LOAD MANAGEMENT IN INDUSTRIAL SECTOR AND ITS IMPACT ON POWER PLANNING – A CASE STUDY OF OMAN

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Abstract— **Load management(LM) which is part of Demand side Management means reducing the electric power consumption and altering the shape of the overall system demand versus time curve, in the aim of achieving better balance between the customers cycle demand and the utilities current and planned generation capacity, transmission and distribution (T&D) resources. With LM the construction of new generating plants and T&D facilities can either be avoided or postponed. LM programs use a variety of different means to manage electricity demand such as, peak clipping, valley filling, load shifting, strategic conservation etc. The basic three LM approaches are; direct load control, indirect load control and storage capacity. This paper estimates the impact of Direct Load Control (DLC) in industrial sector of Oman in terms of generation capacity and energy savings in Central Grid area. The study has found that from the utility point of view the capacity saving at the horizon year is about 130 MW and the overall energy saving for the whole planning horizon is about 9700 GWh. The total avoided cost saving is around M$ 161 (MRO 62).**

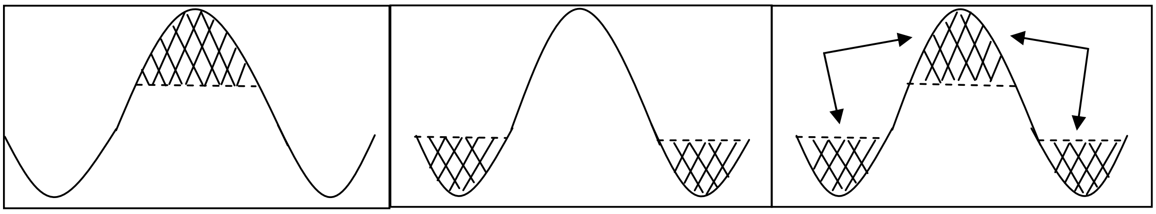
1. INTRODUCTION

The contemporary approach to electric and gas utility planning for future energy requirement is the integrated resource planning (IRP). The goal of IRP is the identification of resources or the mix of resources in order to provide near and long term consumer energy needs in an efficient, reliable and lowest reasonable cost manner while considering the environmental and health concerns. [1].

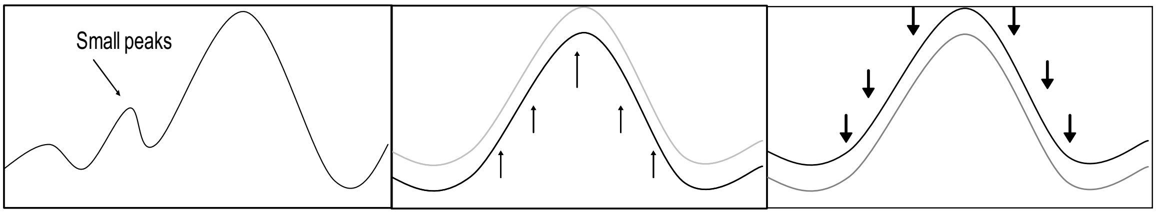
A consistent approach with the IRP is the demand side management strategy (DSM) which is a regulated set of actions on electricity demand to maximize energy efficiency by modifying its use. Instead of focusing on the supply side this strategy focuses in the demand side to minimize the future need for new generation, and T&D capacity. One of DSM actions category is the Load Management. LM employs variety of different means to manage electricity demand such as peak clipping, valley filling, load shifting, strategic conservation etc [2]. Fig 1 shows all the six generic load shape objectives. Peak clipping reduces electricity demand during on-peak periods of the day, thereby lowering the peak demand that utilities must meet. LM programs which reduce peak load are generally those by which the utility or customers control customer use of appliances such as air conditioning or water heating. Conversely, valley filling increases the electrical load during off-peak periods. An example of valley filling is charging electric huge devices at night when the utility is not required to generate as much power as during the day. The process of valley filling during periods of low demand and peak clipping at times of high demand results in reduction in total costs. While load shifting is the movement of loads from peak periods to off-peak periods without any shift in energy use pattern. An example of load shifting is thermal energy storage which enables a customer to use electricity to make ice or chilled water late at night when overall electricity consumption is low. The ice or chilled water is then used to cool the building by day when overall electricity consumption is high. The transfer of energy produced at times of low demand (and hence low marginal cost) to displace the more expensive energy at times of high demand (and hence high marginal cost) results in energy cost savings. The aim of flexible load shape is to smooth down the small peaks in the load line as shown in Fig. 1d. The main reason of avoiding these small peaks is to avoid starting and shutting down the plants which causes extra stress on thermal plants and also incur start-up costs. Strategic load growth aims to increase the load (strategically) in the future and the Strategic conservation aim to decrease the load (strategically) in the future without any shift in demand to another time.

