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Development of Transmission System Master Plan of Oman (2014-2030)

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Summary

The objective of this paper is to present the methodology, challenges and results of the transmission master plan of Oman 2014-2030. The main challenges affecting the planning of transmission investments are:

1. Fast growing demand (currently reaches about 10%),
2. High level of uncertainty due to unbundling (generation, transmission and distribution),
3. Peculiarity of the demand (high variation summer/winter, high participation of air-conditioning to peak demand),
4. Limitation of place for extension of existing substations,
5. High concentration of demand creating high Short-Circuit Current (SCC) levels, and
6. Relatively strict planning criteria.

Tractebel Engineering and Oman Electricity Transmission Company have developed a methodology to optimize transmission investments in such an environment. It proposes the least cost development plan by first building a transmission network target structure (at 2030) that defines the long term vision of transmission, generation and distribution companies and that tackles all technical issues. The combination of probabilistic and deterministic models is used to propose the optimal structure. A new 400kV backbone structure is developed. Then intermediate years' structures (2018, 2020, and 2025) are built by phasing investment identified for the target structure.

Detailed static and dynamic analyses are used. Focus is given to limitation of SCC level, optimal location for compensation means and required investment in SVCs.

The results of the transmission master plan are then illustrated focusing on impact of generation location, ways to limit SCC levels, benefits of optimal power flow for planning and operation of the system, impact of planning criteria, etc.

Keywords: Transmission System, Long-Term Planning, Master Plan.

1. INTRODUCTION

The Main Interconnected Transmission System (MITS) in the North of Oman is owned and operated by Oman Electricity Transmission Company (OETC) [1]. Starting from 2014, the transmission system of Dhofar region in the south on Oman is also owned and operated by OETC. The two systems are interconnected through the network of Petroleum Development of Oman (PDO) [2] which extended in the middle region between North and South areas.

OETC is responsible for the planning of the transmission network. Up to 2014, OETC based its planning activities on Five-Year Annual Capability Statement [3]. This approach is common and allows justifying investments at medium terms. OETC analyzed that due to fast growing demand, high level of uncertainty due to unbundling and specific problematic of SCC [4], a strategic long-term vision for the development of the transmission network is required. This long-term vision has on one hand to give a clear road map for investments in the transmission network but also to reduce uncertainties and level of risk due to unbundling.

Tractebel Engineering (TE) [5] and OETC [1] have developed a planning methodology to optimize transmission investments in such an environment. The Transmission Master Plan (TMP) [6] is based on several preliminary studies including definition of planning criteria, demand forecast and required generation expansion plan. Then the 2030 MITS target structure is studied considering the long-term vision for the network

development. The best structure is selected on the basis of techno-economic analysis to satisfy the transmission security criteria [7] at least-cost. Having defined the 2030 target structure, the TMP team considered phasing the development of the network and required investments amongst selected three intermediate years namerly; 2018, 2020 and 2025.

Other related issues are also investigated including mitigation of high short-circuit levels in some places, dynamic security analysis and benifites of optimal power flow applicaions. Finally, estimation of the required investments over the TMP period is presented.

Section 2 describes the configuration of the existing MITS in 2014. Section 3 presents the methodology of the development of the master plan. Section 4 deals with the load forecast. Section 5 presents the generation expansion plan. Section 6 presents the target structure of the transmission system in 2030. Section 7 concerns with the adopted pocket operation of some parts on the 132kV network in Muscat to overcome the short-circuit issue. Section 8 presents dynamic security analysis and Section 9 presents the benefits of applying the optimal power low to planning and operation of the MITS. Section 10 lists the distribution of the master plan investment costs, and finally Section 11 summarizes the main conclusions.

2. EXISTING TRANSMISSION SYSTEM DESCRIPTION

The existing transmission system [1] in northern Oman has two operating voltages, i.e. 220kV and 132kV. In 2015, the transmission system in northern Oman will also have 400kV operating voltage. The existing transmission system extends across the whole of northern Oman and interconnects bulk consumers and generators of electricity located in the Governorates of Muscat, Batinah South, Batinah North, Dhahirah, Buraimi, Dakhliyah and Sharquiya South, Sharqiya North. Since January 2014, OETC has operated the transmission system at Dhofar Governorate.

The present MITS consists of [3]:

- 1719.07 circuit-km of 220kV overhead transmission lines
- 3138.06 circuit-km of 132kV overhead transmission lines
- 61.6 circuit-km of 220kV underground cables
- 110.658 circuit-km of 132kV underground cables
- 10630 MVA of 220/132kV transformer capacity
- 320 MVA of 220/33 kV transformer capacity
- 11734 MVA of 132/33 kV transformer capacity
- 150 MVA of 132/11 kV transformer capacity
- Six 220kV interconnection grid stations
- Two 220/132kV grid stations
- One 220/33 kV grid station
- Nine 220/132/33 kV grid stations
- Forty one 132/33 kV grid stations
- One 132/11 kV grid station

