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Efficiency Analysis of Energy Storage Systems in Optimizing the Operating Modes of the Power System

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ABSTRACT: Today, new innovative technologies are widely used in all sectors. The energy sector is no exception. Especially in the field of efficient storage and use of electricity. There are many scientific developments in this area. Some of them are at the theoretical development stage, while others have already been transformed into working prototypes. Energy storage technologies store excess power that occurs in the system during periods of minimum consumption and transfer the stored electricity to the system during periods of maximum consumption. These technologies not only ensure the continuity of electricity supply, but also guarantee the energy security of the system. They can quickly provide the system with the necessary power even in the event of various accidents that may occur at power plants. They also allow adjusting the generation schedules of electricity generated using renewable energy sources, which change dramatically due to weather conditions. Energy storage systems are also beneficial for consumers - they can help stabilize electricity prices within the general grid or, with local storage, ensure individual flexibility and independence of consumption in households.

KEY WORDS: energy storage systems, battery storage, optimization, power redistribution.

I.INTRODUCTION

The development of energy storage and accumulation systems is becoming a potential way to solve global problems of the power system. However, there are various technical and economic barriers that prevent the widespread use of energy storage devices. It is necessary to identify innovative processes, mechanisms and systems that will help solve the problems of the power system of developments in the field of energy storage, as well as to ensure the growth of the industry at the expense of companies engaged in the development of technologies. This article reviews current achievements and trends in innovations in the field of energy storage. The scientific novelty of the article lies in a comprehensive review of the current state of affairs in this area and the identification of the main directions of development.

From an economic perspective, the value of storing cheap or free energy (i.e., energy generated from renewable sources during off-peak or low-demand periods that can be sold mainly during peak hours) can be calculated by determining the difference in market prices over time. In this way, energy generated from renewable sources and stored in batteries during off-peak periods can be used during peak demand periods. In contrast, energy from non-renewable sources, such as natural gas turbines, is more expensive to use.

II. AIM OF THE SURVEY

The article presents work on optimizing modes by controlling the load schedule using accumulator batteries, which are widely used in energy storage systems, and considers the optimal management of power losses and voltages by redistributing power flows in the power system.

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The daily schedule of a solar power plant shown in Figure 1 shows that the blocking of solar radiation by clouds leads to a sharp fluctuation in the power generation of the power plant. Such large-capacity, variable power plants operating in a unified power system can dramatically affect the energy balance in the system, leading to frequency drops and major accidents. Solving these problems requires extensive research on a global scale, and energy storage systems are widely used in this regard.

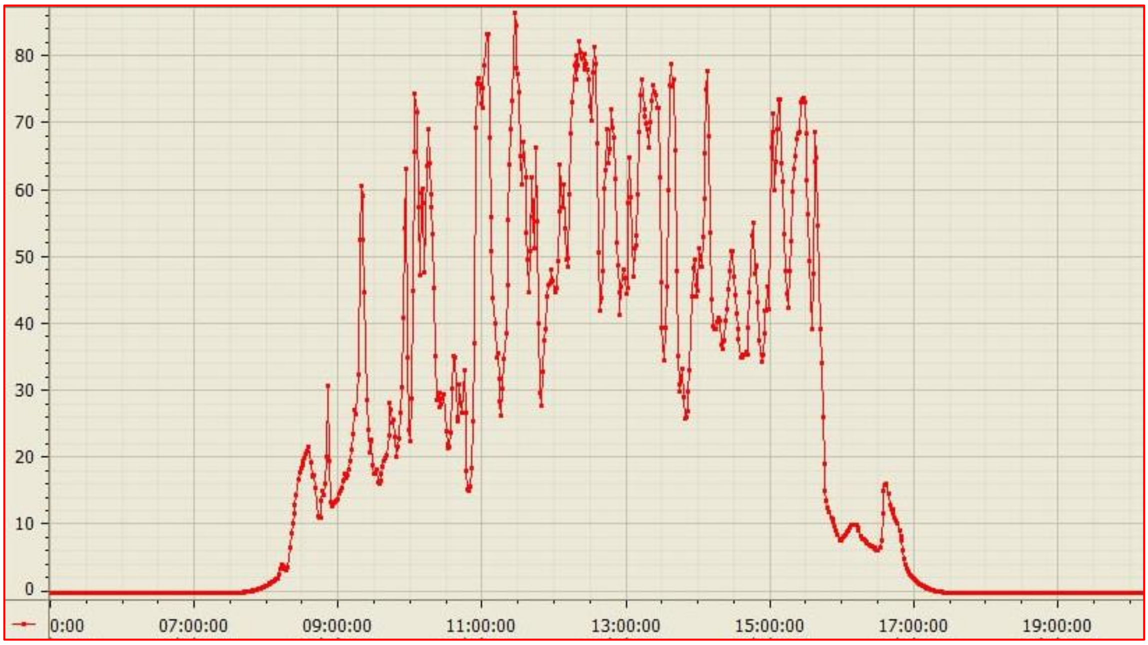

Figure 1. Solar photovoltaic power plant daily production graph (MW)

