Economical Motivation and Benefits of using Load Shedding in Energy Management Systems

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***Abstract*—With declining fossil fuel consumption and rising energy demand for renewable energy, the need for integration of these highly predictable sources into the electricity system increases. At the same time, there is a rise in the price of energy, which increases the willingness of consumers to change their breed in order to reduce the costs, or at least to keep them in an acceptable level. One of the options for optimizing energy savings on the consumer side is to use the principle of demand response. This principle enables the consumer, for example, to have the necessary information to optimize the consumption of electricity so as to minimize it when the energy price is high. In view of the constantly changing conditions in the electricity system, the need for optimization is to be implemented automatically, without the necessity of users of the system. This paper main focus is the formulation and optimization of Demand Side Management using the quasi-quadratic problem (MIQP). The result of such optimization is the use of individual devices that take into account the cost of electricity, the working cycle of the installation, the requirements of the user, the systems And limitations and other input information. The method proposed which, after implementation into the individual member - the energy manager - will ensure the optimal utilization of appliances and other Set up by the witches of a clever house.**

***Keywords*—Demand side management; load shedding; energy management system; energy consumption**

I. INTRODUCTION

Today, the world is in a state of panic and fear as a result of the appearance of some global problems on the surface, the most important of these problems is the energy consumption and depletion of available energy resources, and with the adoption of all aspects of life on energy, the whole world began to develop seeking to secure the needs of them, and while some countries began to store some sources of energy in their territory and prevent exporting their stockpiles from these sources, others began to seize the energy stock of other countries or develop themselves in the direction of alternative energy sources or that it has done all of the above [1].

The high energy required by home appliances, air conditioning and lighting make homes one of the most important areas that affect energy consumption. Smart home technology is a good choice for people who care not only about safety and convenience but also about energy. Utilizing IT-based hardware upgrades such as smart meters, smart devices, PMUs at home, the building, electricity distribution network, and transport network, smart homes and buildings have opportunities to take on more responsibilities in the entire power supply network and face shifting from passive customers to active participants [2-5].

Managing consumption may not only have technical and security reasons but also purely economic. Increasing consumption is necessarily accompanied by increased production, which would not be a problem if production costs grew linearly with the amount of consumption. However, with conventional power plants, when the economic output is exceeded, specific consumption and therefore specific costs will start to grow faster than the output power of the power plant increases [5, 7].

Developing countries such as Gulf Cooperation Council countries (GCC) are in a big problem, especially with the need for energy resources to be one of its exports so as not to affect its economy or to violate international agreements, which helped on the speed of access to its energy reserves which causes a problem of depleting the reserve of its energy resources if for example Oman, one of GCC countries, does not find a quick solution to this problem, it will be a big import for the energy sources which are the movement of all aspects of life in Oman [5-9].

According to the 2012 OECD Annual Report, Oman is seeking to diversify electricity production and reduce the current dependence on oil and gas. In 2012, 97.5% of electricity and 2.5% of diesel oil was produced in gas facilities. In order to ensure energy savings in the coming decades, "the Commission remains keen to find ways to benefit from renewable sources of energy from Oman, thereby reducing the energy deficit in an economic and efficient way. Following the Renewable Energy Authority (RAECO) launch a pilot project cannot be implemented after the power is familiar with both the main Balhajtin: First, there is no policy framework, or the other, Sultanate Oman supports fossil fuels, making renewable energy more expensive [6, 10-11].

The paper will also deal with one of the possible uses of energy management system - relieving the burden of overhead consumption over production. The contributions of the research work can be summarized below [5, 13].

This article offers the idea of reducing energy consumption and saving energy by controlling all costs individually within the home. This depends on the detection of the peak time it takes and reduces the use of the load by stopping unwanted loads with the consumer priority based on an algorithm that plans to use the load by creating many consumer vector plans so that demand never increases. This can be achieved individually and among many users of the community or region.

The result of this paper should be an efficient and effective way of managing hardware and home and intelligent buildings through DSM. The paper path should check the DSM optimization and control approach for load management specified in homes and among multiple users of the community or region.

