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Aims and Scope

The Journal will provide an interdisciplinary forum through which energy conversion, fuel conservation, and energy management can be treated as a coherent, integrated subject. Papers of high technical merit addressing both significant advances in the field and state-of-the-art developments are sought. All sources, forms, and uses of energy are appropriate, as are all conversion processes. This includes, but is not limited to, solar, nuclear, fossil, geothermal, wind, hydro, and biomass sources, process heat, electrolysis, heating and cooling, and electric drive applications, as well as commercial, industrial, transportation and residential uses. The conversion processes include, but are not limited to, thermoelectricity, thermionic processes, photoelectric processes, electrochemistry associated with fuel cells and various forms of batteries, magnetohydrodynamic conversion processes, advances related to dynamic processes, and other new and unconventional conversion processes. As the Journal is international in scope, papers dealing with state-of-the-art developments in various nations, or comparative studies of energy conversion and management in several countries will be accepted.

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THE POTENTIAL AND STRATEGIES FOR DEMAND-SIDE MANAGEMENT WITHIN THE INDUSTRIAL SECTOR IN JORDAN—II

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Abstract—The potential for reducing electricity peak load within the industrial sector in Jordan by load management is estimated to be 22.2 MW (N. J. Rabadi, M. A. Alsaad and A. Alzubi, The potential and strategies for demand-side management within the industrial sector in Jordan—I. *Energy Convers. Mgmt* **32**, 000 (1991); Ref. [1]). This paper discusses the different load management strategies appropriate for Jordan to achieve this potential. A cost/benefit analysis which considers the consumer, the utilities, and the country at large is presented. The expected annual savings that the country can achieve, if the load management program discussed here is successfully implemented, is estimated to be approx. JD 3.6 million (1990 JD values).

Energy Demand-side management Industrial

INTRODUCTION

The number of industrial firms (small and medium) included in the Industrial Energy Department/Ministry of Energy and Mineral Resources (IED/MEMR) report [2] is 547 firms. One hundred and thirty of them are classified as medium plants (plants with total installed capacity of 200 kW or more.) Only 60 of these are presently recognized by the utility as "medium-industrial" and, thus, pay charges for their energy consumption during peak hours.

Part I of this work discussed the potential of load management within the industrial sector in Jordan. It was found that implementing a successful load management program within the 130 medium-sized industrial plants operating in Jordan would result in reducing the peak load of the power system by 22.2 MW [1]. The load management options identified were load shifting and load clipping.

Of these 130 plants, there are 45 plants that operate 3 shifts and can reduce their peak load by 5.6 MW, and 85 plants that operate 1 shift and can reduce their peak load by 16.6 MW.

Moreover, it was found that the potential for reducing peak load due to the use of existing standby generators during peak hours is calculated to be approx. 11 MW. This is based on full utilization of the already existing standby generators within the 130 plants under consideration.

OBJECTIVES

The objectives of this work are to find the most effective strategies to implement load management along with identifying the consumer attitudes to these strategies and their willingness to participate in load management programs, to perform cost/benefit analyses that assess the most viable strategies relative to the consumer, the utilities, and the country at large, and finally, to recommend the most effective load management strategies for the industrial sector and their methods of implementation.

LOAD MANAGEMENT STRATEGIES

A significant amount of work has been done by international bodies and local utilities in developed countries on demand-side management (DSM) techniques. Generic classification of DSM alternatives can be found tabulated in Ref. [3]. Table 1, which is extracted from Ref. [3], shows a list of all different categories of alternatives that may be applied to industrial sectors.

