

DISTRIBUTED VOLTAGE IN OMAN ELECTRICAL POWER SYSTEM

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Abstract — In this paper, we perform a study on the Oman Electrical System to analyze the efficiency of modifying and upgrading the specifications of the Oman Electrical System (OES)^[3] standard for further comparison with the specifications of the International Electrical Commission (IEC)^[5] standard. Technical and economical analysis is conducted on the system using both standards. To ensure the accuracy of our work, number of field Measurements are taken for the voltage and the current on five distribution substations. Based on the measurements, we found that the characteristics of the Omani load are the same as the characteristics of induction load. This is due to the fact that most of the used loads on the system are in the forms of air-conditioning, refrigeration and industrial types of load. Our analysis shows that many power quality problems, annual peak load, total system losses, investment cost of generation and aging of electrical equipments are significantly reduced when OES is modified.

Keywords: Distributed Voltage, IEC, Induction Load, OES.

I. INTRODUCTION

Both utilities and end users of electrical power systems are often concerned about the continuity, reliability and the quality of power supplies with optimal cost. The load demand increases yearly at high level growth rate due to the new industrial projects which need hundreds of Mega Watts (MW). The growth of load demand requires investors to establish and operate new generating units which are capable of supplying power to the residential and industrial customers with high power quality.

The total annual losses, technical and non-technical, are almost 22% of the total electrical energy produced in Oman electrical system^[1]. In accordance with OES #4 published in May 1989, the nominal voltage at the consumers' terminals is 240V and shall not vary by more than 6%. On the other hand, most electrical equipments, apparatuses, appliances ...etc, used in Oman market are designed to operate according to the IEC standard where the nominal voltage is 230V and shall not vary by more than 6%. Therefore, the nominal operating voltage used on the Oman system and delivered to the consumers is above the designed specifications of their devices by 4.35%. The devices still can operate with this increase in the nominal voltage due to the fact that in the manufacturing process, the vendors design the device to operate with a variation of 10% on the nominal voltage. Though, the best performance of any electrical device is achieved when it operates at its designed configuration. The operation of the electrical devices for long durations and over voltage variation condition, especially in winter season where the load is low, leads to abnormal operating

conditions and power quality problems. This motivates us to study the performance of the system when the voltages are as per IEC instead of the OES.

Our main contributions are summarized as follows. We conduct analysis to study the performance of the system using both the IEC and OES voltages. In the analysis, we evaluate the system from many aspects including generation, transmission and distribution of power. We take into consideration system losses in our calculations. We perform field measurements to record the actual values of the current and the voltage of the system. We also discuss the technical and economical enhancements that can be achieved by using the voltages as per IEC in the Oman Electrical System.

This paper is organized as follow. In section II, we briefly describe the Oman Electric Power Network. In section III, we provide the daily load curve of the system. We discuss the nominal voltages defined in the IEC and OES standards in section IV. In section V, we discuss the obtained results of the field measurements we conducted to find the Oman load characteristics. In section VI, we discuss the enhancements we achieve on the daily load factor by applying IEC on the Oman system. The analysis is provided in section VII. Finally, we conclude the paper in section IIX.

II. OMAN ELECTRIC POWER NETWORK^[6]

A. The electricity sector in Oman

The electricity sector in Oman was extensively restructured following implementation of the law for the regulation and privatization of the electricity and water sector, promulgated by Royal Decree 78/2004 on 1 August 2004. The law provided for the unbundling of the electricity and water activities previously undertaken by the Ministry of Housing, Electricity and Water (MHEW).

A number of successor companies are authorized by licenses issued by the Authority for Electricity Regulation to undertake certain regulated activities. These companies include the Oman Electricity Transmission Company (OETC) and three distribution companies Muscat EDC, Mazoon EC and Majan EC.

B. OETC Supply Area

The Oman Electricity Transmission Company (OETC) is authorized to undertake all regulated activities of electricity transmission at 132 kV and

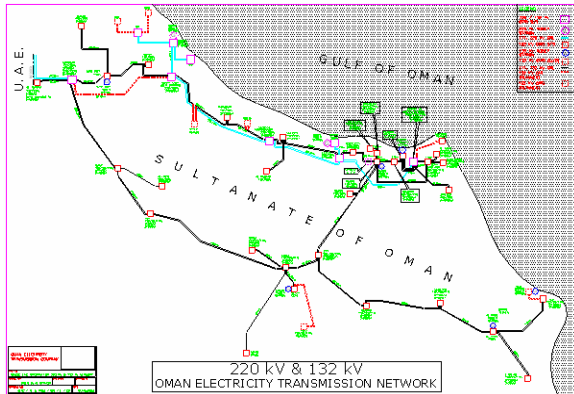


Fig. 1 Oman Transmission System

above. This includes the 220 kV and 132 kV interconnected transmission grid in the north of Oman which serves the three distribution companies, namely Majan EC, Mazoon EC and Muscat EDC, and also directly connected large generators and demand customers. A near geographic representation of the OETC network is illustrated in Fig. 1.

