IMPROVEMENT OF UNCERTAIN POWER GENERATION OF ROOFTOP SOLAR PV IN PEA DISTRIBUTION SYSTEM BY USING BATTERY STORAGE ENERGY MANAGEMENT SYSTEM

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ABSTRACT

As the distribution grid increasingly integrate rooftop solar PV, their power generation outputs are uncertain due to the solar radiation, panel temperature, passing cloud, and v-i characteristic operating level. Therefore, PV grid connected system would require a supplementary source to ensure more stable PV power generation, particularly during cloudy periods. In this paper, the battery storage energy management system (BS-EMS) is investigated to decrease the effect of sudden power generation variation of rooftop solar PV. The balance of power between rooftop solar PV and battery storage is studied by dynamic control of the BS-EMS to maintain stable output power at the point of common coupling (PCC). Simulation results for a 24 hour period indicate the performance of battery storage system capable of smoothing out grid connected rooftop solar PV generation under various conditions.

1. INTRODUCTION

At present, solar photovoltaic (PV) systems have been increasingly installed worldwide. Because of development of PV technology and economy of scale, the efficiency is improving whereas the price is dropping significantly. In fact, grid connected solar PV output is intermittent due to the variation of solar radiation, panel temperature, passing cloud, and v-i operating characteristics. This will affect the power quality at the point of common coupling (PCC)[1].

If the solar PV penetration is large, a large fluctuation of power can affect the utility grid operation in maintaining the constant frequency and voltage. Therefore, a solution to decrease the effect of PV output power fluctuation is to integrate battery storage energy management system (BS-EMS), which can deliver stable solar PV power output to the grid during the daytime.

This paper investigates the capability of BS-EMS of grid connected solar PV which can decrease the sudden output power generation from PV and maintain stable output at PCC in grid-connected PV system under various conditions. The lithium ion battery model considering the minimum and maximum state of charge is used here.

The modeling represents the power balance between PV system, battery storage and load by dynamic control. The results for a 24-hour period will be simulated in PSCAD and examined the capability of battery storage in a system which compose of solar PV with battery storage and linear load connected to the grid[2]and[3].

The organization of the paper is as follows. Solar rooftop PV with battery storage energy management system (BS-EMS) is presented in section 2. The BS-EMS for PV grid connected model is shown in section 3. Simulation results on BS-EMS are given in section 4. Finally, conclusion is given.

2. SOLAR ROOFTOP PV WITH BATTERY ENERGY STORAGE MANAGEMENT SYSTEM

Figure 1 shows the variation of solar radiation during cloudy day at Lopburi solar PV plant.

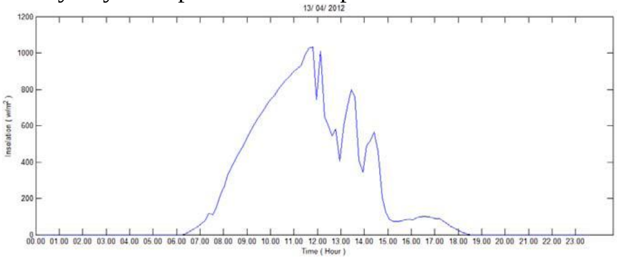

Figure 1 Solar insolation Level (Lopburi solar PV plant)

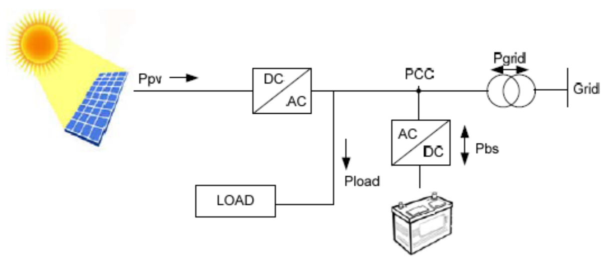

Figure 2 Typical Configuration residential load, Solar PVs and BS system connected to the grid

Figure 2 illustrates grid connected solar PV with battery storage management system. Solar rooftop PV connecting BS system at PCC point can provide a constant power output to the grid during daytime. Using BS-EMS,

- It can mitigate the intermittency of solar PV generation in real time
- It can store the electricity during off-peak and sell it back to the grid during on-peak period[4].

