stability Issues: Year 2015: Case 4 - PSS/E simulation, Tripping the first N.Hamadi500-High Dam500 circuit after 100ms fault then after 10 second tripping the other Year 2018: Case 4 and 6 - PSS/E simulation: Tripping line 4 Samalut-881 FIT circuit after 100ms fault	Response and Behaviour Graphs for Grid Stability Issues: Year 2015: Case 4 - PSS/E simulation, Tripping the first N.Hamadi500-High Dam500 circuit after 100ms fault then after 10 second tripping the other Year 2018: Case 6 - PSS/E simulation: Tripping line 4 Samalut-881 FIT circuit after 100ms fault
Recommendations to Overcome Grid Stability Issues: year 2015: Reinforcement of the 500 kV line High-Dam Nag Hamadi Install a SVC in Nag Hamadi year 2018: Reinforcement of the 500 kV line High-Dam Nag Hamadi Reinforcement of the line FIT-RAS ghareb. Install SVC at Nag Hamadi, Assuit and Hurgharda	Recommendations to Overcome Grid Stability Issues: year 2015: Reinforcement of the 500 kV line High-Dam Nag Hamadi Install a SVC in Nag Hamadi year 2018: Reinforcement of the 500 kV line FIT-RAS ghareb Install SVC in Assuit Install SVC in Hurgharda

9. The Dynamic Transient Stability Analysis for scenario 3 and scenario 4 has identified grid stability issues on case 4 only and mitigation recommendations as outlined in the below table. Please refer to the PSS/E simulations graphs for each case in the dynamic analysis chapter in the report.

Scenario 3

Maximum Demand and No PV Solar and Wind Power

Year 2015:

Grid stability issue on the High Dam to Nag Hamadi 500 kV line.

Year 2018:

Grid stability issue on the High Dam to Nag Hamadi 500 kV line.

Response and Behaviour Graphs for Grid Stability Issues:

Year 2015:

Case 4 - PSS/E simulation,

Tripping the first N.Hamadi500-High Dam500 circuit after 100ms fault then after 10 second tripping the other

Year 2018:

Case 4 - PSS/E simulation:

Tripping the first N.Hamadi500-High Dam500 circuit after 100ms fault then after 10 second tripping the other

Recommendations to Overcome Grid Stability Issues:

year 2015:

Reinforcement of the 500 kV line High-Dam Nag Hamadi

Install a SVC in Nag Hamadi

year 2018:

Install SVC in Assuit

Install SVC in Hurgharda

Scenario 4

Minimum Demand and No PV Solar and Wind Power

Year 2015:

No Issues

Year 2018:

No issues

Response and Behaviour Graphs for Grid Stability Issues:

Year 2015:

No Issues

Year 2018:

No Issues

Recommendations to Overcome Grid Stability Issues:

Year 2015:

No Issues

Year 2018:

No Issues

The Key Outcome of the Study:

The analysis indicates that 750 MW wind power in the base case 2015 can be integrated into the grid system with the reinforcement of the transmission system on the following transmission line.

- 220 kV line SUEZ-S to SK-KOR

The analysis for year 2018 indicates that 3940 MW wind power and 2000 MW of Solar PV can be integrated into the system with reinforcement of the transmission system on the following transmission lines:

<u>500 kV level</u>

- 500 kV line High-Dam Nag Hamadi
- 500 kV line FIT-RAS Ghareb

<u>220 kV level</u>

- 220 kV line ASHMOAN - N GIZA
- 220 kV line ASHMOAN – KALUBIA
- 220 kV line OCTBR-220 - 6-OCT
- 220 kV line C-EAST - HELIOP2
- 220 kV line CAIRO-E - ZAH-MDNTNASR
- 220 kV line N.ASHER - ASHER
- 220 kV line PORTSAID - PROBLEN
- 220 kV line TRUST - DOMIAT-S – PROBLEN
- 220 kV line K-DAWAR – ABIS
- 220 kV line SELWA-ESNA
- 220 kV line A-DAM-WAD.NOKR
- 220 kV line A-DAM-BENBAN

Above 3942 MW and 2000 MW of Solar PV will require additional reinforcement of the transmission system, subject to the site location of the wind and solar power.

