A DEMAND SIDE MANAGEMENT (DSM) PRIORITY SELECTION TECHNIQUE- ITS DESIGN AND IMPLEMENTATION

Mohamed Salah ELSOBKI (Jr.)
Cairo University, 12211, Giza, Egypt
Tel: 2-012-329-1037 – Fax: 2-02-573-6601
Email: sobki@hotmail.com

Samia WAHDAN
Egyptian Electricity Authority, Egypt

INTRODUCTION

The design and implementation of a DSM priority selection technique is presented. It aims at improving the system's overall load factor. It utilizes both sequential ordering and set theory. The developed DSM priority selection technique was applied to 1,691 electric power users in Egypt. The priority selection lists are reported; the associated potential economical and environmental impacts are highlighted.

BASE DATA AND ITS ADAPTATION FOR THE DSM PRIORITY SELECTION TECHNIQUE

The developed technique is formulated in conjunction with three DSM objectives; these are Load Shifting, Valley Filling and Peak Clipping [1-6]; aiming at improving the system's overall load factor. The priority selection technique utilizes parameters representing the individual load profiles and the system overall load profile. These parameters represent the inputs that an electric utility would base its selection process on to enroll end users in DSM programs. These parameters include energy consumption, peak demand and its associated time of occurrence as well as both load factor and coincident demand with the system's overall peak demand. The description of these parameters for individual and the overall loads are shown next.

Parameters of Individual Load Profiles

Demand. The demand profile of a group of individual loads over a specified period of time is presented in an array form **P** as:

$$P = p(i,j), \forall\ i = 1,\ldots, NL\ \&\ \forall\ j = 1,\ldots, ND \qquad (1)$$

Where,
p(i,j): represent the demand level of load number **i** at time interval number **j**,
NL: total number of loads under consideration, and
ND: total number of time intervals (in case of hourly load curves **ND** equals 24).

The Peak Demand. The peak demand of an individual load number **i** at time interval number **m** is $\mathbf{p_{im}}$ and is presented as:

$$p_{im} = \text{Max of } \{p(i,j), \forall\ j = 1,\ldots, ND\} = p(i,m) \qquad (2)$$

Duration of Time Intervals. The duration of the different time intervals are common for all loads and are presented in an array form **D** as:

$$D = \{d(j),\ j=1,\ldots, ND\} \qquad (3)$$

Where,
d(j): is the duration of time interval number j and

$$TD = \sum d(j),\ j=1,\ldots, ND \qquad (4)$$

Where,
TD: is the total duration over which the analysis is considered, this may be daily or weekly or monthly or annually.

Energy. The energy consumption of individual loads are presented in an array form **E** as:

$$E = \{e(i), i=1,\ldots, NL\} \qquad (5)$$

Where,
e(i): is the energy consumption of load number **i** and is presented as:

$$e(i) = \sum p(i,j) * d(j),\ \ j=1,\ldots, ND \qquad (6)$$

Average Demand. The average demands of a group of individual loads are presented in an array form **AP** as:

$$AP = \{ap(i), i= 1,\ldots, NL\} \qquad (7)$$

Where,
ap(i): is the average demand of load number **i** and is presented as:

$$ap(i) = e(i)/TD \qquad (8)$$

Load Factor. The load factors of a group of individual loads are presented in an array form **LF** as:

$$LF = \{lf(i), i= 1,\ldots, NL\} \qquad (9)$$

Where,
lf(i): is the load factor of load number **i** and is presented as:

$$lf(i) = ap(i)/p_{im} \qquad (10)$$

Parameters of Total Load Profile

Total Load. The overall demand of the group of individual loads under consideration and over the specified total duration intervals **ND** is presented in array form **PT** as:

$$PT = \{pt(j),\ j=1,\dots,\ ND\} \qquad (11)$$

Where,

$$pt(j) = \sum p(i,j),\ i=1,\dots,\ NL \qquad (12)$$

The Peak Demand. The peak demand of the total load at time interval **k** is $\mathbf{pt_k}$ and is presented as:

$$pt_k = \text{Max of } \{pt(j)\ ,\ \forall\ j = 1,\dots\dots,\ ND\} = pt(k) \qquad (13)$$

