Simple and Efficient Control Method for Battery Charging in High Penetration Photovoltaic Array

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Abstract - *Energy storage system(ESS) such as (storage batteries, ultra-capacitors, flywheels) has been considered as one of the best ways to achieve stability in electrical grids. It requires to avoid disturbances and fast load changes, as well as stores the surplus of electrical energy. Typically, storage batteries are used as buck up energy for PV systems. So, in this paper, the ESS system is adapted to design and simulate high penetration photovoltaic array. The lead acid batteries are utilized and the required number of batteries is determined. Also, the charging control algorithm is proposed. Software Matlab/Simulink 2017b is considered to model the entire PV system. The results reveal the simulated battery charging control system works efficiently. The proposed algorithm also shows a good response to drive the rated load for one day alone in the worst case.*

Key Words: Photovoltaic system, depth of discharge, charging control algorithm.

1. INTRODUCTION

The solar cell system (SCS) has been received much attention for electrical energy generation. It is clean, safe, reliable and economic. However, SCS faces many problems such as penetration, disturbances and fast load changes. To solve these problems, the control system approaches have been investigated.

For the last decade, many researchers have worked on designing a control system approaches. For instance, two control approaches based on Finite control set model predictive (FCS-MPC) are designed to control and stabilize the Microgrid that consists of multiple distribution generators [1]. The methods of power electronics control are presented for a PV system that is grid connected [2]. The performance of lead batteries in energy application are overviewed. In addition, the paper explains how they are adapted for storage system [3]. An intelligent charger fed by the solar system due to the latest technologies is utilized to deal with the study, simulation, and designing of a storage system. The different condition of load, battery state of charge (SOC) and ambient effect are considered to improve the charging condition of batteries [4].

This work is organized to include an introduction in section 1. In section 2, the Sizing of Battery Energy Storage System (BESS) is explained and how each part is modeled by using its equations. Operation mods of batteries storage are classified and explained in section 3. In section 4, the system Simulink and results are presented in section 5, followed by a conclusion in section 6.

2. SIZING OF BATTERY ENERGY STORAGE SYSTEM (BESS)

In this paper, the lead-acid battery type will be selected. The rated capacity(Ah) required of the BESS for the PV system is determined after complete calculations of the following equations [5]:

Battery storage $(S_{bat}) = (N_d \times E_L) / (DoD \times \eta_o)$ ... (1)

And

$\eta_o = \eta_r \times \eta_v$ ... (2)

where:

N_d: Period of time(days) that the system be able to operate on batteries alone with no input from other generation sources

E_L: Daily demand for energy in kWh
η_o: Efficiency of the system components
η_r: Efficiency of the charge controller
η_v: Efficiency of the inverter
DoD: The depth of discharge is commonly used to give an accurate description of how deeply the battery is discharged. This parameter is important and usually used to analyze battery life [6,7].

A higher DoD value is an indicator of more energy drawn from the battery throughout the discharge period, in contrast, leads to reduce the lifetime of the battery. Thus, there is always a trade-off between the quantity of power extracted from the battery through the discharge period and the lifetime of the battery [6].

$$DoD = 1 - SoC \quad \dots (3)$$

where:
SoC: State of Charge means the percentage of how fully the battery is charged, and it's equal to the inverse of DoD

$$\text{Battery capacity } (C_{bat}) = S_{bat} / V_{bat} \quad \dots (4)$$

where:
V_{bat}: Voltage at the terminal of battery banks(V)

2.1 Mathematical Calculations of Battery Storage Size

In this paper, the BP5170S PV panel model of type monocrystalline is proposed to build a PV array consists of 3600 PV panels organized as 240 parallel string PV panels and each string has 15 series PV panels.

The maximum voltage and current of the PV panel at the standard test condition (STC) are:

V_{mp} = 36 V, I_{mp} = 4.72 A

The terminal voltage of the PV array is 540 V

And, the current output from PV array is 1132.8 A

Hence, PV array capacity = 611.7kW

The battery banks can be sized after performing equations (1-4). The equations' parameters values are given as presented in Table 1.