BS-EMS in conjunction with a BS system will be implemented to support the solar PV (Figure 2) in providing stable power output at PCC during different periods throughout the day. The entire PV system will work according to the BS-EMS. Constant output at PCC will be produced as a result of dynamically controlling the BS under various operating conditions. Here, the control scheme of the total system (solar PV, BS, residential load and grid) is based on the following power balance equation:

$$\sum_t P_{Grid}(t) = \sum_t [P_{pv}(t) + P_{BS}(t) - P_L(t)]$$

The operation of BS system (Figure 3) will be dynamically controlled based on the following charge and discharge characteristics

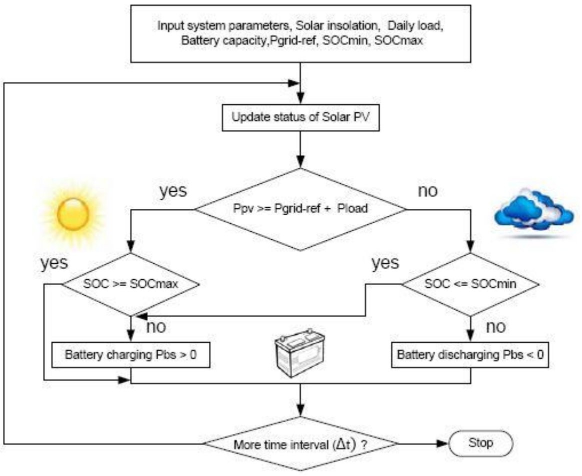

Figure 3 Flow chart of BS-EMS Operation

3. BATTERY STORAGE ENERGY MANAGEMENT SYSTEM MODEL

As shown in Figure 4, solar radiation and cell temperature are input data to PV to convert into current and voltage by PV panel, connected with series diode and parallel capacitor. The function of the diode is to block output from reverse side and capacitor is used for charging the output from PV before delivering the power to the load.

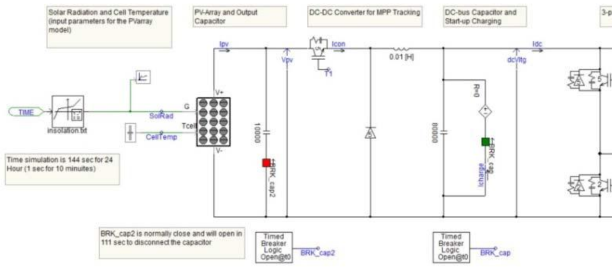

Figure 4 PV System Electrical Circuit

Figure 5 presents the battery system used here. The electrical circuit shows the battery source connected with series diode and parallel capacitor. The function of DC/DC converter is to convert from low voltage to high voltage before changing to AC voltage by inverter.

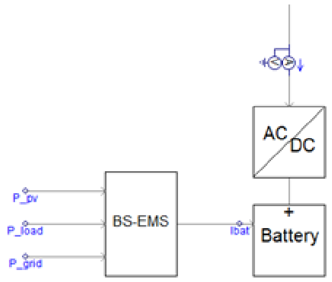

Figure 5 BS-EMS Model in PSCAD

The load system is varied following load profile and the grid connected PV system is shown in Figure 6.

The PV array is connected to the input of a DC-DC converter. The DC-DC converter is a buck converter that is controlled using the MPPT system. The output of the converter is the input to the three-phase inverter.

The three-phase inverter is controlled using a simple P and Q controller.