II. ANALYSIS OF HOUSEHOLD ELECTRICAL APPLIANCES

A. *Electricity Consumption at Homes*

Household consumption growth can be explained by the large-scale use of older inefficient appliances as well as by the increase in the number of electrical appliances. Today, many households have two to three television sets, refrigerators and freezers, and increasingly we have laundry or air conditioners. Also worth mentioning is the growing number of entertaining electronics, without which today one cannot imagine everyday life. In addition, the number of family houses and large apartments is growing (residential area is growing) [12].

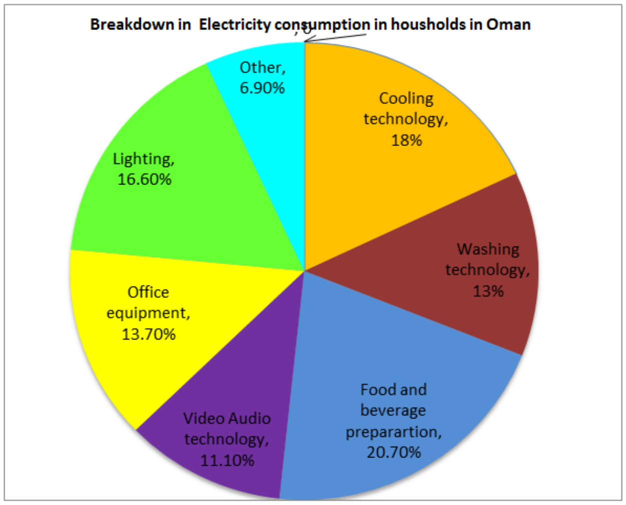

Fig. 1. Breakddown of Electricity Consumption in Households.

TABLE I. DISTRIBUTION OF ELECTRICITY CONSUMPTION IN HOUSEHOLDS – TOTAL

Heating	**Water heating**	**Other electrical appliances**
60%	20%	20%

TABLE II. BREAKDOWN OF ELECTRICITY CONSUMPTION IN HOUSEHOLDS OTHER ELECTRICAL APPLIANCES

Cooling technology	18%
Washing technology	13%
Food and beverage preparation	20,7%
Video technology	8,3%
Audio technique	2,8%
Office equipment	13,7%
Lighting	16,6%
Other	6,9%

Fig. 1 shows an interesting difference between the trend of energy consumption for heating and the consumption of energy for the operation of domestic appliances. In recent years, there has been a significant tightening of standards for the thermal properties of buildings and consequently a corresponding reduction in energy consumption for heating newly built or refurbished houses. However, electricity consumption for normal household operation has increased. According to the average values of the information sources [1], electricity consumption in households is broken down as below.

Every household is of course different. They differ not only in the size and type of living space, the number of people, the equipment of the electrical appliance, but also in their lifestyle. This also corresponds to the range of values as shown in Tables 1 and 2 [14]. The current assumptions relevant directly for the prediction of electricity consumption of small households-households can be summarized in the following points:

- Predictions assume significant energy savings for heating associated with lower energy performance of buildings.
- The forecasts also include the assumption of savings associated with the continuous renewal of electrical appliances, respectively.
- The amount and use of household electrical appliances tends to grow, resulting in increased consumption not only in the other consumption sub-sector but also overall.

Between 2014 and 2040, the prediction, according to the reference scenario, predicts the following savings in electricity consumption [1]:

- Electric heating - a 22% drop in specific consumption.
- DHW heating by electricity a fall in specific consumption by 18%.

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The prediction of electricity consumption is generated separately for the two main areas of consumption: the manufacturing sphere and the sphere of households. The former is reflected from economic forecasting at macroeconomic level, while the second uses demographic projections, particularly projections of households [15-19].

Therefore, any increase in electricity production induced by increased consumption at a given moment will cause an increase in the price of electricity on the market. From Fig. 2 and 3 it is evident that the increase in the load and therefore the electricity price on the daily market occurs in the morning and in the morning hours before noon and in the evening peak. By managing consumption, we try to limit these peaks by reducing demand and, ultimately, to save production costs [1, 11, 20].

