A Distributed and Partially Centralised Form of Energy Storage System Model to Reduce Energy Curtailment of Renewable Energy System

C.Rahul Guptha, Kothuri Ramakrishna, K. Mahesh

***Abstract:** In today's scenario, the difference between energy demand and load consumption is increasing at a rapid pace. The rising difference is faster than the development of technology, but the resources required to generate electrical energy are depleting. So, new technologies are being adapted to generate electrical energy i.e., using renewable energy sources. But the drawback of renewable energy sources is that the magnitude of energy output is not controllable compared to conventional energy sources. This uncontrollable nature results in curtailment of energy generated at the non-conventional source side integrated to the existing electrical grid. This curtailment of energy leads to waste of energy and the capital to generate the energy. So a secondary source of energy is required to effectively utilize the energy from renewable energy sources, which is the Energy Storage System (ESS). The ESS is used to store excess energy from renewable energy sources, but the question arises when you have to choose only one type of system which is simple enough to setup and can act as solution to the complex problems. Usually, the form of energy storage system adopted is the Battery Energy Storage System (BESS) even this kind of system has some challenges in integrating with the grid and the renewable energy sources. In this paper, the disadvantages of the energy curtailment, and a model is proposed by addressing the challenges of conventional or concentrated BESS and to overcome them. A simulation of the switching techniques during charging and discharging to show the switching based on SOC of the individual BESS units comparing with the other BESS units.*

***Keywords:** Distributed BESS unit, Centralised data logging, Regional Control Unit (RCU), Central Control Unit (CCU)*

I. INTRODUCTION

Electrical energy is being used most widely around the world irrespective of race, caste, and creed for a long period. The electrical energy has become a necessity in human life, therefore its availability must be efficient and continuous. Due to technological advancement, the load demand is rising steadily and at a faster pace, but the systems that generate electrical energy not able to quench the thirst for the demand for electrical energy.

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New technologies emerged to generate electrical energy other than conventional means such as using fossil fuels. These new energy sources being Solar, Wind, Tidal and many more. These energy sources are known as non-conventional energy sources as they produce electrical energy different from the conventional means such as Thermal and Hydel power plants. The electrical demand around the world is irregular, the irregularity is due to the needs, climate, and environmental conditions. The paradigms of the new type of energy generation is effective utilisation of the generated energy from the distributed sources. The distributed sources being majorly solar PV power plants, and wind energy plants. The energy generated from these sources are by utilising natural resources such as solar irradiation and wind [1] energy respectively, which can't be controlled by the humans. So, the energy generated can't cope up with the load variations such as sometimes the energy becoming too excessive to utilise and sometimes being too less. As these energy sources are integrated with the existing power grid to supply energy to the load side, such variations might affect the working of the equipment connected to the grid and in some cases, it might even damage the entire grid. If the generated power is more than the load demand, then the Renewable Energy System must cut-0ff from the grid. This condition is known as curtailment of power. So, a secondary source must be considered to balance out the energy variations in the grid with 24*7 availability and economic in installation and operation. An Energy Storage System (ESS) such as battery is the easily available option as the solution to the paradigm of the non-conventional energy sources. Even the ESS have their drawbacks such as requiring large amount of space for installation and the cost become more for a single power plant handler as the number of battery units are more to compensate the difference in energy. In this paper, I have proposed a de-centralised and distributed BESS model as a solution to the paradigm of the non-conventional energy sources integration eliminating the large amount of space required for the installation of the BESS. If the BESS unit is to be installed at the non-conventional energy generation end, it requires lot of circuitry such as large wiring, transformer units, complex control circuitry and involves data logging of the energy unit at that point and cannot be able to compare with the data of another units. When the BESS unit is connected at the load end we can supply the energy to the consumers even in case of grid disruption.

The data can be logged into a centralised unit to compare it with energy status of other BESS unit and can control the energy flow in and out of the grid.

Challenges in using Conventional BESS units:

1. The conventional BESS unit are usually of concentrated type installed at the Renewable Energy generation end.
2. The energy stored data co-ordination with the other units require additional equipment which the company or individual installing the Renewable Energy plant might not be favourable in it.
3. As it is installed at the generating end any faults or malfunctions occurred at the generating equipment will entirely cut-off the energy supply from the BESS units.

