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ОПТИМИЗАЦИЯ ПОТРЕБЛЕНИЯ СЕТИ MICROGRID С УЧЕТОМ ПОТРЕБНОСТЕЙ НА ЭЛЕКТРОЭНЕРГИЮ

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АННОТАЦИЯ

Электрические сети являются продуктом урбанизации и быстрого развития различных инфраструктур по всему миру и за последние столетия. Хотя энергетические компании расположены в разных регионах, они, как правило, используют одни и те же технологии для производства и распределения электроэнергии. Правильная реализация программы реагирования на спрос (DR) должна быть обеспечена определенным оборудованием, чтобы потребители знали о цене на электричество в любое время и, соответственно, обеспечивали должный отклик сети для снижения затрат. Это, в свою очередь, снижает спрос в часы пик. Интеллектуальная сеть, использующая двустороннюю сеть связи и передачу информации потребителям, а также усовершенствованная сеть учета обеспечивают хорошую структуру для полноценной реализации программ DR. В данном исследовании предлагается экономическая модель реагирования на спрос. Модель использует ценовую эластичность спроса, что обеспечивает потребителям более точную оценку относительно факторов, влияющих на спрос (например, цены на электроэнергию, бонусы и штрафы). При применении модели к микросети эксплуатационные расходы значительно снижаются в обоих режимах работы.

Ключевые слова: управление электроэнергией, спрос на электроэнергию, структура энергопотребления.

OPTIMIZATION OF GRID-CONNECTED MICROGRID DEMAND CONSIDERING DEMAND RESPONSE

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ABSTRACT

Electricity grid is a product of urbanization expansion and rapid development of various infrastructures worldwide and over the past centuries. Although power companies are located in diverse regions, they typically use the same technologies to generate and distribute electricity. Proper implementation of the demand response (DR) program should be provided with some equipment to make subscribers aware of electricity price at any time and accordingly provide a proper response to the grid to reduce costs. This, in turn, reduces demand during peak hours. The intelligent grid, using the two-way communication network and the transmission of information to subscribers, and an advanced metering network provide a good structure for fully implementing DR programs. The present study applies a demand response economic model to implement DRs. The model uses price elasticity of demand, which provides subscribers a more precise consumption behavior regarding the factors influencing demand (e.g., electricity prices, bonuses, and fines). Applying the model to the microgrid, the operating cost significantly decreases in both operating modes.

Keywords: energy management, demand response, energy consumption pattern.

Introduction

Today, there are numerous problems ahead of electricity companies around the world. Some of the problems are as follow: currently, only one-third of the fuel energy is converted into electrical energy, and the heat lost is not recovered; 8% of power plants output is lost during the transfer to the consumption load; 20% of the power plant capacity is used only for peak hours (the peak period is 5% of the total time), and there are energy shortages and environmental pollutants.

The current power grid is inherently one-way. In addition, due to the hierarchical structure, the existing electrical network suffers from Domino-Effect. The current power grid cannot eliminate the problems [1].

Energy management (EM) changes customers' pattern of electricity consumption in order to achieve the desired consumption pattern. It reduces consumption, and thus not only an appropriate load curve is provided, and operation and planning costs are diminished. The purpose of the Energy Management Network (EMS) is to decide on the best use of generators to produce power and heat in the microgrid, the best schedule of the storage network, proper demand management, and accurate purchase and sale of electrical networks [2].

The combination of several renewable energies such as wind power and solar energy was investigated to produce and store DC energy in a battery to supply AC energy. The simulation was analyzed via Matlab/Simulink [3]. Their results are used in this paper for sizing with the lowest cost.

A method was proposed for optimal sizing of PV array, diesel generator, and battery storage installed in an integrated building network [4]. Optimization was done to offer a network with minimum cost and maximum reliability. To this end, variables such as solar energy, temperature, wind speed, and direction were applied. They reported the optimal ratio of size (daily energy produced by the source to energy demand per day) as 0.737, 0.46, 0.22, and 0.17, respectively, for PV array, diesel generator, and battery for a network in the Oman desert. A case study was presented by a network consisting of a diesel generator with 30 PV arrays (36%), five kVA (9%), and DR of 200 kWh / day. According to the findings, PV array, wind farm, and diesel generator respectively produced 36%, 55%, and 9% of the energy, costing 0.17 USD / kWh.

