Technical Issues
3/2016 pp. 93-98
ISSN 2392-3954

SELECTED EFFECTS OF THE USE OF AN EXTERNAL BATTERY WITH A PHOTOVOLTAIC FARM

Mateusz Piątek
Politechnika Częstochowska
Wydział Elektryczny
Instytut Elektroenergetyki
Al. Armii Krajowej 17
42-200 Częstochowa
e-mail: mateusz.piatek2015@gmail.com

Abstract: With increased interest in renewable energy sources, such as photovoltaic farms, a number of studies whose aim was the analysis of their positive and negative impact on the power system was carried out. From the point of view of the system operator, the suitable place of installation and the size of such plant in the network can have a positive impact on the value and direction of power flow, voltage levels, the value of the power loss, short- circuit currents and power factor. However, the biggest difficulty in the application of the farm is its unexpected production characteristic which depends mainly on the weather conditions changing randomly during the day. The most desirable case is a period when this farm is capable of being installed in depth of the network to reduce daily peak demand for electricity. The energy from big, centralized plants working in the system must be delivered to the customers at this time, which generates additional costs of starting units, working in short period of time and increases power losses on lines, which must send higher energy values. Accordingly, the sense of use of an external energy storage systems cooperating with photovoltaic installations is clear. For the grid operator, in the case of large PV farm desirable to be able to use the extra energy of the battery power and the ability to use the farm to reduce the afternoon and evening peaks. This may positively affect production costs and transmit additional energy to the system.

Keywords: photovoltaic, power stations, distributed generation, reduction of losses, power system, voltage levels, profitability analysis, energy storage.

Introduction

During last years it has been a trend to install smaller sources of generation closer to its use, connected at the level of the distribution network. The commonly used distributed generation's technologies are mainly based on wind generators, photovoltaic and biomass generators with capacity between several kW to a few MW. Photovoltaic power plants are becoming increasingly cheaper and more popular. They can affect the electric power system through change in grid operation, like power flow direction, voltage profiles in network, reduction of losses, short circuit current or power factor [1]. Continual changes in weather conditions or time during a day cause varying electricity production. The example of production characteristic from power plant with 65 MW, located in Zaragoza, Spain is shown in figure 1. Power plants of this type with high power may impact on the power system due to the nature of the work. They affect the performance and stability of the system. In particular, this applies to power plants located far from the main supply point. They may cause a flickering effect.

Total losses of power in the network increase the amount of energy needed to produce in power plants. Accordingly, the operator must take this into account in the generation of short- term plan. Because the amount of power produced and received must be the same, the losses each time need to be taken into account for the total energy production. The greatest losses and the load exist in the moments when there is the greatest power demand, especially during midday and evening peak. The figure 2 presents the demand for electricity in Spain during a day of maximum demand.

At a time when there is the greatest demand for electricity, it is possible to produce energy from photovoltaic farm. As a result, the operator can theoretically reduce the operating points of neighboring power plants operating in the area. Then it becomes more economically efficient for him. In most of the period of production of energy from the photovoltaic farm, characteristic of generation coincides with the characteristics of demand. It is necessary to use the plant control system connected to the distribution network by the operator. If the high power PV plant is enabled at the point where the power system with enough power short-circuit and stable voltage and frequency parameters are, then the power can be compensated with adequate reserve of available capacity. All this, however, involves high maintenance costs of renewable energy sources. The problems described above can be substantially reduced or eliminated if the PV plant–works with battery. The battery could be used for example during night periods, when there is no production from power plant and the demand occurs in the grid. However, by the fact that the production of energy from this source is highly variable and for periods when sunlight is lower it becomes necessary to install an additional source of energy storage. First of all, it gives a wider possibility of using such a source by an operator, which is normall disadvantageous for him due to its instability. Energy storages load during periods when there is a greater energy production in comparison to demand and discharge to supply the excess loads. By using energy storage it is possible to minimize the negative influence of large photovoltaic farms located away from other sources of energy and causing flicker in the absence of production [2].