Energy Consumption. The total energy consumption of the individual loads under consideration and over the specified time intervals **ND** are presented in an array form as **ET**:

$$ET = \{et(j),\ j=1,\ \dots,\ ND\} \qquad (14)$$

Where,

et(j): is the total energy consumption during time interval number j and is presented as:

$$et(j) = pt(j) * d(j) \qquad (15)$$

The overall energy consumption of the system is **EOT**:

$$EOT = \sum et(j),\ j=1,\dots.,ND \qquad (16)$$

Average Demand. The average demand of the overall demand of the system **APT** is presented as:

$$APT = EOT \ /\ TD \qquad (17)$$

Load Factor. The load factor **LFT** of the overall load is presented as:

$$LFT = APT \ /\ pt_k \qquad (18)$$

FORMULATION OF THE DSM PRIORITY SELECTION TECHNIQUE

The developed DSM priority selection technique utilizes two main mathematical procedures. The first is a sequential ordering mechanism associated with a cutoff-limiting criterion. The ordering mechanism is applied to the electric energy consumption and the peak demand values of the individual loads, while the cutoff-limiting criterion are applied to the cumulative energy and the cumulative coincident demand with the system peak demand. The second procedure is a set theory one resulting in the most effective loads set. This is then complemented with a sequential ordering sub-procedure, which is applied to the load factors of the selected loads resulting from the set theory selection. These developed procedures are presented in a block form in figure 1 and are explained in the following sub-sections.

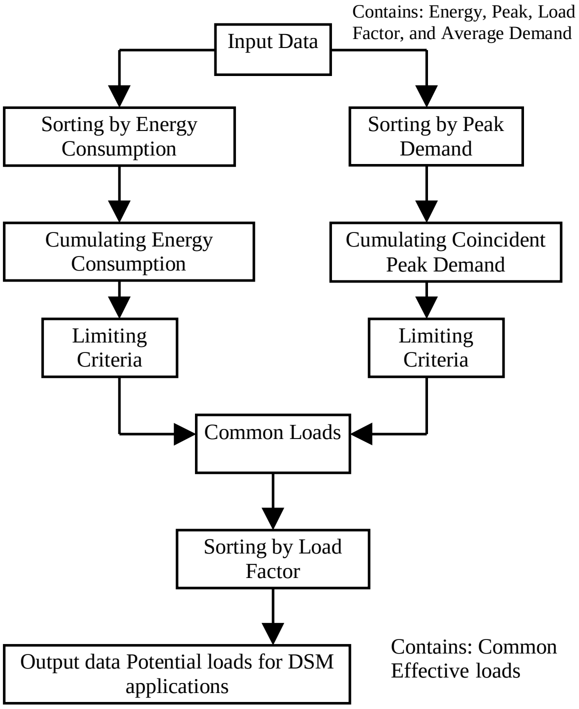

Figure 1: The DSM Priority Selection Procedures

The Sequential Ordering Mechanism

In the developed sequential ordering mechanism the different individual loads are ranked in a descending order: once according to their energy consumption and once according to their coincident demand with the system overall peak demand. The selection procedure is then executed through the implementation of a cutoff limiting criterion reflecting either the cumulative energy consumption of the loads under consideration with respect to the overall system energy consumption or the cumulative coincident demand during the system peak with respect to the overall system peak demand.