The optimal size of the distribution network, including the combined microgrid, was discussed [5]. The microgrid was provided with photovoltaic (PV), batteries, fuel cell (FC) technology, and electric vehicles connectable to grids. Particle Swarm Optimization (PSO) algorithm was used to minimize microgrid costs of distribution by size generation model. Analysis models and impacts of electric vehicles on the desired size of both microgrid distributions as well as reliability of the intended microgrid were also examined.

Sizing was performed assuming that the battery charge cycle was constant. A gradual change in the number of wind generators was also used to complete sizing. The number of solar cells was determined, assuming the constancy of the battery charge cycle [6, 7]. However, the current study is to size the microgrid by assuming variability of battery charge cycle based on the demand and using a meta-heuristic algorithm.

Price elasticity of demand (PED)

The concept of elasticity, or demand elasticity, refers to the sensitivity of a variable to changes in other agents. Demand elasticity is not an absolute elasticity but the relative sensitivity of the quantity demanded to changes in the price, fine, or bonus of the commodity.

When demand is perfectly inelastic, it is called zero elasticity, and if it is perfectly elastic, it is called infinite elasticity. Perfectly inelastic or elastic demand indicate the status of the demand curve.

In the model proposed for this study, the demand increasing over periods is assumed as the consumption load during 24 hours, and time intervals are assumed to be one hour. Thus, the dimension of power and energy are the same. The elasticity matrix can be written as follows:

$$E = \begin{bmatrix} E(1,1) & E(1,2) & \dots & \dots & E(1,24) \\ E(2,1) & E(2,2) & \dots & \dots & \dots \\ \dots & \dots & E(i,i) & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots \\ E(24,1) & \dots & E(24,j) & \dots & E(24,24) \end{bmatrix}. \quad (1)$$

The diagonal elements represent inner elasticity, and non-diagonal elements represent cross elasticity. The following relations explain inner-cross relationships:

$$(i,i) = \frac{p(i)}{D(i)} \times \frac{\partial D(i)}{\partial p(i)}, \quad (2)$$

$$(i,j) = \frac{p(j)}{D(i)} \times \frac{\partial D(i)}{\partial p(j)}. \quad (3)$$

Final modeling of the problem

Grid-connected operation

Objective function:

$$min \quad \sum_{t=1}^{T} \sum_{i=1}^{n} [b_{it} . x_{it} + c_{it} . y_{it}] +$$
$$+ \sum_{t=1}^{T} [PB_t . B_t - PS_t . S_t] + C_{DR} . \qquad (4)$$

The grid understudy

To evaluate the performance of the proposed model, it is implemented with two CDGs and three RDGs as well as various cost factors and capacities. Table 1 presents costs, startup, minimum and maximum capacities of CDGs; production costs of each CDG unit are assumed to be consonant at intervals. Since RDGs are supposed to work at no extra cost, they only have the maximum capacity.

Table 1 – Cost, start-up cost, and DGs capacity

DGs	Cost (Rial)		(KW)Capacity	
	variable	Startup	Minimum	Maximum
CDG1	70	100	0.6	45
CDG2	50	130	0.3	45
RDG1	0	0	0	15
RDG2	0	0	0	3
RDG3	0	0	0	2.5

Table 2 shows the purchase and sale prices of energy of the national grid. The selling price is generally lower than the purchase price. For experiments, prices are set to fluctuate significantly.

Table 2 – Purchase and sale prices of energy from the national electric grid

		Time (t=1,2,…,6)					
		1	2	3	4	5	6
PB_t	Rial	15	25	35	55	65	75
PS_t	Rial	5	15	25	45	55	65

The output of RDG units is predicted in Table 3. As an inherent feature, renewable sources are uncertain in the production of power. The presence of resources in power networks makes operation uncertain. For this reason, in this study, the predicted output is used to eliminate the impact of renewable sources. According to Table 3, the renewable sources of this study don't generate electricity in the early hours of the day, and the maximum production occurs during the peak hours.