The transmission system is interconnected with the transmission system of UAE (Abu Dhabi Transco) at Mahdah (Al Wasit) grid station through 220kV, which will be upgraded to 400kV by 2017 through a new 400kV double-circuit transmission line [8]. The new interconnection will form a part of the GCC Grid that links the electricity supply systems of Kuwait, Saudi Arabia, Bahrain, Qatar, UAE and Oman. This should provide increased security of supply and benefits to the member countries in the form of cost savings from the sharing of reserve capacity and energy resources. The 220kV interconnector between OETC and Abu Dhabi Transco been energised and brought into service since the 14th of November 2011. The OETC transmission system is also interconnected with the Sohar Aluminium system at 220kV via a double circuit cable that runs between Sohar Power Station (SPS) on the OETC system and Sohar Aluminium 220kV busbar. Under normal conditions the power transfer across the interconnection is forecasted to be negligible, but in the event of an emergency on either network the interconnection can facilitate a power transfer of up to 300 MW to address the shortfall.

The OETC transmission system is also interconnected with the PDO transmission network at 132kV via a single circuit overhead line that runs between Nizwa on the OETC system and Nahda on the PDO system [2]. Under normal conditions the power transfer across the interconnection is forecasted to be negligible, but in the event of an emergency on either network the interconnection can facilitate a power transfer of up to 60 MW to address the shortfall.

The transmission system is supplied with electricity generated from ten gas-based power stations located at Ghubrah, Rusail, Wadi Jizzi, Manah, Al Kamil, Barka (ACWA), Barka SMN, Barka III, Sohar I and Sohar II [9]. In addition the transmission system may be supplied from direct customers, such as Sohar Aluminium, PDO, and OMCO. The Sur power plant will be fully commissioned with 2000 MW in 2015.

Four Distribution Licence holders, i.e. Muscat Electricity Distribution Company (MEDC), Mazoon Electricity Company (MZEC), Majan Electricity Company (MJEC) and Dhofar Power Company (DPC) take the bulk of the power transmitted through the main grid, from the 220/132/33 kV, 220/33 kV, 132/33 kV and 132/11 kV grid stations.

In addition to the four distribution companies, ten large private customers are directly connected to the transmission system at the 220kV and 132kV levels.

In 2013, the system gross peak demand was 4634 MW which occurred at 15:00 hours on 16th June. During 2013, the Electric Energy Delivered to the MITS system from connected generating plants & other generators was 22,702.497 GWh whilst that exported from the MITS to the distribution companies was 22,110.651 GWh resulting in transmission system energy losses of 591.846 GWh, which equates to a transmission system energy loss of 2.68 %.

3. METHODOLOGY

The Transmission Master Plan (TMP) is based on several preliminaries studies: definition of planning criteria, load demand forecast and generation expansion plan, as shown in Figure 1. Those preliminary studies are required to pave the way of the TMP. Planning criteria setting has to be achieved according to regulation. Grid code [10] and Transmission Security Standards (TSSS) [7] are used to define the criteria. While the definition of planning criteria is a task developed by OETC in line with regulations, the load demand forecast and the generation expansion plan require in-depth consultations with national stakeholders and in particular the main utilities (OPWP) [9] , DISCOs (MZEC, MJEC, MEDC), and RAEC. OETC decided to involve all stakeholders from the beginning of the study to decrease level of uncertainty and have a coherent vision for the demand and generation over the study period.

The first stage of the TMP is the construction of the 2030 Target Structure, which aims at reflecting the long term vision for the network development. Different solutions are investigated to reinforce the network and meet the transmission security criteria. The selection of the best option is made on techno-economic analysis, i.e. the solution that permits to meet security criteria at least-cost is selected.

The second stage of the TMP deals with the phasing of the investments amongst the three intermediate years selected for this Master Plan (2018, 2020 and 2025). The objective is to define for each intermediate year a transmission system accommodating the generation expansion, supplying the load demand and meeting the security criteria. The reinforcements proposed to solve the identified limitations of the network and respect the security criteria are selected from the Target Structure's portfolio of reinforcements, in order to be in line with the long-term development scheme defined by the 2030 Target Structure.

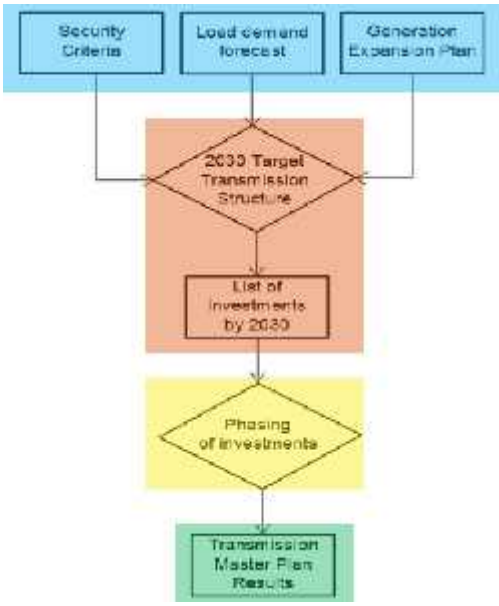

Figure 1: Flowchart of the TMP tasks.

4. LOAD DEMAND FORECAST

The load forecast for Oman is performed using two complementary approaches:

The global method permits to determine the future evolution of the load demand, based on the historical data and the existing correlation between the load demand and macro-economic parameters of the Sultanate: GDP and population.

