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ANALYSIS AND PERFORMANCE OF MVDC DISTRIBUTION SYSTEM WITH ESS FOR WIND AND SOLAR ENERGIES

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ABSTRACT

In distributed power systems, the integration of renewable energy sources and DC loads are increasing day by day. Medium Voltage Direct Current (MVDC) is a modern concept to meet the DC demandwith high reliability and feasibility. A simulation model of hybrid configuration merging both MVDC and ESS (Energy Storage System) for solar and wind energies have been modelled, simulated, and compared. To get a bidirectional power flow, the ESS is connected to a Bi-directional DC-DC converter. In this paper, the comparative performance of the MVDC distribution network integrated with ESS is evaluated for solar and wind energy sources. The study's main contribution is obtaining a coordinated operation of MVDC and ESS, which performs via a supervisory control scheme that defines the set-points for the control loops in each converter.

KEYWORDS: *MVDC, Grid, Distribution, ESS, VSC, Bi-directional DC-DC converters*

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INTRODUCTION

In the earlier stages of the power systems, the use of AC and DC grids was a hot topic. However, AC grids became more prominent since the voltage and power levels are sufficient, and voltage conversion was challenging. But, today, there is considerable progress in the power electronic technologies, DC becoming a more significant component in the power system. In DC grids, transmission technology is a current research topic. The VSC-HVDC transmission technology is preferable than LCC- HVDC technology because the VSC-HVDC's commutation is independent of an AC grid. Thus there is no commutation failure issue, and it can supply power for a passive system. The harmonic content of voltage and current is shallow due to pulse width modulation in VSC- HVDC. Based on the advantages above, the VSC- HVDC has a great prospect in connecting renewable energy, developing rapidly [1] [2].

MVDC technology has an enormous potential to integrate different energy sources, dc systems, and power loads. In the modern power system, the loads are changing a lot [2]. To handle such a change in loads connected to the distribution system, MVDC is the right solution for reliability, efficiency, volume, and cost. Also, the number of conversion stages can be reduced. The critical application of MVDC technology could demonstrate and de-risk novel HVDC systems and components, such as multi-terminal systems [3].

The need for MVDC technology development has been driven by the liberalization of the energy market, which has led to installations of large-scale wind and solar farms at the transmission and distribution level [4] [5]. At the distribution level, end-use consumers are employing these systems at a scaled level, which have several DC interfaces. Considering all of these various aspects and applications, MVDC is feasible, technically advantageous, and certainly economically attractive in many cases, especially where there is a concentration of wind or solar generation combined with local loads [5].

Energy production by some renewable-energy power sources, such as solar cells and wind-power generators, depends on weather conditions. For grid-connected power supplies, this fluctuation of output power causes changes in voltage frequency distributed by the grid. In the case of standalone power supplies, lack of other power generation sources is a critical problem; namely, blackouts occur when renewable energy cannot be obtained. An energy-storage system that can balance the power demand and the power source is key to introducing large-scale renewable energy sources [6]. Consequently, the operation of the MVDC distribution system with ESS for renewable sources leads to improve the quality, efficiency, and reliability of this renewable resource.

This paper focuses on implementing a simulation model for an MVDC distribution system with ESS designed for connecting a wind farm and solar plant to the grid. The study's main contribution is obtaining a coordinated operation of MVDC and ESS, which is performing via a supervisory control scheme that defines the set-points for the control loops in each converter.

