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Battery Energy Storage System for Grid Connected Power System

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Abstract

The electrical energy generated through renewable energy sources is stored and dispatched to the grid using the Battery Energy Storage System (BESS). This study presents a Battery Energy Storage System (BESS) with special design and power conversion system. The power conversion system is provided with an automatic power converter and controller enhanced by a faster response. This study also deals with power quality, grid frequency regulation, energy dispatching, renewable energy smoothing and leveling, reliability improvement and arbitrage. The simulation shows the best performance of the BESS for various step changes in the plant set point. This is a grid level BESS project simulated using MATLAB/SIMULINK model.

Keywords: *Power quality, smoothing, leveling, SIMULINK, MATLAB*

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INTRODUCTION

The fast development of wind power in recent years has been producing major economic and environmental benefits to the world. Meanwhile with the increasing amount of wind energy integrated, its fluctuations are bringing great impact on the power grid. Energy storage, due to its flexible operation, is considered as a promising technical route to effectively mitigate the wind power fluctuations. Among various types of energy storage, Battery Energy Storage (BES) is more suitable to accommodate a high penetration of wind power in terms of its power and energy density [1]. However, BES has a disadvantage of short life cycles. Smoothing fluctuating wind power needs regular charge/discharge, which considerably limits the lifetime of BES. Characterized by long life cycles and high power density, super-capacitor (SC) is the possible complementary energy storage to BES. Also, SC is able to track fast short-term variations of wind power. However, the capacity of SC is limited due to manufacturing technology and costs. Therefore, a hybrid battery-SC energy storage system becomes an effective option for wind power smoothing.

For the hybrid battery-SC energy storage system, the main task is to optimally control and coordinate the battery and SC [2]. According to their different characteristics, SC is to handle fast, high-frequency power fluctuations while battery reports lower frequency fluctuations. In current literatures, a low-pass filter (LPF) has been used by BES to smooth the wind power. The high-frequency part of wind power is compensated by BES and the remaining part passes through the filter to the grid. This idea tells us that the power-sharing between battery and SC could be carried out by a high-pass filter (HPF). The power given to the battery-SC system could be decomposed by an HPF to realize the power allocation between battery and SC. Hence, the time constants or cut-off frequencies of the filters become serious factors to the filtering effectiveness.

The current work usually sets the parameters randomly without taking system economy in to consideration. Therefore, this study proposes a complete optimal coordinated control strategy for a battery-SC system in the application of smoothing wind power output. In this study, the third-order Low Pass Filter and High Pass Filter are used to smoothen the wind power and allocate power between battery and SC. With the objective of reducing the system's depreciation costs, the proposed method fixes the optimal cut-off frequencies of the filters and power-sharing between battery and Super Capacitor while satisfying the requirement of wind power integration.

BATTERY ENERGY STORAGE SYSTEM

Wind is one of the most interesting renewable resources among all other renewable energy resources. This source of energy cannot dispatch directly to the grid since it is intermittent and unpredictable. To cope with this natural challenging behavior of this rich source of energy, different kinds of researches have been done to transform it into a usable power when it is in grid-connected mode.

Many kinds of approaches are there regarding this subject. Some of these approaches have been carried out to smooth the output power of the wind power plant. On the other side, other researches focus on improving the revenue of the wind farm plant regardless of the smoothness of the wind power. The works on smoothing the fluctuation of wind power output for its secure connection to the electricity grid vary from simple schemes of charging and discharging the BESS as the wind power output goes beyond a minimum or maximum threshold to much more refined control algorithms [3–5]. Specifically, the authors applied an optimal control method on the linear model of the lead-acid battery to smooth the generated wind power and make it dispatched on an hourly basis.

On the other side, some studies have been carried out to make wind power more commercial than before by having the wind power generation under control in a grid-connected mode using BESS. Thus, BESS enables wind energy to be stored at off-peak demand times when the price of electricity is relatively low. Such stored energy can be sold simultaneously with the power generated by the wind farm at peak demand times when the price of electricity is significantly high. Such dispatch schedules are highly dependent on firstly, the electricity market rules of the region where the power is sold, and secondly, the constraints of the type of the BESS.

