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Steady-State and Transient Performance of Oman Transmission System with 200MW Concentrated Solar Power Plant

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Abstract

The paper presents steady-state and transient studies to assess the impact of a 200MW Concentrated Solar Power (CSP) plant connection on the Main Interconnected Transmission System (MITS) of Oman. The CSP plant consists mainly of a solar field with parabolic trough collectors, two thermal storage tanks, heat exchangers, piping systems, steam turbine, and electric generator. Two proposed locations are considered to connect the CSP plant to MITS: Manah and Adam 132/33kV grid stations in Al-Dakhiliah region. The transmission grid model of 2015 has been updated to include the simulation of the proposed 200MW CSP at either Manah or Adam. The DIgSILENT *PowerFactory* professional software is used. The results include percentage of transmission line loadings, percentage of transformer loadings, busbar voltages, grid losses, in addition to 3-phase and 1-phase fault levels. Also, simulation studies have been performed to assess the transmission system transient responses to the CSP outage. Steady state and transient analyses have shown that the connection of the CSP plant at Manah or Adam to the transmission system is acceptable. The transient responses have proved that the system remains stable when it is subjected to the CSP plant outage.

Key Words: Concentrated Solar Power; Oman Transmission System.

1. INTRODUCTION

There has been a considerable interest in renewable energies over the world in recent decades (IEA, 1997). A comprehensive study on renewable energy resources in Oman was performed by the Authority of Electricity Regulation (AER, 2008). The study includes technical and technological aspects of generating electricity from renewable energy and covers the following resources: solar, wind, biogas, wave and geothermal energies. Six pilot projects are currently under consideration in Oman to produce electricity from sun and wind. A study of construction of 200MW Concentrated Solar Power (CSP) or 200MW photovoltaic power plant was performed by the Public Authority of Electricity and Water (PAEW, 2010) in Oman. The recent 7-Year Capability Statement of the Oman Power and Water Procurement (OPWP, 2011) Company indicates that the (0-200MW) solar project(s) is expected to be in operation in 2015.

The objective of this paper is to study the impact of the proposed 200MW CSP plant on the steady-state and transient performances of the Main Interconnected Transmission System (MITS) of Oman. Two proposed locations are considered to connect the CSP plant to MITS: Manah and Adam 132/33kV grid stations in Al-Dakhiliah region. The MITS model of 2015 has been updated to include the simulation of connecting the proposed 200MW CSP to either Manah or Adam grid station. The DIgSILENT *PowerFactory* professional software is used to perform system analyses in the following three cases: (i) No CSP IPP; (ii) 200MW CSP IPP connected to Manah 132/33kV grid station; and (iii) 200MW CSP IPP connected to Adam 132/33kV grid station.

Section 2 describes the main power system of Oman. Section 3 provides a brief description of the CSP concept. Section 4 summaries the results of load flow and short circuit analyses. Section 5 presents transient analysis of CSP plant outage. Section 6 summaries the main conclusions.