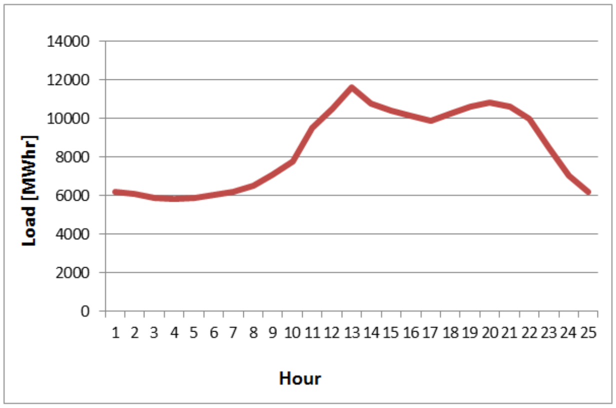

Fig. 2. Example of Power System Load.

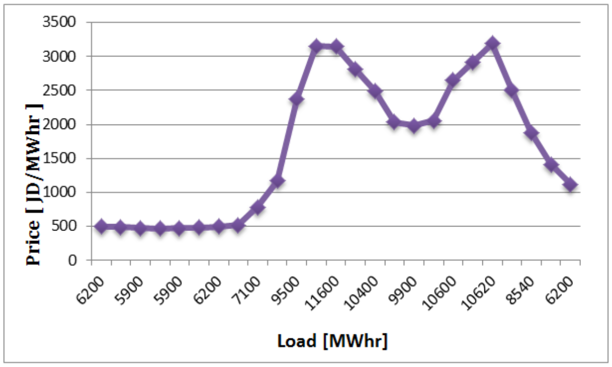

Fig. 3. Example of Electrical Energy Price in the Market.

B. Electricity Production and Consumption in Gulf States

Most Gulf Cooperation Council (GCC) Member States produce and consume electricity produced within national borders [5]. Production, consumption and maximum load are listed below in Table 3.

Source: Kingdom of Bahrain Electricity & Water Authority, Kuwait Ministry of Electricity & Water, Oman Power and Water Procurement Company, Qatar Electricity & Water Corporation, Saudi Electricity Company, Electricity & Cogeneration Regulatory Authority, Abu Dhabi Water and Electricity Company, Dubai Electricity and Water Authority, Sharjah Electricity and Water Authority, Federal Energy and Water Authority, KAPSARC.

The analysis carried out as part of this exploratory study have highlighted a number of interesting trends and have begun to identify energy consumption and saving opportunities that need further investigation and study.

TABLE III. ELECTRICITY PRODUCTION AND CONSUMTION IN GCC COUNTRIES

Country	Production [TWh]	Consumption [TWh]	Peak load [GW]
Oman	31.3	31.3	6.1
Bahrain	14.1	12.6	2.9
Kuwait	68.3	60.5	12.8
Qatar	38.7	36.1	6.7
Saudi Arabia	304.2	274.5	56.6
UAE	116.6	121.7	20.6

III. MATHEMATICAL MODEL FOR THE OPTIMAL SOLUTION

The second area of economic interest where consumption increases are the loss of electricity due to transmission and distribution of electricity to end users. Technical losses that are not caused by human causes can be divided into losses in the lines and losses in voltage transformation. It can be seen from formula (1) that line losses are directly proportional to the quadrant of the maximum current, so the effort to control consumption is therefore to limit the peak of the load during the day, especially morning and evening [18].

$$N_{pT} = \frac{3\rho l}{10^3 A}\, I_{mT}^2\, n_{mT}\, (k_{mT}, j, T_{pT}) \qquad (1)$$

where

N_{pT}: the costs of losses in the power lines in T-year [USD]

ρ: electrical resistivity of the line [Ω.mm2.m^{-1}]

l: power line length [m]

A: wire cross section [mm^2]

I_{mT}: maximum load of the line in the T-th year [A]

n_{mT} : Marginal Costs to Measure losses in the line in the T-Year [USD / kW]

k_{mT}: the coefficient of the maximum loss in the T-year

j: voltage line level

T_{pT}: period of total losses in the T-th year [h]

A similar case occurs due to losses as a result of voltage transformation. Here, the losses are dependent on the transformer's maximum load quadrant as seen from the transformer losses calculation formula (2) [17].

$$N_{trT} = P_o\left(n_{pj} + T_{pr}\, n_{wj}\right) + P_{kn}\, \frac{S_{mT}^2}{S_n^2}\, (n_{pj} + T_z\, n_{wj}) \qquad (2)$$

Where

N_{trT} : the cost of losses in the transformer in the T-th year

P_0: rated transformer losses at open circuit.

