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Key Performance Indicators of a Transmission System

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Summary:

The paper concerns with formulae and calculations of a selected group of Key Performance Indicators (KPIs) for the main electricity transmission system in Oman. These include the following service quality, reliability, security, and financial indicators [1]:

- System Average Interruption Frequency Index (***SAIFI***)
- System Average Interruption Duration Index (***SAID***)
- Energy Not Supplied (***ENS***)
- Average Interruption Time (***AIT***)
- Overhead Lines Maintenance Cost Index (***OHLMCI***)
- Substation Maintenance Cost Index **(SSMCI)**

Results of the main transmission grid in Oman, over the last 3 years, are presented. The results are useful in indicating trends of the KPIs and determination of future targets to improve transmission system performance.

The goal of presenting the paper at the GCC 09 is to open a discussion among transmission utilities in the Gulf region for the possibility of introducing common KPIs to evaluate system performance. This could provide an excellent opportunity to establish acceptable benchmarks of the proposed KPIs

Keywords: ***Power System Performance Indicators, Transmission Systems, SAIFI, SAIDI, Energy Not Supplied, Reliability, Availability, Supply Quality, Maintenance.***

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1. INTRODUCTION

Electricity transmission companies normally measure their achievements by using various types of qualitative and quantitative assessments [1]-[4]. They measure achievements of their objectives through monitoring a number of performance indicators [5], [6]. These quantitative indicators are commonly known as Key Performance Indicators (KPIs). Once company operating objectives are clearly determined, both technical and financial KPIs can be used to measure the degree of achievements.

This paper summarizes formulae and presents calculations of a selected group of KPIs for the main electricity transmission system in Oman. These KPIs are [1]:

- System Average Interruption Frequency Index (***SAIFI***), which measures the average number of interruptions experienced by each customer.
- System Average Interruption Duration Index (***SAID***), which measures the yearly average interruptions duration per customer.
- Energy Not Supplied (***ENS***), which is the summation of MWh not supplied to customers during a period of one year.
- Average Interruption Time (***AIT***), which measures the total number of minutes that power supply, is interrupted during the year.
- Overhead Lines Maintenance Cost Index (***OHLMCI***), which indicate the annual maintenance cost per unit length of transmission lines.
- Substation Maintenance Cost Indices **(SSMCIs)**.

These selected KPIs were recommended by the CIGRE Study Committee C2 and JWG B3/C2-14 Task Force 02, [1]. A customer of a transmission grid is considered to be each company that has a connection agreement with the grid. To account for customers with multi-connection-points to OETC grid, such as DISCOs, we may use the number of connection points in place of the number of customers. An alternative way is to count the number of supply delivery points from the transmission system to distribution networks and direct customers.

Results of the main transmission grid in Oman, over the last 3 years, are presented. The results are useful in indicating trends of the KPIs and determination of future targets to improve transmission system performance.

The goal of presenting the paper at the GCC 09 is to open a discussion among transmission utilities in the Gulf region for introducing possible common KPIs to evaluate system performance. This could provide an excellent opportunity to establish acceptable benchmarks of the proposed KPIs.

The next sections of the paper are organized as follows. Section 2 describes the main transmission system of Oman including generating stations, grid stations, transformers and transmission lines. Some statistical information is summarized in Section 3 to show technical and financial performances. Section 4 concerns with the definitions and equations of the performance indicators. Section 5 gives the results of the recommended KPIs calculated during the last three years. Section 6 presents three additional KPIs, including the Customer Average Interruption Duration Index (***CAIDI***), Voltage Deviation Index (***VDI***), and Frequency Deviation Index (***FDI***). Finally, Section 7 summarizes main conclusions and recommendations.

2. MAIN TRANSMISSION SYSTEM OF OMAN

The existing 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 Batinah, Dhahirah, Dakhliyah and Sharquiya. Figure 1 shows a geo-diagram of the system. It has two operating high voltages, i.e. 220 kV and 132 kV.

After the electrical sector was unbundled; Oman Electricity Transmission Company (OETC) has taken over the operation of transmission system since the 1st of May 2005. The present OETC transmission system consists of:

- 686 circuit-km of 220 kV overhead transmission lines
- 2837 circuit-km of 132 kV overhead transmission lines
- 12 circuit-km of 220 kV underground cables
- 14 circuit-km of 132 kV underground cables
- 5630 MVA of 220/132 kV transformer capacity
- 6970 MVA of 132/33 kV transformer capacity
- Two 220 kV interconnection grid stations
- Two 220/132 kV grid stations
- Four 220/132/33 kV grid stations
- Thirty one 132/33 kV grid supply point substations

The main transmission system of Oman is interconnected, through a 220 kV double circuit transmission line at Al-Wasit in Mahadah, with the transmission system of the United Arab Emirate (UAE). This interconnection will form a part of the GCC Grid that links the electricity supply systems of Oman, Kuwait, Saudi Arabia, Bahrain, Qatar and the UAE. This should provide increased security of supply and benefits to the members of the GCC countries in the form of cost savings from the sharing of reserve capacity and energy resources. The interconnector will be brought into service when the Inter-Governmental agreement is signed.

