Power consumption management and equalization of the load schedules of Azerbaijan power system

Nurali Yusifbayli [1], *Valeh* Nasibov [2]* and *Rana* Alizade [2]

[1] Azerbaijan Technical University H.Javid Avenue 25, Baku, Azerbaijan
[2] Azerbaijan Scientific-Research and Design-Prospecting Power Engineering Institute, AZ1012, Baku, Azerbaijan

Abstract. Foreign experience in applying the principles of power consumption management is analyzed in the paper. A comparative analysis of the main indicators of the load schedules of the power systems of Azerbaijan, Turkey, Ukraine, Russia and Jordan was carried out and it was found out that there is significant potential for improving such indicators of the load schedules as variation factor and the fill factor for the Azerbaijan power system. The positive effects of equalization of the load schedules of the power system of Azerbaijan are studied, based on the technical and economic indicators of the main generating capacities.

1 Introduction

Equalization of load schedules, power consumption management are one of the key trends in the development of the electric power industry in the world. The transition of electricity consumers to the status of active consumers is fully consistent with the innovative transformation of the electric power industry based on the concept of intellectualization of the power system. The basis of the concept of transformation of the electric power industry in the world is the Smart Grid concept, where power systems should be controlled in real time by a network of information and control devices and systems. At that, the management covers not only all generating sources, transmission and distribution networks, but also all types of consumers of electrical energy [1, 2].

2 Smart Grid concept

In the Smart Grid concept, the consumer acts as a full-fledged participant in the electricity market. At that, an active consumer, both by readiness to change his load, and by the change itself, can receive economic benefits, and the power system can also benefit [3, 4].

Despite the fact that the Smart Grid concept provides for the possibility of regulation of the load of all types of electricity consumers, in practice, the greatest application of load control is in the housing sector, in industry and the commercial sector [5,7].

Currently, there are two types of programs of change of the load of consumers: programs based on incentives and programs based on time.

The incentive based programs are given below:

1. Direct load control (DLC). According to preliminary agreement between the supplier and the consumer of electricity, the supplier can remotely control some of the consumer's appliances (air conditioners and water heaters).

Operation notices are usually announced in a short time. To use this method, consumers must be equipped with a remote control system so that the supplier can reassign, turn on or turn off the appliances. Direct load control is mainly used in the residential sector or in the small commercial sector. It is not suitable for the industrial sector, where breakdown in power consumption can lead to undesirable large-scale consequences.

2. Iterruptible/ curtailable (I/C) Service. In comparison with the direct load control, this method is commonly used in the industrial sector and the large-scale commercial sector. When the system is overloaded, consumers are asked to reduce some loads to a certain level. By participating in this management, consumers can receive tariff discount or bill discount. However, if consumers do not respond within a predetermined period of time, they may be fined. In this method, the frequency and duration of operations are limited.

3. Demand bidding buyback (DB). Supplier, based on the situation with production and demand, announces the total amount of electricity that needs to be reduced. Consumers place bets on the amount (on the amount of reduction in electricity consumption) based on their situation and the wholesale market. Once an offer has been accepted, consumers must provide the specified limit, otherwise or they will be penalized. This method is also suitable for major clients. Small consumers can be integrated by the system operator and involved as a single consumer.

4. Emergency Demand Response Program (EDRP). The system operator by means of this program encourages consumers to reduce power consumption when unexpected situations occur in order to increase the reliability of power supply. Under this program,

*Corresponding author: nvaleh@mail.ru

consumers are not penalized for non-fulfillment of obligations.

5. Capacity Market Program (CAP). When there is not enough reserve in the system, consumers must reduce their predetermined consumption. The announcement is usually published a day in advance. These reductions are considered as the system's capacity to replace usual resources of generating capacities. By proving their ability to reduce electricity consumption, consumers can receive a reservation payment, and by providing a discount, consumers can be encouraged. On the contrary, if they do not provide a discount, then they can be fined.