Advantages over conventional BESS units:

1. As the BESS unit is distributed over the entire grid at the load side, any fault at the generating unit will not affect the functioning of the secondary source i.e., reliability of continuous supply.
2. In India as the distribution is done at the regional level, the control of the BESS unit is intergrated to the existing Regional unit and the data logging can be done at the central unit to improve the power flow algorithms of the BESS units based on the generating patterns.
3. The charging and discharging can be controlled based on the charge of the BESS units.
4. When compared to conventional BESS units the maintenance, data logging and monitoring can be divided among different departments of which some might be existing.

II. OBJECTIVE FUNCTION

$$\boldsymbol{P_g(t) - P_d(t) = \sum_{i=1}^{n} \Delta P_{bi}(t)} \qquad \textbf{(1.1)}$$

The objective function depicts that the difference in power generated and the load demand at a particular instant of time will be balanced by the number of BESS units distributed over the entire electric grid at the load points. The distributed BESS will be managed based on the parameters such as availability of generated power more than the load power, SOC of the BESS, and environmental conditions.

III. DESCRIPTION OF THE MODEL

The model is designed such that the BESS individual unit is placed at the load end with a communication and control device. The communication device is used to interact with a decentralised control unit dispersed over the region based on the number of the BESS unit setup at the load ends. The BESS unit only interacts at the time of switching, the control unit sends a command to the communication control unit at the BESS unit to connect it to the grid either to supply the energy to the grid or to consume the energy from the grid, while there is lack of power in the grid and while the power is excess in the grid. The model is distributed and partially centralised in nature. It's partially centralised in nature because the control units are dispersed over the entire grid of a country. The switching is based on the parameters of the SOC of the BESS unit and the power difference in the grid.

The Regional Control Units (RCU) provide the control of the powerflow in and out of the grid of the BESS units at the load side with in that region. The BESS units are placed based on the cluster of energy patterns in a small area of a region. Only the RCU's provide the control over the energy flow and the Central Control Unit (CCU) used only for data logging of the energy control over the time to improve algorithms of the energy flow of the BESS unit.

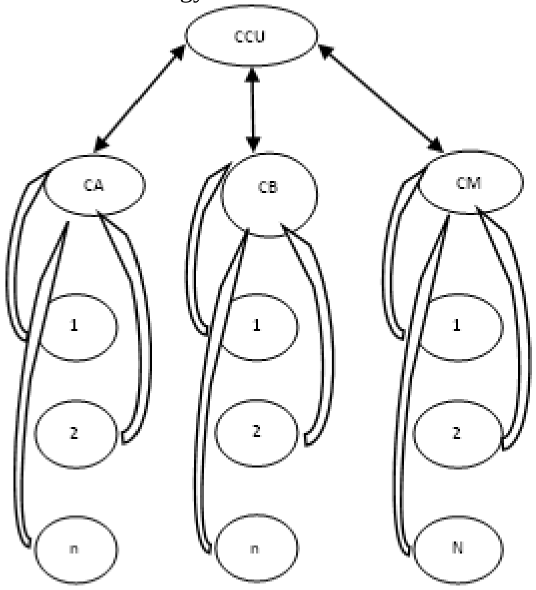

Fig.1. Model of the distributed and partially centralised unit

CCU – Central Control Unit
CA, CB, …. CM = Regional Control Units of m- regions
1,2,3….n = BEES units

Switching Algorithm (Charging):

As the system is a combination of individual units, there should be an algorithm to control the power flow into individual BESS and its working.

Step 1 :

$$\text{Let,}\boldsymbol{P_g(t) - P_d(t) = m} \qquad \textbf{(1.2)}$$

Step 2 : Check if the value of m is zero or non – zero. If the difference in power at a particular instant of time is zero then there is no need to switch on BESS, if it is zero then the power should flow into the BESS.

Step 3: Check the SOC of the batteries of the individual BESS units. Based on the value of SOC of the battery units then the state of the BESS is decided.

Case (i) : If SOC = 100% then the BESS unit should remain idle.

