# Control System of Battery Storage to Eliminate the Power Variation According to the Electricity Prediction

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*Abstract* — **Rapid variations of the output power from photovoltaic power plants can have some significant side effects on the quality of electricity, such as the voltage variation, switching of tap changers, etc. In the other case, these variations also make the difference between the prediction and real electricity production. Generally, the goal of the accumulation of electricity is to charge the storage element in surplus of electricity and discharge when the energy is insufficient. In this paper, the accumulation of electricity in a photovoltaic power plant is not used for this purpose, but to charge and discharge the storage element with respect to the prediction of electricity.**

*Keywords — Photovoltaic power plant, power variation, battery controller, electricity prediction.*

## I. Introduction

The renewable energy sources integration has been extensively increased in the electric power distribution system. To exploit the renewable energy sources more effectively, grid connection of renewable energy sources should be done in the way to eliminate negative local impacts on distribution grids [1], [2]. The output power of the photovoltaic or wind power plants is very depended on the actual atmospheric condition. This strong dependence usually results to the rapid output power variation many times in quite huge range. There is a common approach to use the storage elements in a power system. This approach is to use the accumulated energy in the time periods, when the electricity demand in the power system is required and vice versa. This case of accumulation is more adequate for such systems installed in low voltage distribution systems like transformer substations. Distributed generation especially built in photovoltaic and wind power plants can be beneficial if it meets at least the basic requirements of the system operating philosophy, feeder design and advanced control systems [3]. This paper describes a new approach to utilize the energy storage systems for elimination the unpredictable power variations from the photovoltaic power plant. The control system of the battery is designed and demonstrated on the voltage network simulation model. The main usage of this controller of the storage element is to hold the output power in the photovoltaic power plant at the predicted value.

## II. Distribution Network Model – IEEE 37 Node Test Feeder

For the simulation of a storage element controller, the IEEE37 test feeder model was used. It is a part of 4.8 kV distribution network feed from the transformer 230/4.8 kV, 2500 kVA. Some of the properties of this model were changed due to the simulation needs. In the node number 725, the load was replaced by the photovoltaic power plant including the battery as a storage element. The voltage regulator at the feeder transformer was eliminated. The network topology with the place of the photovoltaic power plant is displayed in Fig. 1.

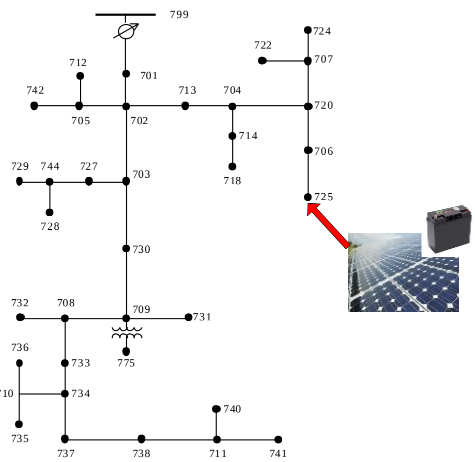


Fig. 1. IEEE 37 Test feeder with the photovoltaic power plant.

Due to the simplification of load types, all the nodal loads have the same load shape multiplication factor. Using the same multiplication factor, the same power and the same shape of all loads is achieved. The multiplication factor can be than expressed as the load shape curve, which defines the variation loads in p.u. during the weekly simulation. The load shape curve is displayed in Fig. 2.

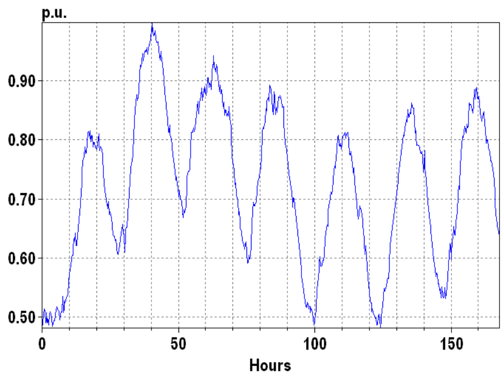


Fig. 2. Weekly load shape curve in p.u.