Little attention has been showed to increase the controllability of wind farm dispatching with BESS in the area of control system, bearing in mind the electricity price and optimal usage of Battery Energy Storage System with the goal of providing the possibility of trading with a competitive electricity market while smoothing the power signal to improve the quality of the power which is sent to the grid. In, an intelligent control system is applied to control and manage the wind power injected to the grid using a BESS in time shifting applications. In some previous models which have been studied, batteries assumed as simple storages that linearly store the energy and had not taken into account the losses inside the battery due to chemical reactions. We consider a model created based on its inputs and outputs and consider a model which shows some nonlinear actions of the battery during charging, discharging and storing period.

POWER QUALITY

Power quality is frequently defined as the grid's ability to supply a clean and stable power supply. In other words, power quality perfectly creates a perfect power supply that is always available, has a pure noise-free sinusoidal wave shape, and is always within voltage and frequency tolerances. However, with increasing and varying energy demands from several industrial processes, many loads regularly impose disturbances on the grid, making deviations from these ideal conditions are frequent.

Electric power quality involves voltage, frequency, and waveform. Good power quality can be defined as a steady supply voltage that stays within the prescribed range, steady AC frequency close to the rated value, and smooth voltage curve waveform (resembles a sine wave). In general, it is useful to consider power quality as the compatibility between what comes out of an electric outlet and the load that is plugged into it. The term is used to describe electric power that drives an electrical load and the load's ability to function properly. Without the proper power, an electrical device (or load) may malfunction, fail prematurely or not operate at all. There are many ways in which electric power can be of poor quality and many more causes of such poor quality power.

SLOW RESET REGULATOR

The theory of the slow reset regulator (SRR) has been used for some FACTS, devices such as static VAR compensators (SVC) or static compensators (STATCOM) for the system voltage control applications [6]. Many SVC or STATCOM applications need an appropriate reactive power (VAR) reserve capacity to handle dynamic events to increase system voltage stability [7–9]. The slow reset regulator in the SVC or STATCOM control system is used to slowly return the SVC or STATCOM to a pre-defined value of reactive power output following a contingency so that it has a maximum reactive reserve for dynamic events. These applications are based on a voltage regulation (V-control) technique, that is, the voltage reference set point of the SVC or STATCOM is gradually being adjusted by the SRR as required.

For some of the transmission applications and renewable energy integrations where the Q-control mode is executed to control the VAR flow at a local and remote point in the transmission systems, a distributed approach to reactive power control and voltage support implements STATCOM systems in multiple locations where voltage issues and reactive power shortage exist [10-15]. This type of STATCOM system design is mentioned to as the Distributed STATCOM (DSTATCOM) system. This distributed method attains redundancy which removes the total loss of reactive power support in the area in the occasion of a single unit being taken out of service [16-20]. In these applications, several devices in one DSTATCOM system or multiple DSTATCOM systems in one area are usually coordinated to share the necessary compensation level through droop controls [21-25]

We deliberate in these paper, different simulation models that were configured, parameterized, and tuned to represent BESS and that were based on real project engineering experiences. Hence, this study provides useful guidelines for the use of these new models to represent a BESS for power system analysis.

SYSTEM DESIGN

A 3-phase source is considered as an input and connected with the circuit breaker followed by the transformer (Figure 1). The transformer is connected to the grid through the controller. The battery system of 2 MW, 12 MWh is connected to the grid. The battery system can be regulated using frequency regulation, voltage regulation, and phase shift. The feedback from the grid is provided to the controller (Figure 2).