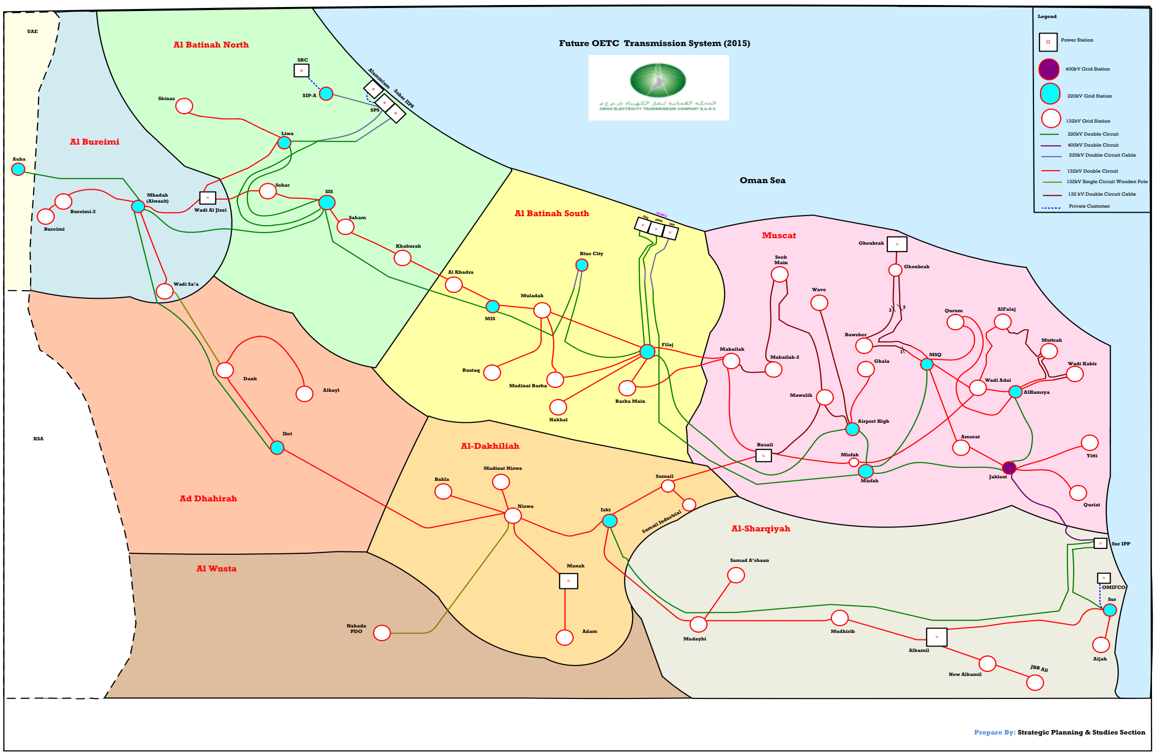

Figure 1: The Main Power System of Oman in 2015.

2. SYSTEM DESCRIPTION

The transmission system extends across the whole of northern Oman and interconnects bulk consumers and generators of electricity located in the Governorate of Muscat and in the regions of Bureimi, Batinah, Dhahirah, Dakhiliyah and Sharquiya (OETC, 2011). Figure 1 shows a geo-schematic diagram of the planned MITS in 2015. The system is composed of three voltage levels: 400kV, 220kV, 132kV. The bulk of the power transmitted through the main grid, is fed, through 220/132/33kV, 132/33kV and 132/11kV grid stations, to the three distribution licence holders, namely, Muscat Electricity Distribution Company, Mazoon Electricity Company and Majan Electricity Company, in addition to a number of directly-connected large private customers at 220kV or 132kV. The development of the electricity transmission system model is described in (Abdalla, Al-Hadi, and Al-Riyami, 2009). The model is used for steady-state and transient analyses using DIgSILENT software.
Currently, the MITS is supplied from eight power stations: Rusail IPP (687MW), Ghoubrah IWPP (469MW), Barka-I IWPP (434MW) Barka-II IWPP (681MW), Sohar-I IWPP (605MW), Wadi Jizzi IPP (290MW), Manah IPP (279MW) and Al Kamil IPP (297MW). Three new power plants will be commissioned during 2012-2014: Bark-III IPP (750MW), Sohar-II (750MW) and Sur IPP (2000MW). The proposed CSP IPP (200MW) is expected to be installed in 2015 (OPWP, 2011). Some large customers have their own generation capability on site and exchange power with the MITS. The interconnection between Oman and UAE is planned to be energised in October 2011.

3. CONCENTRATED SOLAR POWER PLANT

The first parabolic trough system was installed in 1912 near Cairo (Egypt), to generate steam for a 73kW pump that delivered 2000 m^3/h of water for irrigation (Muller-Steinhage and Franz, 2004).

The concept of the CSP system has been well developed during years by using new materials and advanced designs. A recent design of CSP plant (EERE, 2009) consists mainly of a solar field with parabolic trough collectors, two thermal storage tanks, heat exchangers, piping systems, steam turbine, and electric generator. The collector field in the trough technology consists of a large field of single-axis tracking parabolic trough-shaped solar collectors. The solar field is composed of many series/parallel units of solar collectors aligned on a north-south horizontal axis. Each solar collector has a trough-shaped glass mirror reflector that focuses the direct beam radiation of the sun on a linear receiver located at the focus of the parabola. The collector is equipped with a control mechanism to track the sun during the day time, thus maximizing the energy captured from the sun. A heat transfer fluid (HTF) is heated by circulating it through the receiver and returns to heat exchangers to generate high pressure superheated steam. The superheated steam is then fed to a conventional reheat steam turbine driving a generator to produce electricity. The exhausted steam from the turbine is delivered to the condenser to complete the cycle. Thermal storage tanks are used to store thermal energy to extend the operation of the power plant after sunset (typically 3-6 hours). Parabolic trough is currently the most proven solar thermal electric technology. Large scale solar power plants have been in operation in the California Mojave Desert since 1984 with total power of about 350MW (EERE, 2009). The proposed CSP plant of Oman will consist of 2 units, 100MW each.