## III. Prediction of Electricity Production in Photovoltaic Power Plant

The prediction in the photovoltaic power plant is based on the real photovoltaic power plant (PtP) parameters. The long time prediction is calculated using the program PVGIS (Photovoltaic Geographical Information System) with the database of the meteorological condition typical for that place, where the PtP operates [4]. The parameters of the PtP are listed in the following table.

TABLE I.
Photovoltaic Power Plant Parameters

| Parameter | Value |
|---|---|
| Installed power | 950 kWp |
| PV Technology | crystalline silicon |
| Type of construction | stationary system |
| Module inclination | 36 º (optimal) |
| Module orientation | –1 º (optimal) |
| Estimated losses due to temperature | 7.2 % |
| Estimated loss due to angular reflectance effects | 2.8 % |
| Other losses (cables, inverter etc.) | 14.0 % |
| Combined PV system losses | 24.0 % |

Prediction of the electricity production in the PtP is calculated for the cloudy sky and clear sky. This is due to demonstrate, how the precision of the electricity prediction can affect the designing of the accumulation system. The output power of the photovoltaic power plants depends on two main factors. The main factor determining the output power is the solar irradiation on the place, where the power plant operates. The second factor is the air temperature. The dependence of the output power and air temperature is in relation, that if more solar irradiation and lower air temperature, than more output power is achieved and vice versa. The output power, respectively production is also affected by the type of construction (stationary or tracking systems), and the losses of the entire system (wires, inverters). In case of the 2-axís tracking systems, the solar panels are moving during the day to get the best position for the solar irradiation flow. The panels move to by oriented directly to the sun position. This results to better efficiency of the solar irradiation use. Such systems are more sophisticated and more costly due to the tracking control system.

In our study case, the PtP is located at the south part of Slovakia. The following Fig. 3 shows the place, where the PtP operates. It can be seen, that the PtP operates in area with the yearly global irradiation of 1100 kWh/m$^2$.


Fig. 3. The place of the photovoltaic power plant operation.

## IV. Storage Controller Operation

The battery operation within the photovoltaic power plant is demonstrated on the weekly simulation. To control the dispatch mode of the battery, the controller communicates with the open program OpenDSS (Open distribution system simulator) and PVGIS software. The OpenDSS is a comprehensive electrical system simulation tool for electric utility distribution systems. The algorithm of the battery controller was developed in the Matlab software. The load flow calculation for each time step is executed by the OpenDSS software. This program supports all rms steady-state (i.e., frequency domain) analyses commonly performed for utility distribution systems. In addition, it supports many new types of analyses that are designed to meet future needs; many of them are being dictated by the deregulation of the US utilities and formation of distribution companies worldwide [5]. In our controller system, the OpenDSS also includes the network topology, loads, PtP, properties of power devices, etc. The concept of communication between the Matlab, OpenDSS and PVGIS software is shown in the following Fig. 4.

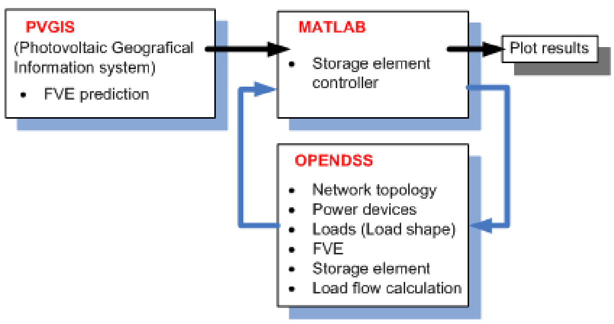


Fig. 4. Concept of the controller communication.

The battery controller ensures the charging and discharging commands for the battery with respect to the prediction values obtained from the PVGIS and data recorded from real production. The controller evaluates also the required amount of power for dispatch. Dispatch commands and the required power of the battery for both states (charge and discharge state) are calculated by the algorithm shown in Fig. 5.