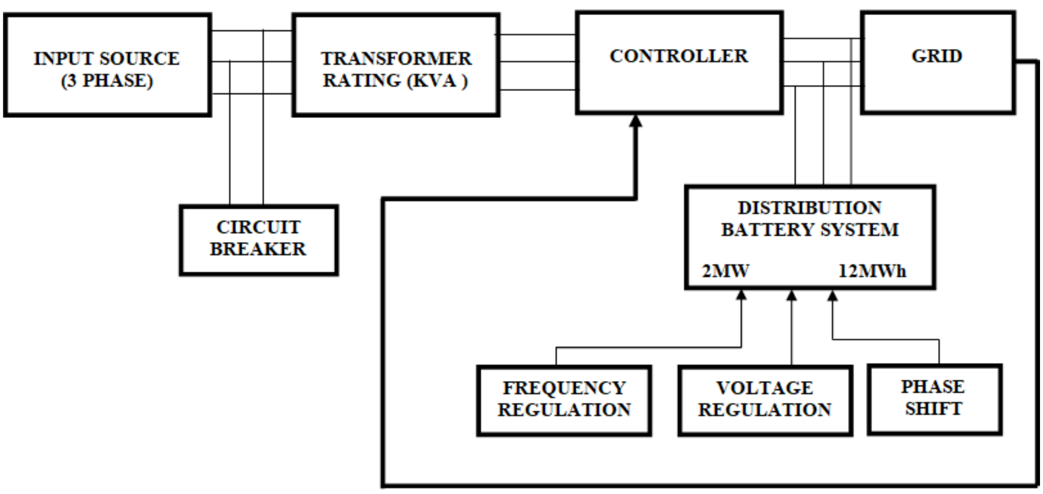

Fig. 1: *Block Diagram of Proposed BESS.*

RESULTS

The simulation has been designed and simulated by providing various set points with some percentage changes; then charging and discharging of the battery is evaluated and the results are recorded (Figures 3–5).

