

Grid Connected Battery Energy Storage System in Microgrid

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Abstract - In recent decades, developments in the field of battery storage have made it possible to establish commercially viable projects to store energy during peak production and release it during peak demand, and to use it when production drops unexpectedly, mainly due to critical environmental issues and the high penetration of renewable energy sources. The large-scale integration of this type of battery storage will have an impact on the operation and performance of the electricity grid. In this article, our attention has been focused on the effect of the presence of large-scale storage batteries as a potential source filling supply and demand response gaps, including load balancing and reducing energy cost reduction. A monitoring strategy has been developed and tested with different scenarios to illustrate the use of ESS battery storage system and a PV generation plant connected to a community distribution system. The aim is to see the actions of ESS equipment connected to a community power grid when an incident occurs or when there is an unavailability of energy produced by the PV system, in order to limit buying more electricity from the grid.. The simulation results demonstrate the ability of the proposed storage system to control the energy flow and to deal with the problem of power interruption and power shortage, ensuring a good energy transfer between the energy sources and the distribution system.

Keywords - Battery Energy Storage System BESS, Grid, Micro-Grid, Photovoltaic System.

I. INTRODUCTION

Energy storage assets are a precious asset for the power grid. They can provide such benefits and services as load management, power quality and uninterrupted power supply to increase efficiency and security of supply. This is becoming increasingly important in view of the energy transition and the need for a more efficient and sustainable energy system.

Any electricity system must balance the electricity generation with its consumption, both of which vary considerably over time [1].

Energy storage devices are an important part of the renewable energy production structure. Renewable energy sources such as solar, wind and hydro are fluctuating resources. In order to provide constant power to the electrical grid, energy storage systems are installed on the power generation system (Fig.1). Again, renewable sources (wind and solar) are unreliable and, in the case of photovoltaics, sunlight may only be available for 6 to 8 hours a day to produce electricity.

When there is no electricity production or high energy demand, energy storage systems supply

electricity to consumers. Therefore, an energy storage system can be an important component of an energy management system to improve the reliability and economic operation of the power system.

There are different forms of energy storage, such as Electric Double Layer Capacitor (EDLC) [2], BESS Battery Energy Storage System [3], Superconducting Magnetic Energy Storage (SMES) [4], Flywheel (FW), Rechargeable Electric Vehicle (PEV) [5], and so on.

Applications could be as diverse as financial energy arbitrage, mitigating line congestion, equipment relocation, solar power smoothing, spinning reserve, voltage regulation, etc.



Fig.1. Battery Energy Storage System with PV system.

As a result, much research has been conducted over the last decade on the implementation of battery storage systems suitable for grid-scale applications, in order to keep them within predefined limits, which vary depending on the grid. Different research has been proposed by researchers in this field :

Babacan and al have developed a charge and discharge planning method for distributed energy storage systems (DES) co-located with solar photovoltaic (PV) systems in order to minimize the monthly electricity expenses of a customer who has a DES. They also proposed a strategy that encourages DES customers to store excess PV solar generation that might otherwise result in a reverse flow of energy into the distribution grid, leading to a reduction in average net peak demand, fluctuations in average demand and an increase in average PV self-consumption [6].

During the large-scale integration of energy storage devices into the power grid, other researchers are applying a cost-benefit analysis [7].

Del Rosso et al have worked on the potential use of battery storage to increase transmission capacity in thermally limited transmission lines [8].

A study has been proposed in reference [9] based on a cost-benefit optimization formulation for the optimal sizing of a storage system in order to find the optimal size of the battery-wind system to avoid congestion by maximizing the monetary value of the wind storage system.

Another paper proposed a Battery Energy Storage System (BESS) design that could lead to costly postponement of grid upgrades and reduced demand-side costs [10].

Wang and al of them have suggested a power-smoothing strategy for a grid-connected solar photovoltaic (PV) power plant based on a hybrid energy storage system (HESS) to smooth the fluctuating power output of the PV plant [11].