4. STEADY STATE ANAYSIS

The aim of the study is to assess the impact of the proposed CSP power plant connection on the transmission grid. The OETC grid model of 2015 has been updated to include the simulation of the proposed 200WM CSP plant connected to either Manah or Adam. Load flow studies and short-circuit analyses have been performed in the following three cases:

A. No CSP IPP
B. 200MW CSP IPP connected to Manah 132/33kV grid station
C. 200MW CSP IPP connected to Adam 132/33kV grid station

The results include percentage of transmission line loadings, percentage of transformer loadings, busbar voltages, grid losses, in addition to 3-phase and 1-phase fault levels. Tables 1 to 6 summarize the main results.

Table 1 shows that the connection of the proposed 200MW CSP power plant at either Manah or Adam grid stations affects the 132kV Manah-Nizwa transmission line by increasing the line loading from about 42% to about 69% at the peak load of 2015. This line transmits the electric power generated by both Manah IPP and the proposed CSP IPP. To exploit the maximum capacity of the CSP and maintaining compliance with the Transmission Security Standard, (N-1) criterion, this line may need reinforcement. All other transmission lines in the grid are within their corresponding firm capacity, i.e. the loading on each is well below 50%. In the case of a single circuit outage, the other will take the load without supply interruption.

Table 2 shows that the transformer loadings are all below 50%. Table 3 shows that the voltages at all busbars are within the allowable range (±10%) according to the Grid Code. Table 4 shows both active and reactive power losses in the transmission grid before and after the connection of the CSP plant at Manah or Adam. The active power losses slightly increase, whilst the reactive power losses decrease after connecting the CSP IPP. Tables 5 shows that the short-circuit levels (3-phase) at all busbars are well within their corresponding ratings (40kA for the 220kV system and 31.5kA for the 132kV system). Tables 6 shows that the single-phase short-circuit levels at the CSP plant and nearby busbars are well below their corresponding ratings.

Table 1: Line Loading (%).

Transmission Line Name	Voltage (kV)	Line Rating (MVA)	Loading (%)		
			No CSP	CSP-Manah	CSP-Adam
Al Wasit-Wadi Sa'a	132	2x89	11.2	11.3	11.3
Alkamil- Mudharib	132	2x261	37.3	31.9	32.0
Alkamil-Sur	132	2x261	27.1	23.1	23.1
CSP-Adam	132	2x261	NA	NA	30.1
CSP-Manah	132	2x261	NA	30.4	NA
Dank-Al Hail	132	2x261	18.3	18.6	18.6
Ibri-Dank	132	2x261	23.7	24.0	24.1
Izki-Mudhabi	132	2x261	6.4	7.9	7.8
Manah-Nizwa	132	2x261	42.5	69.4	69.2
Mudharib-Mudhabi	132	2x261	18.0	12.5	12.6
Nizwa-Izki	132	2x261	40.4	21.0	21.1
Nizwa-Ibri	132	2x261	36.7	46.9	46.9
Rusail-Sumail	132	2x261	33.7	30.9	31.1
SIS-Al Wasit	220	2x762	11.6	9.2	9.3
SPS-SIS	220	2x762	23.2	21.7	21.7
SIS-Sohar	132	2x261	22.2	21.9	21.9
Sumail-Izki	132	2x261	8.4	6.9	7.3
Wadi Al Jazzi-Al Wasit	132	2x163	10.3	7.5	7.5

Table 2: Transformer Loading (%).

Transformer Name	Transformer Rated (MVA)	Loading (%)		
		No CSP	CSP-Manah	CSP-Adam
Al Wasit	2x315	23.3	25.0	25.0
Ibri	2x500	7.3	7.4	7.6
SIS	2x500	26.1	26.2	26.2
Sur	2x500	27.4	25.0	25.0

Table 3: Busbar Voltages (kV).

Busbar Name	Nominal Voltage (kV)	Voltage (p.u.)		
		No CSP	CSP-Manah	CSP-Adam
Adam	132	0.99	1.00	1.00
Al Hayl	132	0.93	0.92	0.92
Bahla	132	0.96	0.96	0.96
CSP	132	NA	1.00	1.01
Dank	132	0.95	0.93	0.93
Ibri	132	0.96	0.95	0.95
Ibri	220	0.98	0.97	0.97
Izki	132	0.98	0.98	0.98
Manah	132	1.00	1.00	1.00
Mudhaibi	132	0.96	0.97	0.97
Mudhairb	132	0.97	0.98	0.97
Nizwa	132	0.97	0.98	0.97

Table 4: Active and Reactive Power Losses in the Transmission Grid

Transmission Grid Losses	No CSP	CSP-Manah	CSP-Adam
Active Losses (MW)	85.37	86.66	87.9
Reactive Losses (MVAr)	803.03	785.34	794.64

Table 5: Three Phase Short Circuit Currents at Connected Busbars.