The total supply area of the three distribution companies is approximately 126,000 km² covering the Muscat Governorate and the regions of Dakhliyah, Batinah, Dhahirah and Sharquiya. The Muscat Governorate area, although only around 3,000 km², has by far the majority of customers and network demand, and has in consequence the majority of distribution system grid station supply points. The supply areas of Majan and Mazoon have some high density customer areas, primarily along the northern coastal strip, but also have many low population density areas in the southern parts of their supply areas, including a number of remote villages with no little or no grid connections. OETC is authorized to undertake all regulated activities of electricity transmission (132 kV and above). This activity includes the provision of 220/33 kV and 132/33 kV grid station transformers and also includes 132 kV and 220 kV circuit breakers at generator connections. Each of the three distribution companies own the network from the 33 kV buses at each grid station down to the customer's point of supply, including the 33 kV, 11 kV and low voltage distribution networks and intermediate primary and secondary substations.

OETC supplies Mazoon EC through eleven 132/33 kV grid stations. Six of the grid stations: Muladah; Barka Main (shared with Muscat EDC); Khabourah (shared with Majan EC); Mudharib; Jaalan Bani Bu Ali; and Sur) are of the standard 2 x 125 MVA transformer design with a crossover arrangement such that the transformers supply both 33 kV busbars. The remaining grid stations are of the more conventional design without the crossover arrangement, three with 2 x 63 MVA transformers (Sumail, Mudhabi and Nizwa), whilst the remaining two grid stations have 2 x 40 MVA transformers (Bahla and Izki).

Majan EC is supplied by OETC through nine 132/33 kV grid stations. Three of the 132/33 kV grid stations (Sohar Town, Sohar Port and Khabourah) are of the standard 2 x 125 MVA transformer design with a

crossover arrangement. The remaining grid stations are of the more conventional design without the crossover arrangement, although only two (Shinas and Ibri) adopt standard 2 x 63MVA transformers, whilst the others (Buraimi, A1 Hail, A1 Wasit and Dank) have non-standard transformer ratings of 60MVA, 40MVA, 30MVA and 15MVA.

Muscat EDC is supplied by OETC through eleven 132/33 kV grid stations, eight of which are of the standard 2 x 125 MVA transformer design with a crossover arrangement. The remaining grid stations are of the more conventional arrangement, although only Seeb Main adopts standard size transformers (2 x 63MVA) whilst Ghubrah and Rusail adopt non-standard 2 x 42MVA and 4 x 75MVA transformers respectively. At Seeb Main the 33kV busbars are operated split, with bus section circuit breaker open.

Most grid stations are supplied via double circuit overhead lines, with the exception of Shinas and Al-Hail, which are presently supplied by a single 132 kV overhead line circuit, there are also two double circuit overhead lines linking Ghubrah Power Station and Madinat Sultan Qaboosl grid station.

The existing 220 kV network runs from Madinat Sultan Qaboosl to Barka but has recently been extended to Sohar for connection of the new Sohar Power Station and Sohar Industrial Port. All 220 kV overhead lines are double circuit and connected to 132 kV either via 2x500 MVA or 2 x 315MVA autotransformers.

There are seven major power stations connected to the OETC network, Ghubrah, Rusail, Manah, Barka Main, A1 Kamil Wadi Jizzi and Sohar. All except AES Barka are connected to the 132 kV networks, with AES Barka connected to the 220 kV systems, as will the new Sohar Power Station.

OETC network borders with, and has network interconnection with Petroleum Development Oman (PDO), which has its own electricity transmission system for oil exploration and development in the central region of Oman.

The network interconnection is provided by a single 132kV overhead line circuit from Nizwa to the PDO transmission system at Nahda. A 220 kV international interconnection with the United Arab Emirates (UAE) is also under construction. This will connect into the A1 Wasit substation in the west of the present main grid network.

The southern part of Oman has a separate transmission and distribution network supplying Salalah town and the surrounding area. This network, which includes Raysut Power Station, is managed in a vertically integrated manner (Generation + Transmission + Distribution) by Dhofar Power Company under a 20 year concession agreement.