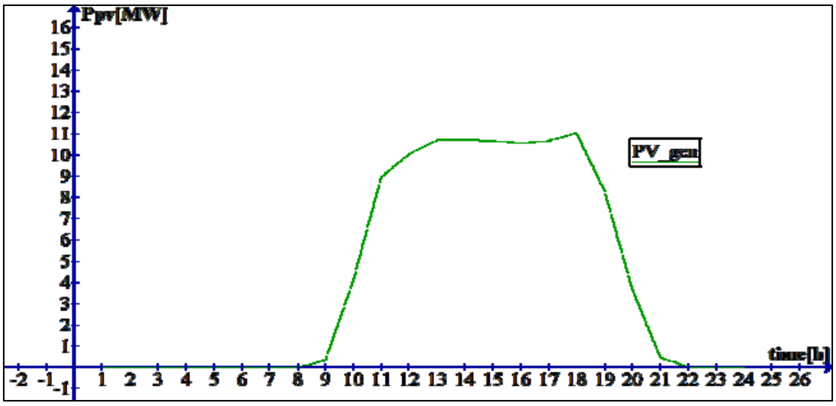


Fig. 1. Power production from the plant [5].

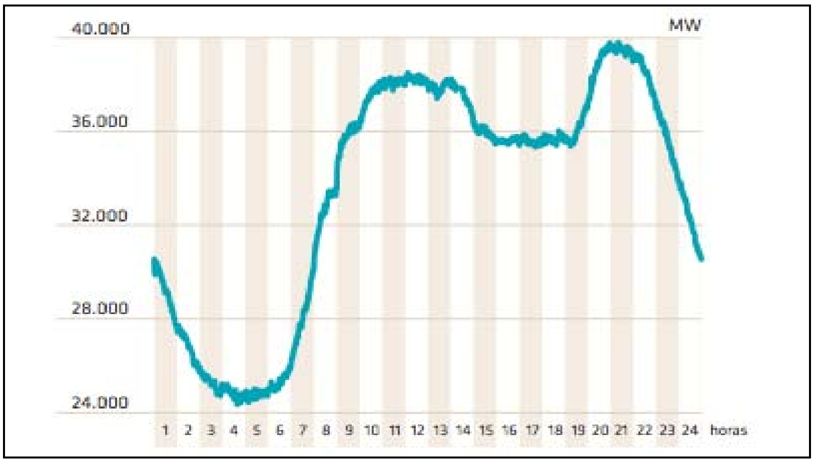


Fig. 2. Demand for electricity in Spain [5].

To store the energy, different types of devices can be used, including batteries, ultra capacitors, flywheels, fuel cells and superconducting magnetic energy storage. These energy storage devices are connected to the electric grid by means of suitable power conversion devices. To achieve maximum profitability of farms with an external battery, its size must be properly selected. Because the solutions are quite expensive, the condition of profits in relation to financial expenditures must be appropriately high.

Materials and methods

All simulations were performed in DigSilent Power Factory 15.2 with real hourly demand for big factories and real hourly generation profile for big photovoltaic plant, working now in Zaragoza, central Aragon in Spain. Simulations were provided for imaginary, double fed grid and grid parameters were selected from manufacturers' catalogs. After power flow for the entire network, power losses on all lines in the grid have been calculated without and with external battery. By seeking a minimum loss function based on the received data, the optimal size of the battery has been selected, which will result in the greatest reduction of losses and costs of operating the network. The analyzed network with parameters is presented in the figure 3.

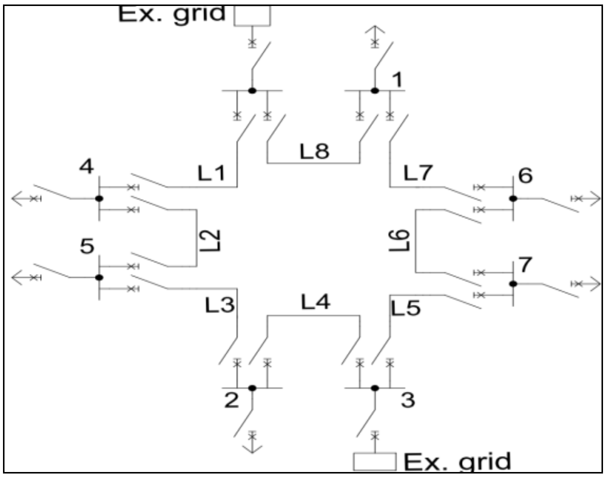


Fig. 3. Tested network: 1÷8− nodes numbers; 1÷8− lines.