The area based method uses the most precise consumption data available and gives the geographical distribution of the load demand, considering the relative development of each area in Oman and the specific large projects expected to be connected to the transmission system.

With the combination of these two methods, the load forecast is realized in terms of energy, peak demand and minimum demand for the MITS, but also for the areas within MITS and for areas that are expected to be connected to the MITS in the long term namely; Dhofar and Duqm.

Three scenarios are developed to take into account uncertainties of socio-economic parameters, plausible delays of industrial projects and level of implementation of demand side management program. Figure 2 shows the global peak load demand forecast. The High scenario will bring demand of Oman from 4.5 GW in 2013 to 19 GW by 2030. In 2030 the demands of Dhofar system (1.7 GW) and Duqm (1 GW) are considered as they will be interconnected with the MITS. It leads to an average growth of 9% with a growth equal or superior to 10% till 2020 and that decreases and stabilizes to 7% after 2020.

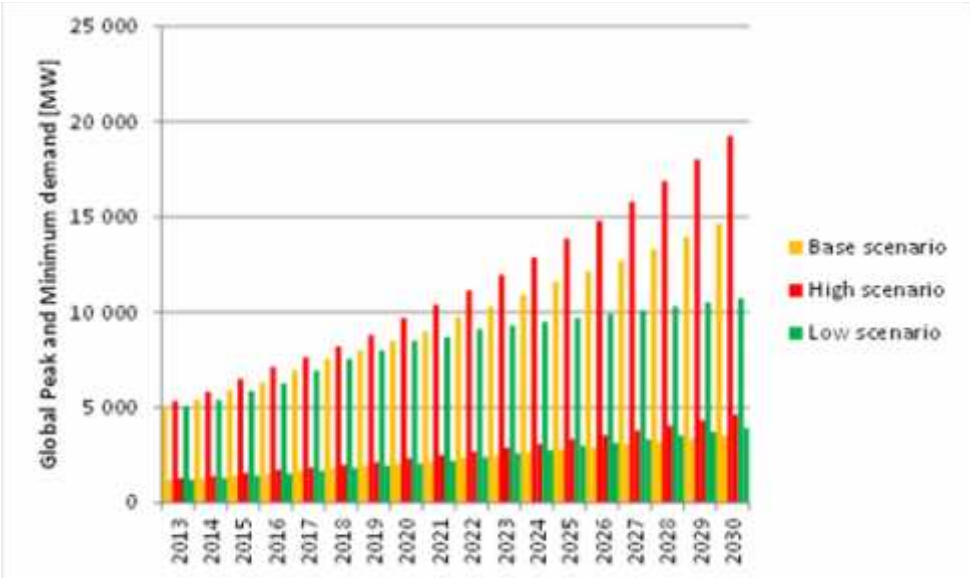

Figure 2: Global peak load demand forecast.

