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Impacts of Demand Side Management on System Reliability Evaluation

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ABSTRACT : *Electricity demand in Saudi Arabia is steadily increasing as electrical loads grows at a rate of about 7% per year, this represents a high rate by all standards, and largely due to population growth, as well as due to government subsidies which may lead to prices much lower than actual production cost. This growth represents a challenge that requires Saudi Electricity Company (SEC) to invest huge amounts of money every year, for the construction of additional generation capacity along with the reinforcement of transmission network to meet the consumption growth.Also the demand varies frequently throughout the day, causing a waste of a large part of the energy. SEC believes the optimum solution lies in altering the load shape in order to have a better balance between customer's consumption and SEC's generation, This paper describes the method for improving the power system reliability by shifting the portion of peak load to off-peak periods This load management scheme can be achieved by lifting the generation during off peak periods and utilizing the stored energy during peak periods. A hybrid set up involving solar and wind energy along with batteries can also be used to store energy and utilize it during peak periods.*

Keywords*: Index Terms- Load management, renewable energy, and system reliability indices.*

I. INTRODUCTION

At present the Saudi Electricity Company (SEC) mainly depends on the conventional energy resources of diesel and natural gas fuels for electricity generation. These conventional energy resource fuels are subjected to cost impacts on electricity generation based on the fuel availability and huge negative impacts to our environment. In other hand, there are several types of renewable energy resources of electricity generation that could lead to less environmental impacts compared to conventional energy generation methods. Also, there will not be any cost impact on the electricity generation due to fuel availability.

This research work is believed to be very important for power company (for example, Saudi Electricity Company (SEC), Saudi Aramco, … etc), as it investigates the impact of Demand Side Management (DSM) on the energy consumption, fuel consumption, Peak Load Reduction, power system reliability and security for the system as also to perceived benefits for both the supplier and customers.Demand of electricity has been rapidly increasing in KSA. The electricity generated should be utilized efficiently to meet the demand of countries. This improves the reliability of the power supply system.

In this regard, electrical energy management (EEM) is the cheapest action that can support the growing electricity demand and allows enough time for the utility companies to plan for investment of new generating plans. The Saudi Electricity Company (SEC) is presently dealing a special business operating environment in which some of its major customer is in position to offer and compete for surplus generation as well as request wheeling of firm power and\or reserve among their local facilities using the main grid. This research presents an assessment for using the different technologies and techniques that can be used in Demand Side Management.

The electricity demand growth in the Kingdom of Saudi Arabia mainly due to the following reasons [6]:

1. The population growth and rapidly expanding industrial sector.
2. The influence of local climate, high temperatures during summer leads to increase in electricity demand by usage of air-conditioning devices.
3. With government subsidies, the electricity prices are lesser in comparison with the actual generation cost. So, the power consumption level increases continuously.
4. The government continuous funding to electricity sectors in execution of many new generation plants and transmission network interconnectivity between all the operating Area.

Because of above reasons, there is a continuous growth in electric power consumption in the Kingdom of Saudi Arabia with annual maximum peak load always reaching on summer time. There is a clear variance in the electricity consumption based on the climate seasons. Also, the daily electricity consumption level varies in accordance with the social conditions, human accomplishments and atmospheric effects. The yearly and daily level increase and variations of electricity consumption causing the electricity consumption profile which will be difficult to deal with particularly when the peak demand exists 3 to 6 hours in a day and during that short time the generating units need to be added to cater the increased demand which is obviously an expensive solution and difficult to achieve economically.

The results in these papers show that both the system and load point reliability indices can be impacted and improved by applying DSM measures and that these improvements can be quantified using a probabilistic approach [3].

There is a wide range of techniques and objectives in DSM, one of which is load management (LM). Peak clipping, valley filling, load shifting, energy conservation etc., are various techniques of load management. Load forecast uncertainty is an important consideration in an electrical power system. The recognition of load forecast uncertainty creates increases in the inadequacy indices in bulk electric system reliability studies and the effect increases as the uncertainty increases. This paper is mainly focused on the effects of load shifting measures and renewable energy on system reliability indices [3].