The main transmission system is supplied with electricity generated from eight gas-based power stations located at Ghubrah (482MW), Rusail (684MW), Waddi Al-Jizzi (290MW), Manah (279MW), Al-Kamil (282MW), Barka AES (434MW), Barka SMN (683MW) and Sohar (590MW). In addition the transmission system may be supplied from direct customers such as Sohar Aluminum Company and Petroleum Development of Oman (PDO).

The bulk of the power transmitted through the main grid, is fed, through 220/132/33 kV and 132/33 kV grid stations, to the three distribution licence holders, i.e. Muscat Electricity Distribution Company, Mazoon Electricity Company and Majan Electricity Company. In addition to the distribution companies, 11 large private customers are directly connected to the transmission system.

OETC is currently investing in tens of new major projects to continue improving transmission services in Oman and cope with the remarkable development in all sectors. These include new grid stations, 220 kV and 132 kV lines, upgrading conductors, adding new transformers, replacing equipment, introducing silicon rubber insulators, etc.

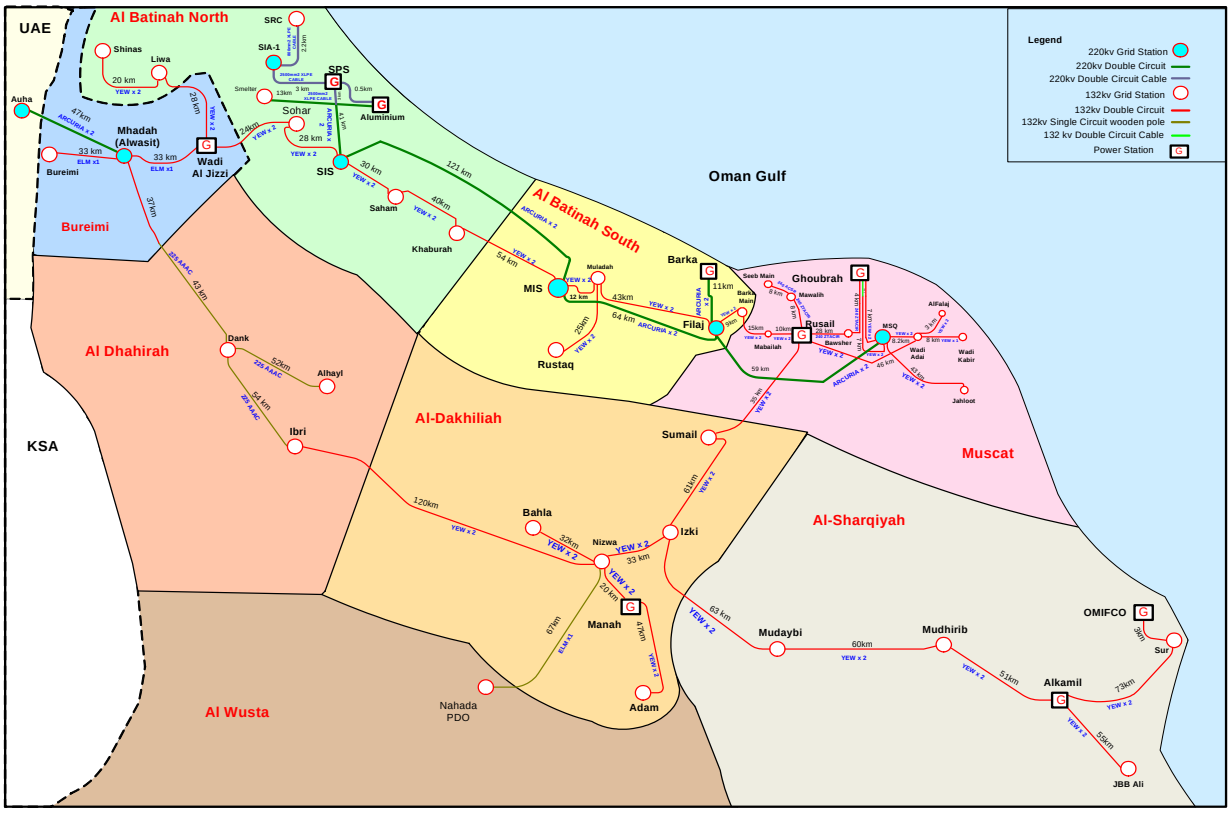

Figure (1): Main Transmission System of Oman.