Ancillary Service Market Proqrams (A/S). Similar to demand bidding buyback, consumers are also betting on power outages. These proposals are offered to the independent system operator/regional transmission organization. These reductions are used as operational reservation. If the offer was accepted, the consumers must comply with the reservation. In this situation, the reservation is paid according to the market price. Once the reduction is announced, consumers are paid according to the spot price. In other words, the consumer is paid for both the willingness to reduce and the reduction in electricity consumption itself.

3 Emergency recovery programs

Time-based emergency recovery programs include as follows:

1) Time of Use (TOU),
2) Real Time Pricing (RTP)
3) Critical Peak Pricing (CPP).

In the TOU program, the electricity tariff is formed for the peak and for the rest of the time.

The RTP program is the same as the TOU program, with the difference that the electricity price is generated for each hour (24 different electricity prices).

The CPP program is used during limited number of days and is divided into four groups:

1. CPP with fixed time – price increase time is known, but day of application is unknown.

2. CPP with variable time of application– time and day of price increase are unknown.

3. Variable of pricing – in this program, the timing of the price increase varies.

4. Critical peak discounts. Consumers receive discounts for reducing their load during critical peak hours.

Diagram that indicates the classification of power consumption management programs is shown in Figure 1.

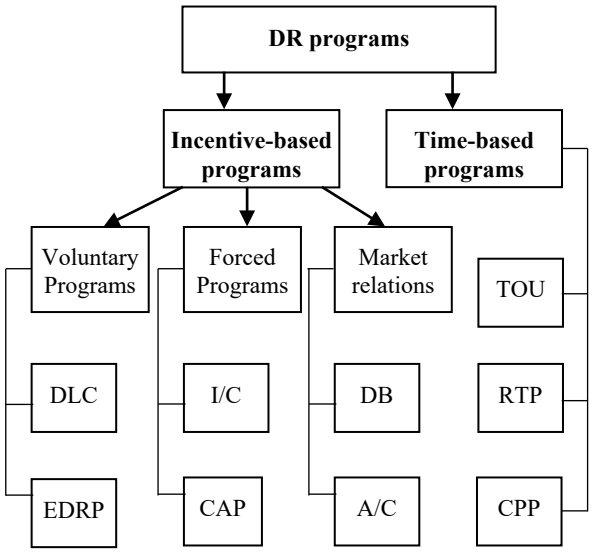

Fig. 1. Classification of power consumption management programs

The use of power consumption management programs can lead to such positive effects for the power system as:

– reduction of power losses in electrical networks,
– reduction of peak power,
– equalization of load schedules,
– reduction in transmitted power, increase in network bandwidth,
– improvement of stability,
– reduction of environmental pollution,
– improvement of voltage profiles,
– reduction or deferment of capital investments in network development,
– reduction or deferment of capital investments in development of generating capacities.

The use of power consumption management programs can lead to such positive effects for the consumer as:

– the ability to transfer power consumption to cheaper hours,
– increase in energy efficiency,
– opportunity to earn income,
– reduction of environmental pollution,
– increase of the reliability of power supply and decrease of the problems of complete disconnection from the network,
– reduction of the diktat of electricity market participants.

Here, the effects of equalization of load schedule will be considered.

It should be noted that the positive effect of equalization of load schedule includes several components:

1. Savings associated with the postponement of the construction of power plants (mainly peak),
2. Decrease of fuel burnout due to minimum and partial loads,
3. Decrease of fuel consumption for starting and stopping of power system units,

4. Reduction of costs associated with the increase in accidents, repairs, etc. due to frequent start-stops,
5. Reduction of the unloading of cost-effective power plants in order to keep the units of the Azerbaijan TPP in operation,
6. Reduction of other losses associated with the growth of expenses for own needs, losses of electricity during the transmission and distribution of electrical energy

4 Daily electrical load schedules

Despite the fact that natural gas and electricity markets have not yet been organized in Azerbaijan, in 2021 the Law "On the use of renewable energy sources in the production of electricity" was adopted in Azerbaijan, which specifies the rights and obligations of an active consumer of electricity. The active consumer can use part of the electricity he produces and sell the other part to the electricity supplier. At that, the consumer can take part in filling the load schedule for the day ahead to receive economic benefits, like other electricity producers [8].