Ordering According to Energy Consumption. The descending sorting order of the different loads according to their energy consumption is presented in an array form as **ES**:

$$\begin{aligned} ES &= SORT \downarrow \ \{e\,(i),i=1,\dots\dots,\ NL\} \\ &= \{es\,(i),i=1,\dots\dots,\ NL\} \qquad (19) \end{aligned}$$

Ordering According to Peak Demand. The descending sorting order of the different loads according to their contribution to the overall system peak demand is based on:

a) the array including the different individual load peak demands **PM**, which is defined as:

$$PM = \{pm(i),\ i=1,\ldots\ldots,\ NL\} \tag{20}$$

b) the peak contribution array **PMC** presented as:

$$PMC = \{pmc(i) = \beta(i) * pm(i),\ i=1,\ldots\ldots,\ NL\} \tag{21}$$

where,

$\beta(i)$: factor representing the contribution of load number **i** to the system peak demand during the system peak interval with respect to its own peak demand.

The loads are then ordered in a descending manner according to their contribution to the system peak and are presented in an array form as **PMCS**:

$$\begin{aligned} PMCS &= SORT \downarrow \{pmc(i), i=1,\ldots\ldots,\ NL\} \\ &= \{pmcs\ (i), i=1,\ldots\ldots,\ NL\} \end{aligned} \tag{22}$$

Limiting Selection Criterion

A number of loads will be selected according to the cutoff limiting criterion; either based on cumulative energy or cumulative contributing demands. These loads are presented as:

Energy Consumption Based Selected Loads. The number of loads which will be selected is equal to **nre** (nre<NL) and is expressed as:

$$\sum es(i) \geq \alpha * EOT\ ,\ i=1,\ldots..,\ nre \tag{23}$$

Where,

α: is the target percentage of the cumulative energy consumption of the loads with respect to the overall system energy consumption.

The reduced ranked set of energy consumption based selected loads **ESR** is expressed as:

$$ESR = \{esr(i)\ ,\ i = 1,\ldots..,\ nre\} \tag{24}$$

Contribution to Peak Demand Based Selected Loads. The number of loads which will be selected are equal to **nrd** (nrd<NL) and is expressed as:

$$\sum pmcs(i) \geq \delta * pt_k\ ,\ i=1,\ldots..,\ nrd \tag{25}$$

Where,

δ: is the target percentage of the system's peak demand resulting from the cumulative contribution of the coincident loads.

The reduced ranked set of loads based on the contribution to the peak demand is denoted by **PMR** and is expressed as:

$$PMR = \{pmr(i)\ ,\ i = 1,\ldots..,\ nrd\} \tag{26}$$

Selection of Common Effective Loads

The common effective loads (CEL) are obtained based on the ranked load sets (equations 24 and 26) representing loads with largest electric energy consumption and largest contributions to the overall system's peak demand. This is executed through utilizing the set theory as the intersection of the two sets PMR and ESR as shown in figure 2.

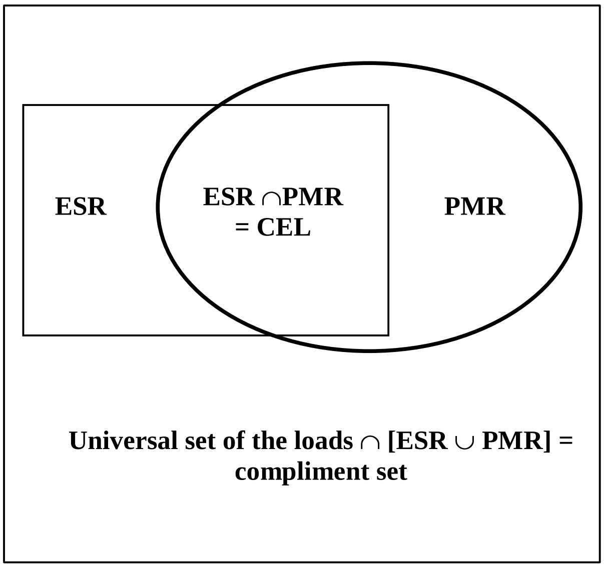

Figure 2: Selection of common effective loads (CEL)

The selection is executed according to the following:

$$CEL = ESR \cap PMR \tag{27}$$

and

$$CEL = \{cel(i)\ ,\ i = 1,\ldots..,\ nc\} \tag{28}$$

Where,

nc: number of effective common loads and **nc** is less than both **nre** and **nrd** or equal to one of them.