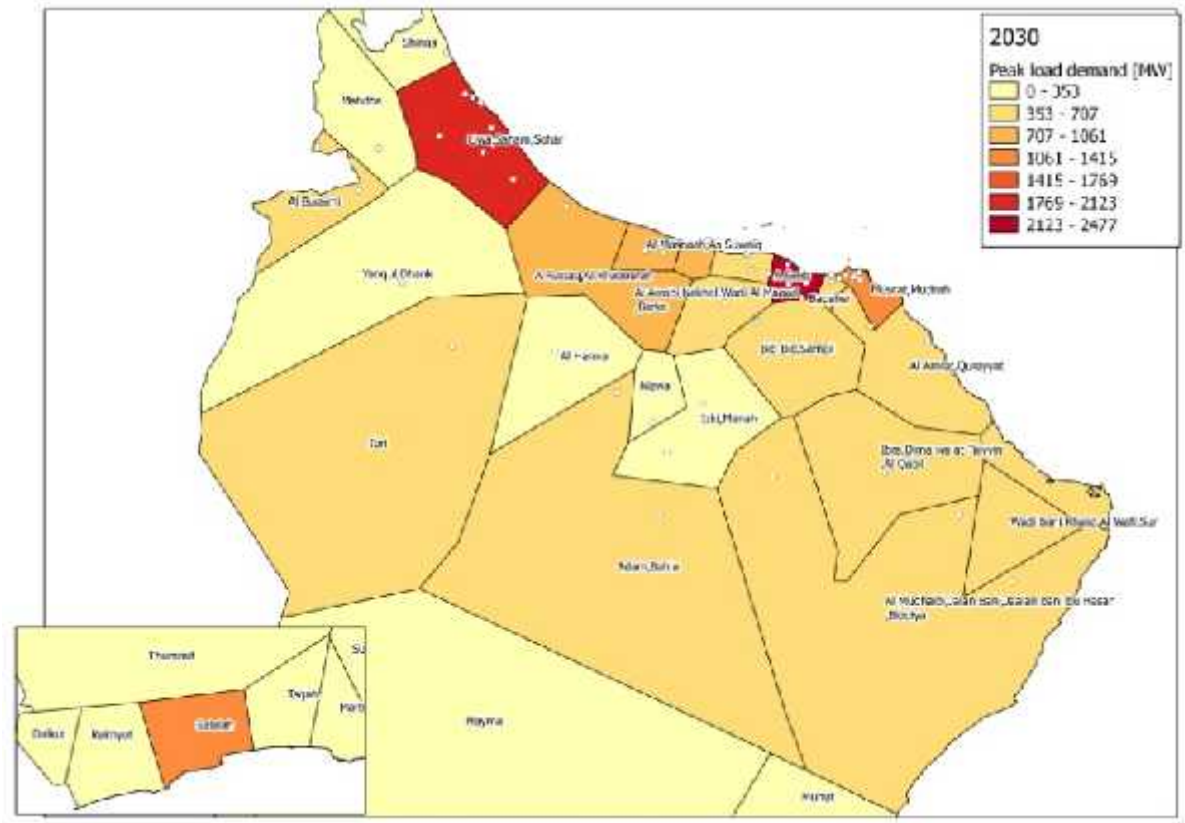

Figure 3: Distribution of Peak Demand load per area in 2030.

OETC and TE also carried-out a forecast per Wilayat on basis of forecast of population, characteristic of Wilayat (specific consumption) and industrial projects. The results are illustrated in Figure 3 for 2030. It can be seen that Wilayat of Muscat and Sohar will present the higher demand reaching consumption above 2 GW.

5. GENERATION EXPANSION PLAN

The generation expansion plan is of outmost importance for the transmission master plan. The collaboration between OPWP, OETC and TE during this phase was very important and leaded to a common understanding of the generation expansion plan for Oman up to 2030.

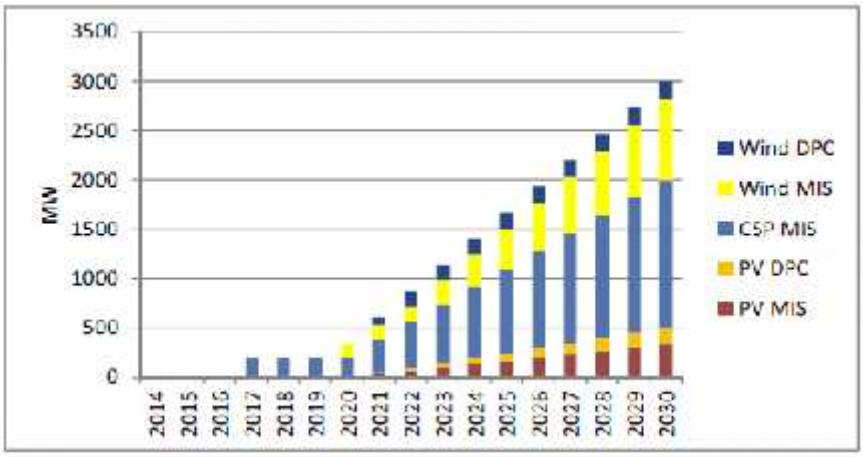

Figure 4: Renewable plants sites distribution.

OETC and TE took as input the generation expansion plan of OPWP but validated through a capacity adequacy study that enough capacity is planned to supply the demand while respecting planning criteria.

The main planning criterion is the Loss of Load Expectation (LOLE) and it was aligned on GCCIA requirement: LOLE of 24 h if OETC network is isolated from GCC network and 5 h if OETC network is interconnected. Results have shown that generation capacity planned by OPWP covers adequately the demand up to 2025 and that some additional capacity may be required after 2025 if high scenario of demand forecast realizes.

Also the capacity adequacy study analyzed the impact of the renewable energy on the generation expansion plan. A scenario of development of renewable was considered with a target of 15% of renewable capacity by 2030. This capacity is distributed among CSP, PV and wind and reaches a total of 3 GW by 2030 as shown in Figure 4.

The addition of renewable capacity allows substituting classic thermal capacity however the ratio is not 1 for 1 due to intermittency of the renewable energy. For a constant LOLE, the addition of 3 GW of renewable capacity allows substituting 800 MW of CCGT.

6. 2030 TARGET STRUCTURE

As mentioned before the first stage of the TMP is the construction of the 2030 target structure. The combination of probabilistic and deterministic models is used to propose the optimal structure.

The probabilistic approach is first used. It is performed by using the SCANNER tool [5]. The model uses the Monte Carlo method that enables to analyze a very large number of operational situations selected randomly throughout the whole year. The power system of OETC is simulated considering the existing and already foreseen investments for 2030. This method enables to detect bottlenecks in the transmission system occurring for various operational situations selected randomly throughout the whole year. These calculations also enable to compute the total expected un-served energy of the system, not only due to the generation but also due to the transmission network.

On basis of the bottlenecks identified several target structures of the transmission grid are built by adding new transmission or transformation infrastructure and/or by changing the operation switching structure of the network.

This phase of the study is achieved on peak and off peak situation. For this deterministic phase, security analysis, SCC evaluation, dynamic assessments are performed to ensure that all proposed target structures meet the planning criteria.

Finally preferred target is selected on basis of cost of investment and operational cost (mainly losses)

6.1 400kV Structure

By 2030, the power system of Oman will present areas with significant excess of generation capacity and other areas with high deficit of capacity, as shown in Figure 5. The reason is the impossibility to locate major generation units close to load centers. Four areas will present excess above 1 GW: Shinas, Ibri, Mussanah and Sur. Three areas will have deficit of capacity above 1 GW: Sohar, Muscat East and West.