The economy of aggregated bundles of LM options is tested by the avoided cost method. The avoided cost has two components of savings the energy costs savings and capacity cost savings. The planning horizon is optimized twice; one with a base case set of loads and another with load shape changed by the expected load impact of LM. Avoided cost is then calculated by the difference in energy and capacity costs of the two optimized cases [3,4].

In Oman until 2005, there was only one study done (not in detail) in late nineties [5] to estimate the DSM and energy saving potential in Oman but no implementation has yet been carried out. This paper presents the results of a recent study, undertaken at Sultan Qaboos University that estimates the LM potential by DLC in industrial sector in Central Grid of Oman and evaluates its impact on generation capacity and energy savings [6]. To evaluate the benefit of energy and capacity savings the generation



a. Peak clipping b. Valley filling c. Load Shifting



d. Flexible load shape e. Strategic load growth f. Strategic load conservation

Fig 1. LM Load Shape Objectives

expansion planning is done using (WASP) software Wien Automatic System Planning (WASP), developed for IAEA, and used by many electric utilities in developing world [7]. The software has its own modeling limitations; for example the transmission and distribution are not modeled. Because of this limitation the savings in transmission and distribution capacity costs and savings in reduced losses due to LM measures are not quantified.

This paper is arranged in six sections. Section one is an introduction. Section two is a theoretical review of power planning concepts. Section three in brief provides a general methodology adopted to carry out the study. Section four provides generation and load data of Central Grid System. Section five presents the results of generation capacity and energy savings. And the last section concludes the paper.

2. GENERATION EXPANSION PLANNING

The objective of electric planning study is to meet the load forecast with high reliability at a minimum cost. A brief discussion on these three keywords is described below.

Cost Minimization

In generation planning the total cost to be minimized include investment cost in new generation facilities, fuel cost, operation and maintenance cost, and energy not served cost. The cost is minimized depending on the financial resources, technical, environmental and political considerations. The following four questions must be answered when the study of capacity planning is done [8]:

i. What type of capacities will be added to the system?
ii. How much capacities will be added?
iii. When these capacities will be added?
iv. Where these capacities will be located?

The first three questions can be answered by using any generation expansion planning software. However, to know where to locate the new facilities a detailed feasibility study has to be carried out. The objective function of the least cost-planning software is normally the following:

Minimize B_j for all j,

$$B_j = \sum_{i=1}^{n} \left(\overline{CC}_i - \overline{SV}_i + \overline{FC}_i + \overline{OM}_i + \overline{UE}_i \right) \qquad (1)$$

Where:

CC is the capital cost; SV is the salvage value; FC is the fuel cost; OM is the operation & maintenance cost; UE is the energy not served cost; n is number of years in study period; and over bar (—) on the above costs represents present worth of all the costs.

Generation Planning Study Period

The study period normally spans from twenty to twenty five years. The study period consists of three-sub periods: pre planning period, planning period and post planning period [9]. Pre-planning period is the first 3-4 years in which the planning was done earlier. This is included in the study period to check the energy production cost and reliability of the system. The planning period is between 4-10 years in which the decision has to be taken now about the plants that have to be added in future to meet the forecast. The post-planning period is added in the study period to avoid the end-effects by making the calculations continue for another 10 years or more so that a proper trade-off between construction costs and operating costs are found. Therefore, the long-term forecasts of 20-25 years of electricity consumption and demand are used in the planning of investment in generating capacity and the development of fuel supplies.