These common loads are the potential loads to be approached first by the electric utility to participate in one or more of the three DSM programs under consideration. These common loads are further ordered according to their load factors. This ranking procedure technique simulates practical selection decision for DSM based effective loads.

Ordering According to Load Factor

The sorting order of the common effective loads according to their load factors is executed in an ascending order and is presented in an array form LFS as:

$$\begin{aligned} LFS &= SORT \uparrow \{lf\ (i), i=1,\ldots,\ nc\} \\ &= \{lfs(i),\ i = 1,\ldots..,\ nc\} \end{aligned} \tag{29}$$

Out of the common effective loads, loads with low load factor are selected first as they represent the highest potential for either the load shifting or the valley filling DSM techniques. Loads with higher load factor, are the least ones to be selected by the utility at the first stage, they would be eligible for either an energy conservation or peak clipping DSM techniques.

IMPLEMENTATION AND RESULTS OF THE DSM PRIORITY SELECTION TECHNIQUE

The presented DSM priority selection technique was applied to a group of **1,691** electric motive power users in Egypt [7-8]. These users include industrial, large service buildings and commercial users. They are supplied with electricity at the low, medium and high voltage levels. The individual demands were in the range of 0.5 MW and up to 375 MW representing 0.006% to 4.4% respectively of the overall system 8,491 MW peak demand recorded during 1995/96. The cumulative energy consumption of these loads represent over than 34% of the total energy consumed in the country which totaled to 54 million kWh during the period from July 1995 to June 1996. The system overall load factor during this considered year (1995/96) was 0.73 which indicates room for either load shifting or valley filling DSM programs. The costs of delivering electricity to these users differ mainly according to the supply voltage level [9]. The price of electricity to the end users differ according to the supply voltage level in addition to the type of its activity (Appendix “A” include a summary of electricity prices in Egypt for motive power electricity users). The developed DSM priority selection technique was applied to the aforementioned group of **1,691** loads with different targeted energy consumption limiting factors **(α)** and different targeted peak demand limiting factors **(δ)**. The priority selection lists were computed and are reported in this sub-section. Highlights of these lists indicate that the highest contributing type of loads to the energy consumption and peak demand in Egypt are the industrial loads and mainly the metallic, chemicals as well as the mining and refractory (cement, ceramics, glass) industries. These loads were found to be characterized with annual load factors as low as 0.076 and up to 0.945, which indicates for low load factor industries, their initial eligibility for either or both load shifting and valley filling DSM programs. They also may be eligible for peak clipping DSM programs if the low load factor is associated with high coincident peak value. A sample of the ranking sorted lists for energy consumption and contributing loads to the peak demand are shown for a limiting factor of energy α =15.45% and a limiting factor of peak demand δ = 15.12%. The associated resultant common effective loads were found to be ten loads with load factors ranging between 0.271 and 0.945. These ranked sets of loads are shown in tables 1-3, respectively for energy consumption, coincident contributing loads to the system’s peak demand and load factors. Other implementing cases were performed for different cutoff limiting values of energy and peak demand (α and δ), these were in the range of 7% to 30%. The corresponding numbers of selected common effective loads were found to be in the range of one to 118 respectively. In tables 4 (a, b) and figures 3 (a, b) summaries of these cases are shown. These results indicate that the electric utility would have to deal with a smaller number of users when its DSM targets are conservative. In addition to that the utility has a higher effort/impact intensity ratio than when dealing with a larger number of users which usually are diversified in their operational use of electricity.

Economical Impacts

Economical impacts associated with implementing the presented DSM priority selection technique are viewed from both the electric utility and the end user points of view and according to the current tariff structures in Egypt.