Table 1. Classification of demand-side management options

End-use equipment control	*Energy storage*
(1) A/C Industrial chillers	(1) Cool storage
(a) Remote control cycling	(2) Heat storage
(b) Water column temperature control	(3) Storage water heater
(c) Capacity reduction	(4) Waste heat utilization
(d) Timers	
	Incentive rates
(2) Multiple loads	(1) Time differentiated
(a) Equipment interlock	(2) Interruptible
(b) Demand limiter	(3) End-use
(c) Energy management system contracts	(4) Load control
(d) Demand controller	(5) Spot pricing
(e) Peak alert	(6) Demand
(f) Timers	(7) Rebates and incentives
	(8) Special programs
(3) Processing loads	
(a) Interlocks	*Dispersed generation*
(b) Alternate source	(1) Standby generators
(c) Prearranged sequence of remote control	(2) Cogeneration
Customer DSM awareness	*Performance improvement equipment and systems*
Utility equipment control	(1) High EER equipment
(1) Voltage reduction	(2) Heat pumps
(2) Feeder control	(3) Evaporative boost cooling for air conditioners
(3) Power factor control	(4) Buildings
	(5) Process
	(6) Economizer
	(7) Utility system improvements

Generally, there are six load management strategies: end-use equipment control, utility equipment control, energy storage, dispersed generation (standby generators or cogeneration), customer DSM awareness, and performance improvement of equipment and systems. A discussion of these strategies and their application to industry in Jordan follows.

End-use equipment control

Application of this strategy demands high capital investment in control equipment. Radio and other communication techniques are needed to control the end-use equipment identified to have load management potential at different industrial locations. Unless this potential is very large, the investment in remote control equipment for the purpose of load management is difficult to justify.

The current economic status of Jordan, as a whole, and of the Jordan Electricity Authority (JEA), in particular, imply that this strategy is not suitable, neither for the present time nor for the near future.

Utility equipment control

Utility equipment control should be considered as part of any comprehensive load management program. Three strategies are usually recognized under this category: voltage reduction, feeder control, and power factor control.

Voltage reduction. It consists of reducing the distribution feeder voltage at the substations by small increments ($< 5\%$). Direct control by the system dispatcher is very favorable for this strategy to succeed. Moreover, the feeder on which voltage reduction is applied must have an adequate voltage profile to be determined by the utility beforehand. Direct control by the dispatcher over the voltage reduction equipment is essential.

Application of this strategy to industrial sectors has many disadvantages, most prominent of which is its unproven effectiveness.

Feeder control. In this strategy, a utility, under emergency conditions, implements a rolling blackout on its distribution circuits. In order to implement this strategy, either the system or distribution load-dispatcher should have remote control on an individual basis.

Application of this strategy to the industrial sector is obviously not practical.

Power factor. Utilities in Jordan apply a power factor penalty on those plants recognized as medium industrial plants. As mentioned before, only 60 out of the 130 plants are billed for power factor violations. The applied policy seems to be lenient. A penalty is imposed on JEA customers if the power factor value goes below 0.85. This penalty is calculated according to a certain formula which is not known for most of the customers interviewed. A slight modification on the value of the power factor below which the penalty is imposed is recommended. In addition, extending closer control on the power factor for all large and medium industrial plants is highly recommended. Plants that responded and raised the power factor to values over 0.90 should be rewarded. In other words, a reward system should be developed to encourage the industrial plants to raise the power factor as high as they could. Also, a penalty should be imposed on all plants that have a power factor <0.9 instead of 0.85.

Energy storage

This strategy is basically buying cheap energy, storing it, and using it during peak hours. The energy stored is primarily thermal. Although the concept of energy storage is very simple and seems to provide both energy savings and demand reduction, its application is difficult and expensive. Unless the source of energy stored is free (e.g. industrial waste heat) and/or the storage system is provided with minimum cost (e.g. natural lakes available at higher altitudes), this strategy could be very expensive and, hence, unattractive for industrial application. Applicability of this strategy in Jordan is very limited if it exists at all.

Dispersed generation, use of standby generators

The IED report [2] showed that 22% of all 437 SMI plants surveyed have standby diesel generators with a total generating capacity of 29% of the total installed capacity of all plants. Although these generators were installed outside the scope of load management, their use to provide electricity during peak demand is worth considering. However, for standby generators to provide demand-side management, the utility must have direct or indirect control over the operation of these generators. Direct control can be achieved by contracting the customer to operate his standby generators to supply all or part of his power needs. Indirect control can be accomplished by incentive rates or by contract for the customer to operate his standby generators upon request from the utilities. Experience in developed countries shows that utilization of standby generators during the maximum demand period has been demonstrated as an effective DSM strategy [4].