Table 3 – Predicted output of renewable sources

	Time (t=1,2,…,6)					
	1	2	3	4	5	6
RDG1(KW)	0	0	5	8	12	15
RDG2(KW)	0	0	2	3	3	3
RDG3(KW)	0	0	2	2.5	2.5	2.5

Table 4 presents the base demand curve of the grid. The curve is divided into three periods of low demand (1, 2, and 3 o'clock), medium demand (4 and 5 o'clock), and peak demand (6 o'clock). Electricity price is unsteady, i.e., 150 Iranian Rial per kWh. In this study, the price of grid-connected electricity is assumed to be 150 Rials. Under CAP and I / C program contracts, customers are required to reduce their demand by up to 20% of the original demands.

Table 4 – Base consumption load curve

Time	Load(kwh)
1	5
2	10
3	15
4	25
5	30
6	40

Demand price elasticity is presented in Table 5.

Table 5 – Inner and cross elasticity

	Peak	Off-Peak	Low Load
Peak	-0.1	0.016	0.012
Off-Peak	0.016	-0.1	0.01
Low Load	0.012	0.01	-0.1

In order to implement DR programs, different scenarios with bonuses and fines are presented in Table 6.

Table 6 – Scenarios

Scenario	A(t) Rial	Pen(t) /Rial
1	0	0
2	100	0
3	100	100

Results

Implementation of DR programmes

Grid-connected microgrid exchanges power with the original network. The operator's goal is to minimize the final operating costs resulting from the exchange.

Table 6 is used to apply DRs (I / C and CAP), which include bonuses and fines. The table presents three scenarios with striking differences in the amounts of bonuses and fines. Using "bonus and fine" and elastic demand in Table 5, the amount of demand was obtained for each scenario. Simulation results and the effect of DRs for different scenarios are stated below:

Scenario 1 is the baseline scenario with the initial load curve where no DR program is implemented.

Scenario 2 assumes a bonus of 100 Rials / kWh and a fine of 0 Rial / kWh. In other words, ISO provides rewards to customers for reduced consumption without penalty. By applying the final model to the initial load curve, the amount of demand is reduced to 0.86 kW at the peak.

Scenario 3 assumes a doubled sum of the bonus and fine compared to Scenario 2; the amount of the reward is 100 Rial / kWh, and the fine is 100 Rial / kWh (200 Rial / kWh totally). Figure 1 shows that the peak consumption is reduced by 1.7 kW (twice more than Scenario 2). Therefore, by increasing the number of rewards and penalties, ISO encourages more consumers' participation in DRs. Rewards and fines have a similar impact on the reduction of the consumption load; the sum value determines the final demand.

According to Table 7, the peak load decreases by 2.15% in Scenario 2 compared to the base load (Scenario 1) by rewarding the consumer. In Scenario 3, the network operator reduces peak load consumption by 4.3% as the result of imposing fines and rewards on the subscribers, which is twice more than Scenario 2.

Optimal grid-connected microgrid simulation

Grid-connected microgrid is capable of receiving and sending power to the global network, i.e., it can buy power from and sell it to the global network. The operator seeks to reduce the final operating costs as much as possible.

According to the Table 8, Purchase and sale prices are 55 and 45 Rials at 4 o'clock. However, since the unit production costs 50 Rials, the purchase and sale of energy will not be cost-effective. Therefore, the network operator decides to generate power at this time. The rate of production will vary depending on the type of scenario. According to the table, the

Table 7 – Demand scenarios

	Scenario	Time (t=1,2,…,6)					
		1	2	3	4	5	6
d_t	1	5000	10000	15000	25000	30000	40000
	2	4106	8213	12320	22433	26920	39140
	3	3213	6426	9640	19866	23840	38293