Grid parameters: P_{LOAD}= 3,2MW; Cosφ= 0,93; U_N= 20kV; S_{Cu}= 70mm^2; I_N= 245A; R'= 0,443Ω; X'= 0,42 Ω; l=1km.
Where: P_{LOAD}- maximum power demanded by customer; Cosφ- power factor of the customer; U_N- nominal voltage in the grid; S_{Cu}- section of the wire; I_N- maximum wire current; R'- resistance of the wire; X'- reactance of the wire; l- length of the wire.
Selected farm parameters: P_{PV}=30MW; Cosφ=0,93.
Where: P_{PV} - power installed in pv plant.

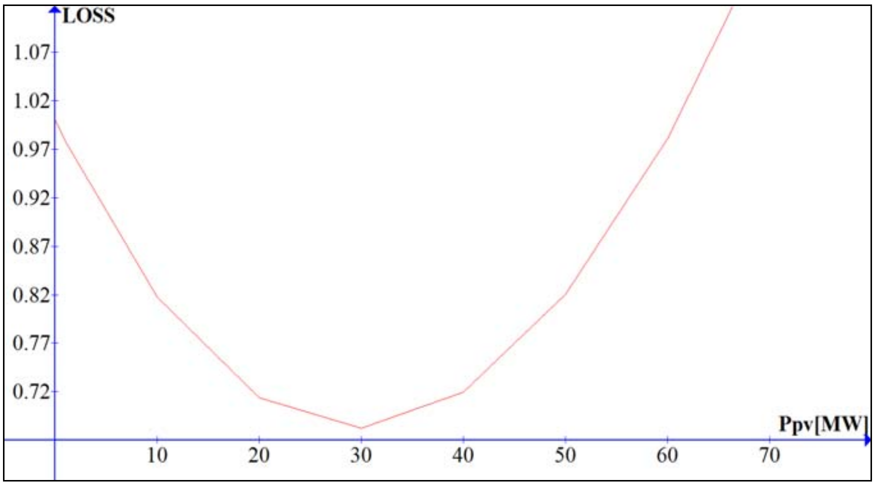
Results and discussion

By searching for the best battery capacity, firstly localization of photovoltaic farm was selected. As the power control derived from the plant cos φ control type have been selected. The best way to reduce losses was searching for the best battery capacity [3]. Because of that simulations were performed with variable battery capacity for the best farm parameters, selected before.
To make it easier to prove the relationship between the usages of the battery in the farm we introduced the parameter of losses, called LOSS, calculated using the formula:

$$LOSS = \frac{\Delta E_{loss}^{pv}}{\Delta E_{loss}^{0}} \quad (4)$$

Where: $\Delta E_{loss}{}^{pv}$− total losses after pv plant connection, $E_{loss}{}^{0}$− total losses before pv plant connection.
The results of simulations are presented figure 4.
By adding an external battery on an annual basis, losses on transmission can be reduced for this type of source in a very wide range. The difference in the results related to the fact that in the case of external source of energy storage is an additional possibility to produce power ~~to~~ for customers at the periods when there is no production of the photovoltaic plant, which produces while sun shines and has a positive effect of the system only in periods of sunlight. After addition of the battery, its influence is higher and may have a suitable effect on the results in a wider range. For the case above it turned out to be the best external battery with a nominal capacity of 4MW. It is almost 14% of nominal power installed for a big industrial plant like in that case. Yearly losses in the system were reduced by 57%, making the energy transmission costs which include the cost of power losses correspondingly smaller. It is, however, important to note that the installation of excessive external source of energy storage can cause the opposite effect to that expected, and even increase the losses in the network. With too large batteries losses are able to achieve even greater value than before adding batteries.
The optimal solution would be the use of such farms with the possibility of control by the system operator, which in addition to the normal state of operation and support of energy supply from the farm, is able to disconnect it in case of high solar radiation, when production is high and if there is a surplus of energy in nearby area system.
To accurately determine the cost-effectiveness of solutions with additional energy store, we need to check whether the solution is cost effective.
Distribution network operators in Poland recorded the loss for 2011 in the amount of 9086 GWh for the price of 1.764 billion zlotys which is 84% the total value of losses in the national electricity transmission. Their losses are therefore most of the losses of the whole national power system [4].
The optimal solution would be the use of such farms with the possibility of control by the system operator, which in addition to the normal state of operation and support energy supply from the farm, is able to disconnect it in case of high solar radiation, when production is high and the system is a surplus of energy. Then the farm would be connected like in the figure 5.