Reliability

In expanding the system the reliability constraints can be exogenously added into the cost minimization process. The following reliability constraints may be added to (1):

$$(1+a_t)D_{tp} \geq P_t \geq (1+b_{t)})D_{tp} \qquad (2)$$

which simply states that the installed capacity P_t must lie between the given maximum and minimum reserve margins, a_t and b_t respectively, above the peak demand $D_{t,p}$ in year t. Another popular reliability criterion is the loss-of-load probability (LOLP) index which may be calculated for each period and a limiting value may be suggested by the user.

3. GENERAL METHODOLOGY

To calculate the LM economic energy and generation capacity saving potential the following steps are carried out:

1. Industrial energy consumption from 1995-2002 taken from [10] is extrapolated and forecasted till 2024 (end of study period).
2. The energy forecast in industrial sector is then converted to industrial peak forecast by using the following expression:
$$Peak\ Demand\ (MW) = \frac{Annual\ Consumption\ (MWh)}{LF \times 8760\ hrs} \quad (3)$$
where LF is the industrial load factor. As the industrial load factor is not available the assumption is made that the industrial load factor is the same as the system load factor of 0.53.
3. The contribution of industrial peak to system peak is calculated by assuming 100 % coincident factor. This assumption is based on the fact that the system peak occurs between 2:00-4:00 pm when all the industry is working.
4. The peak losses are calculated from the average system losses from the following expressions [11]:
$$Peak\ losses = \frac{Average\ System\ losses}{Peak\ loss\ factor} \quad (4)$$
The average of system losses of eight years from 1995-2002 is 18.25% [10]. The peak loss factor in (4) is the ratio of the energy loss in the system during a given time period to the energy loss that would result if the system peak loss had persisted throughout that period. The following empirical approximation is used to calculate the peak loss factor [11]:
$$Peak\ loss\ factor = 0.3LF + 0.7LF^2 \quad (5)$$
5. The industrial peak to be supplied from the generation end is then calculated by the following formula
$$Industrial\,Peak\ to\ be\ supplied = \frac{Industrial\,peak\ (step\ 3)}{100\% - Peak\ losses} \quad (6)$$
6. The reduction in industrial peak due to direct load control in industrial sector is then worked out. The US electric utility experience shows that 20% reduction in industrial peak is possible due to direct load control in this sector [12]. The base load forecast is modified with 20% reduction in industrial peak capacity which is calculated in step 5.
7. The utility benefit in terms of avoided cost of generation capacity and energy is then worked out by optimizing the planning horizon twice; one with a base case set of loads and another with load shape changed, achieved in step 6, by the expected load impact of LM in industrial sector.

4. GENERATION AND LOAD FORECAST DATA

Fixed Generating System

The fixed system is the existing generation system (year 2005) consisting of six plants Ghubrah, Rusail, Wadi Al-Jizzi, Manah, Barka and Al-Kamil. These plants contain many different types and sizes of units. Some of these units are common to most of these plants. Since the WASP model does not include the transmission representation the fictitious power plants were made by grouping same type and size of units. The details of the net capacity, minimum loading level, fixed O&M, variable O&M, forced outage rate, net heat rate at minimum load and average incremental heat rate for each units of the fixed fictitious plants, is given in table 1. Note the last plant (SOHR) in the list is showing 0 numbers of sets. This is because it was a committed plant in 2005 and its 2 sets were planned to be added in 2006 and 1 in 2007.

Committed and Retiring Plants

The committed power plants are the plants which already have been decided to be added to the system in the near future. They are also part of the fixed system. These plants are in different phases of construction and their capital costs are considered sunk. In this study the plants that are going to be added to the system in the first three years of study are considered as committed plants. Similarly the plants that are going to be retired from the systems during the study horizon are also taken into account. Table 2 summarizes the additions and retirements of plants.