As is known, the daily electrical load schedules, regardless of the parameters of the power system, are uneven and have several alternating characteristic sections, such as morning rise, daytime drop, evening peak, deep night dip. The nature of the change in the daily load schedule, in addition to daily rhythms, is also influenced by such parameters as weekly (working days and off-days) and seasonal (winter, spring, summer, autumn) changes in power consumption [9-12].

As can be seen from Figures 2-3, the daily load schedules differ from each other not so much in form as in the level of load and various characteristics of the load schedule.

As a rule, in working days the load is slightly higher than the load in off-days, and the load in summer and winter is higher than the load in spring and autumn.

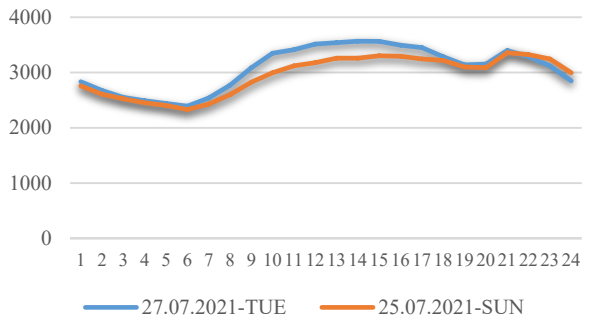

Fig. 2. Summer daily load schedule

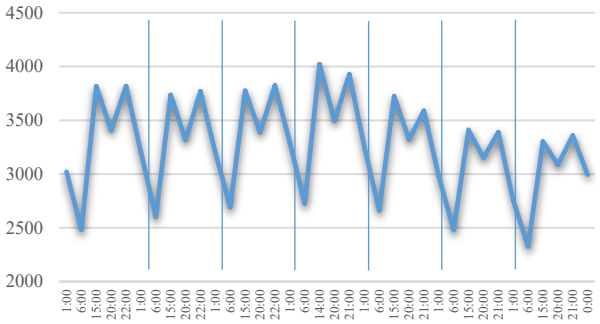

Fig. 3. Weekly load schedule

In the Azerbaijan power system, the maximum load occurs in the summer and is highly dependent on the ambient temperature. To evaluate the characteristics of the daily load schedule, parameters such as the variation factor, the fill factor, the maximum regulation coefficient, etc. are used. The lower the variation and fill factors, the worse the uniformity of the load schedule, and the worse the technical and economic indicators of coverage of the load schedule.

As can be seen from Tables 1-2, the characteristics of the daily load schedules of the Azerbaijan power system are noticeably worse compared to similar characteristics of other countries, and there is significant potential in the Azerbaijan power system to improve the characteristics of the daily load schedules.

Table 1. Characteristics of daily load schedules

Load schedule indicators, MW	Winter		Spring		Summer		Autumn	
	Work day	Off-day	Work day	Off-day	Work day	Off-day	Work day	Off-day
Maximum load (P_{max})	3252	3085	2957	2857	3566	3358	2967	2877
Minimum load (P_{min})	2042	2013	1993	1929	2390	2329	1839	1834
Moring maximum ($P\ m_{min}$)	3120	2772	2801	2532	3538	3259	2652	2517
Evening maximum ($P\ e_{max}$)	3252	3085	2957	2857	3566	3358	2967	2877
Average load (P_{av})	2727	2541	2496	2350	3077	2954	2434	2327
Variation factor (K_{var})	0,63	0,65	0,67	0,68	0,67	0,69	0,62	0,64
Fill factor (K_{fill})	0,84	0,82	0,84	0,82	0,86	0,88	0,82	0,81
Difference between maximum and average load (P_{max}-P_{av})	525	544	461	507	489	404	533	550
Load regulation range (P_{max}-P_{min})	1210	1072	964	928	1176	1029	1128	1043
Regulation coefficient (K_{reg})	0,37	0,35	0,33	0,32	0,33	0,31	0,38	0,36