SINGLE LINE DIAGRAMS

MVDC System with Wind Energy

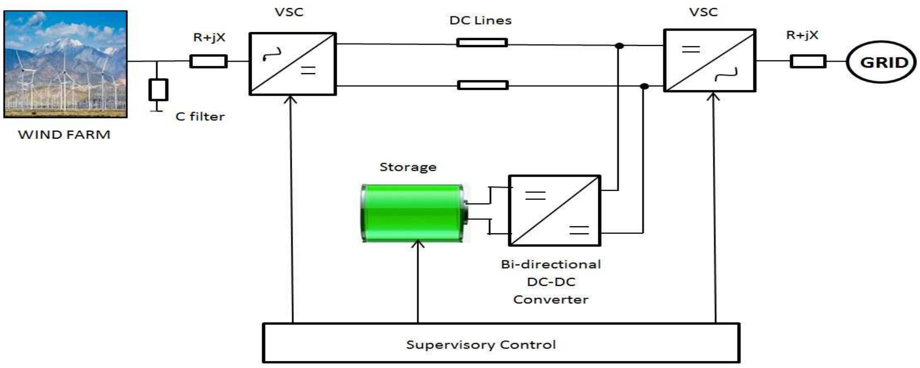

Figure 1: Layout of MVDC – ESS Configuration for Wind Energy.

Fig.1 represents the MVDC - ESS configuration for Wind energy. As shown in the figure, the MVDC system acts as an intermediate system between the wind farm and the grid. The generated power from a wind farm is fed to a VSC converter (AC-DC). Then it is transmitted through a DC line. On the other side, ESS is connected to the DC line, as shown in the figure. In this configuration, windfarm is the primary source for power, and ESS acts as an auxiliary source. The primary purpose of this ESS is to compensate for the power fluctuations.

MVDC System with Solar Energy

Fig.2 is the representation of MVDC-ESS configuration for Solar Energy. In this configuration, the solar plant's generated power is fed to the DC-DC (Boost) converter. Then the generated power is transmitted to the grid through the DC lines.

Energy storage systems (ESSs) are acknowledged as a feasible solution to mitigate the intermittency and unpredictability of renewable power [7] [8].

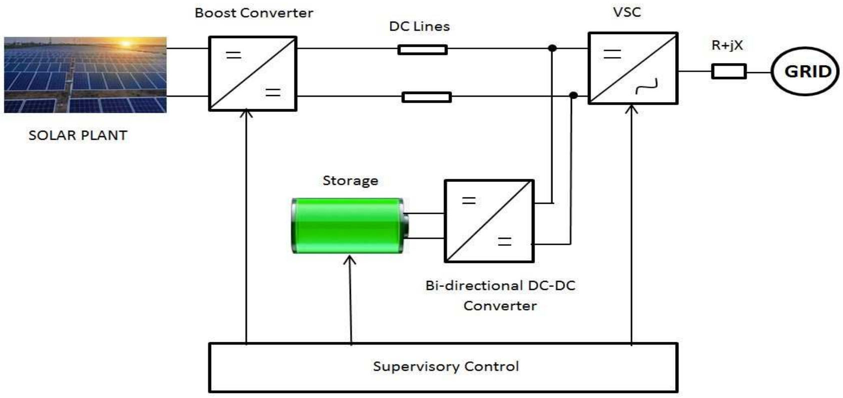

Figure 2: Layout of MVDC – ESS Configuration for Solar Energy.

MVDC DISTRIBUTION SYSTEM

As shown in Figures 1 and 2, the MVDC system acts as a barrier, and it injects the power from generating plants to the grid. Such type configurations result in loss reduction, control of voltage at each end of the link, and the medium range of voltage presents cost-effective, lower risks for specific applications [9]. MVDC offers an adequate alternative for short-distance distribution lines.

The MVDC distribution system consists of the generation plant (wind or solar), DC links, VSC converters, and the grid.

Generation Plant

Wind farm: The detailed model of a wind farm is not incorporated in this paper. The simulation results are carried out under fluctuating wind conditions. As a result, the variable amplitude is delivered by wind voltage and wind current. The wind farm is designed to generate a voltage of 575V. Such that the wind farm acts as a fluctuating source [10].

Solar plant: Solar plant consists of several PV arrays. These arrays are built so that the strings are connected in parallel, and the modules in each line are connected in series. The power generated from the PV array is low compared to energy generated from the wind farm. The simulation results are carried out under variable irradiance values [10].

Voltage Source Converters

There are two voltage source converters present in each configuration. The MVDC link is employed between the two VSCs connected to the generating plant and grid through a phase reactor. In this paper, two-level VSC is used in the simulation.