The researchers in the paper [12] focused their work on the basis of a smoothing control method for the reduction of power fluctuations in the performance of the wind-hybrid/multi-purpose system and the regulation of the state of charge (SOC) of the batteries under typical conditions.

Further research has suggested in reference [13] a new stochastic optimization model that optimizes the bidding strategy for the energy of the day and the rotating reserve of a wind farm that operates in coordination with an energy storage facility.

The case study developed shows how the energy storage facility can help improve the wind farm's position when participating in energy and related markets by helping to manage production fluctuations and reduce unbalances.

The paper [14] proposed a new approach based on cost-benefit analysis for the optimal sizing of the microgrid (MG) energy storage system. The question of the unit contribution to the MG storage tank is taken into account in this process.

The presence of photovoltaic renewables and the unavailability of storage, present particular challenges for power utilities and create many problems, such as the massive use of centralized generation and the difficulty of allocating reserve power due to intermittency and energy expenses could therefore put into question the security and energy efficiency of the power system. However, A large scale storage batteries connected to the distribution grid with a PV generation system can contribute to the generation of electrical power precisely at peak and fluctuation times in order to respect the limits of electricity use allowed by the utility company.

In this paper, an appropriate sizing study of a BESS battery storage system connected to a power distribution system and a photovoltaic park was used to avoid using and purchasing more power from the main grid than agreed upon while ensuring the supply limit dictated by the distribution system operators using the MATLAB Simulink tool.

II. METHODS

A) *Description of the system*

In this work, we will present the simulation of a Micro Grid connected to the power grid, integrating a photovoltaic renewable energy source with a time series of public solar data, a battery energy storage system, variable and constant loads, an equivalent model of the main electrical distribution system as a base power source and transmission lines. It consists of a 120 kV transmission system equivalent to supplying a 25 kV distribution substation.

This system provides electricity to a community that owns the photovoltaic farm and an energy storage system.

The simulation presented in MATLAB/Simulink last one year, which is equivalent to one minute in phaser mode (Fig.2).