As a direct consequence, flows above 1 GW are expected between the different areas. The level of flows requires the construction of a 400kV network among the areas.

This network will rely on three main corridors as shown in Figure 6:

1) The coastal backbone, which is formed by a double circuit 400kV OHL. This route will link the northern areas, going from Muscat East area up to Mahdah area. It will pass by MIS-Mussanah, Sohar City and Shinas & SPS areas. The main purpose of the coastal backbone is to evacuate the power surplus of Shinas & SPS and MIS-Mussanah areas to Muscat West and East areas, which are important load demand centres. It also enables to connect OETC network to the GCCIA planned 400kV grid station at Mahdah and paves the way to a possible interconnection to Iran;

2) The inner-land backbone, which is formed by a double circuit 400kV OHL. This route will link the southern areas, going from Nizwa area up to Ibri area. Its main goal is to evacuate the power surplus of Ibri area to Nizwa area;

3) The southern ring, which is composed of OETC's planned 400kV structure for 2017, plus one new double circuit 400kV OHL closing the loop. This will result in a meshed 400kV network that will increase the reliability of supply of Muscat area.

6.2 Interconnection MIS – Duqm – Dhofar

An 800 km, 400kV OHL is envisaged to interconnect the main interconnected transmission system to Duqm Area and Dhofar System. The objective of this interconnection is first to improve reliability of supply of Duqm that will be a major industrial site of Oman and Dhofar that is the main city in the south of the country. Second by pooling the three generation systems, operational and investment cost savings will be realised. As an illustration figure, between 300 MW and 400 MW of installed capacity can be saved to keep the same LOLE level. Third, this interconnection will allow increasing the level of penetration of renewable energy in Dhofar and Duqm areas. Those areas have high resources of renewable energy that cannot be fully exploited if the networks remain islanded.

The interconnection will also bring new opportunities such as the development of coastal investments between Duqm and Salalah or the interconnection of the OETC power system with the Petroleum Development Oman power system.

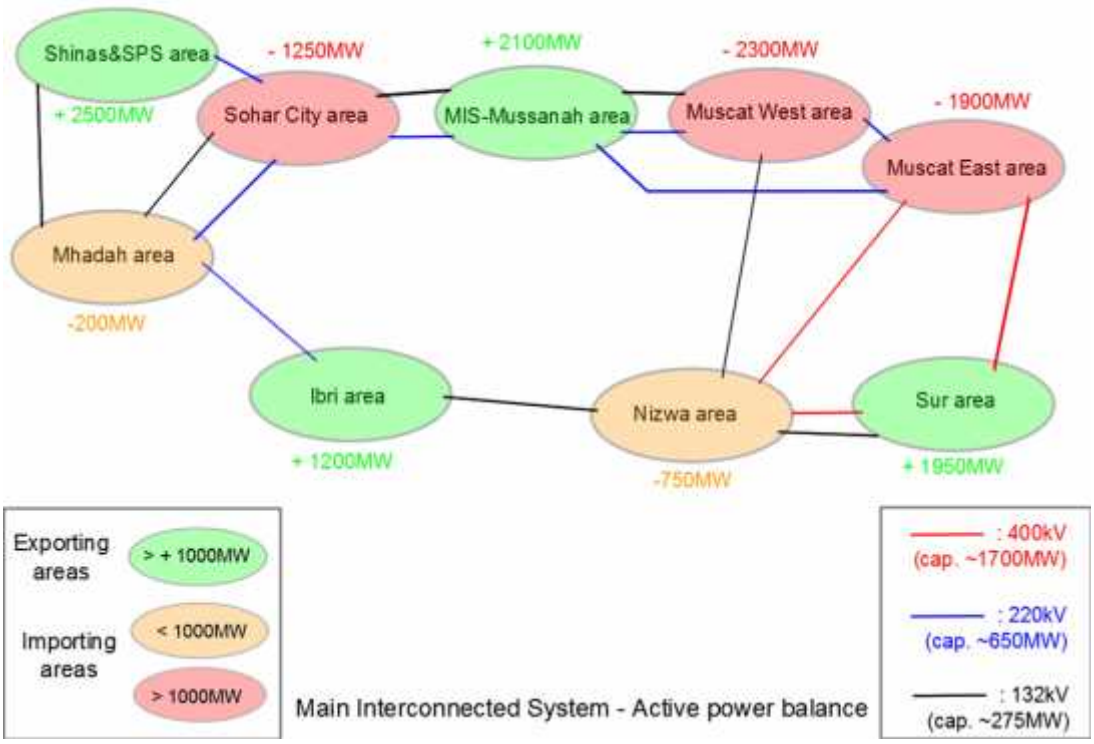

Figure 5: Power balance in each area of the MITS in 2030.