3. PRESENT OETC PERFORMANCE INDICATORS

At present a number of performance indicators are used in Oman Electricity Transmission Company. Details can be found in the Annual Reports [7]–[9]. Some operational and financial statistics as well as performance indicators are summarized here.

A. Operational and Safety Performance

Table (I) summarizes some statistical information on the operational performance of the main transmission system of Oman. The average annual increase in the regulated units transmitted is 13.1%. The peak load increases with a rate of 10.4% per year. Four new grid stations ware installed in 2007, but no additional grid stations was introduced during 2008. More than 20 new grid stations are planned to be build during the five year plan (2009-2013). In the field of HSE activities, OETC achieved zero injury lost time in 2008.

B. Financial Performance

Table (II) shows some financial performance statistics during the past three years. There are increases in the revenues, assets and return on investment in 2008 compared with the previous two years 2006 and 2007.

Table (I): Operational statistics.

Item	2006	2007	2008
Regulated Units Transmitted (GWh)	10,821	11,380	13,838
Peak Load (MW)	2,444	2,582	2,977
Number of Substations	34	38	38
Total Capacity of Transformers (MVA)	10,627	10,746	10,746

Table (II): Financial statistics.

Item	2006	2007	2008
Total Revenue (RO×1000)	26,549	27,125	31,602
Net Profit (RO×1000)	10,854	9,412	8,836
Total Assets (RO×1000)	231,249	263,110	299,369
Return On Investment	5.79%	4.76%	5.95%

C. System Availability

Table (III) shows the transmission system availability during 2006, 2007 and 2008. These include both summer period availability and annual availability.

Table (III): System availability index.

Item	2006	2007	2008
Summer Availability	98.49%	95.96%	98.75%
Annual Availability	98.23%	95.99%	98.49%

The system availability is calculated in terms of the summation the availabilities of individual circuits of the transmission grid expressed as a percentage of the total number of circuits. A circuit is defined as an overhead line, cable, transformer or any combination of these equipment items controlled by one or more circuit breakers. The formula for calculating this availability indicator is given as follows:

$$Availability\% = \frac{\sum_{0}^{Period} \sum_{1}^{All\ Circuits} (Circuit \times Hours\ Availabl)}{Number\ of\ Circuits \times Number\ of\ Hours\ in\ Period} \times 100$$

The availability index is calculated in OETC on monthly and yearly bases. The summer period availability is the average availability over the six months: April to September. The annual availability is calculated over the twelve months. The availabilities of the 2007 are affected by the cyclone Gonu which hit the Sultanate of Oman during the period from 5 to 8 June 2007 [10].

The total system unavailability index is calculated as follows:

$$Total\ Unavilability\% = (100 - System\ Availability\%)$$

Total unavailability includes planned and unplanned outages. It is also calculated in OETC on monthly and yearly bases.

D. Transmission Losses

This KPI gives indirect indication of the transmission grid efficiency. Transmission losses can be calculated as the difference between the total electrical energy received from the generating plants and the total energy supplied to all transmission customers. It is usual to express losses as a percentage value rather than absolute value. The losses are measured over a definite period (e.g. one year or one month). The total energy received is the sum of energies measured at the connection points with generators. Similarly, the total energy supplied to customers is the sum of energies measured at grid supply points to all transmission customers. These include all DISCOs and all directly connected customers. Time of measurement and position and accuracy of the instrumentation used should be carefully considered.

4. CIGRE STUDY COMMITTEE C2 RECOMMENDED PERFORMANCE INDICATORS

It is important to note that many detailed performance measures can be used internally in the company, but only those relevant general interests are published. For example, the main KPIs reported by the National Grid in UK [4]. This section describes the KPIs selected by the CIGRE Study Committee C2 and JWG B3/C2-14 Task Force 02, [1].

Supply Availability KPIs

The following availability KPIs provide a measure for indicating the level of readiness of the system to deliver electric energy to the customers. These are defined as follows:

A. Energy Not Supplied (ENS)

This is defined as the summation of energy not supplied due to supply interruptions over a year period. It can be calculated by using the following formula:

$$\boldsymbol{ENS} = \sum [\text{Interruption power (MW)} \times \text{Duration (h)}]$$

Network losses are not included.