The task team discussed this issue with all plants that have standby generators. Generally, plant management showed little enthusiasm toward using their standby generators for process purposes. Irregular voltage output from these generators induce problems to process equipment. In addition, operation and maintenance of these generators are somewhat troublesome.

Incentive rates have to be adopted to convince industries to use standby generators during peak demand period. Standby generators may be used to provide only part of the electrical energy needed during peak hours.

Customer DSM awareness

A large percentage of the industrial plants visited were unaware of DSM programs. They claim that no information was ever made available to them by the utilities. As a matter of fact, the task team was often asked to explain the electricity bill and how the power distribution companies calculate those mysterious numbers that appear on the bill.

Technical and managerial staff at the plants visited did not know the peak load duration. The maximum demand period (5.00–10.00 p.m. during winter) which was imposed 3 years ago was thought to prevail. Seasonal changes of peak load hours set by MEMR have not been well advertized.

Performance improvement, equipment and systems

Selecting electric equipment that is more efficient to operate, whether for new installations or for replacing old equipment, is usually a well calculated decision due to their high cost relative to regular equipment. Given the constraints the local industry put on the payback-period, and given

Table 2. Long run marginal cost of capacity and energy (1990 prices)

Supply level	Capacity LRMC (JD/kW/yr)	Energy LRMC FILS/kWh On-peak	Off-peak
Generation		58.0	14.2
Sent out	31.428	59.3	14.4
Bulk (33 kV)	32.760	61.8	14.9
Low voltage	35.580	67.1	15.8

Source: JEA.

the present electrical energy cost, these types of equipment can hardly be justified to decision makers at the management level.

ECONOMIC ANALYSIS OF LM STRATEGIES APPLICABLE TO JORDAN

Table 2 shows the long marginal cost of capacity and energy during both on- and off-peak periods. These figures are based on data provided by JEA [5] and will be used together with the presently applied electricity tariff in Jordan in the cost/benefit analysis of the strategies applicable to Jordan.

Strategy 1: Application of Medium-industrial Tariff to all Plants with Total Installed Capacity of 200 kW or More

This is a status-quo strategy. It simply implies that the 70 plants, which are currently classified as "small-industrial", yet their total installed capacity exceeds 200 kW, should be reclassified as "medium-industrial" and, hence, subjected to the medium industry tariff.

Implementing this strategy is very important for other load management options to be effectively implemented. The 70 plants which are classified as small-industrial are not expected to act positively towards reducing their peak load if they are not subject to the peak-load tariff.

The outcome of the cost/benefit analysis is as follows.

Impact on the industrial sector

The net effect on the industrial sector is an increase in energy cost by JD 580,992.

The increase in electricity cost of the 70 plants would be around 15% of their present total electricity cost. Since the cost of electricity represents, on the average, 2–3% of the total cost for the manufacturing industries, this increment in electricity cost would increase the total cost of production by approx. 0.4%. Thus, one can safely assume that no significant effect on production cost is expected due to this strategy.

Impact on JEA

The revenue of JEA would not change. However, revenue for the distribution companies will increase by the additional amount paid by the 70 reclassified plants (JD 580,992). The additional cost to the utility will be the cost of installing new metering equipment which is relatively small.

Impact on Jordan

The above transaction is only a redistribution of income. It does not impose any additional benefits or costs except for the cost of the new metering equipment necessary to enforce the suggested scheme.