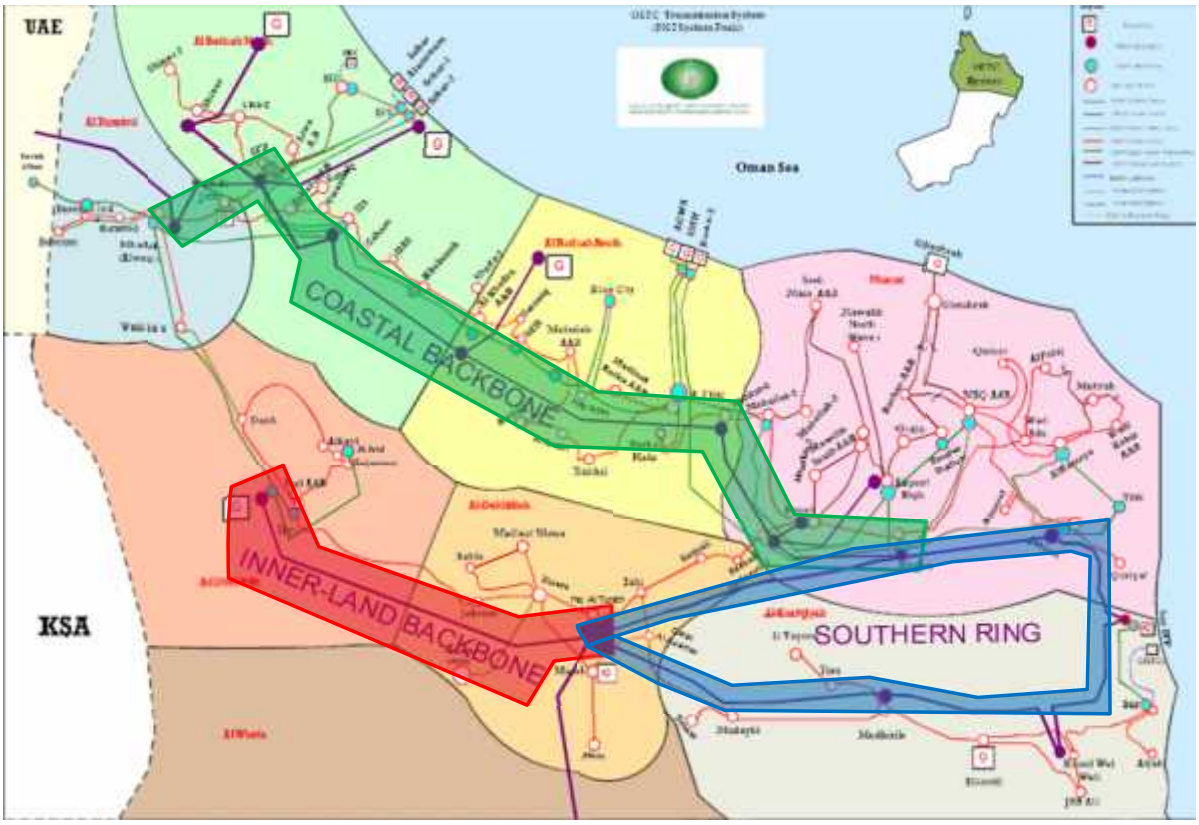

Figure 6: The three main corridors of the 400kV structure.

7. POCKET OPERATION

The transmission master plan also focused at the problematic of short circuit levels. As many countries in the Gulf area, Oman faces and will face very high level of short circuit currents. The inherent reason being the high concentration of demand in some areas of the country.

Several countermeasures have been proposed such as connection of major power plant at 400kV, replacement of circuit breakers to higher capacity standards, use of current limiters in some substations.

In Muscat area, those measures could not limit the short circuit currents to acceptable values, Therefore, OETC and TE opted to operate the 132kV network of Muscat in pockets. A total of 6 pockets are proposed by 2030. Figure 7 shows the configuration of pockets in Muscat area. Each 132kV-pocket supplies a load between 700 MW and 900 MW and is supplied by one or two 400/132kV or 220/132kV grid stations. Each pocket is connectable to neighbouring pocket to allow maintenance of main grid stations. With this pocket arrangement, the SCC at all busbars are kept within the GIS fault rating levels.

8. DYNAMIC SECURITY ASSESSMENT

Dynamic security assessment of the 2030 structure has been conducted. The main conclusion was that almost all short circuit fault simulation tests on 132kV, 220kV and 400kV transmission lines in Muscat area resulted to unacceptable voltage recovery. Figure 8 shows an example of a simulation short-circuit test. Although, the initial voltage at Muttrah and Hamriyah was about 1.04 pu before the fault, it falls transiently to about 0.55 pu during the fault and then settles at about 0.73 pu.

The reason for this unacceptable voltage recovery is the large amount of induction motor load demand, mainly air-conditioners and the lack of voltage support in the 132kV network of Muscat that implicates low voltage during the short circuit and possibility of motor stalling.

The Transmission Master Plan demonstrated that capacitive shunt compensation does not solve the voltage recovery problem, and thus recommended the installation of Static VAR Compensators (SVC)s at identified 132kV locations.

The installation of SVCs is a good alternative to generating units, as it does not increase the short-circuit current level. Nevertheless, the use of the SVCs should be dedicated to dynamic voltage support, i.e. they shouldn't be used in healthy state in order to keep sufficient margins.