Table 2. Characteristics of the daily load schedules of the countries of the world

Load schedule indicators MW	Azerbaijan		Turkey		Ukraine		Russia	
	Sum	Win	Sum	Win	Sum	Win	Sum	Win
Maximum load (P_{max})	3566	3252	39131	41590	21572	28435	110851	142381
Minimum load (P_{min})	2390	2042	28882	29521	16011	20597	89812	122162
Variation factor (K_{var})	0,67	0,63	0,73	0,70	0,74	0,72	0,81	0,85
Fill factor (K_{fill})	0,86	0,84	0,89	0,87	0,89	0,87	0,92	0,94
Regulation coefficient (K_{reg})	0,31	0,37	0,26	0,29	0,25	0,27	0,18	0,14
Relationship ($P_{sum.min}$/ $P_{win.\ min}$)	1,17		0,97		0,77		0,73	
Relationship ($P_{sum.max}$/ $P_{win.max}$)	1,10		0,94		0,75		0,77	

It should be noted that regardless of the day of the week or season, the basic part of the daily load schedule is mainly covered by thermal power plants with good technical and economic indicators, such as Janub PP-780 MW with specific fuel consumption (SFC) of 233 g/kWh, Shimal PP –800 MW, with specific fuel consumption of 214 g/kWh and Sumgayit PP–525 MW, with specific fuel consumption of 224 g/kWh. Half peaks and peaks of the daily load schedule of the Azerbaijan power system are mainly covered by the Azerbaijan TPP-2400 MW and relatively small modular power plants with total installed capacity of 1200 MW.

As can be seen from Figure 4, the Azerbaijan power system itself fully covers its own demand for electricity and exports a certain amount of electricity to neighboring states (mainly to Georgia and Turkey). The technical and economic indicators of coverage of the daily schedule of the Azerbaijan power system mainly depend on the operating mode of the Azerbaijan TPP with specific fuel consumption of 330-337 g/kWh.

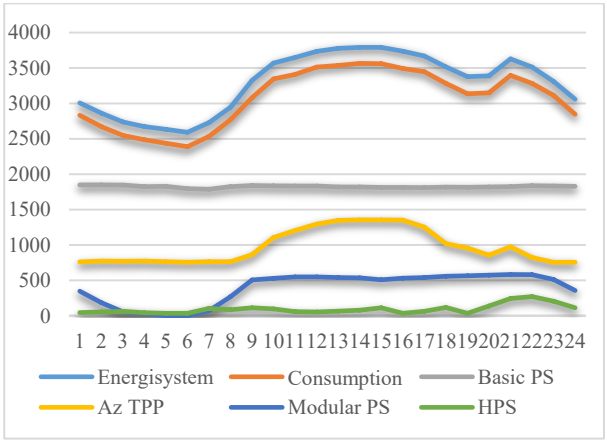

Fig. 4. Coverage of the daily load schedule

The characteristics of the load coverage modes mainly depend on the number of connected units with a capacity of 300 MW at the Azerbaijan TPP: 2-unit, 3-unit, 4-unit and 5-unit (no more than 10 days a year it is necessary to include the 6th unit in operation). At night, modular power plants usually stop, and the switched on units of the Azerbaijan TPP are unloaded to a technical minimum. In the morning, modular power plants are put into operation, and the capacity of the Azerbaijan TPP is gradually increased, if necessary. The components of the effect of equalization of the load schedule are discussed below.

The construction of 410 MW power plant (corresponding calculations and negotiations are being carried out with suppliers and civil engineers) would cost 450 million dollars, while the cost of 1 kW of power is 1,100 dollars. If we take the effect of postponement of construction to a later date (9-10 years), we will get an annual effect of $47 million.

Fuel burnout associated with the partial load of the Azerbaijan TPP is calculated based on the operating modes of this TPP. In 2021, the units of the Azerbaijan TPP were in operation: 5 units - 87 days, 4 units - 73 days, 3 units - 45 days, 2 units - 160 days.