Table -1: Battery bank equations' parameters

Equations' parameters	Character	Value
Daily demand for energy in (kWh)	E_L	14680.8kWh/day
Period of time in days	N_d	1day
The efficiency of the charge controller	η_r	0.92
The efficiency of the inverter	η_v	0.9
Depth of Discharge	DoD	0.75
Battery storage	S_{bat}	23640.5kWh
The voltage at the terminal of battery banks	V_{bat}	1000V
Battery capacity	C_{bat}	23.64kAh

Based on mathematical calculations are given in Tabel1, a battery of capacity 3000 Ah, 2Vis selected.

Accordingly, the battery storage system is constructed in eight parallel branches, each branch has a series string of 500 batteries, so the total size of batteries become of 4000.

3. OPERATION MODES OF BATTERY STORAGE

In this paper, the charging control algorithm for battery storage has been proposed to achieve energy management. The flowchart for the proposed charging control algorithm of battery storage is shown in Fig. (1). The following operating modes clarify the procedure of the proposed algorithm.

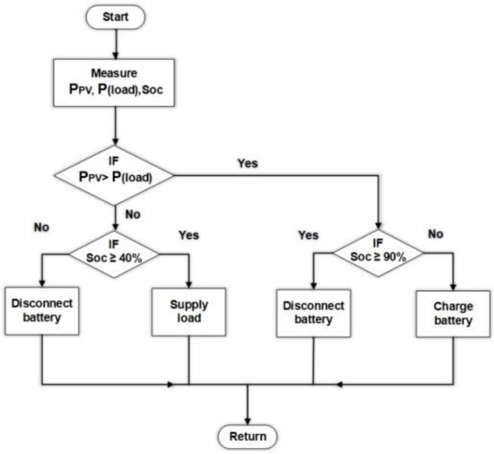

Fig. (1): Flowchart of charging control for a battery storage system

Mode1: The first mode activates when the power generated from PV array is greater than the demand power at the same time the rate of SoC ≥ 90%, Accordingly, stop the charging process by disconnect the battery banks.

Mode2: The second mode starts also when the harvesting energy from PV array is more than the demand power but the rate of SoC<90%, thus the battery charging process is achieved. Throughout this manner, the power delivered from PV array not only provided energy to the loads but also supply the surplus of power so as to charge the battery banks.

Mode3: The third mode initiates when the harvesting energy from the PV array is less than demand power at the same time the rate of SoC ≥ 40%, So the battery banks will supply backup power to the loads besides the power provided by PV array.

Mode4: The last mode activates when the harvesting energy from the PV array is less than demand power and the rate of SoC < 40% simultaneously, thus at this state the battery banks are disconnected in order to keep the life of the battery banks as long as possible.

4. SIMULINK MODELS OF CHARGING CONTROL FOR BATTERY STORAGE SYSTEM

The Simulink models of charging control for battery storage system consisting of the main two parts, the first one concerns the relation between PV power production and electrical demand and the second part regulates the charging and discharging process of the batteries based on SoC status. With these two parts together, the proposed algorithm can be worked properly as desired. Figs. (2) - (4) show Simulink models for charging control of the batteries.