The location and size of the SVCs has been iteratively optimized in order to minimize the reactive requirements and respect the dynamic stability criteria. A total of 640 MVAr of SVC will be required by 2030.

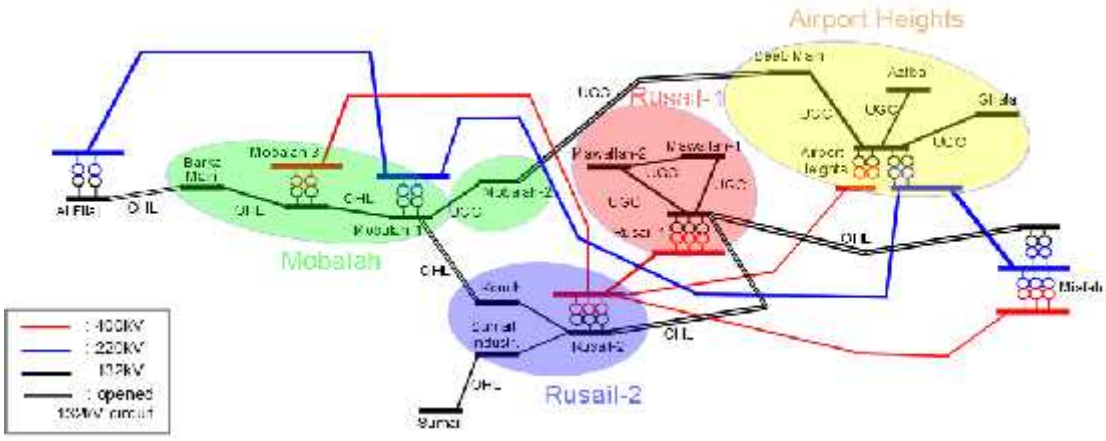

Figure 7: Pocket operation in Muscat area.

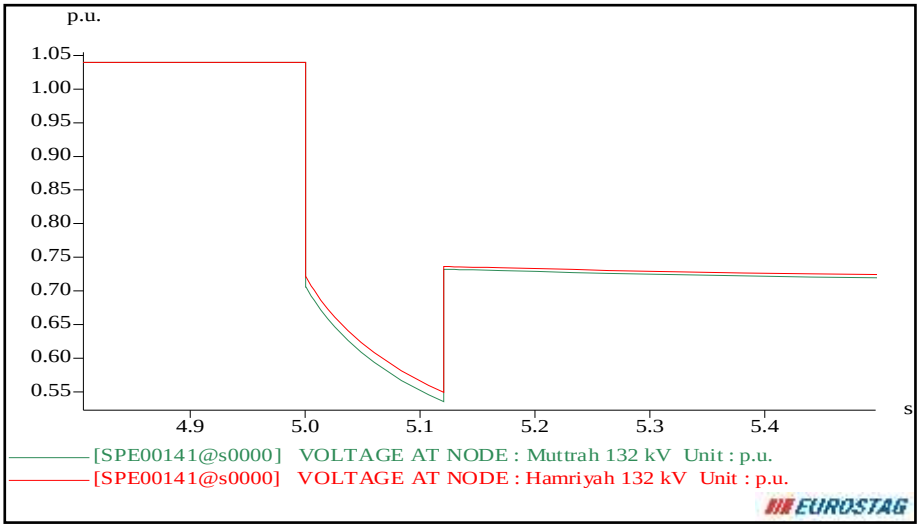

Figure 8: Unacceptable voltage recovery in Muscat area.

9. OPTIMAL POWER FLOW

All results presented in the transmission master plan are based on operating points defined by an OPF module. OETC and TE demonstrated that the use of an OPF for planning activities allow reducing investments required by an optimal use of all control means. Indeed the voltage profile on the network and the reactive margin on the power plants can be substantially improved by optimal use of tap changers, compensation means, and voltage set point of generating units as defined by an OPF. As a consequence, lower investment is required for voltage support in the system.

Figures 9 and 10 illustrate the gain of application of the OPF on the 2017 situation. For a same total generation of reactive power, the voltage profile is optimised between 0.98 and 1.05 pu after the use of the OPF while it was between 0.95 and 1.1 without OPF, as shown in Figure 9. Concerning the reactive margin on the power plants, it can be seen from Figure 10 that 80% of power generating units have a reactive margin above 40% after OPF while only 50% have the same level of reactive margin without the OPF.

10. PHASING OF INVESTMENT

The last stage of the TMP deals with the phasing of the investments amongst the three intermediate years selected for this Master Plan (2018, 2020 and 2025). The objective is to define for each intermediate year a transmission system accommodating the generation expansion, supplying the load demand and meeting the security criteria. The reinforcements proposed to solve the identified limitations of the network and respect the security criteria are selected from the target structure's portfolio of reinforcements, in order to be in line with the long-term development scheme defined by the 2030 target structure. Table 1 lists the distribution of the MTP estimated costs up to 2030.