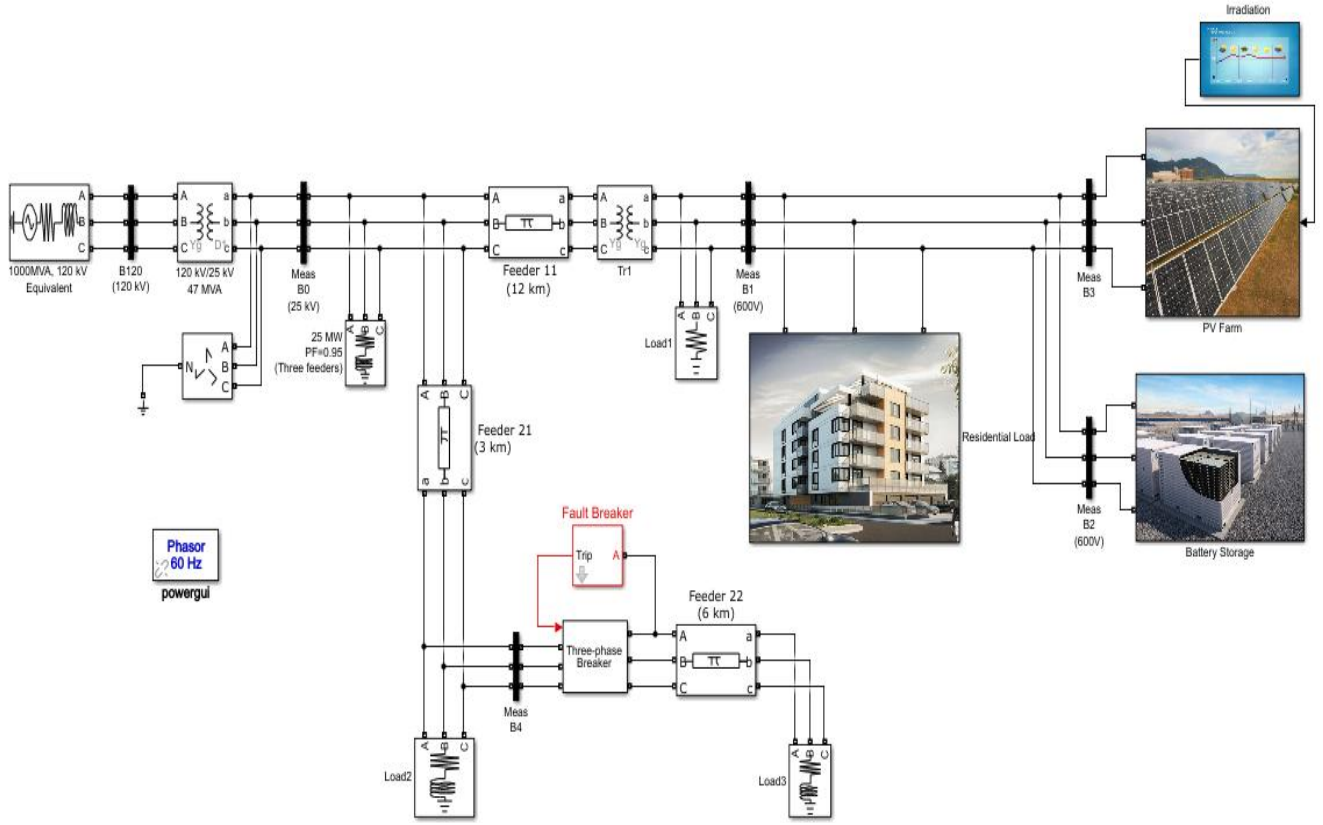


Fig. 2. Grid-connected energy storage system modelling with MATLAB/Simulink

The following table presents the simulation data :

Table 1. Parameters of the simulation model

Source	Power
Grid	1000 MW
PV system	600 kW
Battery Storage	250 kW
Variable Load	1400 kVA
Constant Load	32.5 MW

B) Dynamic load model

The dynamic load model implements a three-phase three-wire load model with a voltage of 600V, a power of 1600KVA and a power factor of 0.95 based on load profiles. The active power P and the reactive power Q absorbed by the load vary as a function of the positive sequence voltage V and the load profile data as shown in equation (1) and (2).

The P & Q vary as follows:

$$P = P_{Load\ profile} * \left[\frac{V}{V_0} \right]^{np} \quad (1)$$

$$Q = Q_{Load\ profile} * \left[\frac{V}{V_0} \right]^{nq} \quad (2)$$

Where,

- V_0 is the initial voltage of the positive sequence.

- P_0 and Q_0 are the initial active and reactive powers at initial voltage V_0 .

- V is the positive sequence voltage.

- np and nq are exponents (usually between 1 and 3) controlling the nature of the active and reactive charge respectively.

In this simulation $np = 1.8$ and $nq = 1.4$.

Using the phasor mode equations, the active and reactive powers and the voltage are given as follows:

$$S = 3 * \frac{(V * I')^2}{2} \quad (3)$$

Where :

S : is the apparent power in VA.

V is the positive sequence voltage.

I' is the conjugate of the current at the system "power to current" output of the phasor-mode.

Load profiles are daily load data specified on an hourly basis. The annual load profile is given by (Fig. 3).

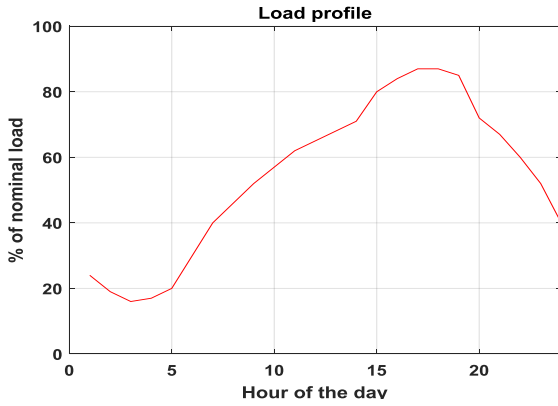


Fig.3. The daily load profiles.