II. METHODOLOGY

The data collection are to establish the quantity of energy and peak-demand savings and to support comparisons, projections, and program design. Almost all impact evaluations seek to quantify kW and kWh saved.

The collection of this type of data also makes it possible to develop predictive models, which can be used to estimate program performance for different service the system reliability indices are used to illustrate the reliability effects of Demand side Management (DSM), customer segments, and economic conditions. Being able to posit causal relationships opens the possibility of projecting impacts for programs with different designs and of reassessing program impacts in response to changes in avoided costs, the economy, or utility or regulatory priorities. It also supports program redesign to improve future performance.

Energy efficiency seemingly glittering promises to all-savings for utilities and consumers, improvements in industrial productivity and reduced environmental impacts. As energy demand continues , actions to increase energy efficiency will be essential. but consumers and utilities have so far been slow to invest in the most cost-effective, energy-efficient technologies available. The energy efficiency of buildings, electric equipment, and appliances in use falls far short of what is technically attainable. therefore This paper describes apply energy efficiency to reduce the high costs of operating generating units by shifting loads from peak to off peak and applying renewable energy on the system.

Table 1: Installed generation capacity of the Riyadh System

Bus NO.	Unit Name	No. of Unit	Unit Capacity (MW)
1	LAYLA	6	87
2	PP 4	11	308
3	PP5	12	473
4	PP 7	23	1218
5	PP 8	20	877
6		14	990
7	PP 9	38	2578
9		22	1496
10	PP 10	40	2261
11	PP11	9	1758
TOTAL		195	12046

We used in this study the generation of Riyadh system (RS) in 2013, in Table 1 shows the amount and fuel type of each power plant in the system. [3].In this study, choose two days (weekday and weekend) of two seasons (summer and winter). most of the machines undergo maintenance schedule in winter, the forced outage of the machines are considered to be higher during minimum load period. The (FOR) for summer is 0.05, and for winter is 0.2.

The first step for the study of any electric power system starts from the Load Profile. Peak demand of (RS) 9,364 MW in 2008 which increased to 12,962 MW in summer of 2013 with an annual average growth rate of 6.72%, in Fig.1 shows peak demand of Riyadh system. Because of the increasing growth in loads, we studied the peak load reduction and power system reliability. [2]

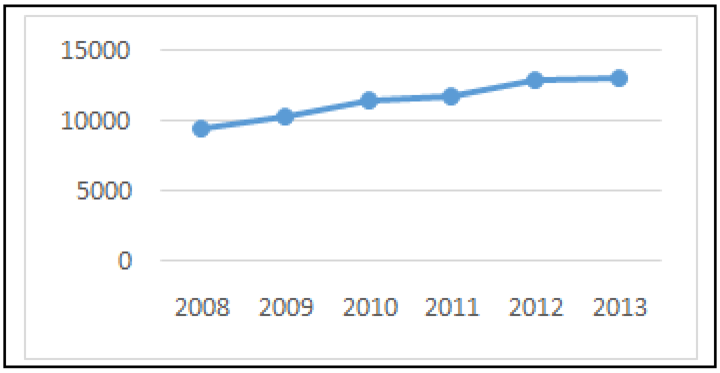

Fig.1: Peak Demand of Riyadh System (MW)

In the reliability analysis of generating system, the yearly growth of system demand is an important factor. Both the load variation pattern and the annual peak load have impacts on the system reliability performance. [6]

III. CASE STUDY

As we described before that we have selected two days in the summer and winter separately. And also subtracted EOA transfer power from the load demand to get net loads demand, in Fig.2 shows net load curve of the Riyadh system. By study the impact of load shifting on the system reliability indices and energy saving without renewable resources and compare the performance after added renewable resources.