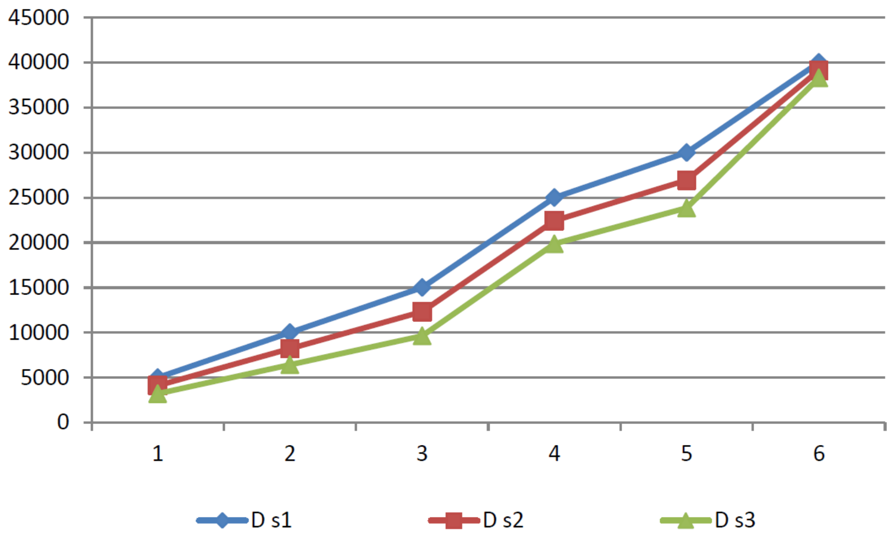

Figure 1 – The effect of DRs on the base load curve

production rate of Scenario 3 is the lowest. As the price of selling power to the national network (55 and 65 Rials) is higher than the production cost (50 Rials) and since income is earned from power generation during 5 and 6 o'clock, the operator decides to produce at maximum unit capacity in order to sell the surplus of production to the global network. Table 9 presents to purchase and sale amounts.

Table 8 – CDG production rate in grid-connected operation

	1	2	3	4	5	6
X s1	0	0	0	11500	45000	45000
X s2	0	0	0	8933	45000	45000
X s3	0	0	0	6366	45000	45000

Table 9 – Power purchase/sale amount

	1	2	3	4	5	6
B s1	5000	10000	6000	0	0	0
B s2	4106	8213	3320	0	0	0
B s3	3213	6426	640	0	0	0
S s1	0	0	0	0	32500	25500
S s2	0	0	0	0	35580	26353
S s3	0	0	0	0	38660	27206

Moreover, with the application of scenarios, the amount of energy purchase in Scenario 3 is less than in other scenarios, but the amount of power sale to the network is more. By a reasonable bonus and fine, power generation and energy purchase from the grid decreases; though, the sale amount increases.

According to the Table 10, using Scenario 3, the operator can optimize power exchange in order to reduce costs. Improper rewards and fines to implement DRs impede the minimization of operating costs. Further, DRs with non-optimal bonuses and fines may increase operating costs.

Table 10 – Final costs in grid-connected operation

Final costs in grid-connected operation	
Scenario 1 cost	$10^6 \times 2.16$
Scenario 2 cost	$10^6 \times 1.66$
Scenario 3 cost	$10^6 \times 1.02$

Conclusion

Increasing demand for electricity is associated with deficiency and backlog of investment in electricity infrastructure and reduced stability of the generation and distribution grid. Any unforeseen increase in demand or deviation in power distribution networks may lead to equipment failure, consequent global blackouts, and severe economic losses. However, demand for high-quality electricity, as well as electricity consumption, is expanding. Microgrids are a flexible solution for the problems caused by grids distributed generation. The MicroGrid Central Controller (MGCC) is responsible for minimization of island operating costs and optimization of power exchange with the global grid to reduce grid-connected operating costs. The present study applied a kind of decentralized control to manage energy. In decentralized control, each microgrid is controlled by a controller. It is a possible solution for the elimination of microgrids control and EM problems. The use of multi-function systems is a good candidate for decentralized control of power microgrids. Each factor of a multifunction system uses its intelligence to determine the leading activities and make decisions independently of other factors.

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