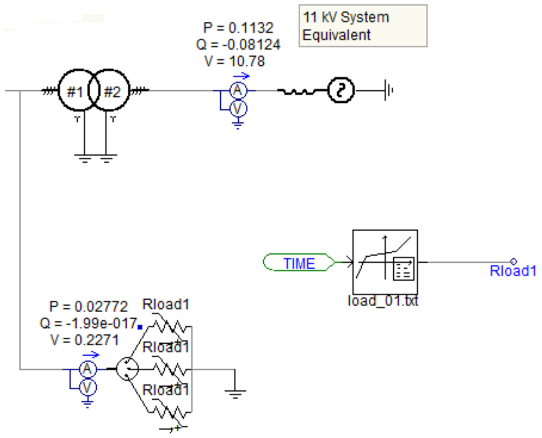

Figure 6 Load System and Grid Connected PV System

4.SIMULATION RESULTS

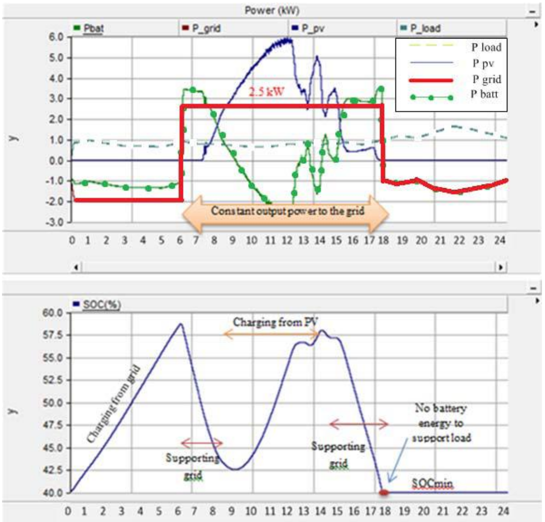

Figure 7 Case I : Basecase , Simulation results with battery capacity of 40 kWh

Figure 7 illustrates the performance of BS-EMS which can maintain constant power output during the daytime. Note that the grid is feeding the residential load and partially charging the battery during 00.00 – 06.00 a.m. due to a lower tariff during off peak period. Simulation results show that BS-EMS can maintain a higher near stable power output of 2.5 kW. The stored energy will be delivered to the grid during 06.00 a.m. – 06.00 p.m. A battery energy profile demonstrates the battery charge power from the grid (00.00-06.00 a.m.) and the store energy will be feed to the grid in daylight (06.00 – 09.00 a.m. and 03.00 – 06.00 pm.) to maintain the constant output power. Besides, the PV power will be charged to battery (09.00 a.m. – 03.00 p.m.). For the simulation of Figure 7 shows the battery can fully discharge at 06.00 p.m. at SOC $_{min}$ = 40%