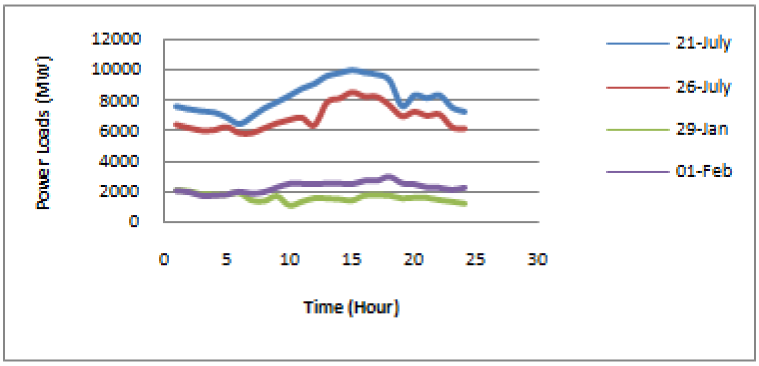

Fig.2: Net Load curve of the Riyadh system

3.1 Load Shifting

The load shifting initiative transfers all or part of the energy not supplied during the peak hours to the off-peak hours if possible.[3]

In this paper, the on-peak and off-peak hours are determined by the pre-specified peak load and the valley load values respectively. The energy reduced during a day is shifted to the immediately following off-peak hours. The peak clipping and valley filling procedures can be applied to the entire bus load or a particular load sector, in Fig. 3 shows illustration of peak shifting and valley filling. [3]

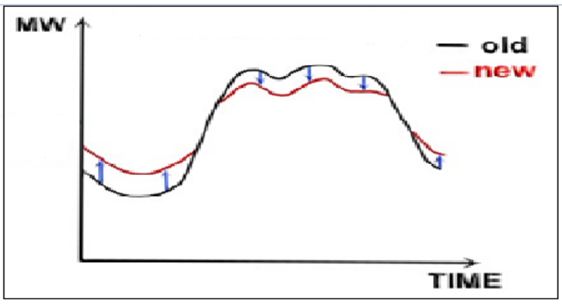

Fig.3: Illustration of peak shifting and valley filling.

Load flattening scheme transfers loads that would occur on-peak to off-peak periods, thus combining peak clipping and valley filling. This can be achieved by implementing two distinctive load management functions, namely peak clipping and valley filling. These two functions are described as follows:

Peak Clipping: Peak clipping aims at reducing the peak demand on a utility system by decreasing the on-peak electricity consumption. Let P(t) denote the system load (MW) as a function of time t (hours), between 0 and T, and Pc be the clipped power in MW. The total saving in energy as a result of peak clipping is given by

$E_{sav} = \int_0^T (Q(t).dt(1)$

Where Q(t) is the difference function which is given as

$$\mathrm{Q(t)} = \begin{Bmatrix} 0 & \text{for } \mathrm{P(t)} \leq \mathrm{P_C} \\ \{\mathrm{P(t)} - \mathrm{P_C}\} & for\ P(t) > \mathrm{P_C} \end{Bmatrix} \quad (2)$$

Valley Filling: Valley filling is designed to increase load during off-peak periods. Let P(t) denote the system load (MW) as a function of time t (hours), between 0 and T.

The total energy (MWh) added to increase the valley portion of the load curve to a new power level of PV (MW) is given by

$E_{add} = \int_0^T (R(t).dt(3)$

Where R(t) is the difference function which is given as

$$R(t) = \begin{Bmatrix} 0 & for\ P_V \leq P(t) \\ \{P_V - P(t)\} & for\ P_V > P(t) \end{Bmatrix} \quad (4)$$

In the present application of load flattening, the efficiency of the energy reallocation (shift from/to peak/off-peak) process plays an important role in assessing the overall merits of the load management scheme employed.

The main objectives of the application are as follows:

1. Simulate the load flattening technique for (RS) average load curve during the next twenty years as a case study.
2. Prove that at the ideal case where the efficiency of energy shift during the load flattening process is unity, the optimal clipping point of the peak load at which a maximum revenue in SR is achieved (due to saving in future capacity additions) will be at the average load level.
3. Find this optimal clipping point in actual cases where the efficiency of energy shift process is less than one, which expected to be at load level between the average and the maximum load depending on the ratio of loosed energy due to flattening of the load curve (value of the energy conservation efficiency).