B. Average Interruption Time (AIT)

This KPI is calculated from the ***ENS*** as follows:

$$AIT = \frac{8760 \times 60 \times ENS}{\text{Annual Electricity Demand (MWh)}}$$

System Reliability KPIs

C. System Average Interruption Frequency Index (SAIFI)

This indicator, which is recommended by the IEEE, measures the average number of interruptions experienced by each customer. All planned and

unplanned interruptions are used in calculating the index. This indicator can be calculated as follows:

$$SAIFI = \frac{\text{Number of Interruptions During One Year}}{\text{Number of Customers}}$$

Notes:

- ***SAIFI*** is normally calculated over one year. If it is required for other periods, its name and equation should be modified accordingly.
- ***SAIFI*** can be calculated for each voltage level.
- A customer of a transmission grid is considered to be each company that has a connection agreement with the grid.

D. System Average Interruption Duration Index (SAIDI)

This indicator, also recommended by the IEEE, measures the yearly average interruptions duration per customer. The following formula is employed for calculating ***SAID***:

$$SAIDI = \frac{\sum^{One\,Year} \text{Duration of Interruption (min.)}}{\text{Number of Customers}}$$

The same notes mentioned above for ***SAIFI*** are also applicable here for ***SAIDI***.

Maintenance Cost KPIs

E. Overhead Transmission Line Maintenance Cost Index (OHTLMCI)

This KPI indicates the annual maintenance cost of transmission lines per route length. It is calculated as follows:

$$OHTLMCI = \frac{\text{OHTLs Maintenance Cost}}{\text{Route Length (km)}}$$

The OHTLs maintenance works include mainly live line washing and line patrolling.

F. Substation Maintenance Cost Index (SSMCI)

This includes all costs within all substations fences and can be calculated as follows:

$$SSMCI = \frac{\text{SS HV Equipment Maintenance Cost}}{\text{No. of CBs} + 2 \times \text{No. of Transformers}}$$

The substation maintenance activities include, but not limited to the followings: Daily, routine, monthly, quarterly, annual, preventive, predictive, break down and emergency maintenance work for grid stations (including maintenance of all equipment like transformers, circuit breakers, 220 kV, 132 kV and 33 kV cables (incomer feeders), CT's, VT's, lightning arrester, relays, air conditioning systems, fire systems, etc) in addition to civil maintenance works. These are normally performed in accordance with best practice as per manufacturer manuals and OETC maintenance manuals.

5. RESULTS

The following results summarize the recommended KPIs calculated for the transmission system in Oman during the last three years 2006-2008 [11]. Table (IV) shows the energy not supplied ***ENS*** and the average interruption time ***AIT*** key performance indicators.

Table (IV): Supply availability indicators.

KPI	2006	2007	2008
ENS **(MWh/year)**	1995	2028	2080
AIT **(min/year)**	96.91	93.66	79.00

Figures 2 and 3 show the trend in these performance indicators during the period of the three years. From these figures and Table (IV), the company can monitor the trend in the supply availability, analyze the results, take appropriate actions and set targets for coming years to achieve performance improvements. Also, when international benchmarks are available, comparison can be made.

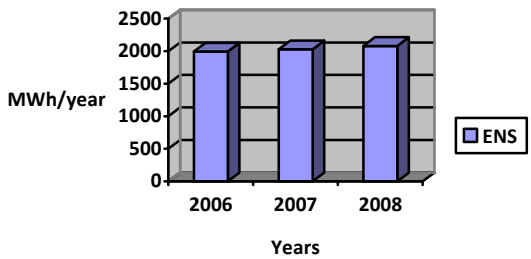

Fig. 2. Trend in energy not supplied.

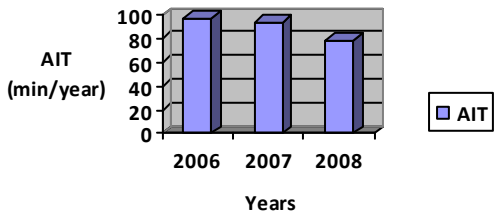

Fig. 3. Trend in average interruption time.

Table (V) and Table (VI) show the calculated system reliability indicators ***SAIFI*** and ***SAIDI***. Figures 4 and 5 show the trends in ***SAIFI*** and ***SAIDI***, respectively.

Table (V): *SAIFI* reliability indicators.