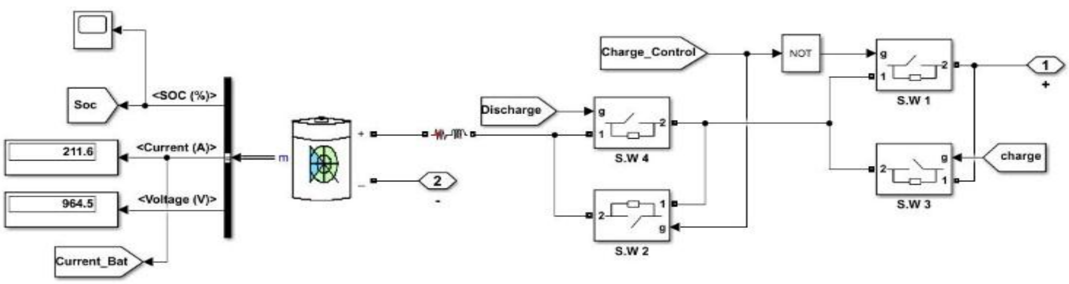

Fig. (2): Simulink model for a battery storage system using Matlab/Simulink

For simulation purposes, the ideal switches are utilized as switching devices in an electrical circuit for battery storage system instead of circuit breakers as shown in Fig. (2), because the breaker block will not operate properly for DC circuits in Matlab/Simulink.

The initial state of the ideal switches which are (S. W1=1, S. W2=0, S. W3=0, S. W4=1) is arranged in this way to make the proposed design operates correctly.

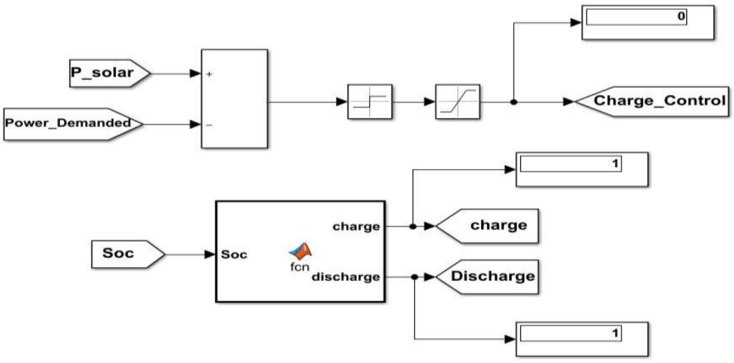

Fig. (3): Charging control algorithm for battery storage system using Matlab/Simulink

```
% Charging control for battery storage based Soc Conditions
function [charge,discharge] = fcn(Soc)
charge=0;
discharge=1;
if(Soc>=90)
    charge=0;
 discharge=1;
else
    if(Soc>=40)
        if(Soc<90)
        charge=1;
        discharge=1;
        end
    else
    if(Soc<40)
        charge=1;
        discharge=0;
    end
    end
end
```

Fig. (4): Charging control for a battery storage system based SoC using a script file

It can be seen the simplicity of the proposed design of the battery storage system as compared to the state of the art of the conventional methods that utilized power electronics converters, for instance, bidirectional DC-DC converter which already requires high efficiency. Also, the proposed design avoids switching losses and harmonics contents which inherently exists by switching process, hence power quality is improved, especially when the produced power is transferred to the utility grid through an inverter.

5. SIMULATED RESULTS FOR ESS

By combining the Simulink models of both ESS, PV array, boost converter, and MInC algorithm, as illustrated by Fig. (5), the simulation results for ESS under different modes of operation can be achieved. Figs. (6) -(8) show results for several states of operation.

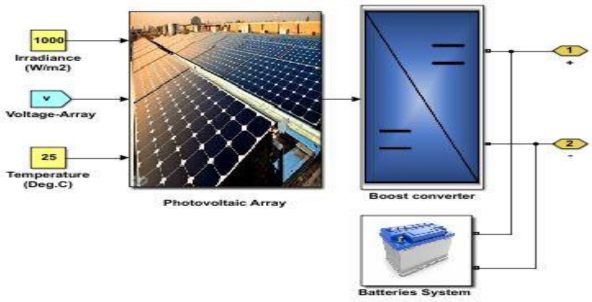

Fig. (5): PV array combines with both boost converter and battery system using Matlab /Simulink

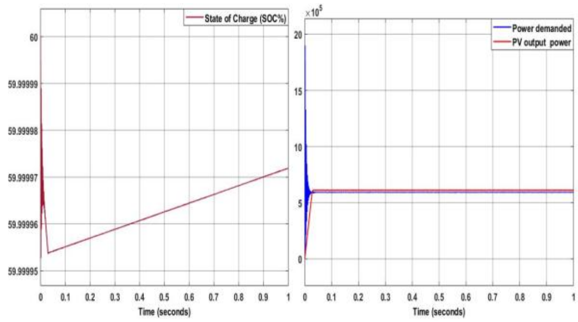

Fig. (6): PV output power and the load demanded during charging

The figure above displays the charging mode for batteries storage. The validity is achieved at SoC of 60% and when PV array power at maximum rate STC condition. The simulation result shows that the charging process is started when PV array producing power greater than power demanded even with a slight rate.