Consider the load shifting scheme illustrated in Fig.4 in which the peak energy E1 is to be reallocated to the two valley portions as E2a and E2b. The energy reallocation process is assumed to take place with certain efficiency. [6].

The load shifting can be simulated by a set of expressions and relationships. The amount of shifted energy is given by

$$E_{2a} + E_{2b} = E_1.\xi \quad (5)$$

Our goal is to find the optimal clipping point (Pc = P2) at which area is peak energy (E1) equal to area is off peak (E2a + E2b) at valley filling point (Pv = P3). This point (P2) the high economical clipping benefit from the scheme will be achieved. As shown Fig. 4.

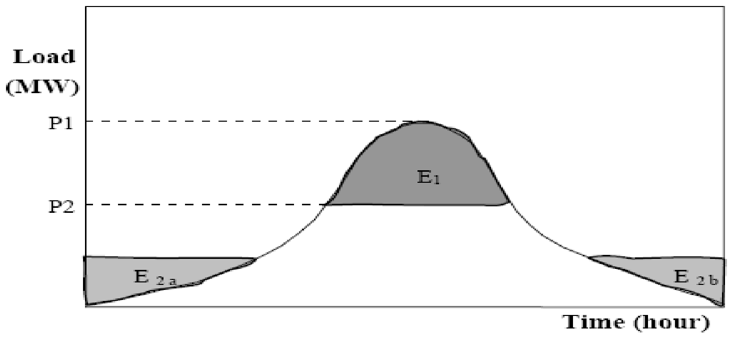

Fig.4: Illustration of load flattening

3.2 Capacity Outage Probability Table (COPT)

The COPT is a table contains all the capacity states in an ascending order of outages magnitude. Each outage (capacity state) is multiplied by its probability. COPT provides the capacity model, which is necessary to calculate reliability indices. The inputs of the capacity model are individual generator name plate capacities and FOR. The loss of generation probability gives the possible arrangements between the generators and the capacity outage probability of the system.

The LOLP is not widely used, at the present time, as a criterion for power system planning because it indicates only the probability of system failure. The LOLP can be defined as:

$\mathrm{LOLP} = \sum \mathrm{P_i}$ for all $(\mathrm{L_{max}} > \mathrm{C_{Ai}})$ (6)

The LOLE risk index is the most widely accepted an used probabilistic method in system reliability evaluation for generating systems. Two models are required and employed. One is the previously studied Load Duration Curve (LDC), and the other is the COPT. These two models are convolved (combined) in the process. The units of the LOLE is in days per year (d/y). The LOLE evaluation method is expressed in the following mathematical formula [12]:

$LOLE = \sum_{I=1}^{n} \mathrm{t}_i \mathrm{p}_i \quad (d/y) \quad (L_{max} > C)$ (7)

In power system planning, we need sometimes another reliability index beside the LOLE, to know the magnitude of load that has been lost due to a severe outages (i.e. when Lmax> C). So, the EDNS can be found as follows [12]:

$\varepsilon\mathrm{DNS} = \sum_{I=1}^{n} \mathrm{O}_i \mathrm{p}_i \quad (MW/y) \quad (L_{max} > C)$ (8)

Since the power systems are in fact energy system, where energy sale is the real revenue for the electric company, so, another essential and most needed reliability index known called the EENS can be deduced as follows [12]:

$\varepsilon\mathrm{ENS} = \sum_{I=1}^{n} \mathrm{ENS}_i \mathrm{p}_i \quad (MWh/y) \quad (L_{max} > C)$ (9)

The ratio of expected energy not served (EENS) to the system Total Energy Demanded (TED) can be found as [12]:

$\varepsilon\mathrm{ENS}_{pu} = \frac{\varepsilon\mathrm{ENS}}{TED}$ (10)