Candidate Plants

The Candidate power plants are plants with which we do our expansion. The candidates are selected based on their economic and technical suitability for the system. Their capital costs are included in the objective function. The data for the candidate units are shown in table 3.

Load Data

The study of the impact of LM in the Central grid was divided into two cases; Case1 is the base load forecast and Case2 is the modified load forecast. The modification of the load forecast was obtained as explained in section 3. The results are as shown in Fig 2.

Economic Data

The discount rate used for the study is 10.0 % and the cost of un-served energy as 1.6 $/kWh [13].

5. RESULTS AND DISCUSSION

As mentioned earlier, the avoided cost of generation capacity and energy is worked out by optimizing the planning horizon twice; one with a base case set of loads and another with load shape changed by the expected load impact of LM in industrial sector. Tables 4 and 5 provide optimization results. The tables show the annual present worth of all the costs and the cumulative objective function of (1) in thousands of dollars. The tables also provide the annual loss-of-load probability index and the cumulative candidate plants selected over the planning horizon. Comparison of the two tables shows that in the first three years of the study the total capacity in both the cases is the same which represents the pre-planning or already planned period. Optimization starts from 2008 and onward where the optimal mix and the total capacity in the two cases are different. At the horizon year the

Table 1. Summary description of thermal plants in year 2005

No .	Plant Name	No. of Sets	Min. Load MW	Capacity MW	Heat Rates Kcal/kWh		Fuel Cost Cents/ 10^6 Kcal	Fast Spin Res %	FOR %	O&M (FIX) $/kW-month	O&M (VAR) $/kWh
					Base Load	Incr Load					
1	FR5P	12	13	18	3900	2637	608	0	5	1.37	3.1
2	FR6B	15	20	27	3529	2219	608	0	5	0.91	2.8
3	FR9E	9	67	93	3284	2100	608	10	5	0.31	2.6
4	ST13	3	8	8	3294	3294	608	0	5	1.5	3.3
5	STM4	1	35	50	2985	2652	608	10	5	1	2.7
6	ST56	2	21	30	3529	2219	608	5	5	0.91	2.8
7	FR9B	6	60	83	3467	2102	608	10	5	0.31	2.6
8	BRKA	1	363	427	1980	1520	608	5	5	0.2	1.0
9	SOHR	0	121	165	2324	1672	608	10	5	0.25	1.2

Table 2. Summary of additions and retirements from 2005-2024

	Years										
Name	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
FR5P	-5	-1	-1						-5		
FR6B					-2		-2		-6		-1
ST13	-3										
ST56			-2								
FR9B				-2	-1						
SOHR	2	1									

Table 3. Summary description of candidate plants

No	Name	Min. Load MW	Capacity MW	Heat Rates Kcal/kWh		Fuel Cost Cents/ 10^6 Kcal	Fast Spin Res %	FOR %	O&M (FIX) $/kW-month	O&M (VAR) $/kWh	Capital Cost ($)	Construction Time	Plant life (yrs)
				Base Load	Incr. Load								
1	FRM9	67	93	3284	2100	608	10	5	0.31	2.6	531	3.0	20
2	FRM6	20	27	3529	2219	608	0	5	0.91	2.8	728	2.0	20
3	BRKA	363	427	1980	1520	608	10	5	0.2	1	780	3.5	20