C) Photovoltaic system

A photovoltaic farm produces energy proportional to three factors: the size of the area covered by the photovoltaic farm, the efficiency of the solar panels and the irradiation data. The power at the output of the photovoltaic farm is given by the relation:

$$P_{pv} = A * Irr * \eta \quad (4)$$

Where :

P_{PV} : the power delivered by the photovoltaic system in kW.

A : Total surface area of solar panels in m^2 .

Irr : Solar irradiation W/m^2 .

η : Efficacité globale du système en %.

D) Energy Storage System (ESS)

The "Energy Storage System" block contains the following items:

- Control system.
- Unavailability controller.
- Stored energy calculator.
- Model SPS Power-to-Current and a 240/600V step-up transformer.

At any time of the day, the control system determines the energy required from the ESS in order to keep the power below the specified value of the maximum power allowed on the grid [15, 16]. This

power signal is sent to a current power block connected to a 240/600V Step-up Transformer.

Although the nominal power and capacity of the modeled BESS are specified in kW and kWh respectively as for a Battery Energy Storage System (BESS), the following two tables determine the storage system parameters and its control.

Table 2. Storage System parameter ESS

Battery Storage	Power parameters
Rated power (kW)	250
Rated capacity (kWh)	1000
Initial stored energy %	90
System efficiency %	95

Table 3. Control system parameters ESS

Control parameters	Value
Range of operation [min-max] in % of Stored Energy	[10-90]
Maximum charging power (kW) during night time	150

The implemented control system is given by (Fig. 4).

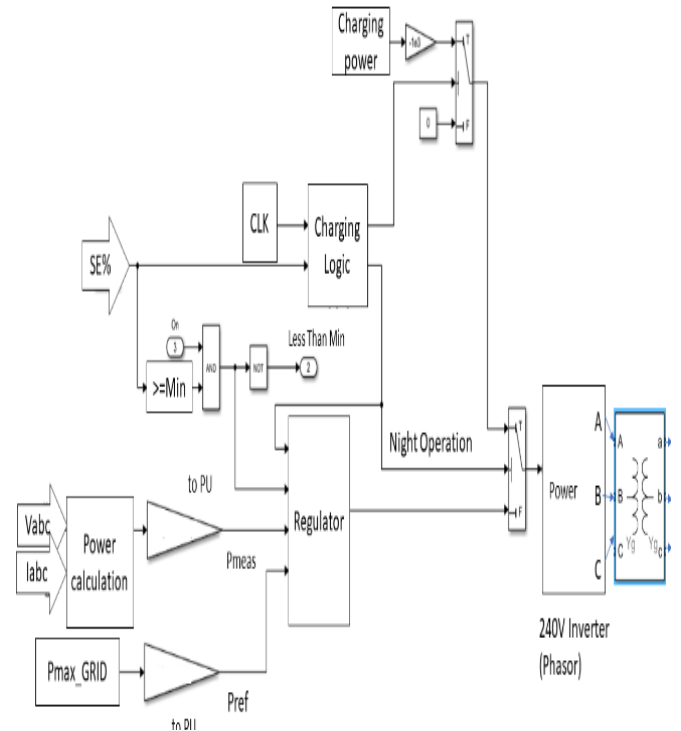


Fig.4. Block diagram of the proposed control topologies for BESS.

The recharge is allowed between midnight and 6 am. If the stored energy is less than 90%. The charging logic block receives the stored energy to allow the switch to inject the power intended for

recharging and programs the period during which the batteries must be charged (Fig.4). If the stored energy is greater than 10%, the controller compares the current available power with the reference power (P_{\max_GRID}) to determine the discharge power and then generates a discharge command to the battery during the day.

III. RESULTS AND DISCUSSION

Using MATLAB Simulink software, the model of the microgrid connected to a community distribution system using an energy storage system and a photovoltaic generation system was simulated over a one-year period, with two scenarios:

Scenario 1 : Fluctuation in PV production.

Scenario 2 : a disturbance on the bus 4.

The simulation results show the role of the storage system in the production of electricity in the microgrid as well as the variation of the electricity produced and consumed.