Strategy 2: Increased Awareness of the Industrial Sector Regarding Benefits and Costs of Reducing Peak Loads

Whatever is the strategy adopted, a promotion program should be undertaken to enable consumers to learn about the adopted strategy and to readjust according to the new parameters. As explained earlier, industrial consumers lack information about the peak-load hours, prices,

Table 3. Effect of Strategy 2 on the cost of electricity for industry

Controllable load reduced (%)	Reduction in cost for the industrial sector (JD)
20	228,029
40	456,058
60	684,086
80	912,115
100	1,140,144

Table 4. Effect of Strategy 2 on the cost of electricity for the JEA

Controllable load shifted (%)	Reduction in cost for JEA (JD)
20	446,210
40	892,420
60	1,338,631
80	1,784,841
100	2,231,051

Table 5. Effect of Strategy 2 on the cost of electricity for Jordan

Controllable load shifted (%)	Reduction in cost for Jordan (%)
20	718,212
40	1,436,424
60	2,154,637
80	2,872,849
100	3,591,061

billing system, etc. It is not possible to quantify the effects of the awareness program to consumers. Nevertheless, it should be part of any load management strategy.

Assuming that firms will respond to financial benefits and reduce their peak-loads, the following cost/benefit analysis results are based on the removal of 100% of the controllable load from peak hours, i.e. reduction of peak load by 22.2 MW.

Impact on industrial sector

The net effect on the industrial sector is a reduction in energy cost by JD 1,140,144. Table 3 displays the savings of the industrial sector under the assumptions that 20, 40, 60, 80 and 100% of the controllable peak load is removed from peak hours whether by shifting, clipping, and/or uniform reduction.

Impact on JEA

The total reduction in annual energy cost will be JD 2,231,051. Table 4 displays the saving of JEA under the assumptions that 20, 40, 60, 80 and 100% of the controllable peak load is removed from peak hours.

Impact on Jordan

Table 5 shows the net savings for the country at large when 20, 60, 80 and 100% of the controllable peak load is shifted. The maximum saving for Jordan is JD 3,591,061/yr.

Strategy 3: Changing the Electricity Tariff

This strategy depends on using price signals to alter consumer's behavior. It is assumed that people respond positively to financial incentives and adjust their energy consumption pattern to reduce their energy bill. However, other adverse responses may develop, if prices are increased.

The results obtained under this strategy are by no means accurate or representative. Tariff design is an involved matter and is definitely beyond the scope of this study. However, it is fair to assume that a higher increase in the peak-load tariff should result in a higher reduction in the peak load.

The following results are obtained for the case where 100% of the controllable load is shifted to off-peak hours with no change in peak tariff.

Impact on the industrial sector

The net annual savings are JD 1,140,144. Table 6 represents a pay-off matrix that displays the outcome of various alternative tariffs on the industrial sector (the 130 plants).

Table 6. Effect of Strategy 3 on the cost of electricity for industry

Increase in peak-load tariff (%)	Percentage of controllable load removed				
	20%	40%	60%	80%	100%
	Benefits (JD)				
0	228,029	456,058	684,086	912,115	1,140,144
25	−208,975	59,680	328,334	596,989	865,644
50	−645,979	−336,698	−27,417	281,863	591,144
75	−1,082,983	−733,076	−383,169	−33,262	316,644
100	−1,519,987	−1,129,454	−738,921	−348,388	42,144

Table 7. Effect of Strategy 3 on the cost of electricity for the JEA

Increase in peak-load tariff (%)	Percentage of controllable load removed				
	20%	40%	60%	80%	100%
	Benefits (JD)				
0	446,210	892,420	1,338,631	1,784,841	2,231,051
25	790,082	1,204,324	1,618,567	2,032,809	2,783,586
50	1,133,954	1,516,228	1,898,503	2,280,777	2,663,051
75	1,477,826	1,828,132	2,178,439	2,528,745	2,879,051
100	1,821,698	2,140,036	2,458,375	2,776,713	3,095,051

Impact on JEA

Under the assumption that 100% of the controllable load can be shifted to night hours, the changes in JEA's cost structure will be JD 1,140,144.

The net benefit to JEA depends on the decrease in cost of producing electricity as compared to the reduction in its total revenue. For example, if the increase of peak-load tariff by 50% results in a shift of the controllable load of the industrial sector by 60%, the net benefit to JEA will be JD 2,050,135. Table 7 represents a pay-off matrix that displays the outcome of various tariff changes and various responses of the industrial sector.