From the typical daily load schedules, when 5 units are in operation, the fuel overspending is calculated as follows: the units carried minimal loads for 10 hours with the overspending of 21 g/kWh, while 7651 MWh of electricity was generated. For 8 hours, the units of the Azerbaijan TPP operated at power close to rated power with the overspending of 2.7 g/kWh, while 10,273 MWh were generated. During the remaining 6 hours, the units operated at average power with the overspending of 14.3 g/kWh, while 5501 MWh of electricity was produced. The total overspending for one day of operation of the Azerbaijan TPP with 5 units is approximately 21 g/kWh * 7651000 kWh + 2.7 g/kWh* 10273000 kWh + 14.3 g/kWh * 5501000 kWh = 267 t.e.f.

Considering that there were 87 such days in 2021, the annual overrun from the operation of the Azerbaijan TPP with 5 units is 267 t.e.f. * 87 days = 23229 t.e.f. in a year. Similar calculations were performed for other modes of the Azerbaijan TPP, and the results are summarized in Table 3.

Table 3. Calculation results for units of Azerbaijan TPP

Number of turn-on units	Number of days	Fuel overspending associated with partial load, t.e.f.
5	87	23229
4	73	16644
3	45	8478
2	160	22310
Total		**70661 t.e.f.**

As shown above, modular power plants stop at night and start working in the morning, in order to regulate the load schedule, the units of the Azerbaijan TPP are also sometimes stopped and then turned on (start-stop can be carried out both in weekly and

seasonal regulation of the load schedule). Considering that approximately 130,000 m^3 of gas is consumed during the cold-starting of unit of the Azerbaijan TPP, 60 m^3 of gas at low-capacity modular power plants, and 130 m^3 of gas at medium-capacity modular power plants, the overspending associated with the start-stop of the units is approximately 7 million m^3 of gas per year.

In order to prevent shutdown of units of the Azerbaijan TPP, it is often necessary to operate more cost-effective power plants with partial loads, which leads to fuel overspending due to partial loads of cost-effective power plants. The table shows the values of fuel overspendings at cost-effective power plants.

Table 4. Fuel overspending values

Power Plant	Fuel overspeding in 2021, t.e.f.
Janub PP–780 MW	42000
Sumgayit PP–525 MW	10000
Shimal PP–800 MW	8800
Total	**60800**

If we bring the above values of the equivalent fuel overspendings into the volumes of natural gas (natural gas is used at the power plants of Azerbaijan), we will get 115 million m^3. Taking into account the gas overspending for the start-stop of the units, we will get 122 million m^3 of natural gas.

We are conducting special studies to determine the costs associated with the increase in accidents, repairs, etc. due to frequent start-stops, as well as losses associated with the growth of expenses for own needs, losses of electricity during the transmission and distribution of electrical energy. Without taking into account these components, the annual effect of equalization of the load schedule (at current prices for a thousand cubic meters of natural gas at $1,740), taking into account the effect of postponement of the construction of a peak station, can be estimated at $260 million per year. More than 80% of this amount falls on the share of natural gas, the price of which has recently been characterized by great instability, and therefore one can operate with the amount received conditionally.

Strategic trend for the development of the electric power industry, which provides for the widespread introduction of renewable energy sources, is adopted in Azerbaijan. Modular power plants will make it possible to cover the electrical load of the power system when introducing renewable energy sources in the amount of up to 500 MW, the coverage of large volumes will be accompanied by significant problems, primarily the need to build peak power and large capacities for the electric energy accumulation.

Thus, at current natural gas prices, the amount that can be used for the equalization of the load schedule can be estimated at $260 million. The main means of equalization of the load schedule is the use of multi-tariff systems. To do this, it is necessary to introduce modern electricity meters with appropriate functions.

Currently, the two-part tariff applied in Azerbaijan for continuous productions (production of aluminum, steel, etc.) does not contribute to equalization of the load schedule (their share in total consumption is not significant). In order to equalize the load schedule, it is necessary to stimulate the development of industry with continuous automatic production [13-15].