Case (ii) : If SOC ≠ 100% then

(a) The system whose SOC value is less than or equal to 20% should be given the first priority
(b) The system whose SOC value is greater than 20% but less than 50% should be given the second priority.

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(c) The system whose SOC value is greater than 50% should be given the last priority.

Note: The value of SOC mentioned is the average value of SOC of an individual BESS unit.

Step 4: Switch ON the individual BESS units as per the instructions in Step 3. After that repeat Step 2 for different values of time with Δt as an incremental value within a given period. If the value of m is zero stop the process and maintain the BESS units at idle position, if the value is non-zero continue the process until the value of m is zero.

Switching Algorithm (Discharging):

During discharging it should be taken care that the power inflow should be absent.

Step 1: Check for the difference of power i.e., from equation 1.2 if the value of m is less than zero then only discharging should start.

Step 2: After checking the value of m, check for the SOC of the BESS unit

Case (a) : If the SOC of the BESS unit is greater than or equal to 20% then only discharging should commence.

Case (b) : If the SOC of the BESS unit is less than 20% the discharging should be stopped.

Step 3: After the period of discharging is completed then check for the value of m from equation 1.2, if it is greater than zero then charging of the BESS unit is commenced until the value of m is zero.

IV. SIMUALTION OF THE PROPOSED MODEL

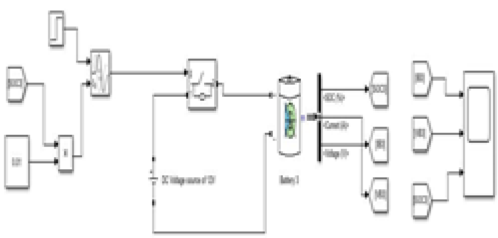

Fig.2 Battery charging model

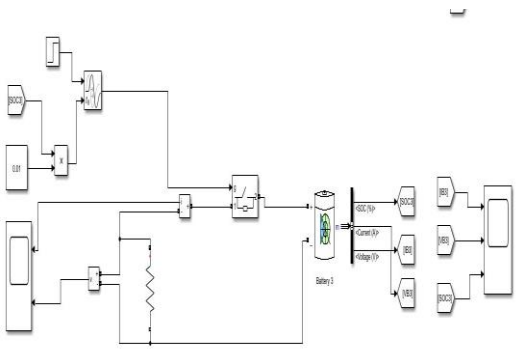

Fig.3 Battery discharging model

The simulation model during charging consists of three battery units of same configuration representing individual BESS unit with different SOC values. A sample charging model is shown in the Fig.2. The simulation model during discharging consists of three models of same configuration with different SOC values. A sample discharging model is shown in the Fig.3. The values of SOC of the batteries during charging and discharging are 20%, 50% and 80%. During charging the value of 'm' from equation 1.2 is greater than zero and during discharging the value of 'm' from equation 1.2 is less than zero. The specifications of battery units are Li-ion battery with 7.2 V and 5.4 Ah, a DC voltage source during charging 12V and resistance during discharging 1 ohm.