The stable dynamic transient stability simulation for year 2018 shows that in order to compensate for the variation in load and reactive losses three SVC is suggested at the following locations:

- Naga Hamadi: 600MVAr
- Asyut: 600MVar
- Hurghada: 300MVAr

For year 2018, above 3942 MW, it is important to focus on the frequency control and MVAr control in order to avoid violations of reliability and operating code requirements. The technical requirements shall be grouped as follows for the wind turbine and solar PV requirements:

- Control of reactive power
  - This includes requirements to contribute to voltage control on the network in normal operation but also during faults, the typical requirements can be given as constant reactive power Q, constant PF and voltage control.
  - The behaviour during faults

- Control of active power
  - This includes to lower the production during constrains in the power system, but also to minimize impacts on large foreseen events causing suddenly changes of all renewables as the huricans, Dawn, sunset, solar elicpes etc.
  - The behaviour during faults
  - Facilitate auxiliary services as secondary reserve and others
  - Frequency support outside a specified deadband

Above 2000 MW Solar PV might pose technical and reliability concerns for EETC due to the location of Solar PV at BenBan and the load on the existing 500kV system. The BenBan location of solar PV impose problems for the power system control, since the 500kV lines between High dam and Cairo is increased in load and thereby decrease the damping between the conventional power plants in Cairo and High Sam. Therefore, further extension of Solar PV should take place in areas, such that the 500 kV circuit in North-South is not further loaded.

The requirements for low voltage ride through shall secure that wind power and Solar PV maintain voltage support during the failure and controlled production immediately after failures. This again should reflect the demands for the duration of clearing the failures from the power system.

The Solar PV Plants equipped with inverters have similar control behaviors to the Type 4 wind turbines, and therefore it is foreseen that Solar PV can comply with grid code requirements. However for type 1 and type 2 wind turbines, the requirements in the grid code is not expected to be fulfilled even though some developers will suggest STATCOM to be installed together with the wind farms.

The wind power and Solar PV will introduce a larger power flow and variation on the power flow in the Egyptian grid system, which will increase the focus on keeping the voltage/MVAr in balance. The next steps for establishing a validation/verification process of the Egyptian grid system, updating the existing grid codes for wind/PV and furthermore introducing forecasting systems in power system operation/planning is very essential.

An important bird migration route of soaring birds passes through the Gulf of Suez. The impacts of bird migration in this region are modelled by decreasing the wind power output by 0%, 25%, 50%, 75% or 100% (partial shut-down of the wind farm) during the potential flight hours of the birds. These hours are identified between 9 a.m. and 7 p.m. during 3 months in spring (starting 17th of February) and 3 months in fall (from 18th of August). The shut downs are randomized ensuring a total decrease in annual generation of 8%.

Grontmij A/S experience on working with NREA on the Gabel-El-Zayt Wind Farm for the spring season 2016, has shown that the establishment of the shut-down on demand modality is well functioning and minimizing the shut-down of wind turbines.

The running reserve for year 2015 and year 2018 is as following:

	Running reserve / MW	2015	2018
No wind power, no Solar PV	Base case	6502	15515
Maximum Wind Power and Maximum Solar PV	Maximum demand	4507	6031
	Minimum demand	4056	7248
No Wind Power and No Solar PV	Maximum demand	4657	6702
	Minimum demand	4600	4681

The wind farms and Solar PV plants are configured so that the maximum amount to be disconnected during a failure is 500 MW.

9 Next Steps for the Study

The 2nd phase is expected to cover:

- Analysing the requirements for power system protection, operation and control strategies as per the ToR of the project.
- Modifying the existing Wind Integration Grid Code and the PV Code.
- Developing suggestions on how to integrate wind forecasting system in the power system operation and planning in Egypt (to be reviewed).

Training workshops for EETC staff in power system protection, operation and control.

The need for establishing a validation and verification process of the Egyptian Power System steady state electrical simulation model and capacity training in verification/validation is necessary through a separate study.

The main steps for establishing this, shall include:

1. Form a dedicated project team with the NECC dispatch centre, with the objective of defining the recommendable verification process for the steady state electrical simulation model for the existing Egyptian power system and gathering required measurements for training..
2. Training of EETC staff at Energinet.dk in Denmark for 2 weeks. The training will focus on step by step knowledge transfer to EETC team on how to implement the verification process on the steady state electrical simulation model for Egypt and capacity training, hands-on experience with verification/validation state estimators and simulation tool kits.
3. During the training EETC will be trained to operate their State Estimator and Simulator Toolkit for Egypt.
4. Preparing a project roadmap by gathering the outcomes from the workshop in Egypt and training in Denmark and formulate a detailed verification process action plan and report it to EETC and NECC.
5. This report shall outline:
    i. the work packages required for performing the tasks for the verification process of the steady state electrical simulation model.
    ii. agreed role for Consultant and EETC/NECC staff,
    iii. proposed milestones for the defined work packages
    iv. proposed meeting schedule for follow up in Cairo combined with interim reporting and regular follow-up via teleconference.
6. EETC shall in Cairo provide the required EETC staff resources to operate their state estimator and simulator toolkit.
7. Performing workshop in Cairo with the EETC and NECC staff to start the implementation as agreed in action plan.
8. Performing workshop in corporation with EETC/NECC to analyse the results from the work packages and propose actions to updated PSS/E file from Phase 1 study, for the EETC staff to correct identified deviations between the steady state simulation model and actual measurements.

9. Follow up on the EETC procedure in accordance with agreed work plan and technical assistance with the action plan.