III. METHODOLOGY

When managing the power system modes, it is necessary to consider the state and depth of charge of all battery systems. In this case, a mathematical model of energy storage systems is created and on this basis the state of reserves is checked. Battery modeling is a major problem for power plants operating on renewable energy sources, since the service life of battery cells is one of the main costs for power systems. It is very difficult to determine a general model that covers all factors of battery cells. Accordingly, depending on the application of the model, different approaches have been used. Battery modeling is divided into three categories: chemical models, electrical models, charge accumulation and empirical models. Most modeling focuses on three types of features: operating or charging model, voltage model and shelf life model.

The capacity of the battery is estimated by the following equation:

$$C_B = \frac{E_L * S_D}{V_B * DOD_{max} * T_{cf} * \eta_B} \qquad (1)$$

where, EL is the hourly load demand, SD is the days of autonomy, VB is the operating voltage of the battery, DODmax is the maximum discharge, Tcf is the temperature correction factor, and ηB is the charge/discharge efficiency.

The most important factor in managing systems with renewable energy power plants is knowing the state of charge (SOC) of the battery at each stage. Overcharging or undercharging the battery can lead to irreversible damage to the battery, which will result in significant costs for the system.

There are various methods for determining the state of charge (SOC) of the battery. One such method is to determine the AMP by dividing the available ampere-hours by the rated ampere-hours, which is expressed by the following equation:

$$SCB = \frac{Available\ charge\ (Ah)}{Rated\ charge\ (Ah)} * 100 \qquad (2)$$

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Optimization of an autonomous system is usually carried out using the iteration technique, which is the AMP required at any given time or in a specific load mode. Therefore, it can be calculated as follows:

$$SCB(t) = SCB(\mathrm{t}-1)(1-\sigma) + \left[E_{Gen}(t) - \frac{E_L(t)}{\eta_{inv}}\right] * \eta_B \quad (3) \quad \text{and}$$

$$SCB(t) = SCB(\mathrm{t}-1)(1-\sigma) + \left[\frac{E_L(t)}{\eta_{inv}} - E_{Gen}(t)\right] \quad (4)$$

where σ is the hourly discharge rate, EL(t) is the load demand, and EGen(t) is the energy generated by the power plant operating on alternative energy sources. The first equation is used when the battery is charging, and the second equation is used when the battery is discharging.

IV. EXPERIMENTAL RESULTS

Within the framework of the research work, work was carried out to prevent power shortages in the evening peak hours of the power system, that is, to optimize load schedules through energy storage systems, in the conditions of the presence of a large number of solar power plants in the power system. Figure 2 shows the general load schedule, and studies were carried out using a mathematical model of storage batteries to introduce energy storage systems taking into account all types of plants. Based on the following daily power generation schedule, the BESS with an installed capacity of 300 MW provides a 300 MW power transmission reserve in the control sections by charging during the night minimum hours and redistributing power during the maximum load at the beginning of the day. In addition, during the day, it transfers the energy received from solar power plants to the system during the evening peak hours. By implementing 500 MWh BESS power redistribution during the evening peak hours shown in Figure 2, the control sections serve to increase power transmission reserves and adjust voltages.

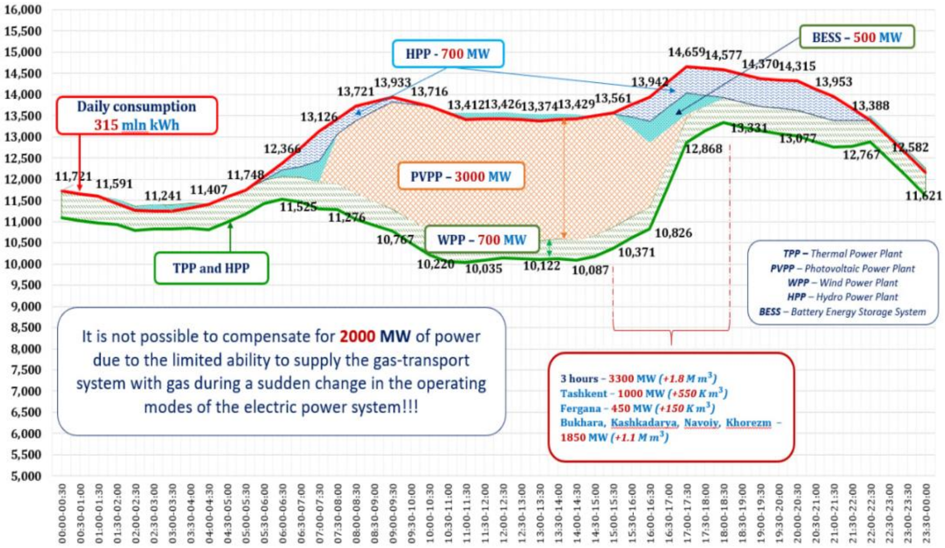

Fig 2: Graph of optimal control of the daily load schedule of the energy system with all types of power generation and storage systems.