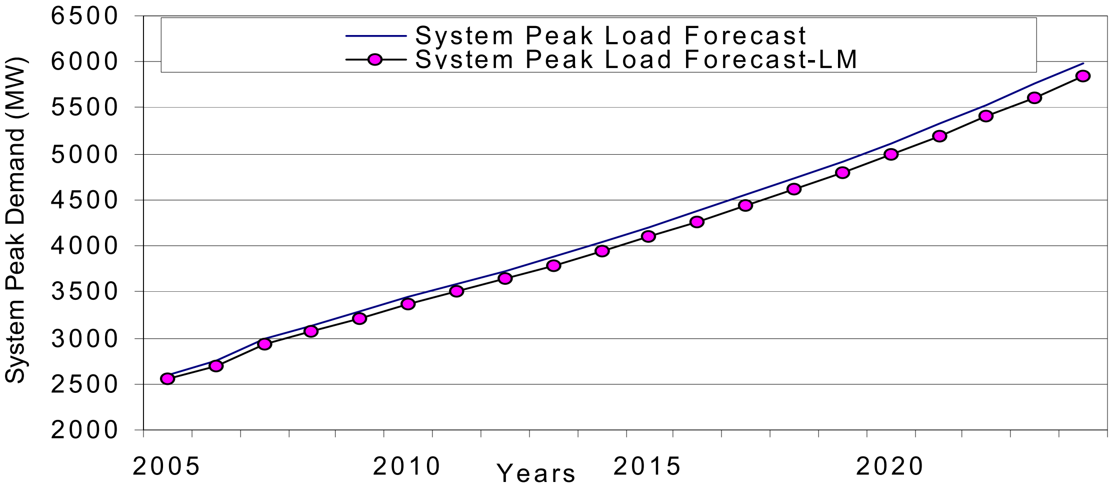


Fig 2. System peak load forecast and the modified forecast due to LM in industrial sector.

capacity difference is about 130 MW and the total energy consumption difference (not shown in the tables) over the planning horizon is 9700 GWh. In the first three years in

Table 4. Optimal generation expansion plan from 2005 to 2024 without LM (Base Case)

Year	Present worth cost of the year (thousand $)----------------Obj. Fun.						LOLP %	Candidate Plants Cumulative			Total Capacity
	$\overline{CC}$	$\overline{SV}$	$\overline{FC+OM}$	$\overline{UE}$	Total	$B_{j,base}$ (Cumm.)		FRM9	FRM6	BRKA	
2005	0	0	249367	38372	287739	287739	2.689	0	0	0	2517
2006	0	0	225420	22605	248025	535764	1.664	0	0	0	2734
2007	0	0	216994	33901	250895	786659	2.567	0	0	0	2882
2008	148521	8583	207813	10284	358033	1144692	0.898	4	0	0	3176
2009	227485	18433	183490	6712	399253	1543945	0.599	4	0	1	3437
2010	206804	22044	163367	3514	351641	1895587	0.337	4	0	2	3726
2011	0	0	155847	7614	163460	2059047	0.737	4	0	2	3726
2012	170912	28310	139897	2261	284760	2343807	0.246	4	0	3	4099
2013	0	0	133489	4938	138427	2482234	0.543	4	0	3	4099
2014	141250	33489	119188	5022	231970	2714204	0.569	4	0	4	4275
2015	19054	5302	114206	6385	134343	2848547	0.764	5	0	4	4368
2016	116736	37770	103783	2005	184755	3033302	0.279	5	0	5	4767
2017	0	0	99271	4435	103707	3137008	0.625	5	0	5	4767
2018	96476	41307	90893	1338	147400	3284408	0.217	5	0	6	5194
2019	0	0	86966	3073	90039	3374447	0.5	5	0	6	5194
2020	23662	13126	83340	2836	96712	3471159	0.503	7	0	6	5380
2021	21511	13502	79892	2711	90613	3561772	0.522	9	0	6	5566
2022	19555	13843	76563	2708	84984	3646756	0.562	11	0	6	5752
2023	17777	14153	73251	2802	79678	3726433	0.624	13	0	6	5938
2024	24242	21653	70317	1982	74887	3801320	0.494	16	0	6	6217