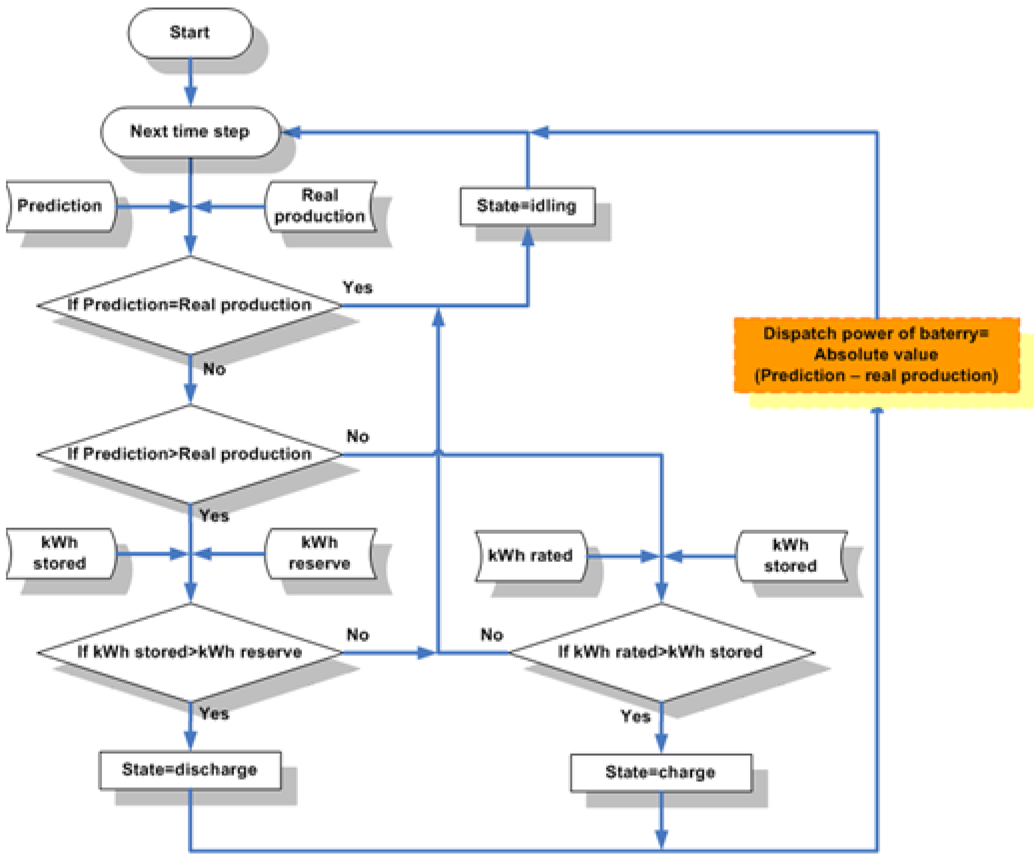


Fig. 5. The algorithm of the storage controller.

The value marked as $kWh_{reserve}$ contains the storage capacity to be held in the reserve for normal operation. (Minimum energy discharge level unless there is an emergency). The controller calculates the required output power and sends the commands to charge and discharge the battery to keep the output power of the PtP for each period at or near to the predicted value. The battery executes the discharge command, until the present amount of the stored energy is greater than the $kWh_{reserve}$ value. The battery will take charge only when the present amount of the stored energy is less than the rated storage capacity ($kWh_{Rated}$). The basic concept of the battery as storage element is shown in the following Fig. 6 [6].

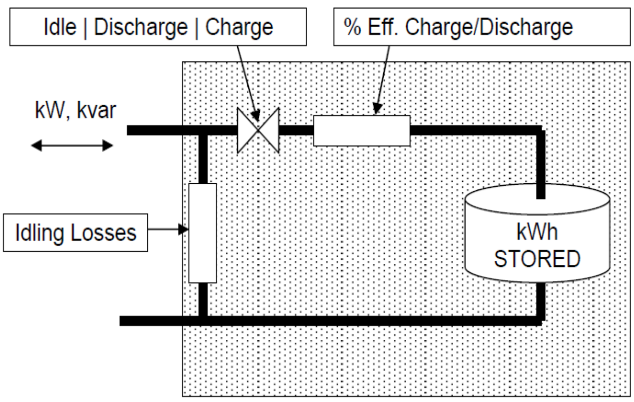


Fig. 6. Basic concept of the battery storage system.