This ratio, in fact is so small because of the small nature of the EENS and large nature of the TED, so, we can deduce another important reliability index called the EIR, and can be expressed as follows [12]:

$EIR = 1 - \varepsilon\mathrm{ENS}$ (11)

3.3 Renewable generation

Concerning renewable energy because of its intermittent model, there are two types most commonly used arethe multi-state generating model and the load modifier model. Assumes this study the load modifier. In this section, we have another way to evaluate the contribution of renewable generation production to the system reliability is to show its beneficial effect on peak shaving. renewable generation systems could improve system reliability indices and contribute in peak load demand. The contribution of renewable generation systems with load shifting together to system reliability indices will be evaluated. The methodology will be analyzed along with the resulting improvements. And compare with load shifting before add renewable generation. [8]

3.3.1 Contribution of PV system

The modelling of the PV resource is based on the one year data collected from KACST. Considered by the KACST as a forecast for the expected PV power production during summer and winter. Considering this power production, an estimation about the contribution of PV units in meeting energy demand in the SEC could result in decreased load shedding. The contribution of power production from PV units to peak shaving is shown. As expected maximum output of PV units occurs around midday, which is also the time period of peak load demand. Fig.2 it is concluded that, during a two days in summer and two days in winter a significant amount of peak loads in Riyadh system, some of them can be covered by power production from PV units. Finally, it is also clearly shown that peak load between hours 7:00 and 18:00 could be reduced it.

Further, this availability of solar irradiance also varies according to the seasons where there is variation in the sunrise time, sunset time and intensity of solar irradiance at that particular time. The daily irradiance (W/m2) from the sun is calculated taking the average of each particular daily and the corresponding power produced from the solar PV array is being calculated by solar power output equation as shown in Equation below:

$P = A_c * \eta_{mp} * \eta_e * R_s$ (12)

Where :

P = Power output in PV

A= the array area (≈1.663m*0.998m).

η_{mp} = the maximum power point efficiency of the array (≈14.4%).

η_e= the efficiency of power conditioning equipment. (≈ 98.1%).
R_s= the incident solar radiation on the array.

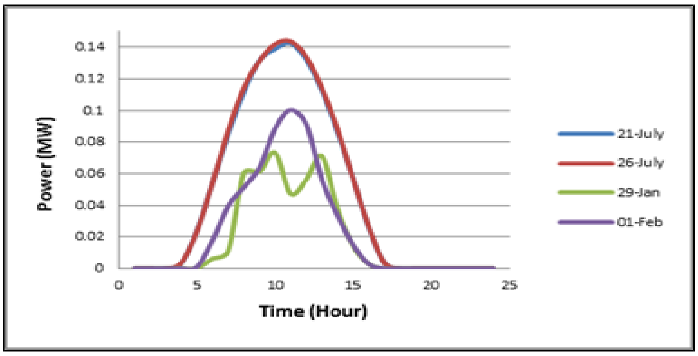

Fig.5: The profiles per days of PV power

3.3.2 Contribution of wind system

The modelling of the wind resource is based on the one year data collected from KSU. Data carried out by KSU wind speed at the expense of the city of Riyadh. Then according to The average daily speed (m/sec), through wind power equation calculated corresponding wind power . The wind power equation is given below [4], [9]:

$$P = \frac{1}{2} C_p * \rho * A * V^3 (13)$$

Where:
P = Power output in Watts
ρ = Air density (about 1.23 kg/m3 at sea level, less higher up).
A = turbine rotor swept area that is exposed to the wind (m2)
V = wind speed (m/s)
Cp = Power Coefficient (0.4)
Wind power output varies during the day, it is clear from Fig. 6 that be the peak power output in day.