Table 5. Optimal generation expansion plan from 2005 to 2024 with LM

Year	Present worth cost of the year (thousand $)----------------Obj. Fun.						LOLP %	Candidate Plants Cumulative			Total Capacity
	$\overline{CC}$	$\overline{SV}$	$\overline{FC+OM}$	$\overline{UE}$	Total	$B_{j,LM}$ (Cumm.)		FRM9	FRM6	BRKA	
2005	0	0	242409	26109	268518	268518	1.844	0	0	0	2517
2006	0	0	218683	15074	233757	502275	1.127	0	0	0	2734
2007	0	0	210597	22299	232896	735171	1.747	0	0	0	2882
2008	111390	6437	201196	12626	318775	1053945	1.099	3	0	0	3083
2009	227485	18433	177289	7923	394263	1448209	0.698	3	0	1	3344
2010	206804	22044	157430	3992	346183	1794391	0.382	3	0	2	3633
2011	0	0	150353	8359	158712	1953104	0.809	3	0	2	3633
2012	170912	28310	134126	2415	279142	2232246	0.262	3	0	3	4006
2013	0	0	128174	5115	133289	2365535	0.564	3	0	3	4006
2014	141250	33489	114303	5077	227140	2592675	0.577	3	0	4	4182
2015	19054	5302	109436	6278	129467	2722142	0.757	4	0	4	4275
2016	116736	37770	99571	1909	180446	2902588	0.268	4	0	5	4674
2017	0	0	95204	4159	99363	3001951	0.592	4	0	5	4674
2018	14315	6129	91150	5584	104920	3106871	0.83	5	0	5	4767
2019	87705	42838	83551	1731	130149	3237020	0.298	5	0	6	5194
2020	11831	6563	79963	2493	87724	3324744	0.448	6	0	6	5287
2021	21511	13502	76593	2328	86930	3411674	0.456	8	0	6	5473
2022	9778	6921	73301	3498	79655	3491329	0.712	9	0	6	5566
2023	59904	47692	67507	1329	81047	3572376	0.313	9	0	7	5993
2024	8081	7218	64622	2160	67645	3640021	0.523	10	0	7	6086

table 4 unserved energy cost and the LOLP is high comparing to the LM case in table 5. This is because the LM helps to reduce the peak demand and hence when the generation capacity is the same for both the cases the reliability is high in LM case and therefore, the cost of unserved energy is low. The overall cumulative cost difference over the planning horizon (avoided cost = Bj, base – Bj, LM) is about 161 million dollars.

6. CONCLUSIONS

A preliminary study is carried out to see the impact of load management due to direct load control in the industrial sector of Central Grid of Oman. The long-term impact of 20-years is quantified in terms of energy and capacity savings. The study has shown that from the energy supplier point of view the capacity saving at the horizon year (2024) is about 130 MW and the overall energy saving for the whole study period (2005-2024) is about 9700 GWh. The total avoided cost saving is around M$ 161.

The above benefits are estimated based on several assumptions. Some of these assumptions may be more realistic whereas others may be questionable. It is, therefore, recommended to do a detailed study and carefully scrutinize the assumptions made in our preliminary study in order to assess the 'the more realistic' benefit of load management. The assumptions that could be scrutinized are mentioned below:

- Energy load forecast in industrial sector is based on linear trend projection of past 8-years of data. This linear trend projection may not be applicable in Oman as Oman is seeing a new industrial growth at present and in near future.
- Industrial peak loads are estimated using system load factor. However, the actual industrial load factor may be quite different from the system load factor. Similarly industrial peak losses are estimated from average system losses which necessarily include distribution losses and the un-metered energy consumption or theft, whereas most of the industrial customers are connected at 11-kV level; the system losses up to 11-kV level could be quite different from the system losses up to 230-V level. Another assumption made is that the industrial peak coincidence factor is the same as system peak.
- Peak capacity reduction of 20% due to direct load control is assumed based on the US electric utility experience. This target may or may not be achievable in Oman.
- No attempt is made to modify the load curve profile except reducing the peak. Some of the peak energy may be shifted to off-peak hours.

The detailed study should also look at the cost of implementing the load management program. Other problems that might face the actual implementation of the program are known little such as industrial customers' acceptance, load-shedding from a remote location requires a communications protocol, which party has the actual authority to reduce load through the load management system, what is the optimum way to implement load management – for 100 hours of operation, 200 hours of operation, or possibly 300 hours of operation during a year, is the load management system maintained well, how much load reduction benefit can take place at a given time of day or season, what type of technology is best used to implement the load management program and who pay for the program.

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