C. Development of Existing Network

In 2000 the maximum demand on the OETC system was around 1725MW, and over the period 2000 - 2005



Fig. 2 Peak Daily Load

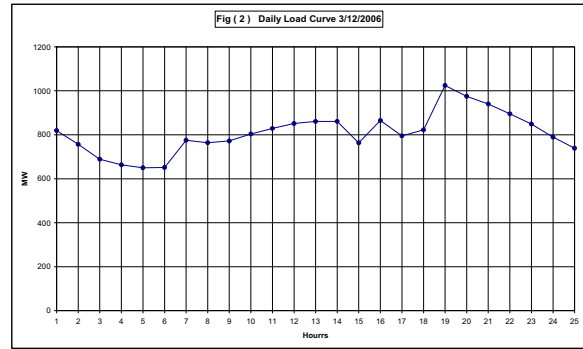


Fig. 3 Minimum Daily Load

the peak demand has grown at an average annual rate of 7.7%, which resulted in an additional 770MW of demand on the network. To accommodate this increase in demand the grid station capacity would ideally have kept pace with the actual load growth assuming no initial overcapacity, but this has not been the case. Only three new grid stations have been commissioned during this period, one each within Muscat (Bausher), Mazoon (Sumail) and Majan (Khabourah) supply areas. Consequently, the utilization of grid station transformers has steadily increased since year 2000.

III. DAILY LOAD CURVE^[2]

Fig. 2 and 3 show the peak and minimum daily load of Oman system, the difference between summer and winter loads are very high. The summer peak load is almost four times the winter peak load. In July 2006 the summer peak load was 2638 MW, and the minimum load up to the beginning of Dec 2006 is 650.1 MW and it is expected that by the end of Dec 2006 the load shall drop to 600 MW. This great difference causes long duration over voltage variation, in winter period on many consumers' connections, because the set point of automatic tap changer of distribution transformers could not reset correctly in addition to that, the specification of all distribution transformers in Oman electrical grids (national grid, Dhofar grid and Masandam grid) are 33kV/11.5kV and 11kV/0.433kV, i.e. the actual value of nominal low voltage side is 0.453kV.

IV. DISTRIBUTION VOLTAGE

In accordance with Oman Electrical Standard (OES) No.4, May 1989, Distribution Code^[4] defines the voltage at the Consumer's terminals shall not vary from the System nominal voltage by more than 6%. The values of the voltage are shown in Table 1.

Consumers Connected at	Nominal voltage	Tolerance
HV	33/11kV	+6.0% to -6.0%
LV single phase voltage	240V	+6.0% to -6.0%

i.e., for single phase, the distribution voltage is between 225.6 - 254.4 Volts.

And in accordance with International IEC Standard, the voltage at the Consumer's terminals shall not vary from the System nominal voltage by more than 6%. The values of the voltage are shown in Table 2.

Consumers Connected at	Nominal voltage	Tolerance
HV	33/11kV	+6.0% to -6.0%
LV single phase voltage	230V	+6.0% to -6.0%

i.e., for single phase, the distribution voltage is between 216 - 243.8 Volts.

By surveying the Oman market, it shows that, most of the electrical equipments, apparatuses, appliances, etc... were designed on IEC Standard Base.

The best performance & characteristics of any electrical equipment, if and only if, it operates on its design configuration.

In our case, the distribution operating voltage > normal rated voltage (designed value), where upper limit of operating voltage is greater than normal designed voltage with 10.61%, which can cause power quality problems, according to international IEC and American National Standards Institute (ANSI).

Table 3
Measurements of electrical quantities (V & I), taken in Intercontinental 33/11 kV substation, on 33, 11 & 0.415 kV sides on transformer # 1

Tap No.	TX-1										TX-1 Load (MVA)		
	InterContenante1 (33KV Side)					11KV Side		415 V Voltage V		1-ph Volt	V _{res} × I _r × 3 ^{0.5}	Load (MVA)	Saving (MVA)
	Voltage kV		Current Amps			Voltage kV		Voltage V					
5	33.5	33	33	86	89	85	11.1			248.8	5.0872	0	
4	33.7	34	34	85	87	85	10.91			245.5	4.9083	0.1789	
3	33.8	34	34	82	86	82	10.75			242.1	4.7647	0.3225	
2	33.7	34	34	75	78	75	10.61			238.5	4.5935	0.4937	
1	33.7	34	34	72	75	71	10.45			235	4.4778	0.6094	