The objective is to determine the appropriate sizing (power and capacity) of an ESS storage system connected to a 600 V community power grid, in order to avoid that the community buys more electricity than has been authorized by the public distribution system operators [17-19].

After simulation, we obtained the results of the electricity produced by the distribution grid, the storage system and the photovoltaic field as well as the load consumption (Figs. 5 and 7).

Based on a load profile, the production of a photovoltaic farm and the capacity of the ESS, the simulation runs two unavailability scenarios for two days.

Figure 5 shows the results for days 212 and 213 where the ESS control system determines the ESS power required to avoid exceeding the maximum power allowed by the grid operators at 950 kW.

On day 212 given by the N°1, as shown in the figure 5 the ESS output (210 kW) was sufficient to avoid exceeding the maximum power allowed by the grid operators, we can see that the collaboration between the storage system and the photovoltaic production ensures the load without using the excess power (above the allowed limit $P_{\max_GRID}=950\text{KW}$) of the grid.

On day 213 given by N°2, it can be seen that the ESS has not been able to provide the necessary

amount of electricity, and the community has no choice to buy more electricity from the grid. It can be seen that the amount of power delivered by the storage system does not ensure the load, which causes the production supplied by the grid to be exceeded, and this is due to an unexpected fluctuation in photovoltaic production at midday [20].

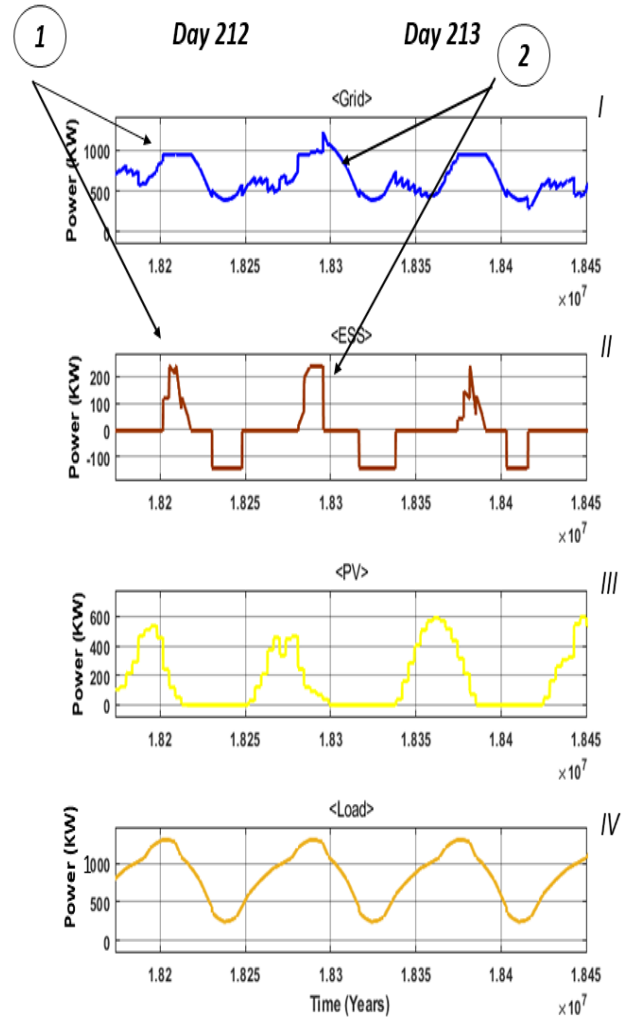


Fig. 5. Active power variation of Grid-Storage-PV and loads.

Fig. 6 shows the stored energy for the two days 212 and 213 in which recharging is allowed except from midnight to 6 a.m. if the energy is less than 90%.

The energy stored during this period will contribute to power generation at the time of unavailability. caused by a fault at 2:30 p.m. on Day 126 (April 4) given by Scenario N°2 (Fig.7).

We can see that the Phaser solution produced simulation results to the accuracy at the time the fault was programmed.