Peak reductions due to DSM load shifting programs will lead to substantial deferred investments at least at the generation supply side by around 700 US $per kW (average recorded values in Egypt over the last four years). This investment reduction would offset lost revenue to the utility due to the reduction of peak demand charges for end users that are subject to that. This is in addition to avoiding using either small generating peaking units or old units during the system peak, and hence resulting in operating the system at a higher efficiency and less fuel consumption. Peak reductions due to DSM peak clipping programs will also lead to substantial deferred investments similar to the load shifting case, but additional lost revenues will be realized due to the lost energy sales. These lost revenues are still reduced by the amount of deferred investments. It was found for the implemented case in this paper that the need for peak clipping in Egypt is minimal due to the margin supply capacity available.
Load shifting DSM programs will be associated with minimal changes in both financial revenues to the electric utility and changes in financial burdens to the end user, especially for flat rate energy pricing schemes.
Valley filling DSM programs will be associated with increased financial revenues to the electric utility.

Environmental Impacts

The corresponding environmental impacts will result from operating the supply generation side of the electric utility at higher load factors (optimum operating conditions); this will lead the generation side to operate at a higher efficiency value. Corresponding to that, reductions in the fuel use are realized and hence reduction in the pollutants production. These reductions are estimated at: 3,080 kg of CO2, 67 kg of SO2, 3.7 kg of NOx, 0.4 kg of CO and 0.09 kg of HC(s) for each saved 1,000 kg of fuel number 6. These pollutant’s reductions are computed according to the chemical composition of the fuel used in power stations in Egypt and average efficiency for these power stations. Furthermore, additional environmental positive impacts are realized due to both the load shifting and peak clipping DSM procedures, due to the peak reduction and hence avoiding the need to operate low efficiency power stations such as old ones or small power stations during peak hours.

Table 1: Sorting By Energy Consumption (Limiting Criteria 0 - 15% Energy Consumption)

#	Type of Ind.	**Sorted Energy consumption "ES" (MWh)**	% Age of "ES" to National Energy Cons.	Cumulative Energy Cons. (MWh)	**% Age of Cumulative Energy Consumption to National Energy Cons.**	Peak Demand "PM" (MW)	% age of "PM" to National Peak	Contribution Coincident Peak Demand "PMC"	% age of "PMC" to National Peak	LF
232	4 Metallic	**3,103,030**	5.70%	3,103,030	**5.70%**	375	4.42%	375	4.42%	0.945
1	1 Chemical	**1,664,830**	3.06%	4,767,860	**8.75%**	218	2.57%	593	6.98%	0.872
229	1 Metallic	**1,114,460**	2.05%	5,882,320	**10.80%**	178	2.10%	771	9.08%	0.715
230	2 Metallic	**724,622**	1.33%	6,606,942	**12.13%**	108	1.27%	879	10.35%	0.766
250	22 Metallic	**422,810**	0.78%	7,029,752	**12.91%**	74	8.72%	1,619	19.0%	0.652
376	34 Cement	**348,628**	0.64%	7,378,380	**13.55%**	53	0.62%	1,672	19.69%	0.752
2	2 Chemical	**345,290**	0.63%	7,723,670	**14.18%**	47	0.55%	1,719	20.24%	0.839
377	35 Cement	**314,400**	0.58%	8,038,070	**14.76%**	50	0.59%	1,769	20.83%	0.718
378	36 Cement	**259,550**	0.48%	8,297,620	**15.23%**	46	0.54%	1,815	21.37%	0.644
742	318 Alex. W.	**115,405**	0.21%	8,413,025	**15.45%**	49	0.57%	1,863	21.95%	0.271

Table 2: Sorting By Peak Load (Limiting Criteria 0 - 15% Peak Demand)