Table 4
Measurements of electrical quantities (V & I), taken in Intercontinental 33/11 kV substation, on 33, 11 & 0.415 kV sides on transformer # 2

TX-2													
Tap No.	InterContenanteI (33KV Side)						11KV Side			415 V	TX-2 Load (MVA)		
	Voltage kV			Current Amps			Voltage kV			Voltage V	V _{ph} x I _{ph} x 3 ^{1/2}	Load (MVA)	Saving (MVA)
	R	Y	B	R	Y	B	R	Y	B	1-ph Volt			
5	33.8	34	34	72	72	70	11.1			NA	4.2401	0	
4	33.8	34	34	69	70	67	11.0			NA	4.1224	0.1177	
3	33.9	34	34	67	67	68	10.84			NA	3.9457	0.2944	
2	33.9	34	34	65	66	64	10.67			NA	3.8868	0.3533	
1	33.6	34	34	65	65	63	10.51			NA	3.8279	0.4122	

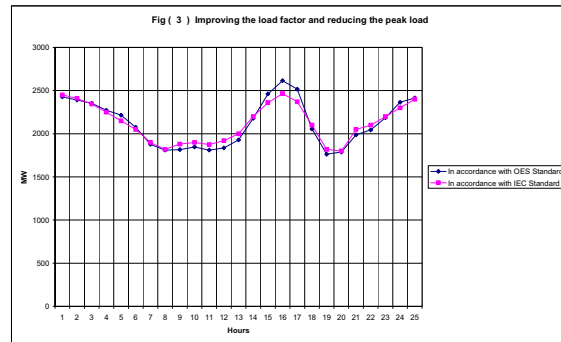


Fig. 4 Daily Load Curve (OES and IEC)

V. OMAN LOAD CHARACTERISTICS

To classify Oman load, number of field Measurements for electrical quantities (V & I) in five distribution substations were carried out. Tables 3 and 4 include measurements recorded on 33, 11 & 0.415 kV sides of distribution transformers numbers 1 and 2 after changing the taps of 33/11kV transformed tap changer between numbers 1 and 5, The results of measurements, in Intercontinental Substation at Al-Qurm area, are recorded in tables 3 and 4, it shows that, on 33kV side the three phase current and power flow are reduced when reducing 11 kV terminal voltage by changing the tap-changer from number 5 to 1; and the load changes are proportional to the square voltage.

This indicates that the characteristic of Oman load is almost considered as induction load.

The characteristic of Oman load behaves as the characteristic of induction motor since most of Oman loads are air-conditioning, refrigeration and industrial loads. By taking the whole load as one unit, table 5 shows its characteristics.

VI ENHANCING THE PATTERN OF THE DAILY LOAD CURVE

Central air conditioning and refrigerating units and most of domestic small units operate to induce thermal units (BTUs) by converting the electrical energy to thermal energy until the above units reach the required cooling or freezing temperature. After that, the thermostat will stop the unit's operation. This process takes a certain period of time.

Assume that, if the operating voltage is according to OES standard or according to IEC standard, the system energy product, in one day, is the same.

During one day, assume the total energy MWH under the load duration curve is transferred to the same Quantity of BTUs, in case the operating voltage is according to any one of above standards.

Let central air conditioning and refrigerator load operate during peak load, and the terminal voltage 10% more than nominal designed voltage, the load needs 21% energy more to produce certain quantity of required cooling. Suppose it will take 60 minutes to contribute required quantity of BTUs, and it will continue the operation in "off peak" period region. If same load operates on its nominal designed voltage, the load does not need any extra energy to produce certain quantity of cooling; it will take time more than 60 minutes to create the required quantity of BTUs and it will continue the operation in "off peak" period region. In this case the curve becomes more flat, shaving or reducing the peak load, and improves the load factor as shown in Fig 4, i.e. if the voltage is used in accordance with international IEC standard, the load factor is enhanced and the peak load is reduced.

VII ANALYSIS

If the distribution voltage is applied on electrical equipments according to IEC base, instead of Oman standard base (V_{ph}= 230Volt), the following results will be achieved.

A. Load reduction

Load reduction is proportional with square voltage $(230/240)^2 = 0.9184$
i.e., % reduced load = $(1.0 - 0.9184) \times 100 = 8.159722\%$

Assume that we applied the correct voltage on 70% of total load

Hence, load saving = $0.08159722 \times 70 / 100 = 5.71666\%$ of total load (power or energy)

If we assume the annual growth load is 7.5% and 2006 peak load is 2638 MW

Hence the reduction of peak load is:
 $2638 \times 1.075 \times 0.0571666 = 164.7 \text{ M.W}$

Table 5. General Effect of Voltage Variation on Induction Motor Characteristics when the terminal voltage is increased or decreased.

