# Application of Moving Averages for PV power smoothing using Battery energy storage system

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**Abstract:**

With the increase in demand of electrical energy, it becomes imperative to switch towards Renewable energy generating system (REGS) because of limited availability of conventional sources of energy. Major disadvantage of REGS includes its intermittency. Energy storage systems (ESSs) can play a major role in compensating the intermittent nature REGS. In this paper, A Photovoltaic (PV) module along with Battery energy storage system (BESS) is modeled using MATLAB/Simulink. Moving Average methods along with its proposed modification is implemented to check the possibilities of power smoothing.

**Keywords-** Battery energy storage system (BESS), Energy storage systems (ESSs), Photovoltaic (PV), Renewable energy generating system.

## 1. Introduction

The uncertainty and intermittency of renewable sources of energy is the major challenge in grid integration. Sudden voltage rise, fluctuations, and increase in power losses are some of the impacts, reducing the reliability and efficiency of the system. [1] Energy storage system (ESS) can be used to overcome the intermittency of the RGS and improve the reliability of the system by storing the energy when demand is less and compensating when the demand is greater than generated power. Almost every ESS is proved to be cost effective. Various ESSs includes BESS, Flywheel, Superconducting magnetic energy storage (SMES), supercapacitors (SCs). Advantages of energy storage system includes energy transfer , Network sharing, Kinetic advantage.[2] With the major improvement being made in battery chemistries, Battery will play a important role in renewable grid integration and it can be used as a new utility technology[3] Lead-acid battery is the most widely used technology and is used in much power system application because of its low cost as compared to other battery technology available. Lithium ion batteries have low-weight, high energy and power density and low cost but the battery lifetime degrades with deep battery discharge. [4]Lithium ion battery module is used in this paper to implement battery module. Some authors also described Vanadium-Redox battery (VRB) as the future of battery technology because of its high efficiency, huge capacity and negligible self discharge. However it is not cost effective at the moment and major drawback of VRB is its low efficiency when operated in less than 20% of its rated power.[5]

A Hybrid energy storage system (HESS) can be used to overcome the disadvantages of each ESS used such as BESS and SCs, BESS and SMES, SCs and SMES. [6]

BESS have variety of application in solar power generation such as ramp rate control, frequency control, and reactive support. It can also be used to enhance economic profile of the system. [7]- [9] A coordinated control algorithm for mitigating voltage and frequency deviation is also developed for more desirable control.[10]Determining the power and energy capacity of BESS for particular PV penetration is also discussed by some authors. Method to determine capacity of BESS to compensate for PV fluctuations to obtain flat voltage profile is developed. [11]

In this paper BESS is used to compensate for the fluctuations in PV power generated. A smooth PV curve is produced by using power smoothing algorithms. Various smoothing algorithms can be used such as Low pass filter( LPF), Median Method, Moving average (MA) method, Ramp Rate Control(RRC) Method. LPF method can be used for simulation purpose but it is not desirable for practical implementation. [12]

MA method is used in this paper. One of the major disadvantages of MA method is delay/advance .Several modifications have been implemented in MA method to obtain the best results possible. Modeling of the system in MATLAB/Simulink is described in Section-2. Proposed Algorithm with simulation graphs are described in section-3. Results are discussed in section-4. Conclusions with necessary points are presented in section-5.

## 2. Modeling

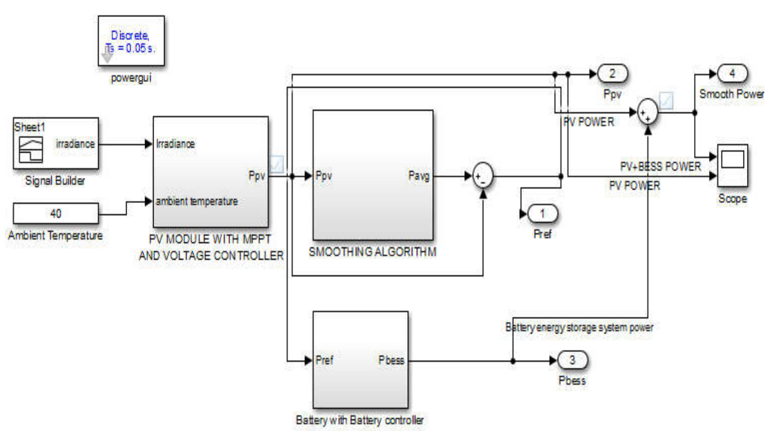


Fig. 1 Simulink Model of Solar Power smoothing with battery energy storage system