#	Type of Ind.	Energy Consumption "E" (MWh)	% age of "E" to National Energy Cons.	Cumulative Energy Cons. (MWh)	% Age of Cumulative Energy Consumption to National Energy Cons.	**Sorted Contributing Coincident Peak Demand "PMCS" (MW)**	% age of PMCS to National Peak	Cumulative Contributing Coincident Peak Demand "PMCS" (MW)	**% age of Cumulative Contributing Coincident Peak Demand "PMCS"**	LF
232	4 Metallic	3,103,030	5.70%	3,103,030	5.70%	**375**	4.42%	375	**4.42%**	0.945
1	1 Chemical	1,664,830	3.06%	4,767,860	8.75%	**218**	2.57%	593	**6.98%**	0.872
229	1 Metallic	1,114,460	2.05%	5,882,320	10.80%	**178**	2.10%	771	**9.08%**	0.715
230	2 Metallic	724,622	1.33%	6,606,942	12.13%	**108**	1.27%	879	**10.35%**	0.766
250	22 Metallic	422,810	0.78%	7,029,752	12.91%	**74**	0.87%	953	**11.22%**	0.652
376	34 Cement	348,628	0.64%	7,378,380	13.55%	**53**	0.62%	1,006	**11.85%**	0.752
377	35 Cement	314,400	0.58%	7,692,780	14.12%	**50**	0.59%	1,056	**12.44%**	0.718
742	318 Alex.W.	115,405	0.21%	7,808,185	14.34%	**49**	0.57%	1,104	**13.01%**	0.271
2	2 Chemical	345,290	0.63%	8,153,475	14.97%	**47**	0.55%	1,151	**13.56%**	0.839
378	36 Cement	259,550	0.48%	8,413,025	15.45%	**46**	0.54%	1,197	**14.10%**	0.644
381	39 Cement	192,491	0.35%	8,605,516	15.80%	**44**	0.52%	1,242	**14.62%**	0.496
678	254 Ass. W.	2,475	0.00%	8,607,991	15.80%	**42**	0.50%	1,284	**15.12%**	0.007*

*: This load was partly operated during the year and was excluded from the DSM selection procedure.

Table 3: Intersection and Sorting By Load Factor (Limiting Criteria 0 - 15% Energy Consumption and Peak Demand)

#	Type of Ind.	Energy Consumption "E" (MWh)	% Age of "E" to National Energy Cons.	Cumulative Energy Cons. (MWh)	% Age of "E" to National Energy Cons.	Peak Demand "PM" (MW)	% age of "PM" to National Peak	Contribution Coincident Peak Demand "PMC"	% age of "PMC" to National Peak	**LF**
742	318 Alex.W.	115,405	0.21%	115,405	0.21%	49	0.57%	49	0.57%	**0.271**
378	36 Cement	259,550	0.48%	259,550	0.48%	46	0.54%	95	1.11%	**0.644**
250	22 Metallic	422,810	0.78%	682,360	1.25%	74	0.87%	169	1.98%	**0.652**
229	1 Metallic	1,114,460	2.05%	1,796,820	3.30%	178	2.10%	347	4.08%	**0.715**
377	35 Cement	314,400	0.58%	2,111,220	3.88%	50	0.59%	397	4.67%	**0.718**
376	34 Cement	348,628	0.64%	2,459,848	4.52%	53	0.62%	449	5.29%	**0.752**
230	2 Metallic	724,622	1.33%	3,184,470	5.85%	108	1.27%	557	6.57%	**0.766**
2	2 Chemical	345,290	0.63%	3,529,760	6.48%	47	0.55%	604	7.12%	**0.839**
1	1 Chemical	1,664,830	3.06%	5,194,590	9.54%	218	2.57%	822	9.69%	**0.872**
232	4 Metallic	3,103,030	5.70%	8,297,620	15.23%	375	4.42%	1,197	14.10%	**0.945**

Table 4(a): Number of loads for different Limiting Criterion (7% - 15%)