a)



b)

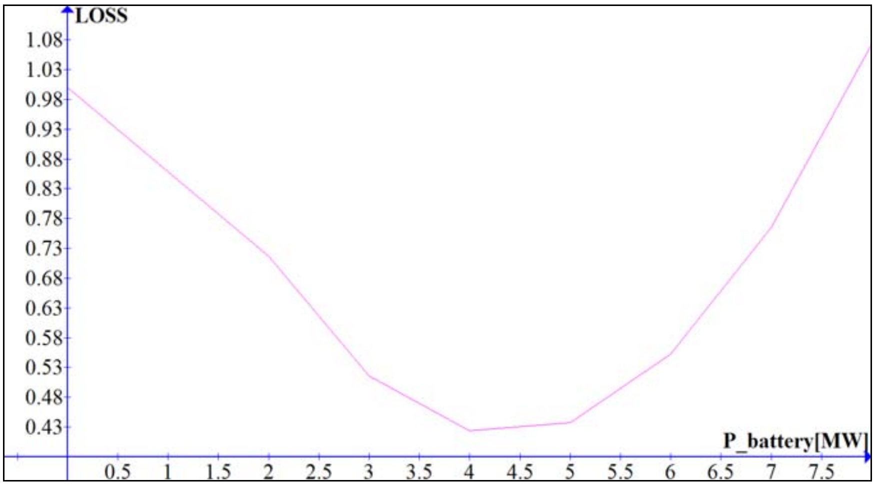


Fig. 4. Results for reducing losses in the system: a) PV plant with optimal parameters; b) External battery added.

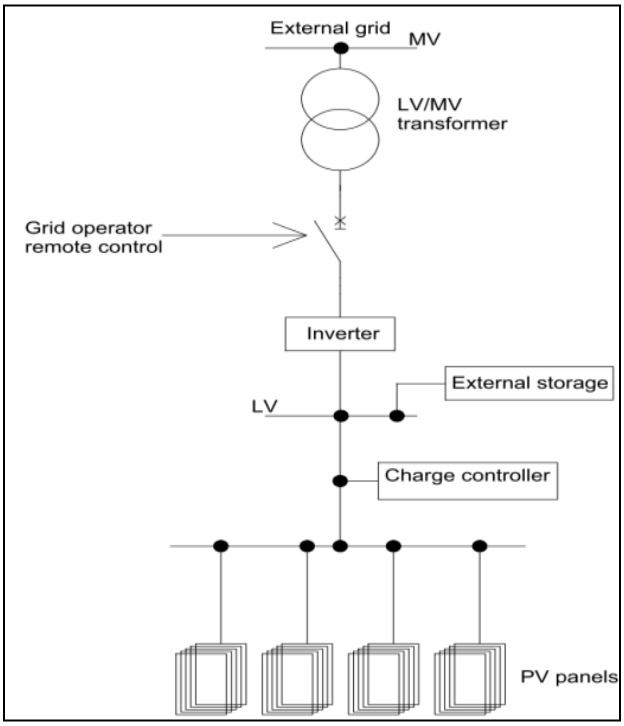


Fig. 5. Possibility of operator farm control.

In such a situation, if the operator has the ability to control when turning on and off the farm, it would become a very effective source to him that he would be glad to exploit. In that case plant could use cloud - based wireless communication and control capability that should meet some requirements specified in regional energy distributor user guide of running and exploitation of the grid.

Total losses in analyzed network without pv farm were 2896.313 MWh. After installation of pv farm with external batteries, whole losses were reduced to 2058.661MWh. And within the same battery, losses have been reduced by the value of 25.5 MWh.

Total cost of losses in the grid assuming electricity prices for Spain is 420 mln euro (0.145 € per kW). This amount is very big and could be reduced.

Total cost of external battery is one-off and its amount is 6mln euro.

By installing energy storage system in this industrial grid some losses can be saved to the amount of 369.75 thousand euro during the first year.