2.1. Irradiance: Figure.3 shows the Irradiance data from Brisbane, Australia recorded on 1/1/2015. This data is used for the simulation of implemented system.

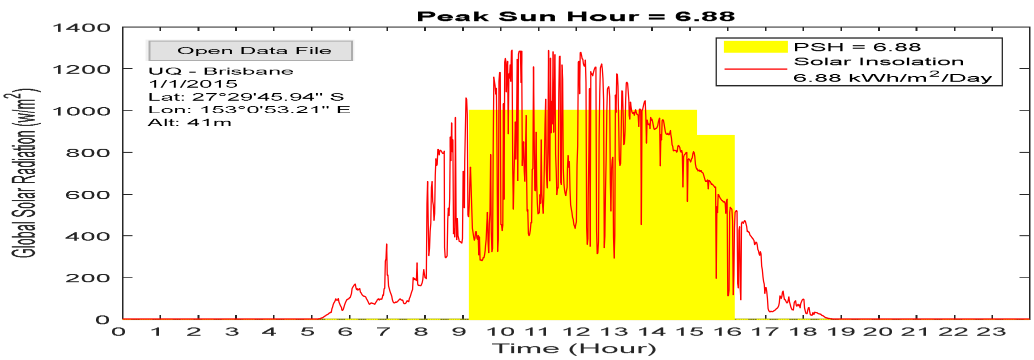


Fig. 2 Solar Radiation V/s Time plot used in simulation

2.2. Pv Module: A PV array with MPPT and voltage controller is designed. Perturb and observe method is used for MPPT.

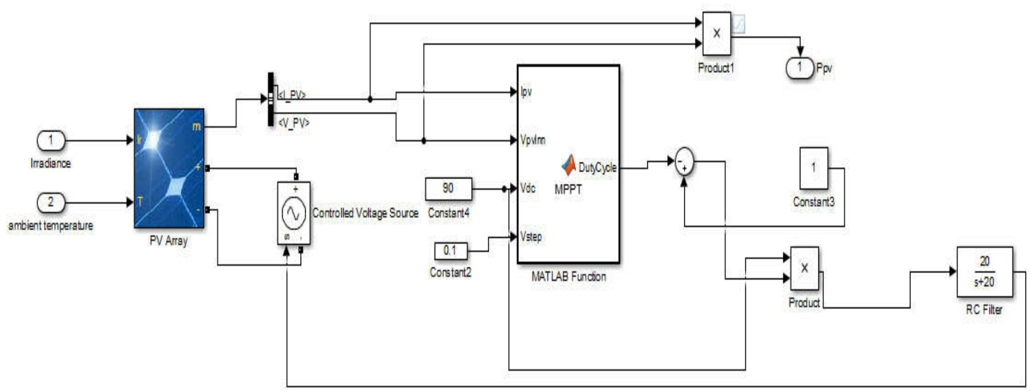


Fig. 3 Simulink model of PV module

2.3. Battery energy storage system:Lithium ion battery module with nominal voltage 500V is used.

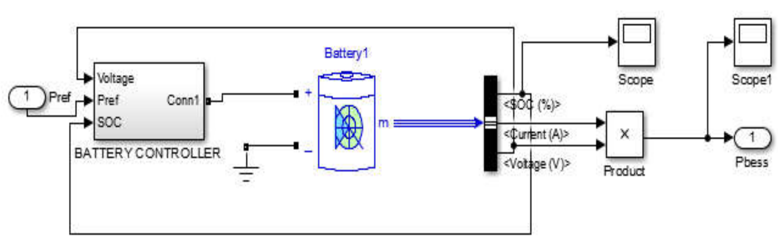


Fig . 4 Simulink Implementation of Li-ion Battery configuration with Battery Controller

2.4. Battery Controller:Battery Controller for controlling the battery current and SOC according to the reference power generated by smoothing algorithm is designed.