Impact on the country at large

The total benefit to society is represented by the savings on capital units, fuel oil, maintenance material, etc, that can be saved due to this load-shifting strategy. These benefits are equivalent to the savings in JEA's costs of JD 3,591,061 at current prices. The large part of these savings will accrue to JEA (and electricity companies).

It may be worth mentioning that the higher increase in costs of imported material will increase the long run marginal cost of producing electricity. This will be reflected in higher losses for JEA under current prices. Thus, any savings in cost, through load shifting or other strategies, will benefit Jordan with its scarce resources.

Strategy 4: Utilizing Consumer-owned Standby Generators

Forty percent of the sample plants have installed standby generators of 847 kW total capacity (see Table 8). Accordingly, the 130 medium-industrial plants have 11 MW of total standby generating capacity. The cost/benefit analysis results presented next are based on the assumption that standby generators do exist in these plants and are used only during peak hours.

Table 8. Existing standby generators at the selected sample

Plant name	Peak-load (kW)	kW generated peak load (%)	Total capacity of stand-by generators
National plant	250	100	250
Paper & Cardboard	1367	20	273
Rockwool	241	60	145
Tobacco & Cig.	538	33.3	179
Total			847

Table 9. Effect of Strategy 4 on the cost of electricity for industry

Increase in peak load tariff (%)	Reduction in energy cost (JD)	Reduction in peak-load charge (JD)	Increased cost of using generators (JD)	Net reduction in cost (JD)
25	228,855	503,250	361,350	370,755
50	228,855	603,900	361,350	471,405
75	228,855	704,550	361,350	572,055
100	228,855	805,200	361,350	672,705

Impact on industry

Based on our sample, the capacity of the industry-owned standby generators is about 11 MW. Although using these generators during peak-hours will cost 0.03 JD/kWh generated as operating and depreciation costs (based on site interviews), the savings on energy cost and peak load charges may make it beneficial for the industrial sector to use such owned generators. The effect of such an alternative on industry if 100% of these generators' capacity is used during the three peak hours is a net reduction in electricity cost by JD 270,105. Table 9 displays the estimated savings to industry due to the use of standby generators if the peak load charges is increased by 25, 50, 75 and 100%.

Impact on JEA

A net saving of JD 653,945.

Impact on Jordan

If the industrial sector uses available standby generators, society will benefit so long as the cost of using these generators is less than the cost of generating electricity through JEA. Under the above assumptions, the benefit of using the industry's own generators to society at large is JD 838,250.

Strategy 5: Applying Medium-industry Tariff to all Plants with Capacity of 100 kW or More

Using the data presented in the IED report, it is estimated that there are about 104 plants with capacity between 100 and 200 kW (see Table 10). The estimated total capacity for these plants is 15 MW, and their estimated annual energy consumption is 54,000 MWh.

Impact on industry

The effect of this strategy on the industrial sector depends on the plants' capacity utilized during peak hours and the proportion of this capacity that will be shifted to off-peak hours after applying this strategy. For example, assuming that 20% of the plants' capacity (or 15 MW × 20% = 3 MW) is utilized during peak hours, and none is shifted to off-peak period after applying the new tariff, the impact on the industrial sector will be a net reduction in cost of JD 108,840 annually.

Table 10. Industrial plants with installed capacity between 100 and 200 kW

Industry	Total number of plants	101–150 kW		151–200 kW		101–200 kW	
		%	Number	%	Number	%	Number
Food	85	13.4	11	7.3	6	20.7	17
Construction	98	14.1	14	9.9	10	24	24
Metals	92	4.9	5	8.6	8	13.5	13
Chemicals	53	17.6	9	2	1	19.6	10
Plastic	60	16.4	10	14.5	9	30.9	19
Leather	15	15.4	2	0	0	15.4	2
Paper	43	9.3	4	7	3	16.3	7
Textiles	60	2.1	1	4.2	3	6.3	4
Furniture	41	14.8	6	3.7	2	18.5	8
Total	547	11.3%	62	7.7%	42	19%	104