We notice that the storage system (II) injects part of its power at the fault time to ensure the loads despite the fluctuation of the photovoltaic system (III).

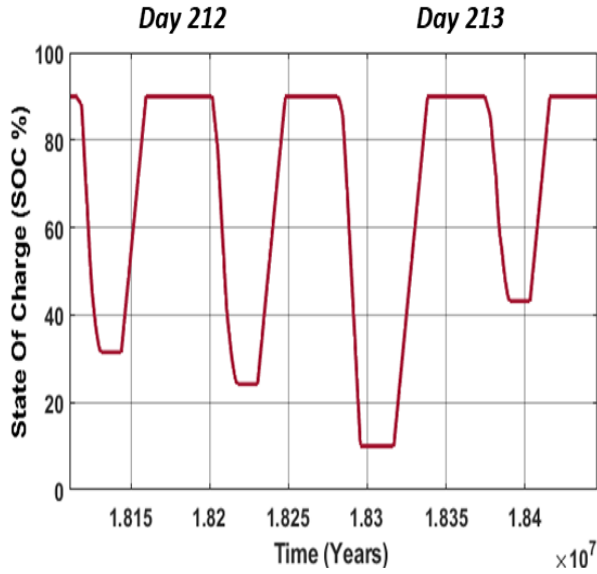


Fig.6. Charge and discharge cycle of the battery during the day.

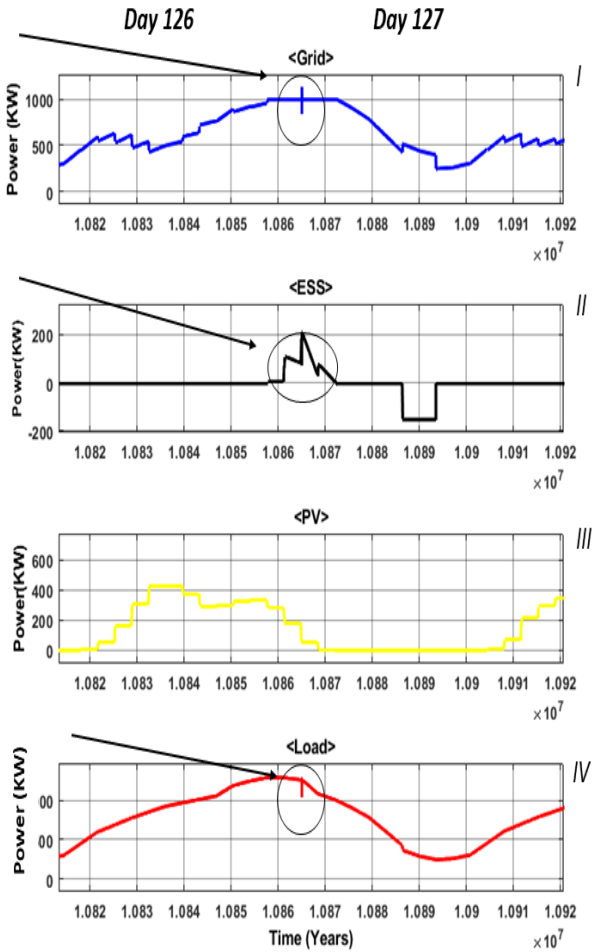


Fig. 7. Active power variation of Grid-Storage-PV and loads during a transient caused by a fault at bus B4.

IV. CONCLUSION

In this paper, our attention was focused on an ESS storage system connected to a distribution system in a micro-grid as an effective means of energy compensation and independence from centralized production.

The simulation results allowed us to analyze several points and aspects related to smart grids and to address the energy efficiency issue. The idea was to use batteries to store energy. The aim was to decide, by means of a control system, whether when the battery is charged its power will be used to contribute to electricity production at peak times or during a fluctuation of photovoltaic energy and to limit the exceeding of the permissible value dictated by the grid operators. In addition, this approach reduces the depletion of fossil fuels, lowers the carbon imprint and reduces energy expenses. In addition, the battery control and management system demonstrates the performance provided by micro grids in terms of optimal energy management.

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