The storage element is essentially a generator that can be dispatched to either produce power (discharge) or consume power (charge) within its power rating and its stored energy capacity. The model is used in a Snapshot power flow mode to compute simply the power flow for a selected state of the storage element flow control. In this case, we set simply the state to one of idling or charging or discharging and then solve the steady state. A storage element can either act independently or be controlled by a build in storage controller element. In our case, we designed a new storage controller to control the battery independently.

## V. Simulation Results of Controller Operation

The controller operation was simulated in both conditions with respect to the prediction for cloudy and clear sky. The following set of figures (Fig. 7, Fig. 8, Fig. 9, and Fig. 10) shows the weekly simulation results. The real production in the PtP measured at its output terminal is displayed as the blue curve; prediction is represented by the red curve. The green curve displays the output power from the photovoltaic power plant with the controller system dispatching the battery of 350 kWh capacity. The value $kWh_{reserve}$ was set to the value equal to 1 %. The charge and discharge cycles of the battery and the kWh stored value are also displayed to show the present lack of stored energy in the battery. The Figs. 7 and 8 show the simulation results considering the conditions in a cloudy sky. The Figs. 9 and 10 show the simulation results considering the clear sky.

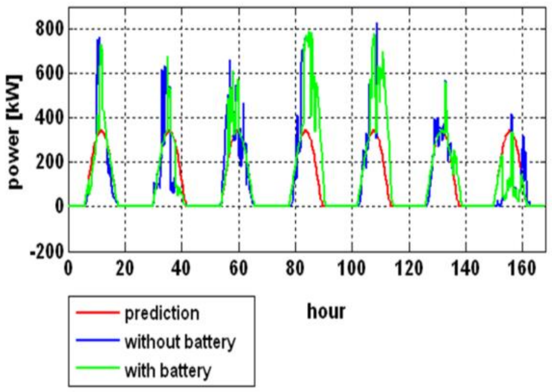


Fig. 7. Simulation results of the storage controller operation with cloudy sky.

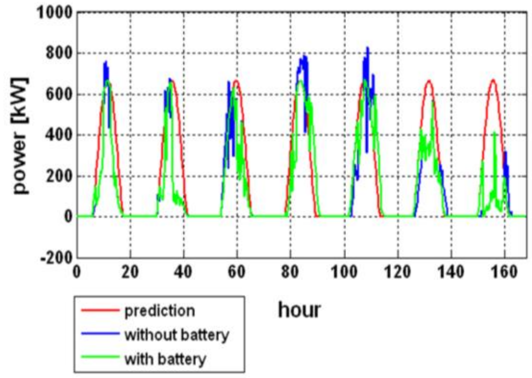


Fig. 9. Simulation results of the storage controller operation with clear sky.

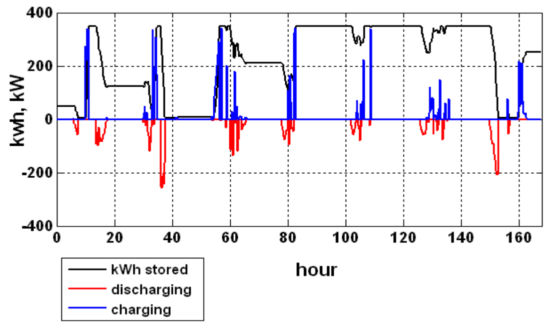


Fig. 8. Battery cycles with cloudy sky.

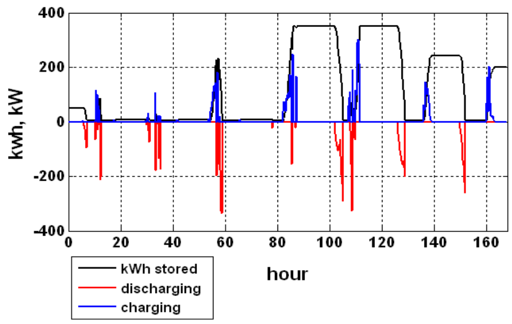


Fig. 10. Battery cycles with clear sky.