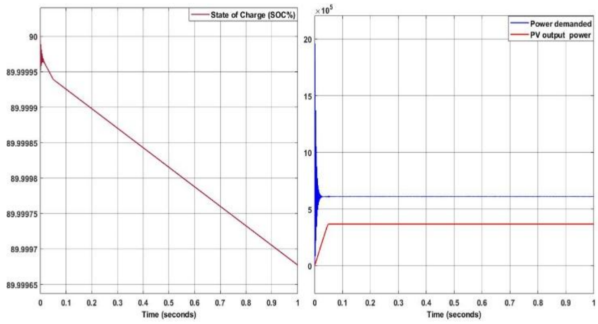

Fig. (7): PV output power and the load demanded during discharging

Fig. (7) demonstrates discharging mode of battery storage. The verification is performed by creating suitable conditions to activate the discharging process. When the solar radiation of 600W/m^2, the ambient temperature of 25℃, and in order to decrease the power produced by PV array which became 367.5kW which is less than power demanded, with at SoC of 90%. The simulation results show that the discharging process for battery storage is working properly as required.

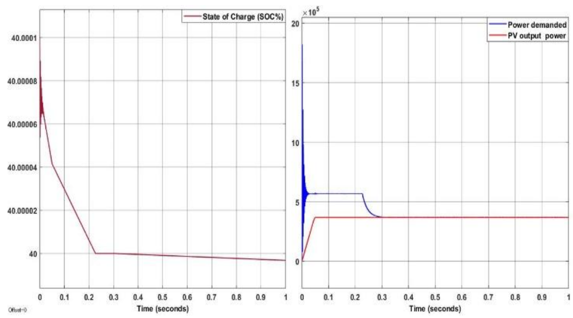

Fig. (8): PV power and the load demanded during discharging and when SoC<40%

Fig. (8) illustrates the discharging mode of operation at PV array power of 367.5kW and SoC is a little bit greater than 40% with the same power demanded of the previous test. When SoC became lower than 40%, the battery storage is disconnected according to the control procedures which suggested. Also, the results present a slight decreasing in SoC of battery storage after the disconnected process and this is denoting to the natural self-discharge of the battery.

The battery discharging curve at 610A is presented in Fig. (9).

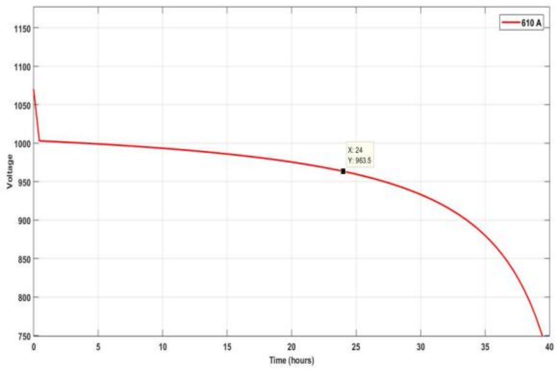

Fig. (9): Battery discharging curve

From Fig. (9), it is clear that the voltage of the battery banks drops to 963.5V after 24 hours at discharging current of 610A, also at this point the SoC is 40%, which indicate the sizing of battery storage is perfect and sufficient to operate a load of 600 kW for one day alone in the worst case.

3. CONCLUSION

Based on the simulated results, the charging control system for battery storage operates efficiently as anticipated and according to the proposed algorithm. Also, it has some flexibility, allowing some adjustments to be done in the future to meet the new requirements.

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BIOGRAPHIES

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