V. RESULTS AND DISCUSSION

Graphs of Voltage, Current and SOC of battery units during charging

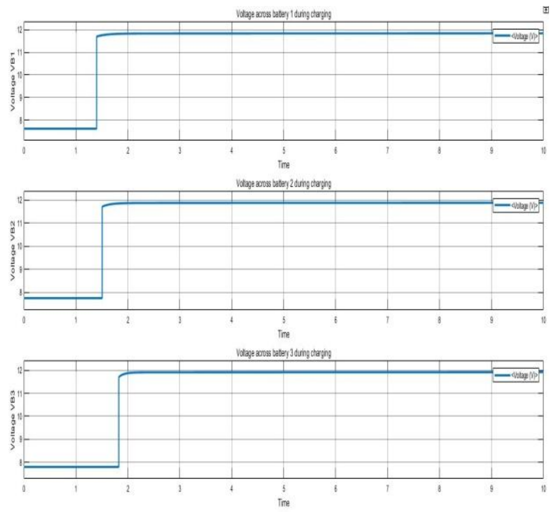

Fig. 4. Voltage of the batteries during charging

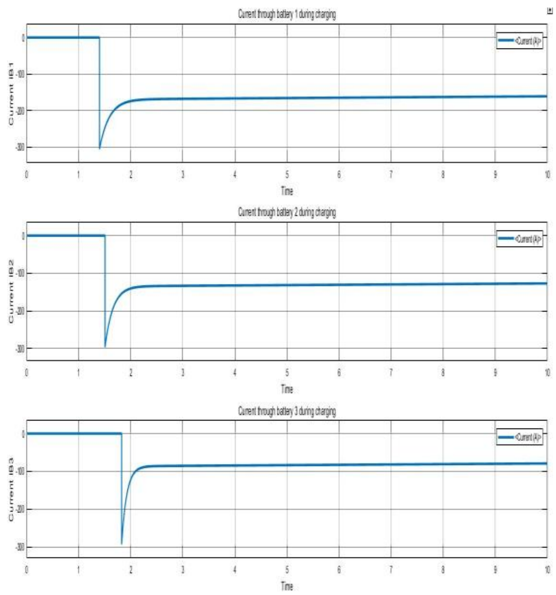

Fig. 5. Current of the batteries during charging

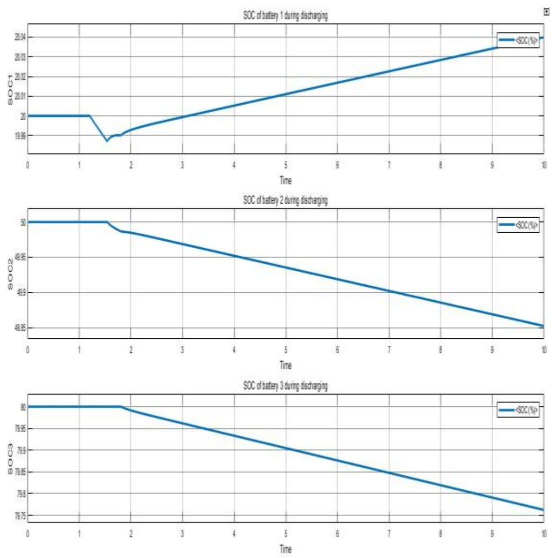

Fig. 6. SOC of the batteries during charging

Graphs of Voltage, Current and SOC of batteries along with Voltage and current across load during discharging.