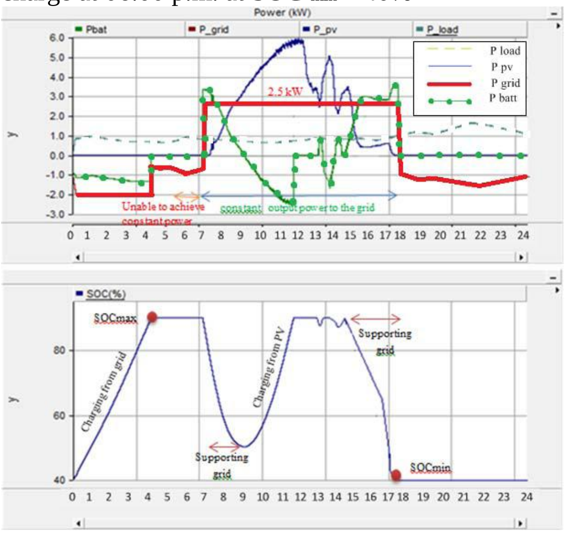

Figure 8 Case IIa : Impact of small battery capacity is 10 kWh

Figure 8, to examine the effect of small battery capacity on the operation of BS-EMS, the battery capacity will be decreased to small size of 10 kWh and presented in figure 8 In this case, the battery can charge power from grid only the period of 00.00 – 04.00 a.m. and fully charge at 04.00 a.m. The capability of BS-EMS is unable to achieve the constant output power at 2.5 kW only one in the morning (06.00-07.00 a.m.). Then the system is still able to continue support a constant output power to the grid from 07.00a.m.- 06.00 p.m. A battery energy profile demonstrates the battery charge power from the grid from 00.00 a.m. to 04.00 a.m. and the store energy will be feed to the grid in daylight (07.00 – 09.00 a.m. and 02.30 – 06.00 p.m.) to maintain the constant output power. Besides, the PV power will be charged to battery (09.00 – 11.00 a.m.) until it reaches SOC max = 90%. For the simulation of Figure 8 is shown the battery can fully discharge at SOC min = 40% at 06.00 p.m. and the grid will continuing support the load until 00.00 a.m.

According to Figure 9, to examine the effect of large battery capacity on the operation of BS-EMS, the battery capacity will be increased to large size of 60 kWh. In this case, capability of BS-EMS can maintain the constant output power at 2.5 kW to the grid during period of daytime (06.00 a.m. – 06.00 p.m.). A battery

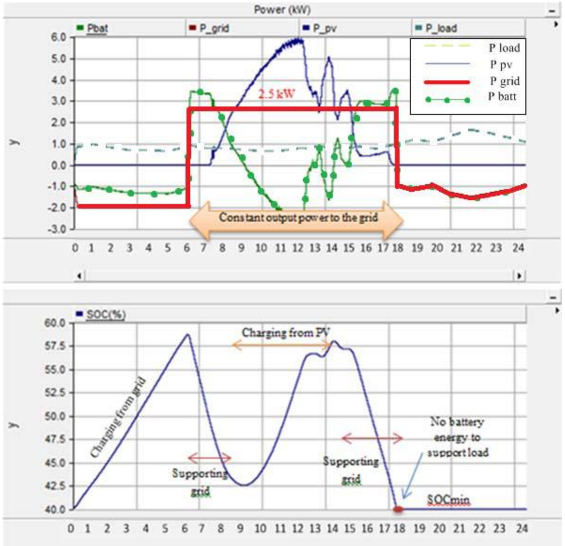

Figure 9 Case IIb : Effect of large battery capacity is 60 kWh

energy profile demonstrates the battery receives power from the grid (00.00 – 06.00 a.m.) and discharges to the grid in two time which are the period of 06.00-09.00 a.m. and 02.30 – 06.00 p.m.. The battery charges power from PV from 09.00 a.m. to 02.30 p.m. until it reaches SOC = 58%. Then the grid will continuously support the load until 00.00 a.m.

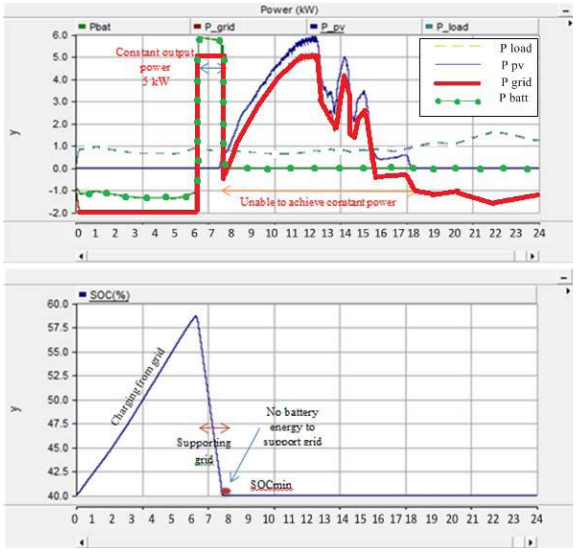

Figure 10 Case IIIa : Effect of sending large output power is 5 kW to the grid

According to Figure 10, the operation of BS-EMS is able to provide the constant output power of 5 kW only a few periods (06.00-08.00 a.m.). Another time, BS-EMS cannot provide the constant output power to the grid all daytime as it reaches SOC min = 40% during 08.00 a.m. until 00.00 a.m. A battery energy profile presents the battery receive power from the grid (00.00 – 06.00 a.m.) and send the stable output power of 5 kW to the grid from 06.00 to 08.00 hour until it reaches SOC min = 40%. Then the battery has no energy to support the grid. On the other hand, the grid feed power for upporting load from 08.00 a.m. to 00.00 a.m.