P_{kn} : rated transformer losses at open circuit.

n_{pj} :Steady state component of long-term marginal costs including power losses up to the j-th voltage level [USD / kW].

n_{wj}: Variable component of long-term marginal costs including work losses up to the

j-th voltage level [USD / kWh].

S_{mT}: annual maximum transformer load in T-th year [MVA].

S_n: Transformer rated power [MVA].

T_{pr}: Annual transformer operation time [h]

T_z: Annual transformer losses [h]

An integral part of the operation of both transmission and distribution systems is the development and expansion of the power system network to meet customer needs. The big issue is the design of the power lines so that it can transfer power at the time of the peak load and, on the other hand, that the design of this line cost is not over-sized above economic efficiency.

The mathematical model for optimal solution is given as explained in [1, 11] as follows:

$$\begin{aligned} &\sum_{i=2}^{24}(P_{2i} - P_{2i-1})^2 = Min \\ &P_{2i} = P_{1i} - \Delta P_i \\ &|P_{2i} - P_{1i}| \leq |\Delta P_{mi}| \\ &\sum_{i=1}^{24} \Delta P_i = 0 \end{aligned} \quad (3)$$

Where

P_{1i} : the power of the original load at hour i [MW]

P_{2i}: the power of the balanced load at hour i [MW]

P_{mi}: Limits of power change in hour i [MW]

ΔP_i: change of power in hour i [MW]

i: day hour

IV. ECONOMIC BENEFITS OF MANAGING THE CONSUMPTION OF SMALL CUSTOMERS

From the previous considerations and studies, we have come to the conclusion that the most suitable sector for consumption management in Oman as a study case of this paper is the low level consumption of households through indirect control of appliances, which can change the time of operation without greatly reducing the comfort of using this appliance. For the initial analysis, a smaller area in Oman having 115 households with a total annual consumption of 345 MWh has been chosen. As input data, the average diagrams (2015-2017) for individual seasons - spring (March-May), summer (June-August), autumn (September-November) and winter (December-February) have been chosen [1, 13].

In order to keep a complete comfort of the customers, we had to manage only the appliances that would not limit the customers. In this case, the thermal storage devices just like water heaters that are currently mostly controlled by BRC global standards and can be used to reduce the load in an emergency are the most suitable. The opposite direction of cooling has the same inertia effect.

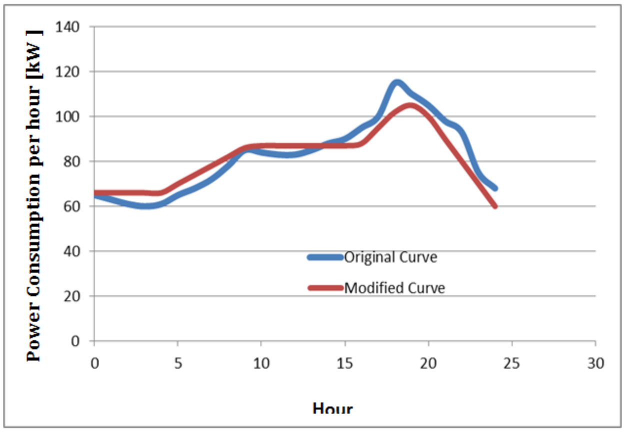

Fig. 4. Load Duration Curve Modification in One Day in Autumn.

TABLE IV. ESTIMATION OF COST SAVINGS OF ENERGY PURCHASE DURING CONTROL

		Spring		**Summer**		**Autumn**		**Winter**	
		Working day	**Weekend**	**Working day**	**Weekend**	**Working day**	**Weekend**	**Working day**	**Weekend**
average daily consumption of the area [kWh]		2166,3	2 270,5	1 690,6	1 694,7	2 122,7	2 202,0	2 644,9	2 761,5
maximum daily potential shedding	**[kWh]**	84,6	170,7	84,6	170,7	84,6	170,7	84,6	170,7
	%	3,91	7,52	5,00	10,07	3,99	7,75	3,20	6,18
used daily potential shedding	**[kWh]**	52,6	81,7	44,7	44,4	64,8	110,3	55,3	104
	%	2,43	3,60	2,64	2,62	3,05	5,01	2,09	3,77
Days no.		66	26	66	26	65	26	64	27
Original cost of energy per day									
The difference in energy costs per day		7,26	7,54	8,03	9,02	22,06	33,15	22,06	42,29
The difference in energy costs for the whole period [USD]		479	196	530	235	1 434	862	1 412	1 142
Total difference per year [USD]		6289							

The BRC global standards for both small consumers (households), where switched appliances are predominantly storage stoves for heating and hot water boilers, and large consumers (enterprises) that control non-industrial appliances such as water pumps, air conditioning and heating.