Busbar Name	Switchgear Rating (kA)	Three-Phase Short-Circuit Currents Ik" (kA)		
		No CSP	CSP-Manah	CSP-Adam
Adam	31.5	6.77	7.65	11.42
CSP	31.5	NA	16.84	11.01
Izki	31.5	17.58	18.77	18.45
Manah	31.5	14.73	19.70	18.13
Nizwa	31.5	16.28	19.17	18.33

Table 6: Single Phase Short Circuit Currents at Connected Busbars.

Name	Switchgear Rating (kA)	Single-Phase Short-Circuit Currents Ik" (kA)		
		No CSP	CSP-Manah	CSP-Adam
Adam	31.5	7.02	7.61	11.33
CSP	31.5	NA	17.33	11.63
Izki	31.5	18.01	18.77	18.58
Manah	31.5	17.11	22.01	19.94
Nizwa	31.5	18.84	21.20	20.54

1. TRANSIENT STUDIES

Simulation studies have been performed to assess the transmission system transient responses to the CSP plant outage when it is operated at 2015 summer peak demand. The dynamic model of the system is used. Two sample results are given here. Figure 2 shows the generator rotor angle responses to tripping of the CSP plant at Manah.

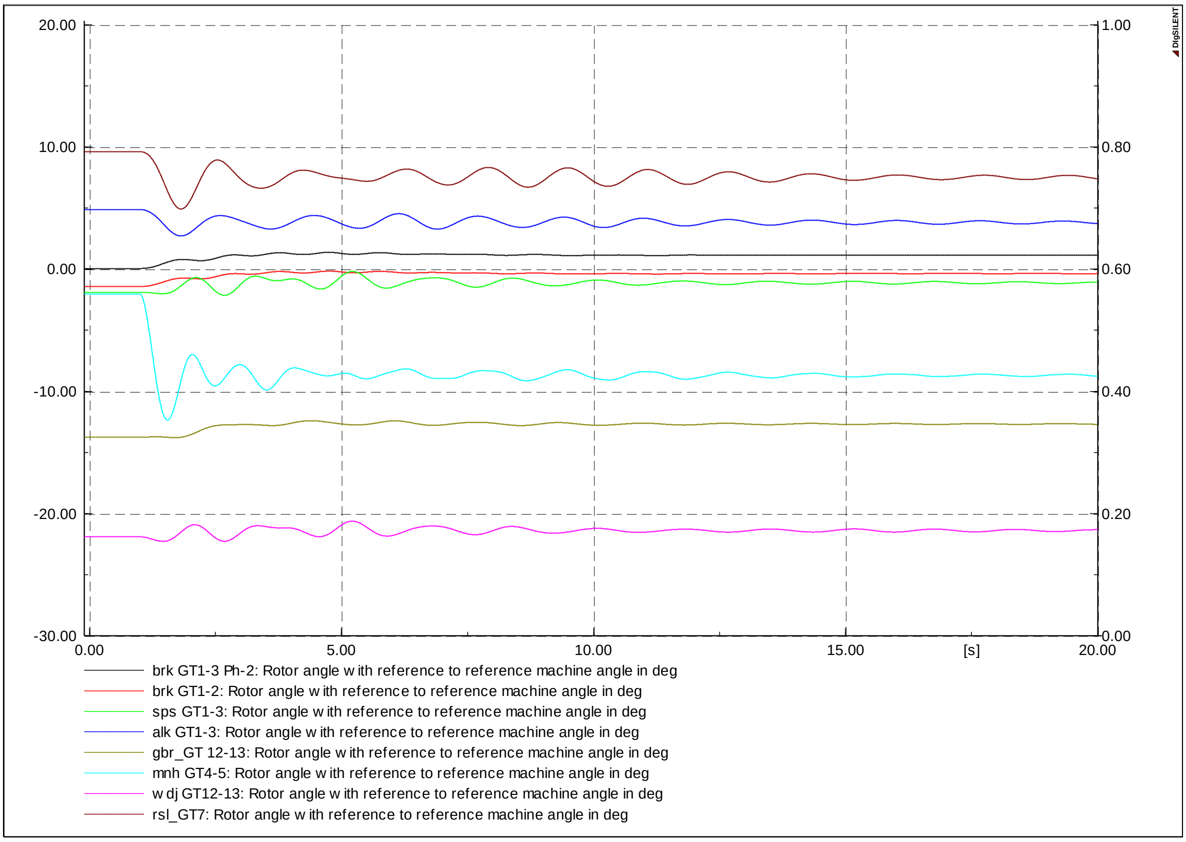

Fig 2: Rotor angle response to tripping the CSP plant at Manah.