The next Fig. 11 shows detailed power curves for selected one day to understand the controller algorithm and to see the differences between the particular curves. During the first part of the day, the battery was able to keep the output power of the PtP on the predicted value.

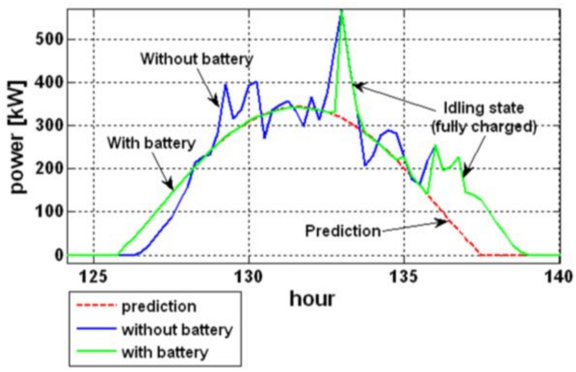


Fig.11. Simulation results for selected day.

It can be seen, that if the stored energy is insufficient, or the battery is fully charged, the battery switch to idling state and the blue and green curves have the same shape. If the lack of the stored energy allows to charge and discharge the battery, the real power supplied to the network from the PtP is equal to prediction. Next Fig. 12 shows the total absolute value of the deviation after one week. This deviation is calculated as a sum of the absolute values between the real production with the battery and the prediction after one week. This deviation is evaluated for several different capacities of the battery from 50kWh up to 1000kWh. The simulation of deviation was performed also for such scenario, when the battery was disconnected. This is illustrated as the battery with zero capacity.

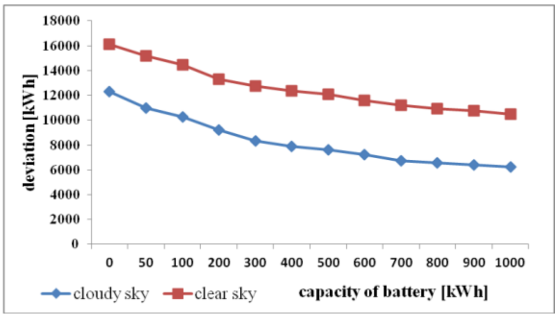


Fig.12. Total deviation of energy with several capacities of the battery.

If the controller dispatches the battery with respect to the prediction calculated for cloudy sky, the total deviation is much better. Deviation dependence on storage capacity is not linear. It can be seen, that increasing the stored capacity from 400 kWh to 1000 kWh doesn't change significantly the total deviation.

## VI. Conclusion

Accumulation systems are becoming an important part of power systems at last mile level, especially in the area of smart grid solutions and services. The described approach using the storage systems to minimize the deviations between the prediction and real electricity production in the photovoltaic power plant is suitable more for the stand alone power plants with higher powers, usually above 1 MW. Such power plants are built to be connected directly to high voltage networks and produce the electricity to the network. In these types of plants, there is no load (except of auxiliary systems), where the produced electricity could be primary consumed. All the produced electricity flows to the distribution network. For this reasons, it is reasonable to use the storage system together with the controller to keep the predicted electricity. These simulation experiments were based on the long term prediction. This is the reason, why the accumulation system has not eliminated the deviation enough to acceptable limits. Nowadays, there are many of systems providing short term predictions for solar power plants. It is recommend to use short term prediction for solar plants, which will increase the optimization of storage system operation. Many of the battery controllers, so called smart energy routers are widely used in households equipped with a small photovoltaic system and storage systems. The smart energy routers are programmed to direct the energy primary to electrical equipments in consumer premises and ensure that, the most of the produced energy is consumed within the consumer premises. Thus the proposed controller concept is not suitable for small household photovoltaic systems. The controller operation based on the proposed algorithm ensures that the battery sustains the daily diagram of production at or near to the predicted values. In this paper, the controller operation was simulated with one photovoltaic power plant during one week. The model can be extended and used for assessment and development of accumulation systems in more complicated systems, such controlling the accumulation within the smart grids, yearly simulations with several photovoltaic power plants including the synergy effect in decentralized production and more.

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