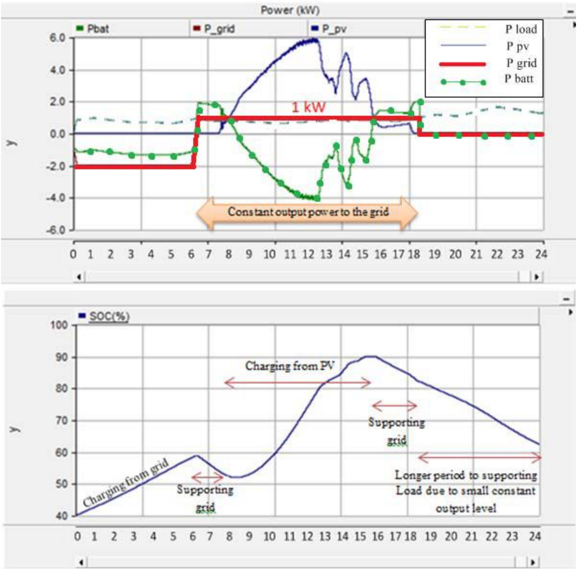

Figure 11 CaseIIIb: Effect of sending small output power is 1 kW to the grid

According to figure 11, operation of BS-EMS can continue to feed the stable output of 1 kW to the grid since 06.00 a.m. until 06.00 p.m. A battery energy profile presents the battery receive power from the grid (00.00 – 06.00 a.m.). Then battery discharges power to the grid in the period of 06.00 – 08.00 a.m. The Power of PV is charged from 08.00 a.m. to 03.00 p.m. Then the battery feed power to the grid and load until 00.00 a.m. In this case, the battery cannot fully discharge because of small battery.

From Figure 10 and 11 show the energy profiles of battery which have different results. The simulation results present the effect of large constant output power. If there is more power sent to the grid, the battery will drop to SOC_{min} rapidly. From this case, the battery can no longer support grid and the system is not able to complete constant output power to the grid. For sending small output power, the battery can achieve the constant output power and has longer period to support grid and load.

5. CONCLUSIONS

A BS-EMS operation is efficiently providing a stable power output to the grid during daytime time after feeding a residential load. This BS-EMS is modeled by PSCAD program which is appropriate for transient analysis. Based on simulation results, the conclusions are:

1. The BS-EMS performance can control the BS system for charge/discharge operations. This process can provide a constant power output to the grid during the daytime.
2. The small battery capacity results in less BS-EMS performance because the BS system can supply a constant power output only from 07.00 a.m. – 06.00 p.m. which is one hour less.
3. For larger constant output power of 5 kW, the BS-EMS is able to supply a constant power output only 2 hours during 06.00 a.m. – 08.00 a.m. because of insufficient energy storage capacity. The energy of battery reaches SOC_{min} rapidly within 2 hours.
4. The BS-EMS can supply limited stable outputs power during system peak load hours. For instance,
During 01.00 p.m. – 02.00 p.m. peak load, the BS-EMS can supply a constant power output of 27.0 kW.
During 01.00 p.m. – 03.00 p.m. peak load, the BS-EMS can supply a constant power output of 13.5 kW.
During 01.00 p.m. – 04.00 p.m. peak load, the BS-EMS can supply a constant power output of 9.0 kW.
5. The BS-EMS can purchase power from the grid during off peak period at a lower electricity price and sell a stable power output at a higher price back the grid during system peak load period, leading to net profit and system peak load reduction.

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