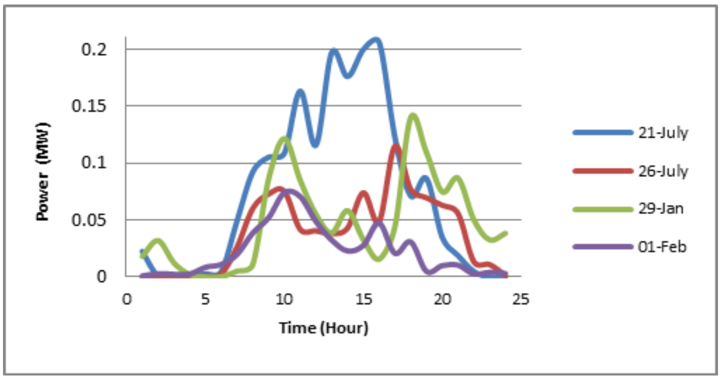

Fig.6 : The profiles per days of wind power

The model of this part (Fig.7) is divided into two parts: the first one gives through SEC network the forecast of power generation of the plant and load consumption. The second part gives the forecast of renewable energy.

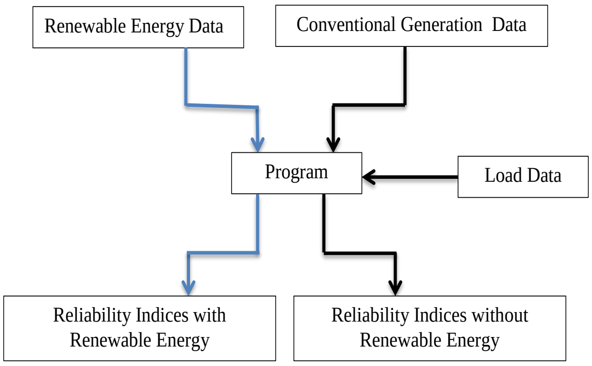

Fig.7 : The profiles per days of wind power

IV. Simulation Results

In this section, two scenarios for (RS) loads are studied. First scenario, calculated reliability indices and compared results between base case and after applied energy conservation efficiency (ξ). And second scenario, applied PV and wind power system on the same (RS) loads and compared the result with first scenario. Calculate the reliability indices are given depict for risk in the system. Demonstrative implementation case scenario of the load management scheme has been analyzed for a typical daily demand pattern (load curve) of Riyadh system. Reliability indices provide a good appraisal of the system performance in the long run.

Reliability index probability distributions provide additional information on the dispersion and the annual variability of the indices.

4.1 Effects Load Shifting on System Indices

A Matlab simulation module was used to simulate the daily load curve of the considered Riyadh system. The simulation module was run at base case and different values of energy efficiency and the benefit in reliability indices. The reliability indices for (RS) with the application of the load shifting measures to different loads.

Table 2: The Energy and Power for the IEEE-RTS with various load shifting measures

DAYS	eff (ξ) %	E2	E1	Pc	Pv	LOLE hr/day	EDNS MW
29-01	0	0	0	2803	1836	0.0023	0.1359
	60	1748.54	1748.8	2441	2212	0.0019	0.0446
	70	2040.29	2035.6	2415	2247	0.0019	0.042
	80	2336.53	2329.1	2389	2280	0.002	0.0397
	90	2623.66	2629.4	2363	2310	0.002	0.0373
	100	2920.33	2912.4	2339	2338	0.0019	0.0353
01-02	0	0	0	2180	1135	0.0005	0.0235
	60	1230.28	1233.6	1765	1588	0.0004	0.0073
	70	1442.18	1440.7	1739	1612	0.0004	0.0067
	80	1650.76	1649.9	1714	1633	0.0004	0.0063
	90	1858.33	1851	1691	1651	0.0004	0.0059
	100	2068.23	2063.7	1668	1668	0.0004	0.0055
21-07	0	0	0	10052	6514	0.5684	68.599
	60	6081.55	6081	8789	7927	0.2137	10.748
	70	7094.6	7097.1	8656	8027	0.2148	8.6461
	80	8108.3	8112.2	8529	8122	0.2178	6.7846
	90	9126.141	9128.8	8407	8213	0.1904	5.5016
	100	10144.8	10147	8298	8297	0.2087	4.5269
26-07	0	0	0	8578	5880	0.0581	7.4564
	60	4764.495	4757.4	7325	6655	0.0215	0.8355
	70	5552.678	5555.3	7199	6727	0.0201	0.646
	80	6349.205	6349.2	7092	6796	0.0203	0.5139
	90	7147.457	7138.8	7005	6861	0.0191	0.4234
	100	7936.991	7933.2	6924	6922	0.018	0.3588

It can be seen in table 2, that the LOLE and EENS decreases significantly with increase in the energy conservation efficiency (ξ) for each case. The lower the indices, the lower the pre-specified peak load.