To better illustrate (Fig. 6) the possibility of cost savings with this solution, an analysis of the economic profits at the turn of the battery life, taking into account the decrease in capacity of 10% at the end of every 5 years was performed. A battery life of 15 years was assumed.

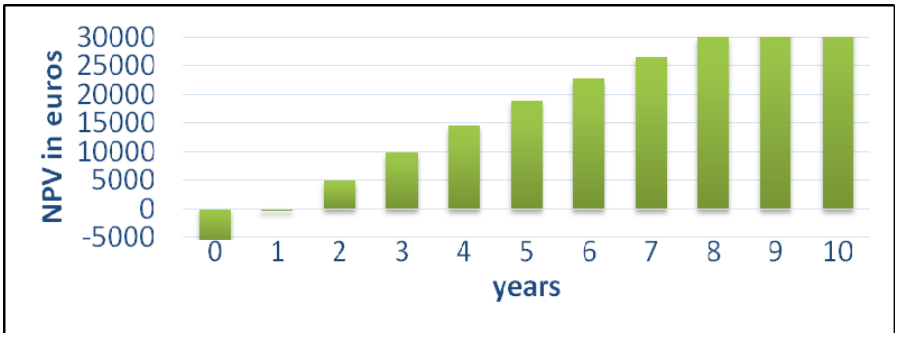


Fig. 6. NPV analysis for this system.

Installing external storage system in this case with suitably chosen photovoltaic plant will be profitable after the second year and will bring the operator profits from energy savings from power losses. At the end of several years of investment in this type of device requests generate very large profits at a very fast pace and over time. Based on the above analysis, it can be stated that the investment is highly profitable. Expenditures spent on external sources of energy storage are quite low compared to the profits that can be achieved with them.

Conclusions

Energy transmission losses are associated with additional costs for energy distribution in medium voltage networks. These costs are charged to the recipient in total electricity prices. The greatest value of the losses occurs when demand for electricity is highest, that is, during the day, while factories work. In such circumstances, a very good option seems photovoltaic farm, now gaining more and more popularity. However, these sources do not have stable characteristics of production, which is the adverse solution during formation of the balance energy production by the operator. Sometimes, in case of big sources of PV installed in the system, in the absence of other power plants in the vicinity, there may be dips or voltage fluctuations. All the disadvantages characteristic to farm production can be reduced through the use of external sources of energy storage. Connecting the farm, along with storage results in a reduction of annual losses in the transmission system, particularly during the peaks southern and evening, when the farm or the battery are the support for the system and the operator does not need to run additional sources of energy. By installing the battery, it is possible to reduce power loss in the periods of the night and overcast when the farm does not produce energy, which is a more efficient way of using power than the source without storage. In the analyzed case system with energy storage reduced annual losses throughout the network better than in a case without external storage system.

The costs of the chosen energy storage seem very large, but compared to the costs of transmission losses in the network and their possible reduction through the use of such sources of energy storage it can produce benefits for the operator in the short term.

Very important is to choose optimal battery capacity in the system. Based on these studies it can be stated that the use of external energy storage is beneficial not only for the investor who profits from the sale of energy, but also for the system operator who, in addition to lower costs transmission, is also able to save on no necessity for running additional units in case of peaks in demand thanks to photovoltaic power plants with energy stores.

References

1. Premm, D., Glitza, O., Fawzy, T., Engel, B., Bettenwort, G., Grid integration of photovoltaic plants - a generic description of pv plants for grid studies, 21st International Conference on Electricity Distribution, Paper 1190, Frankfurt, 2011.
2. Srivastava, A.K., Kumar, A.A., Schulz, N.N., Impact of distributed generations with energy storage devices on the electric grid. Science Direct, *Case Studies in Thermal Engineering*, 2012, 2, pp. 1-7.
3. Nowak, W., Straty mocy i energii w elementach elektroenergetycznego układu przesyłowego. AGH, Kraków 2013.
4. Analiza nt. wielkości strat w przesyle energii elektrycznej w Polsce, https://www.bbn.gov.pl/pl/prace-biura/publikacje/analizy-raporty-i-nota/4148,Analiza-nt-wielkosci-strat-w-przesyle-energii-elektrycznej-w-Polsce.html (access 2.01.2016).
5. www.ree.es (access 2.01.2016).