Table 11. Effect of Strategy 5 on the cost of electricity for industry (in 1990 JD)

Capacity utilized during peak-hours (%)	Portion of peak load reduced 0%	50%	100%
0	218,640	218,640	218,640
10	163,740	191,190	218,640
20	108,840	163,740	218,640
30	53,900	136,290	218,640
40	−960	108,840	218,640
50	−55,860	81,390	218,640
60	−110,760	53,940	218,640

Table 12. Effect of Strategy 5 on the cost of electricity for the JEA (in 1990 JD)

Capacity utilized during peak-hours (%)	Portion of peak load reduced 0%	50%	100%
0	0	0	0
10	0	5,085	10,170
20	0	10,170	20,340
30	0	15,255	30,510
40	0	20,340	40,680
50	0	25,425	50,850
60	0	30,510	61,020
100	0	50,850	101,700

Table 13. Effect of Strategy 5 on the cost of electricity for Jordan (in 1990 JD)

Capacity utilized during peak-hours (%)	Portion of peak load shifted 0%	50%	100%
0	0	0	0
10	0	26,685	53,370
20	0	53,370	106,740
30	0	80,055	160,110
40	0	106,740	213,480
50	0	133,425	266,850
60	0	160,110	320,220

However, assuming that the peak load for this group of industry is 100% controllable and is all shifted to off-peak hours, then the net reduction in the cost of industry becomes JD 218,640 annually. Table 11 shows the net savings for the industry under various assumptions of capacity utilization and load shifting due to this strategy.

Impact on JEA

Table 12 displays the net savings of JEA. It is evident that, unless this industrial sector is presently consuming electric energy during peak hours and is willing to shift their consumption to off-peak hours, the JEA total revenue from this sector will be reduced.

Impact on Jordan

Table 13 shows that the country will benefit from this strategy if plants are presently using electricity intensively during peak hours and will shift their electric loads to off-peak hours in response to implementation of this strategy.

It is important to state that the data collected in this study are not sufficient to determine whether applying medium-industry tariff to all plants with a capacity of 100 kW is economically feasible to any of the parties involved. More detailed data on the energy consumption pattern of the plants targeted under this strategy are needed. However, the present analysis resembles a preliminary analysis which would help in further research of this strategy.

RECOMMENDATIONS

Application of medium-industry tariff

Implementation of this strategy necessitates little effort from the distribution companies. If the industry (the 130 plants) remove 100% of their controllable load (the best case) from the peak hours, the annual savings for JEA will be about 2.23 million JD/yr, while the annual savings for Jordan will be about 3.5 million JD/yr.

Tariff change

Price signaling is a powerful and effective tool to enforce changes in patterns of energy consumption. The authors realize that amendment of the existing tariff for Jordan's power system is an involved matter and cannot be justified by the present study. More scrutinizing analysis is recommended if this strategy is to be implemented. However, the authors feel that this strategy has to be implemented if a successful load management program is to be achieved.

The percentage of tariff increase, particularly peak-load tariff, should be carefully studied. Those industries that operate 3 shifts and cannot avoid peak load consumption may be hard hit if some sort of compensation did not accompany the increase of peak-load tariff.

Utilization of standby generators

The use of standby generators in developed countries has been proven to be an effective method to reduce peak load on utilities. However, adopting this strategy in Jordan needs further detailed studies and discussions with local industrial managers. Legal, technical, administrative and incentive issues should be considered before implementing this strategy.

Customer awareness

A promotion campaign should be launched to inform industry on the validity and seriousness of load management, emphasizing the benefits to the industrial customers. Such a campaign can be launched by JEA and/or the distribution companies through several channels, most prominent of which are the following:

(1) The use of electricity bills to pass important information to the customers. For example, the maximum demand period, primed once a year by MEMR, could be highlighted in the monthly electricity bill.
(2) Industrial site visits by JEA experts and/or private consultants to explain load management procedures showing results of real examples.
(3) Develop a computer code and make it available to the industry whereby quick results can be obtained on the cost and benefits of implementing appropriate load management strategies.

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