When optimizing the load schedule of the power system, energy storage systems are charged during the night or in the middle of the day and connected to the power system as a load, and transfer their stored power when there is a power shortage at the beginning and end of the day. In this case, the redistribution of power flows not only optimizes the load schedule, but also reduces active power loss in the network.

There is also an opportunity to optimize the conditional fuel consumption of traditional power plants operating in parallel modes in the power system, and calculations have also been made on these. The calculations take into account

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the technological maximum and minimum modes of the units. There are a total of 10 units in the Syrdarya TPP, the conditional amount of fuel consumed per kWh of electricity, depending on their load capacity, is given in Table 2.

Table 1. The 24-hour power generation, average fuel consumption, unit load capacity and number of units of Syrdaryo TPP are presented.

Hour	Power per hour (MW)	Existing units (pcs)	Generation capacity of every existing unit (MW)	Amount of fuel being spent for the generated power kW·h by every unit depending its loading (kg)
1	939,3	3	313	0,317
2	948,6	3	316	0,316
3	942,4	3	314	0,316
4	949,6	3	316	0,316
5	940,3	3	313	0,316
6	1047,8	4	262	0,323
7	1177,9	4	294	0,321
8	1033,3	4	258	0,324
9	973,4	3	324	0,316
10	1198,6	4	299	0,318
11	1157,3	4	289	0,321
12	1012,6	4	253	0,326
13	981,6	4	246	0,326
14	971,3	3	324	0,316
15	976,5	3	325	0,317
16	973,4	3	324	0,316
17	1203,8	4	300	0,318
18	1384,6	5	277	0,321
19	1405,3	5	281	0,321
20	1012,6	4	253	0,326
21	992,0	4	248	0,326
22	992,0	4	248	0,326
23	995,1	4	249	0,326
24	997,1	4	249	0,326

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Table 2. The average conditional amount of fuel used for the production of electricity, depending on the load of the units, provided by the producer of the units.

Technological maximum and minimum modes of units (MW)	160	180	200	220	240	260	280	300	325
Conditional amount of fuel (grams) used for each kW of electricity produced depending on the load of the units	345,20	338,72	333,54	329,84	326,27	323,34	321,02	318,92	316,53

In order to prevent fuel consumption from increasing due to insufficient load of the units at certain hours, optimization by introducing energy storage systems was considered. In this regard, it was considered to reduce the average fuel consumption by increasing the capacity of the units operating at a load below 280 MW and loading the excess energy generated into the energy storage systems. Table 3 presents data on the calculations performed.

Table 3. The 24-hour power generation, average fuel consumption, unit load capacity, number of units and charging hours of energy storage systems of Syrdaryo TPP are presented.

№	Power plant generation per hour (MW)	Number of units under operation (pcs)	Generation of every unit under operation (MW)	Amount of fuel being spent for the generated power kW·h by every unit depending its loading (kg)	Charging power of energy storage system (MW)
1	939,3	3	313	0,317	
2	948,6	3	316	0,316	
3	942,4	3	314	0,316	
4	949,6	3	316	0,316	
5	940,3	3	313	0,316	
6	1047,8	4	280	0,321	-72
7	1177,9	4	294	0,321	
8	1033,3	4	280	0,321	-88
9	973,4	3	324	0,316	
10	1198,6	4	299	0,318	
11	1157,3	4	289	0,321	
12	1012,6	4	280	0,321	-108
13	981,6	4	280	0,321	-136
14	971,3	3	324	0,316	
15	976,5	3	325	0,317	
16	973,4	3	324	0,316	
17	1203,8	4	300	0,318	

18	1384,6	5	277	0,321	
19	1405,3	5	281	0,321	
20	1012,6	4	280	0,321	-108
21	992,0	4	280	0,321	-128
22	992,0	4	280	0,321	-128
23	995,1	4	280	0,321	-124
24	997,1	4	280	0,321	-124

By shifting the load times of the station taking into account energy storage systems, the average conditional fuel consumption per kilowatt was 319.5 grams. The conditional fuel consumed per kWh of electricity at the power plant was reduced by 0.5 grams or 0.15%.