KPI	2006	2007	2008
***SAIFI* (for 132 kV)**	0.800	0.367	0.321
***SAIFI* (for 220 kV)**	0	0.020	0.094

Table (VI): *SAIDI* indicators.

KPI	2006	2007	2008
***SAIDI* (for 132 kV)**	47.04	19.65	19.32
***SAIDI* (for 220 kV)**	0	2.12	16.98

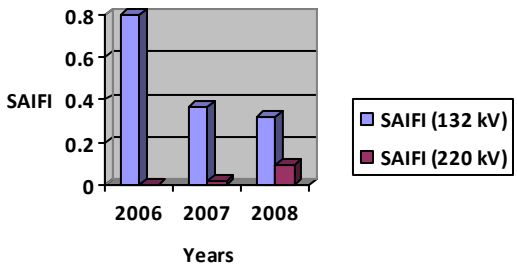

Fig. 4. Trends in SAIFI for 132 kV & 220 kV circuits.

Fig. 5. Trends in SAIDI for 132 kV & 220 kV circuits.

The calculated cost indicators of the overhead transmission lines and substations HV equipment, ***OHTLMCI*** and ***SSMCI,*** are given in Table (VII). Figure 7 shows the trends in maintenance costs.

Table (VII): Maintenance cost indicators.

KPI	2006	2007	2008
***OHTLMCI* (RO/km)**	271	681	268
***SSMCI* (RO/HV Equip.)**	1370	1239	1073

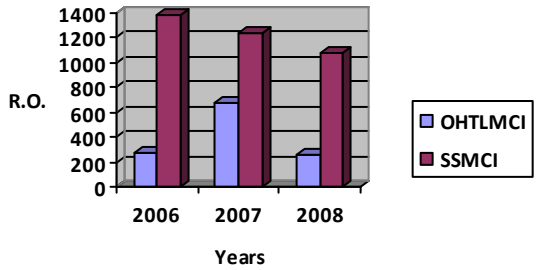

Fig. 8. Trend in maintenance costs.

6. ADDITIONAL SELECTED KPIs

The following additional performance indicators are selected by the authors. They may be added to the 6 KPIs described above.

G. Customer Average Interruption Duration Index(CAIDI)

This index can be directly calculated as long as ***SAIFI*** and ***CAIDI*** are available:

$$CAIDI = \frac{\text{SAIDI}}{\text{SAIFI}}$$

H. Voltage Deviation Index (VDI)

This voltage quality [12] index can be calculated during a specific period, and is defined as follows:

$$VDI\% = \frac{\text{Number of Hours that Voltage is Out of Range During Period}}{\text{Number of Hours of that Period}} \times 100$$

This KPI can be calculated for each transmission voltage level. In Oman, for example, these include 220 kV and 132 kV. According to the Grid Code [13], both

220 kV and 132 kV transmission voltage ranges are within ±10% of the corresponding nominal voltages. For the 33kV distribution voltage the range is ± 6% of the nominal value.

I. Frequency Deviation Index (FDI)

The frequency deviation index [12] can similarly be calculated during a specific period:

$$FDI\% = \frac{\text{Number of Hours that Frequency is Out of Range During Period}}{\text{Number of Hours of that Period}} \times 100$$

In Oman, the condition ASC4.1 of the Ancillary Services Code [13], determines the allowable System Frequency range during the following operating conditions:

a) During normal operating conditions, the nominal system frequency of the transmission system shall be 50.00Hz and will be controlled normally between 49.95Hz and 50.05Hz.
b) During exceptional steady state conditions, frequency deviations will not exceed 49.90Hz to 50.10Hz unless disturbed circumstances prevail.
c) Under disturbed conditions, system frequency could rise transiently to 51.50 Hz or fall to 48.0 Hz, but not exceed these limits.

7. CONCLUSIONS

The paper has described a number of key performance indicators for electricity transmission system. These include a group of six KPIs recommended by the CIGRE Study Committee C2 and JWG B3/C2-14 Task Force 02 and results of the application to Oman electricity transmission system. A group of three additional selected KPIs have been also proposed. The two groups cover important practical performances of electricity transmission systems. These include availability, reliability, quality and maintenance cost indicators. The KPIs can be used to measure the system performance compared to benchmarks and to illustrate the trends in these indicators. Thus, companies can set targets and take corrective actions, if necessary, to improve system performance.

These KPIs may provide a useful tool for evaluating the operational performance of transmission systems in the Gulf region. The GCC CIGRE is encouraged to establish a task force committee from the countries in the region to further study the possibility of using these KPIs. Precise definitions, methods of calculations, procedures, etc, need to be agreed among all parties.

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