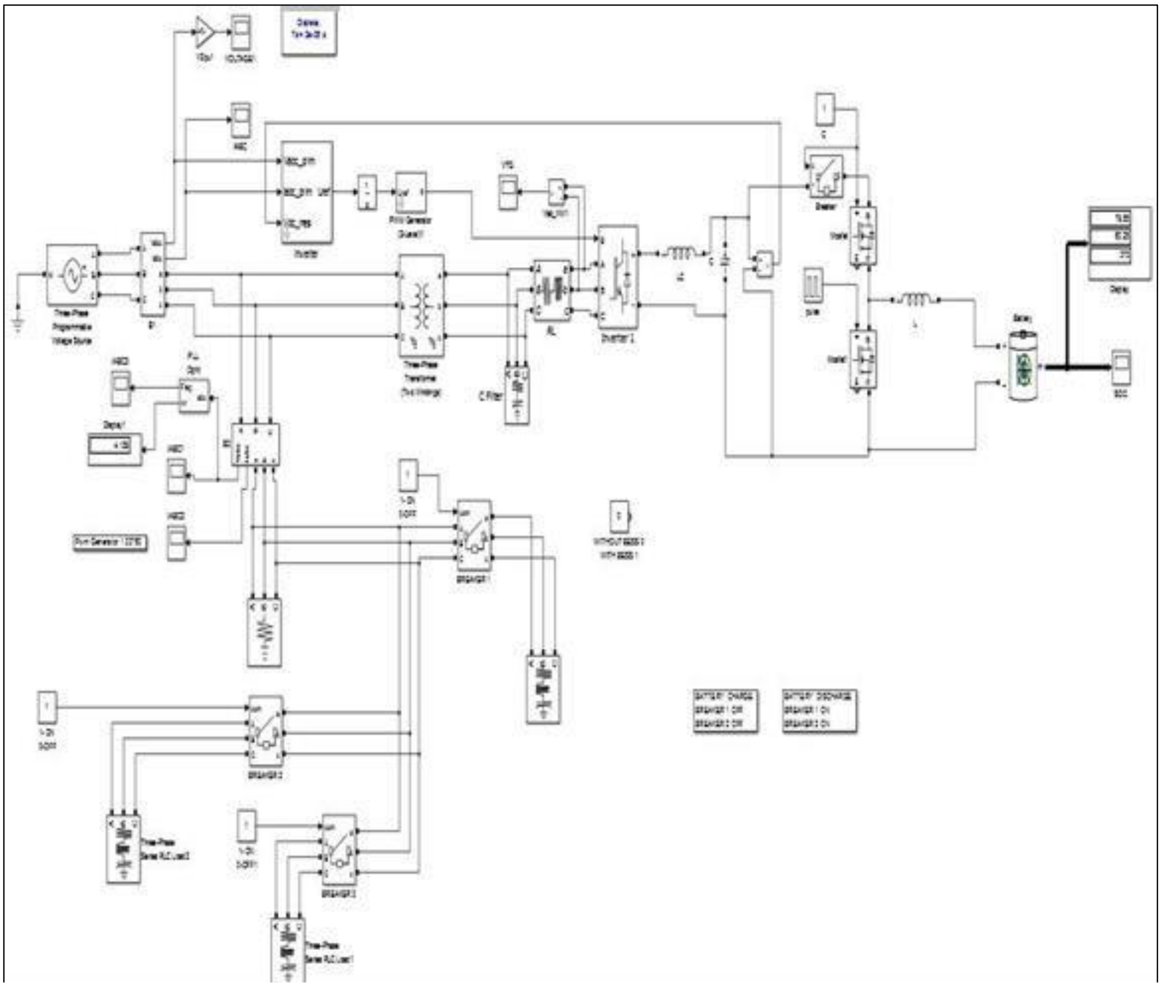

Fig. 2: *Simulation of WECC Generic Plant Controller.*

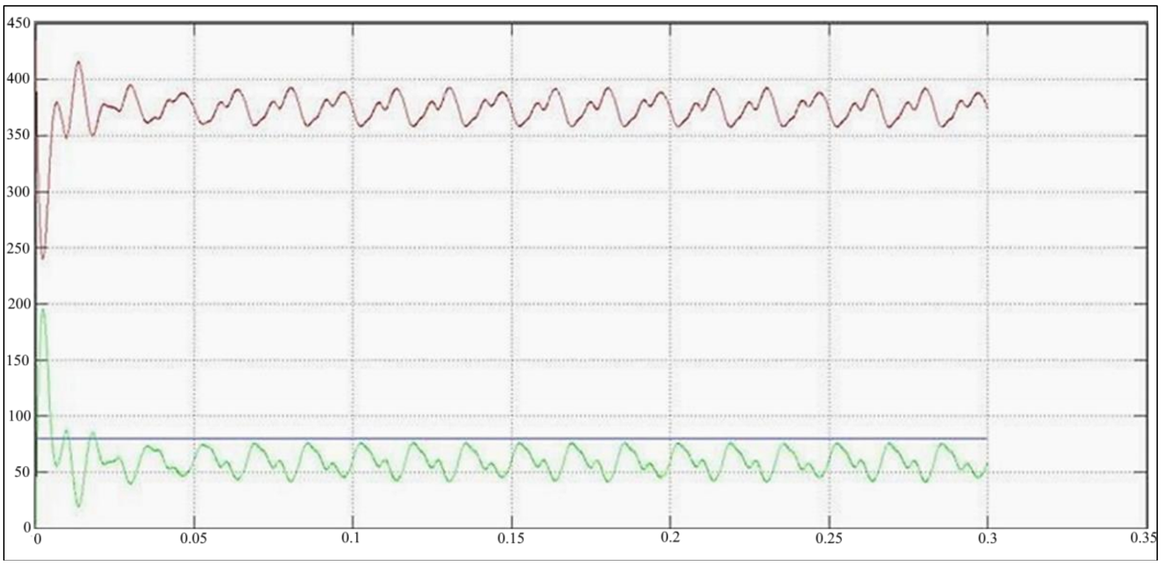

Fig. 3: *BESS in Charging/Discharging.*

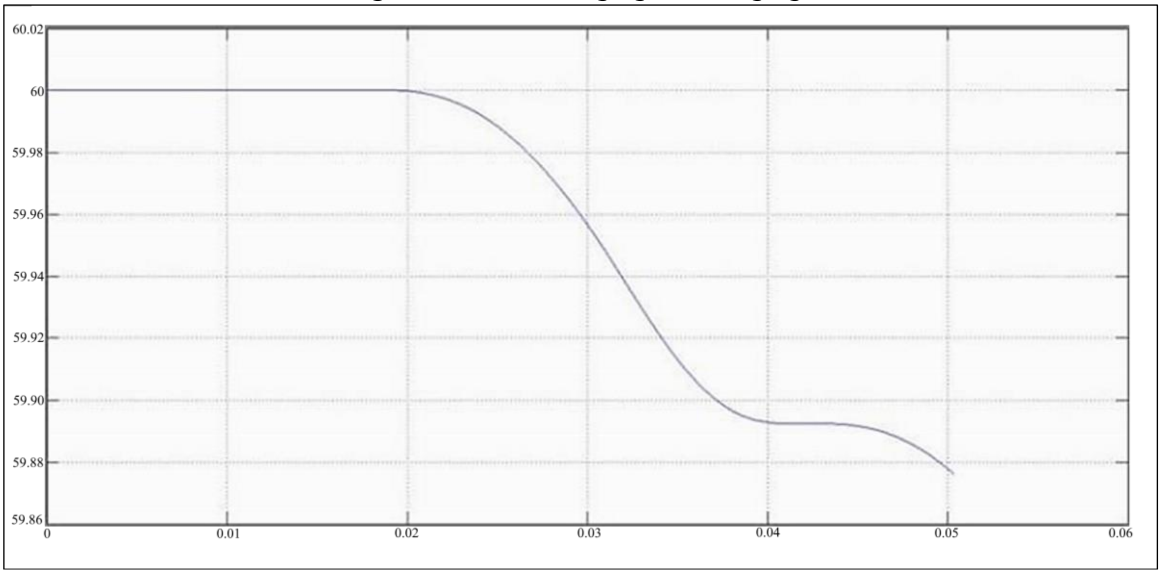

Fig. 4: *Battery Charging MW Power after a Negative 2% Step Change in the Plant Set Point.*

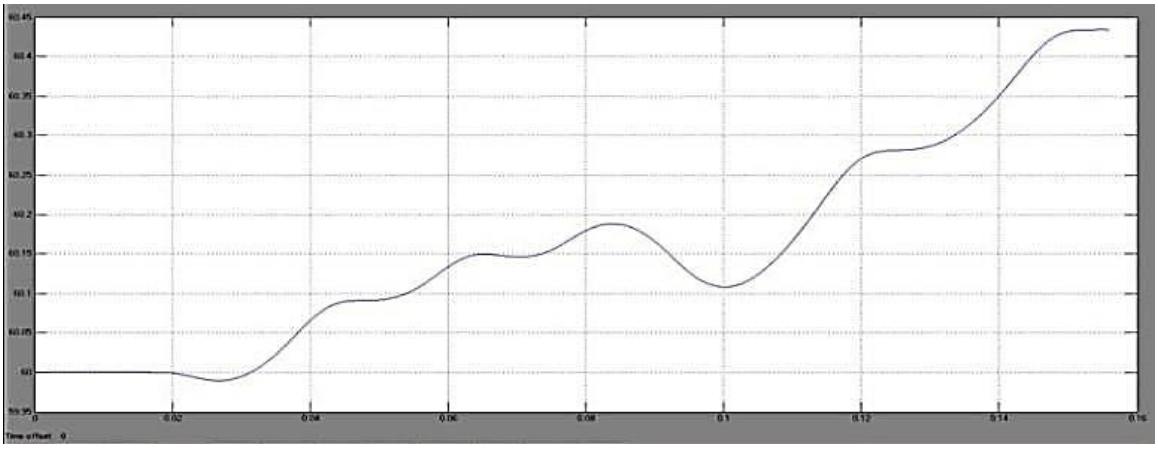

Fig. 5: *Battery Discharging MW Power after a Positive 2% Step Change in the Plant Set Point.*

CONCLUSION

This study presents power system applications of some battery energy storage engineering projects designed and implemented power conversion and control systems. These projects showed such functions as grid frequency regulation, renewable energy smoothing and leveling, energy dispatching and arbitrage, power quality and reliability, and islanding operations, and smart grid applications in power systems, etc. A grid level Battery Energy Storage System project usually makes an interconnection request with utility power grids in the project development stage and is required to submit simulation models of equipment for a system impact study (e.g., power flow and/or stability analysis), which is required by utility grid code requirements. This study defines the technical feasibility and impact of connection of the project on the power grid. This study also presents a new battery storage model that was configured, parameterized and tuned for use in system impact studies as well as transmission planning studies.

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