Based on the proposed mathematical model and algorithm, the cost of conditional fuel saved per day is determined using the following expression:

Nopti= B*n* N= 25206000 * 0.0000005*1358000= 17 114 874 soums

Where:

B – conditional fuel saved, t.sh.o.;

N – price of 1 t of conditional fuel, soums (as of 01.10.2024).

n - the average amount of conventional fuel saved per kWh of electricity generated during a day.

V. CONCLUSION

The use of energy storage systems at small enterprises and on a system scale helps to reduce active power loss and optimize the voltages at the nodes. This mathematical model allows small and medium-sized industrial enterprises to optimally manage energy storage systems in the system. In addition, it allows for the optimization of the operating modes of thermal power plants, which leads to a reduction in the cost of electricity generation.

REFERENCES

1. Akagi H., Sato H. Control and performance of a doubly-fed induction machine intended for a flywheel energy storage system // IEEE Transactions on Power Electronics. 2002. V.17.N.1.pp. 109–116.
2. Eurostat. (2016), Simplified energy balances–annual data. Available at: http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_100a&lang=en.
3. Ciamician G. (1912). The photochemistry of the future. Science. P. 385–394.
4. Díaz-González F., Sumper A., Gomis-Bellmunt O., Villafáfila-Robles R. A review of energy storage technologies for wind power applications // Renewable and Sustainable Energy Reviews. 2012. V.16. N.4. pp. 2154-2171.
5. Divya K.C., Ostergaard J. Battery energy storage technology for power systems. An overvie //
Electric Power Systems Research. 2009. V.79.N.4. pp. 511–520.
6. DOE Global Energy Storage Database. (2016), Available at: http://www.energystorageexchange.org/.
7. Dufo-López R. Optimisation of size and control of grid-connected storage under real time electricity pricing conditions // Applied Energy. 2015. V.140. pp. 395–408.
8. Chen H., Cong T.N., Yang W., Tan,C., Li Y., Ding Y // Progress in electrical energy storage system: A critical review. Progress in Natural Science.2009. V.19. N.3. pp. 291–312.
9. Fertig E.,. Apt J. Economics of compressed air energy storage to integrate wind power: A case study in ERCOT // Energy Policy. 2011. V.39. N.5. pp. 2330–2342.
10. Gallagher K. (2009). Acting in time on energy policy. Washington, D.C.: Brookings Institution
Press
11. Hadjipaschalis I., Poullikkas A., Efthimiou V. Overview of current and future energy storage technologies for electric power applications // Renewable and sustainable energy reviews. 2009. V.13(6). pp. 1513–1522.
12. Jacobsen M. // Economies and Policy of Large Scale Battery Storage. Kleinman Center for Energy Policy, University of Pennsylvania. 2016. Available at: http://kleinmanenergy.upenn.edu/policy- digests/economics-and-policy-large-scale-battery-storage.
13. Lu N., Chow J.H., Desrochers A.A. Pumped-storage hydro-turbine bidding strategies in a competitive electricity market // IEEE Transactions on Power Systems. 2004. V.19. N2. pp. 834–841.

14. Lundmark R. Bäckström K. Bioenergy innovation and energy policy. Economics Of Innovation And New Technology. 2015. V.24. N8. pp. 755–775.
15. Noe M., Steurer M. High-temperature superconductor fault current limiters: concepts, applications, and development status // Superconductor Science and Technology. 2007. V.20(3). R15.
16. Soloveichik G.L. Battery technologies for large-scale stationary energy storage //Annual review of chemical and biomolecular engineering. 2011.V.2. pp. 503–527.
17. Suberu M.Y., Mustafa M.W., Bashir N. Energy storage systems for renewable energy power sector integration and mitigation of intermittency // Renewable and Sustainable Energy Reviews. 2014. V.35. pp. 499–514.
18. Urbaniec M. Towards Sustainable Development through Ecoinnovations: Drivers and Barriers in Poland, Economics and Sociology. 2015.Vol.8. N.4. pp. 179–190.
19. Vazquez S., Lukic S.M., Galvan E., Franquelo L.G., Carrasco J.M. Energy storage systems for transport and grid applications // IEEE Transactions on Industrial Electronics. 2010.V.57.N.12. pp. 3881– 3895.
20. Winter M., Brodd R.J. What are batteries, fuel cells, and supercapacitors? // Chemical reviews. 2004. V. l.104. N.10. pp. 4245–4270.
21. Young K., Wang C., Wang L.Y., Strunz K. // Electric vehicle battery technologies. In Electric Vehicle Integration into Modern Power Networks 2013. pp. 15–56. Springer New York.
22. Zhao P., Dai Y., Wang J. Design and thermodynamic analysis of a hybrid energy storage system based on A-CAES (adiabatic compressed air energy storage) and FESS (flywheel energy storage system) for wind power application // Energy. 2014. 70. pp. 674–684.

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