Conclusions

1. Power consumption management is one of the main components of the concept of modern development of the electric power industry.
2. Currently, there are two types of programs of change of the load of consumers: programs based on incentives and programs based on time.
3. The characteristics of the daily load schedules of the Azerbaijan power system are noticeably worse compared to similar characteristics of other countries, and there is significant potential in the Azerbaijan power system to improve the characteristics of the daily load schedules.
4. The technical and economic indicators of load coverage mainly depend on the number of connected units with a capacity of 300 MW of the Azerbaijan TPP.
5. The effect of equalization of the load schedule of the Azerbaijan power system at current natural gas prices can be $260 million, which can be directed to the introduction of multi-tariff systems, the development of accumulation systems and continuous automatic production with uniform power consumption.

References

1. Md Rahat Hossain, Amanullah Maung Than Oo, A B M Shawkat Ali Smart Grid, p. 24 (2013)
2. Gurtovtsev A.L., Zabello E.P. *Alignment of the graph of the electric load of the power system. Energy and fuel and energy complex*, No. 7/8., p.13-20, (2008)
3. Voropay N.I., Stennikov V.A. Active consumers in an intelligent electric power system http://energystrategy.ru/projects/Energy_21/3-6.pdf
4. Volkova I.O., Shuvalova D.G., Salnikova E.A. Active consumer in the smart energy system: opportunities and prospects, https://publications.hse.ru/mirror/pubs/share/folder/xnto5eu7bd/direct/71899800
5. Eid, C. Time-Based Pricing and Electricity Demand Response: Vxisting Barriers and Next Steps C.Eid, E.Koliou, M. Valles [et al.] Elsevier Utilities Policy, Volume **40**, p. 15-25 (2016)
6. Pazouki, S., Mohsenzadeh, A., Haghifam, M. R. *Optimal planning of parking lots and DLC programs of Demand Response for enhancing distribution networks reliability. IEEE Pes General Meeting Conference & Exposition,*

National Harbor, MD, USA, p. 1-5 (27-31 July, 2014)

7. Robertson, G., Harrison, G.P., Robin Wallace, A. OPF Techniques for Real-Time Active Management of Distribution Networks. IEEE Power & Energy Society General Meeting, Chicago, IL, USA, p. 3529-3537 (16-20 July, 2017)
8. Nasibov V.Kh., Alizade R.R. *Study of characteristic load curves of the Azerbaijan energy system to determine the load power reserve*, 85th meeting of the International Scientific Seminar named after. Yu.N. Rudenko "Methodological issues in the study of the reliability of large energy systems", Reliability of liberalized energy systems, Irkutsk, Russia, p. 119-124 (June 30-July 4, 2013)
9. Papkov B.V. *Active elements of consumers in the electric power system*, Methodological issues in the study of the reliability of large energy systems. Issue. 66., Minsk, Irkutsk: ISEM SO RAN, p. 218-224 (2015)
10. Hayder O. Alwan Compass Load Scheduling with Maximum Demand and Time of Use pricing for Microgrids, Virginia Commonwealth University VCU Scholars, p. 154 (2019)
11. Jun Du, Zongnan Zhang, MenghanLi ,JingGuo&Kongge Zhu Optimal scheduling of integrated energy system based on improved grey wolf optimization algorithm, Scientifc Reports (2022)
12. Jia, H. et al. *Research on some key problems related to integrated energy systems*. Autom. Electr. Power Syst. **39(7)**, p. 198–207 (2015)
13. Dunnan, L., Guangyu, Q. & Qi, Li. Research on optimization operation of integrated energy microgrid considering multi-type energy conversion and storage. South. Power Grid Technol. **12(3)**, p. 105–115 (2018)
14. Li, W. et al. Optimal dispatch model considering environmental cost based on combined heat and power with thermal energy storage and demand response. Energies **12(5)**, p. 817 (2019)
15. Zhang, X. et al. Hourly electricity demand response in the stochastic day-ahead scheduling of coordinated electricity and natural gas networks. IEEE Trans. Power Syst. **31(1)**, p.592–601 (2015)