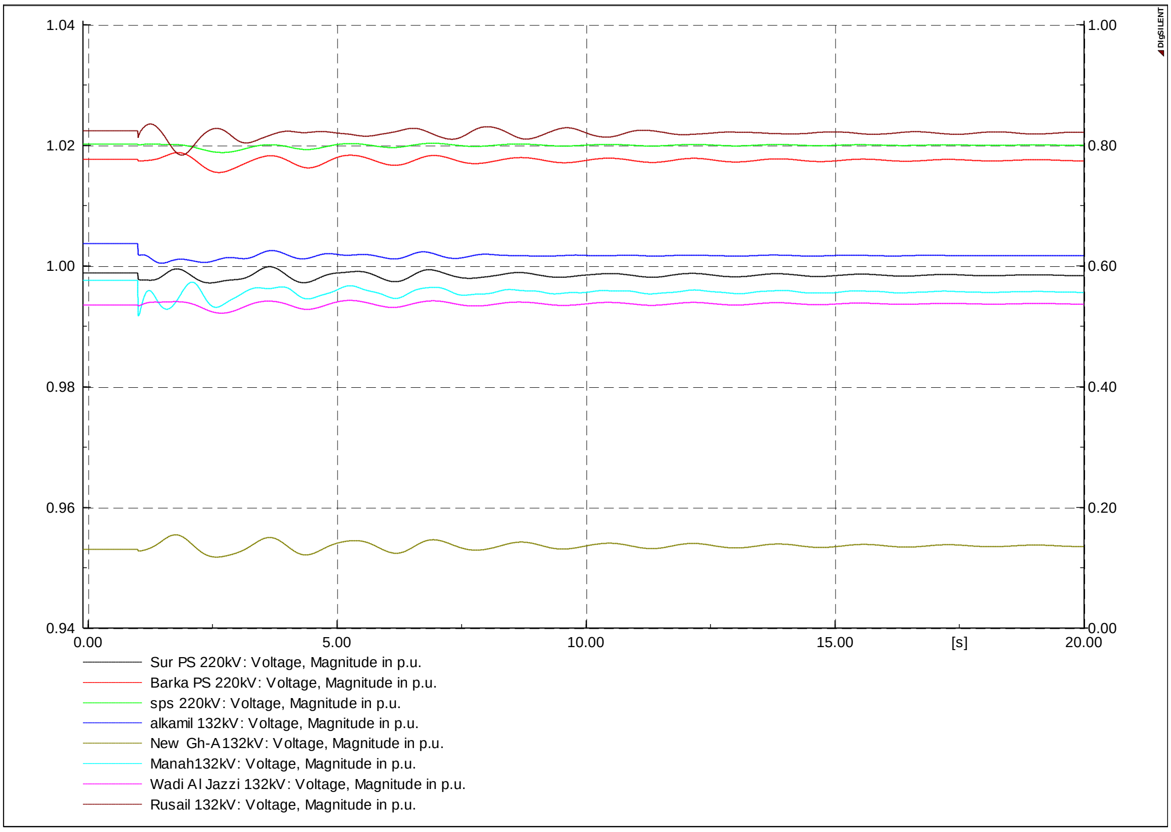

Fig 3: Voltage response to tripping the CSP plant at Adam.

Figure 3 shows the busbar voltage responses to tripping of the CSP plant at Adam. The transient results show that the transmission system is capable of withstanding this type of severe disturbance.

2. CONCLUSIONS

Steady state and transient analyses have shown that the connection of the CSP plant at Manah or Adam to the transmission system is acceptable. All lines and transformers are within their loading capabilities except the Manah-Nizwa 132kV double-circuit transmission line. At the 2015 summer peak demand, the loading on this line can reach about 69% and will need reinforcement to comply with the (N-1) criterion of the Transmission System Security Standards. The three-phase and single-phase fault levels at the CSP plant and nearby busbars are within their corresponding short circuit ratings. The transient responses have proven that, at 2015 summer peak, the system remains stable when it is subjected to the CSP plant outage.

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