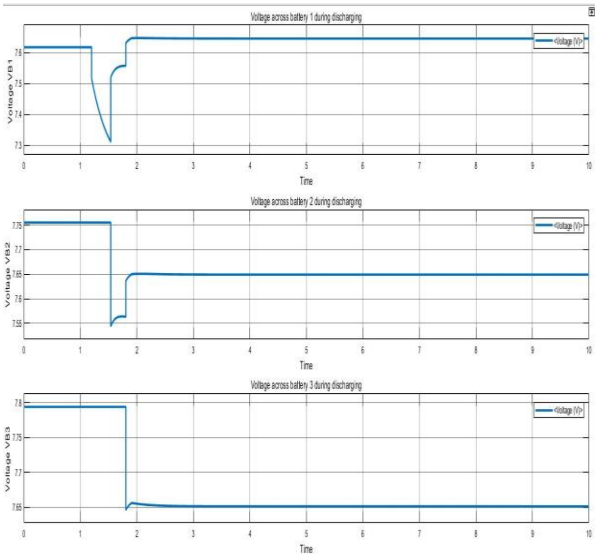

Fig.7. Voltage of the batteries during discharging

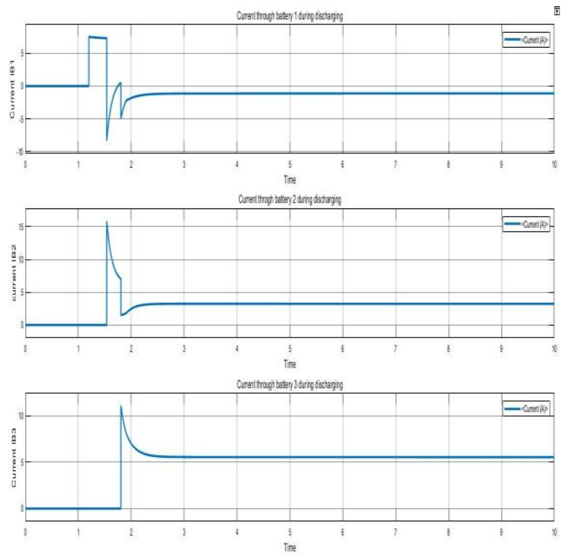

Fig.8. Current of the batteries during discharging

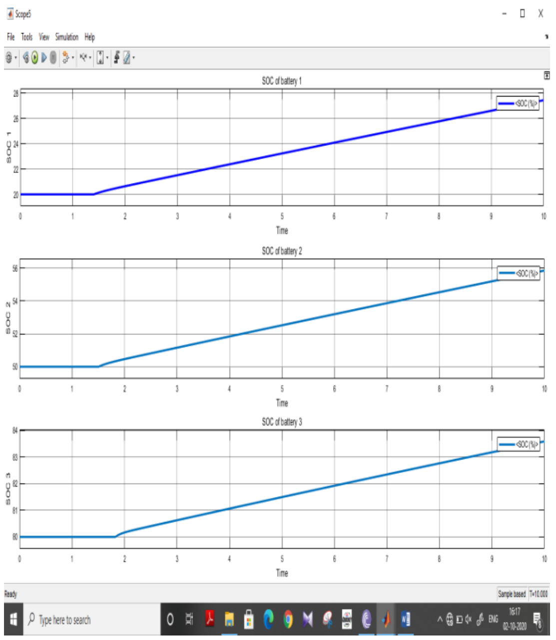

Fig. 9. SOC of the batteries during discharging

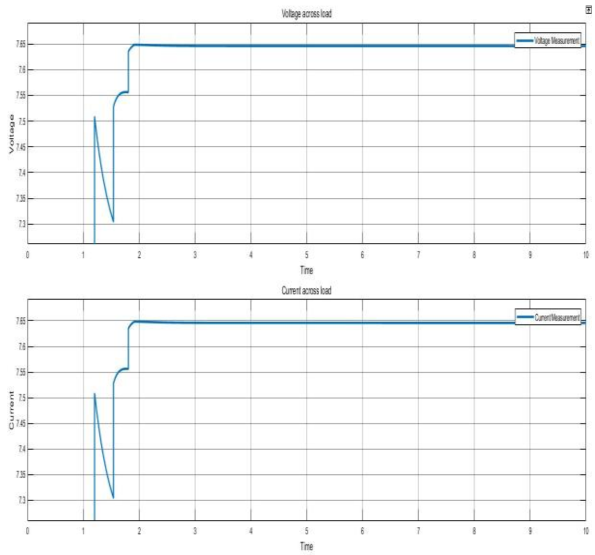

Fig.10. Voltage across the load and current through the load during discharging

Table 1. Comparision of conduction periods of the battery units during charging and discharging.

Parameters	Charging	Discharging
Battery 1 (SOC = 20%) Duration of voltage and current from/into the battery	1.4 sec – Start 10 sec – end Conduction period = 86%	1.2 sec – Start 10 sec – end Conduction period = 88%
Battery 2 (SOC = 50%) Duration of voltage and current from/into the battery	1.52 sec – Start 10 sec – end Conduction period = 85%	1.56 sec – start 10 sec – end Conduction period = 84.4%
Battery 3 (SOC = 80%) Duration of voltage and current from/into the battery	1.84 sec – Start 10 sec – end Conduction period = 82%	1.82 sec – start 10 sec – end Conduction period = 82%

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The graphs of voltage, current and SOC of the battery show the delay in switching based on SOC i.e., smaller the SOC smaller the delay, larger the SOC larger the delay. The values of conduction periods of battery units during charging and discharging are tabulated in Table.1 showing that higher SOC units have lower conduction periods and vice-versa. This shows that the conduction period of the distributed and partially centralised BESS units can be controlled based on the situation to reduce energy curtailment.

VI. CONCLUSION

We can conclude that the battery conduction period can be varied based on SOC to match up with the energy generated from renewable energy supplied at the load end. This model not only curtails energy generated but also ensure continuity in supply of power as the BESS units are installed at the load end, and can overcome the challenges of conventional BESS units and increase the battery life.

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