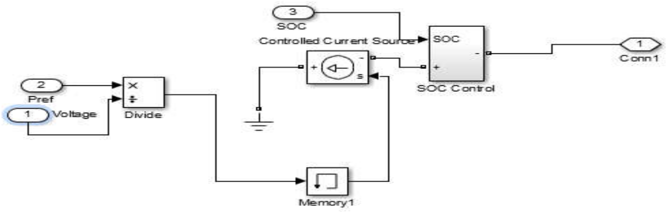


Fig. 5 Battery Controller

2.5. Smoothing algorithm:Moving Average Algorithms with different window sizes and modifications are used and results are compared for best possibilities. A reference power is obtained by difference of Average smooth power and solar power. Resulting difference is the required battery power.

## 3. Proposed Algorithms

Simple Moving Average (SMA): A window based moving average algorithm is proposed for solar power smoothing. Window size can be varied according to the variability of generated solar power. Let 'A' be the moving average of the power curve with window size n. The mathematical expression for the required moving average at point 'i' is given by

= (1)

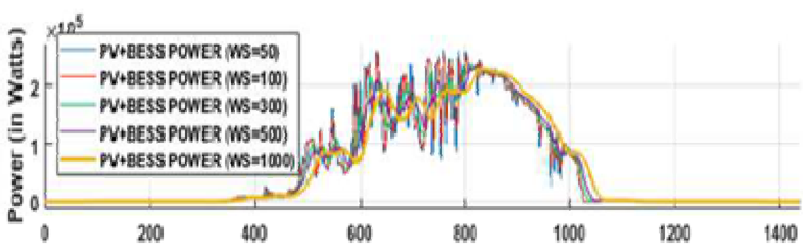


Fig. 6 Generated PV power and Smooth Power Curves with different window sizes

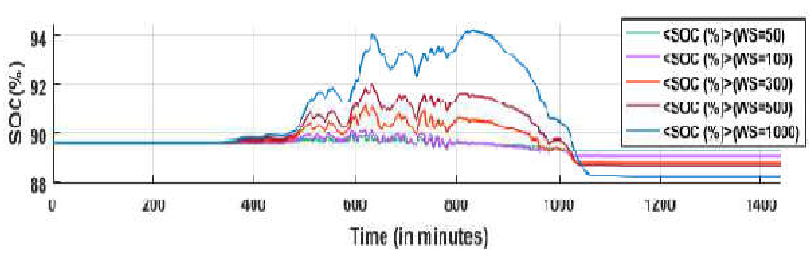


Fig. 7 Variation of SOC with different window sizes

*Double Moving Average (DMA):* Simple moving average algorithm is used twice to obtain even smoother Curve. The required double moving algorithm be 'B' will be given by

= (2)