Cutoff Value	**Sorting by Energy**	**Sorting by Peak**	**Intersection**	**Range of LF**
7%	**1**	**2**	**1**	**0.945**
10%	**3**	**4**	**3**	**0.715 - 0.945**
15%	**10**	**12**	**10**	**0.271 - 0.945**

Table 4(b): Number of loads for different Limiting Criterion (20% - 30%)

Cutoff Value	**Sorting by Energy**	**Sorting by Peak**	**Intersection**	**Range of LF**
20%	**32**	**26**	**24**	**0.271 - 0.945**
25%	**126**	**59**	**52**	**0.084 - 0.945**
30%	**467**	**131**	**118**	**0.067 - 0.945**

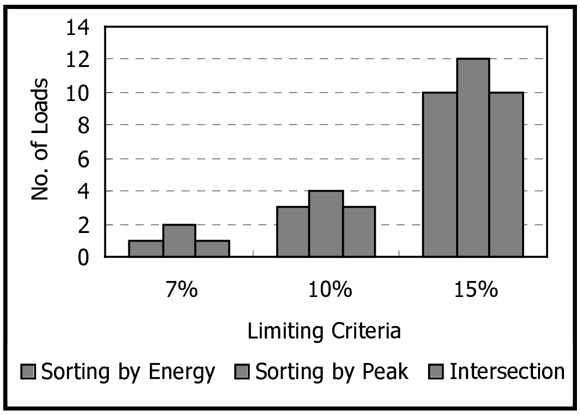

Figure 3(a): Common effective loads for different limiting Criterion

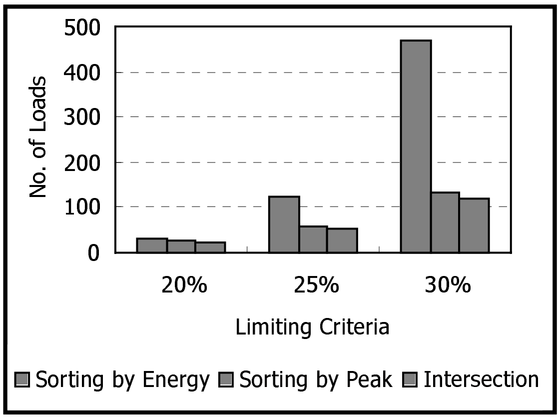

Figure 3(b): Common effective loads for different limiting Criterion

CONCLUSIONS

In this paper the design and implementation were presented for a DSM priority selection technique aiming at improving the system overall load factor. The developed priority selection technique used sequential ordering and set theory procedures to simulate particle decision steps of electric utilities when selecting eligible plants for DSM programs. It was applied to 1,691 electric motive power users in Egypt. These users included industrial, large service buildings and commercial users, which are supplied at the low, medium, and high voltage levels with demands exceeding the 500 kW. Financial impacts associated with the implementation of the DSM programs were highlighted. Also the corresponding pollutants reductions for CO2, SO2, NOx, CO and HC(s) were computed. The developed DSM priority selection technique would facilitate for electric utilities selecting candidate end users in an optimal order way for participation in its DSM programs leading to better use of the available system resources and reduction of environmental pollution.

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APPENDIX (A)

Electricity Tariffs in Egypt for Large Customers

End User Type	Price of Electricity*
1. Very High Voltage	
Kima plant	4.7 pt/kWh
Other users	6.8 pt/kWh
2. High Voltage	
All customers	11.34 pt/kWh
3. Housing Companies	
All customers	9.0 pt/kWh
4. Medium and Low Voltage	
4.a Over 500 kW demand	
Demand charge LE/kW/month	7.3 LE/kW/month
Energy charge pt/kWh	15.35 pt/kWh
4.b Under 500 kW demand	
All customers	18.0 pt/kWh
4.c Agriculture customers	
All customers	7.0 pt/kWh

*** :** 1 LE =100 pt ≅ 0.3 US $.