	Voltage Variation*			
	90% Voltage	Function of Voltage	105% Voltage	110% Voltage
Starting and Maximum				
Running Torque	Decrease 10%	(Voltage) ²	Increase 10.25%	Increase 21%
Synchronous speed	No change	Constant	No Change	No Change
Percent slip	Increase 23%	1/(Voltage) ²	Decrease 9%	Decrease 17%
Full load Speed	Decrease 1.5 %	(Syn. Speed-Slip)	Increase 0.5%	Increase 1%
Efficiency				
Full load	Decrease 2 %		Increase 0.25 to 0.5 %	Increase 0.5 to 1%
¾ Load	Practically No change		Practically No change	Practically No change
½ Load	Increase 1 to 2 %		Decrease 0.5 to 1 %	Decrease 1 to 2 %
Power factor				
Full load	Increase 1 %		Decrease 1 to 2 %	Decrease 3 %
¾ Load	Increase 2 to 3 %		Decrease 2 %	Decrease 4 %
½ Load	Increase 4 to 5 %		Decrease 3 to 4 %	Decrease 5 to 6 %
Full Load Current **	Increase 11%		Decrease 4%	Decrease 7%
Starting Current	Decrease 10% to 12%	Voltage	Increase 5 to 6%	Increase 10 to 12%
Temp. Rise Full Load	Increase 6 to 7 °C		Decrease 1.5 to 2 °C	Decrease 3 to 4 °C
Max. Overload Cap	Decrease 19%	(Voltage) ²	Increase 10.25 %	Increase 21 %
Mag. Noise - No load in Particular	Decrease Slightly		Increase Slightly	Increase Slightly

* This table shows general effects, which will vary somewhat for specific rating.

** Some rating will vary somewhat depending upon the particular design.

B. Installation Savings

Delay investment in installing generators

The cost of generation units (164.7MW Capacity) almost 30 Million OR.

Let the annual interest = 8%

Investment saving = $30 \times 8 / 100 = 2.4$ Million OR./year

C. Power Production Saving

Total energy (MWh) produced in 2006 = 12248.312 MWh.

Assume the energy annual growth is 7.5% and production cost is 16 Biza/kWh.

The cost of energy saving (5.71666% of total energy) is = $12248.312 \times 1.075 \times 16000 \times 0.0517666 = 10.905593$ Million OR

D. Electrical Losses Reduction

- Saving 10% of total losses
- Total losses = 22% of total energy production
- Total energy(MWH) produced in 2006 = 12248.312 MWH
- Assume the energy annual growth is 7.5% and production cost is 16 Biza /kWh

$$12248.312 \times 1.075 \times 16000 \times 0.22 \times 0.1 = 4.63476 \text{ Million. OR. /year}$$

E. Load Reduction of The Electrical Network Elements

- Saving 10% capacity of most Transformers
- Saving 10% capacity of most Transmission lines
- Saving 10% capacity of most Distribution Feeders (Cables & over Head Lines).
- Saving of most Electrical Equipments by deceleration the aging of its insulation material.

F. Power Quality Improvements.

Since most of the products of electrical equipments, apparatuses, appliances, in Oman Market were designed on IEC Standard Base, the correction of Voltage shall improve the performance & characteristics of electrical equipments, as it operates at its design configuration. The improvements are illustrated in the followings. Avoid the damage and reduce the aging of the electrical equipments. Avoid the appearance of additional harmonics on the system which increase electrical losses, heat the electrical equipments, and affect sensitive loads.

IIX CONCLUSION

Changing the operating distribution low voltage in OES and Distribution Code to 230+/_6% instead of 240+/_6%, the following could be achieved.

- Reduction of annual peak load by 164.7 M.W
- Delay the annual investment for installation of generators, which is equivalent to 2.4 Million OR.
- Saving of generation MWH production, which is equivalent to 13.3905595 Million OR.
- Saving of Electrical Losses, which is equivalent to, 4.63476 Million OR/year
- Saving of Electrical Network Elements capacity.
- Many power quality problems, annual peak load, total system losses, investment cost of new generators and aging of electrical equipments shall be reduced.
- The loads of existing generators, transmission & distribution equipments shall be reduced by 10%.
- Improving the load factor of daily load curve.

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