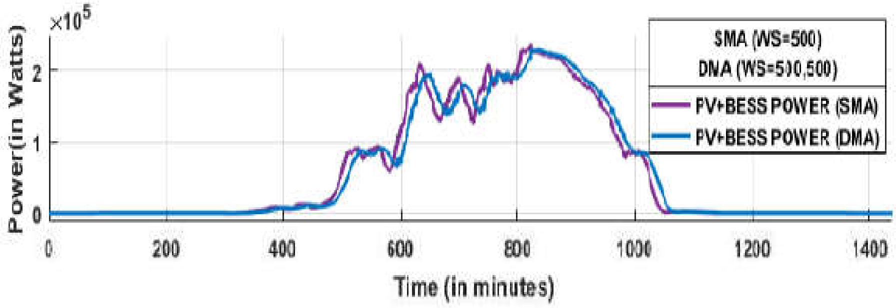


Fig.8 Comparison of Power smoothing with Simple moving and Double moving average

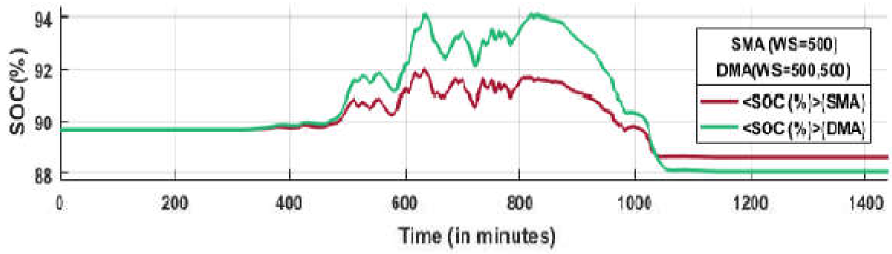


Fig .9 Variation of SOC with Simple moving and Double moving average algorithm

Fig. 9 shows Power smoothing using DMA, Blue-Curve shows that smoothing is better with DMA but the delay increases and SOC falls rapidly.

*Simple and Half Moving Average (SHMA):* In this method the average is obtained for entire window size as well as for the second half window period to resolve the delay/advance problem. Let the average for entire window size be u and the second half of window size is v. Then the resulting moving average would be 2v-u.

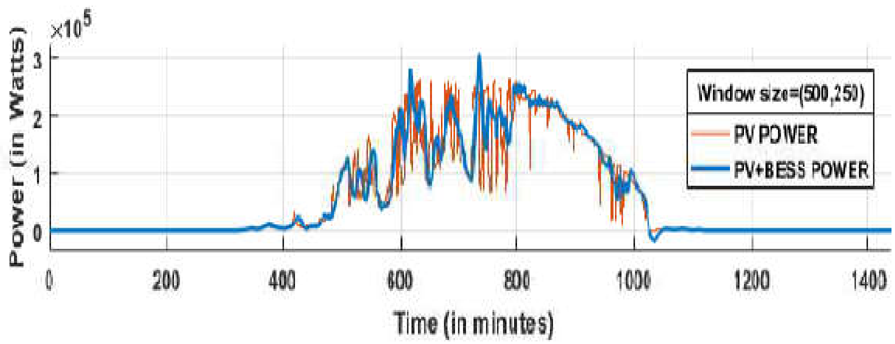


Fig .10 Simple and Half moving average based power smoothing

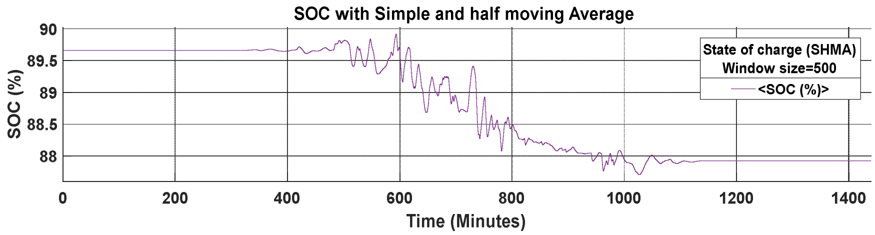


Fig .11 Variation of SOC with Simple and Half moving average

## 4. Results

a. Simple moving Average Algorithm: As the window size increases extent of smoothing increases but there is also an increase in delay which leads to increase in battery size.
b. Double moving Average Algorithm: Smoothing is better but delay increases further.
c. Simple and half moving Average Algorithm: Smooth curve follows the power curve and delay/Advance problem is resolved, but several peaks can be observed and end of the day SOC decreases remarkably.

## 5. Conclusion

Simple moving average and double moving average can be used with lower window sizes for power curves with minor fluctuations but it does not give satisfactory results for PV power curves on a variable day because of increase in delay. The Size of the battery increases with increase in window size. Simple and half moving average resolves the delay problem but several peaks can be observed in the smooth curves leading to increase in size of the battery. End of the day SOC also decreases which means battery will be in discharged state for next day operation. This is the major disadvantage of this method.

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