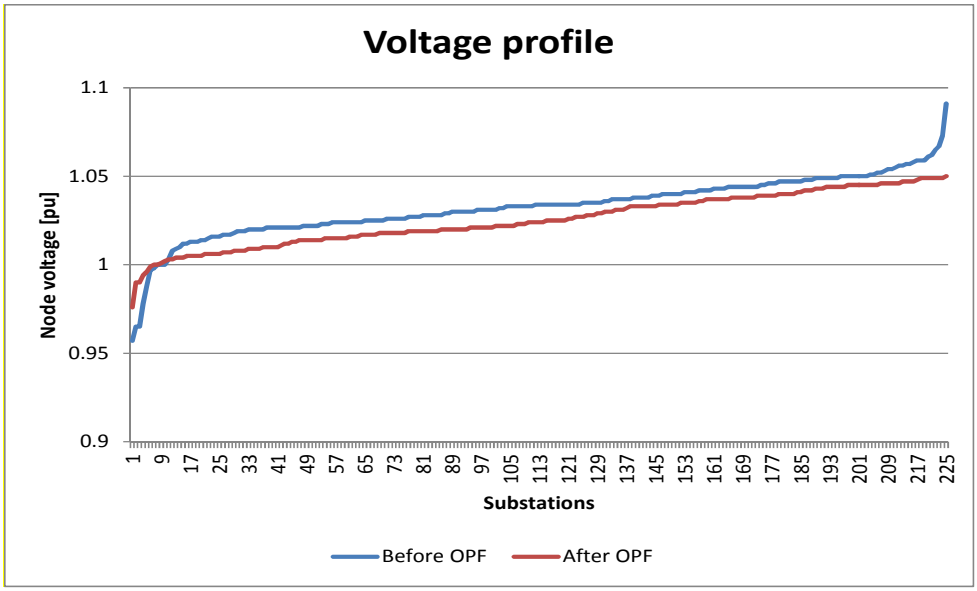

Figure 9: Voltage profile before and after application of OPF.

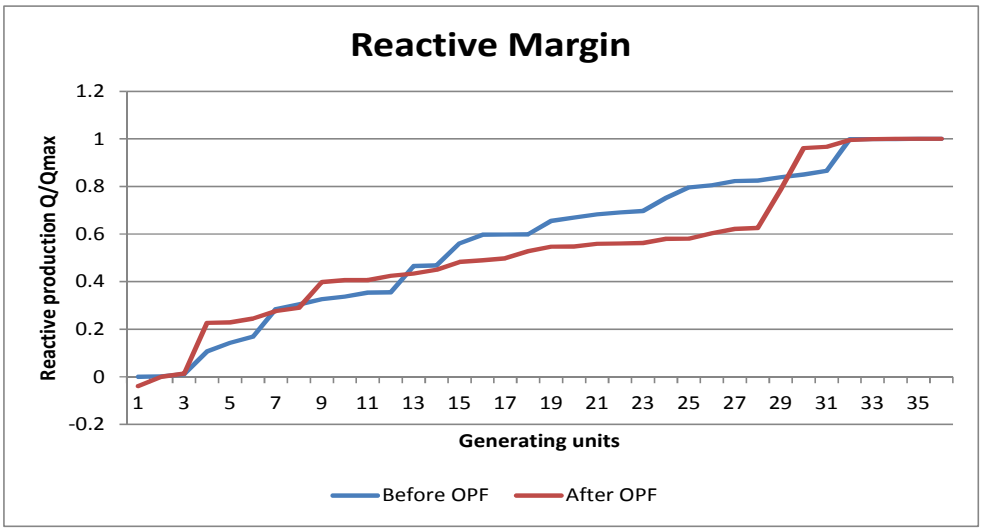

Figure 10: Generation reactive power before and after application of OPF.

Table 1: Distribution of master plan investment costs.

	2018	2019-2020	2021-2025	2026-2030	2018-2030
Lines&cables [MOMR]	88.6	4.8	123.8	35.1	252.3
Grid stations [MOMR]	62.1	29.7	147.3	94.8	333.9
Interconnection MIS-Duqm-Salalah [MOMR]	0	0	165.3	0	165.3
Total [MOMR]	150.7	34.5	436.4	129.9	~750MOMR

The total investment cost of the additional infrastructure defined under the TMP amounts to 750 million OMR over a period of 13 years. Those investments are not distributed equally over the years. The reason is the necessity of major punctual investments during the period. Those investments are mainly related to the development of the 400kV network and are driven by the development of new major large power plants.

11. CONCLUSIONS

The main conclusion of the transmission master plan of Oman is that the development of a strong 400kV network is the least-cost structure to ensure a reliable and secured supply of the demand by 2030. This 400kV structure implicates a new role of the different voltage levels the 220kV that was formerly responsible for bulk power transmission has now a role of sub-transmission in support to 400kV. The 132kV level become a distribution level and is operated in pocket some areas of the Network.

It is worth mentioning that this conclusion was reached thanks to the decision of OETC to have a long term strategic vision of the development of the Omani power system. This conclusion would have been difficult to reach with short-term or medium-term development plans.

12. ACKNOWLEDGEMENTS

The authors are grateful to all staff of the main electricity companies OETC, OPWP, MDEC, MJEC, MZDC, DPC, RAEC and PAEW who have contributed in providing data and useful discussions to facilitate performing the transmission master plan of the Sultanate of Oman 2014-2030.

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