Fig. 4 shows an example of load shedding on a working day in the autumn, where the positive control values represent a delay in consumption (turning off the appliances) and the negative value represents the switching on of the appliances. We have determined the shedding values so as to limit the power consumption as much as possible and to balance the load diagram as much as possible.

The main objective was therefore to shift the consumption from midday (weekends) and afternoon peak to morning hours when the load is the smallest. From the calculation of the maximum load shedding potential in the given area, 84.6 kWh could be shed during the working day and 170.7 kWh during the weekend, which represents from 3 to 10% of the daily energy consumption (Table 4). When calculating the difference in the cost of purchasing electricity at average prices on the daily market, I saved 6,289 USD per year.

V. SIMULATION RESULTS

Economical benefits of Demand Side Management are obtained through adopting soft options like higher prices during peak hours, low rates during off-peaks, interruptible tariffs which improve the efficiency of various end-users through developing and promoting energy efficient technologies. An example is the use of energy storage units to store energy during off-peak hours and discharge them during peak hours DSM, also includes options such as renewable energy systems, independent power purchase, etc. thus to meet the customer’s demand at the lowest possible cost.

When setting control limits, it is assumed that all devices will be connected to the information network and will be able to drive according to the system's instructions. In the real situation, these limits will be reduced by parts of appliances that will not be in the system.

It is also assumed that all customers will proceed to control their appliances. A further reduction in potential will be due to the unwillingness of customers to engage in the management system.

This unwillingness is mainly due to an interference with the daytime activities of a person, thereby losing a certain amount of freedom and comfort, and moving the function of relatively noisy appliances (dishwasher, washing machine) into the early morning hours (3-6 hours).

In such a small area of management, it encounters a problem of very small values, where these control values correspond only to the power of several units of appliances, so such average values will in most cases be different from the real situation.

The larger the area will be taken into account and the greater the number of appliances will be involved in the management, the average estimates will be closer to the actual values, so it is advisable to count with the whole territory of Amman.

VI. CONCLUSION

The energy demand manager DSM, described in this work, is subject to the following goals:

Encourage consumers to use less energy during peak hours, or to transfer the time of energy utilization to valley hours, such as night and weekends.

Reduce the need for investments in networks and/or power generation plants to meet the peak needs. Demand management does not necessarily lead to a reduction in total energy consumption.

One of the main objectives of demand management is the burden of consumers on the basis of the real price of the facilities and services they receive. If it is possible to charge consumers amounts to lower electric power during peak hours, and more during peak hours, supply and demand will encourage consumers to theoretically use less electricity during peak hours, which is achieved Main objective of demand management.

The problem of small values does not occur with such a large sample of households, with the participation of only 20% of them. The average values in this case are very credibly close to the real values.

By estimating the potential of indirect management, it can be said that consumers have a greater value of free use of their appliances at their liking than the price advantage of electricity for these appliances.

The maximum indirect control potential ranges from 6 to 20% of the daily MOO energy consumed, depending on the day of the week and the season. The usable potential is only between 3 and 8% and only about 1% to 2% for 20% of households.

As a result of indirect management, losses due to MOO are reduced by 3% at full potential and by 1% in 20% of households.

If the electricity for indirect management was purchased on the daily market, it would save several million crowns annually, but after including the price advantage, this procedure would be very wasteful.

As a result of the alignment of the subscription diagram, the use of the line would increase and increase safety due to the lower peaks in the take-off but would not save on the payments for the reserved capacity of the transmission system.

In spite of all these positive issues, it should be realized that for this management a massive infrastructure connected to each household and processing huge volume of data would have to be built. According to estimates, the net present value of expenditures could reach up to USD 4.2 billion by 2040 [17].

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