This gives the impression that the system is getting better when transferring loads of peak load to off peak which means the system is reliable when transferring loads.

The most benefit in this case was achieved when the load was clipped at the average load level. We can therefore say that, at the ideal energy shift (efficiency = 100%), as shown in Table 2.

4.2 Impact of Renewable generation integration

In this section, the effect on the reliability indices after the addition of PV and wind generating on the base case. It can be seen in table 3, depict the effect of PV and wind generating sources on system LOLE, EENS respectively. These results indicate that the addition of PV and wind significantly improves the reliability of the existing system.

Table 3: The Energy and Power for the IEEE-RTS with various load shifting measures

DAYS	eff (ξ) %	E2	E1	Pc	Pv	LOLE hr/day	EDNS MW
29-01	0	0	0	2803	1836	0.0022	0.1319
	60	1748.54	1748.8	2441	2212	0.0019	0.0421
	70	2040.29	2035.6	2415	2247	0.0019	0.0397
	80	2336.53	2329.1	2389	2280	0.0019	0.0374
	90	2623.66	2629.4	2363	2310	0.0019	0.0354
	100	2920.33	2912.4	2339	2338	0.0019	0.0334
01-02	0	0	0	2180	1135	0.0005	0.0235
	60	1230.28	1233.6	1765	1588	0.0005	0.0235
	70	1442.18	1440.7	1739	1612	0.0004	0.0069
	80	1650.76	1649.9	1714	1633	0.0004	0.0063
	90	1858.33	1851	1691	1651	0.0003	0.0058
	100	2068.23	2063.7	1668	1668	0.0003	0.0054
21-07	0	0	0	10052	6514	0.4911	58.769
	60	6081.55	6081	8789	7927	0.1867	9.2351
	70	7094.6	7097.1	8656	8027	0.1878	7.1974
	80	8108.3	8112.2	8529	8122	0.1795	5.7341
	90	9126.141	9128.8	8407	8213	0.1763	4.6835
	100	10144.8	10147	8298	8297	0.162	3.9594
26-07	0	0	0	8578	5880	0.0519	6.5867
	60	4764.495	4757.4	7325	6655	0.0189	0.7288
	70	5552.678	5555.3	7199	6727	0.0176	0.5682
	80	6349.205	6349.2	7092	6796	0.0178	0.4545
	90	7147.457	7138.8	7005	6861	0.0166	0.3817
	100	7936.991	7933.2	6924	6922	0.0176	0.3195

V. Conclusion

This paper has presented an effective load management technique to reduce the operation of inefficient generators during the periods of high load demand. The method requires controlled operation of generators which are maneuvered (up and down) through the system peak/minimum load demand. The power from renewable sources can also be used to provide portion of off peak valley filing energy. Through simulation it is observed that there is a significant improvement in the system reliability by appropriately shifting of loads. It is also seen that increasing the efficiency of energy shift process and operating at or close to optimal clipping can improve the net benefit obtained from the peak shifting process.This technique of demand side management can be beneficial to both customers and electric power utilities.

Acknowledgements

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At Ontario Hydro, he progressed through several engineering and management positions where he ultimately filled the position of Development Planning Manager in 1986. He has been (since 1993) with the College of Engineering, King Saud University, Saudi Arabia. He has authored and coauthored over 300 publications in various power system and engineering topics. In addition to his academic activities, he has also been participating in industry funded projects and studies on issues relating to re-structuring of power utilities, energy market studies, development of bulk electricity plans, standardization of electricity services, energy efficiency, and environmental assessment.

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