The modulation index is expressed as,

$$m = V_{nom} * 2 * sqrt(\frac{2}{3})/V_{dc}$$

Where V_{nom}= R.M.S phase to phase nominal voltage

V_{dc}= DC link voltage.

The control loops compute this modulation index, and thus the controllable voltage is obtained at AC terminals.

DC Link

DC link is the interconnection between both plant side and grid side converters. It is the transmitter of power from the plant to the grid. As shown in the single line diagrams of configurations, the ESS is connected at one end of the DC link and plays a vital role in order to maintain the constant voltage in the link.

Capacitors are equipped on both dc sides of the converters to reduce the DC voltage's ripple content. The rated capacity of the capacitors is 333µF. π section lines have been used as positive and negative terminals of the DC line. These lines are placed between the plant and grid side converters to represent a short distance distribution line.

Grid

The grid side VSC is connected to an ideal three-phase voltage source. This element resembles the connection of the MVDC distribution system with energy storage to a stiff AC grid. This voltage source's amplitude and frequency remain constant throughout the simulation, as it occurs in large power systems.

Control of Converters

The Control system of converters plays a crucial role in the entire simulation. The vector control technique is employed on both side converters [11]. The switches' conduction states are controlled by the d and q components of the AC voltage at the phase reactor of each converter.

For the wind farm side converter, the control strategy is accomplished by the two control loops (inner and outer) based on PI controllers. The frequency is maintained as 50 Hz at the abc-dq transformation. The control strategy implemented in the plant side allows the decoupled control of the active and reactive powers by acting on the rotor voltage d and q components. This control loop is responsible for controlling power generation and for power conversion.

A similar control strategy has been developed for the Grid side converter since the active and reactive powers can be controlled independently by acting on the components d and q of the grid side voltage. The main objective of this control strategy is to achieve the power balance in the DC system. Additionally, DC voltage error is compensated by this control scheme.

For a boost converter employed in the configuration shown in Fig.2, the switch action state is controlled by the control system based on PI controllers.

ENERGY STORAGE SYSTEM (ESS)

The energy storage system is connected at one end of the dc-link in the MVDC distribution system. It consists of a Bi-directional DC-DC converter with control and a battery.

Bi-Directional DC-DC Converter with Control

A Bi-directional DC-DC converter is designed to control the charging or to discharge power of the battery. The converter consists of two switches with a PWM control circuit. During the charging period, the DC bus's energy flows to the battery through the switch connected to the DC line. Therefore, the converter acts as a unidirectional buck converter. However, the battery discharges through the switch connected across the battery. In this case, the converter acts as a unidirectional boost converter.

There are two control loops to control the charging or discharging of the battery power. The reference power, which is obtained by the supervisory controller, is regulated by a PI controller. A second PI controller is used to control the battery's current to protect the battery [12].

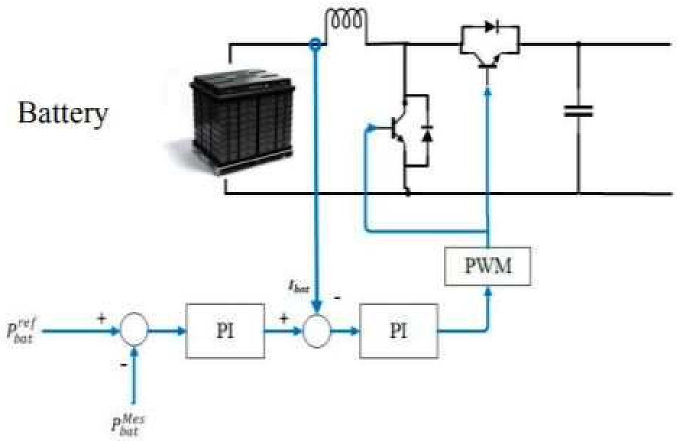

Figure 3: Control Scheme of Bi-Directional DC-DC Converter.

Battery

Batteries are one of the most employed components in ESS technologies, readily available in the market. The electrical energy is stocked as electrochemical energy in a set of numerous cells linked in parallel or series or both form. Lithium-Ion type battery has been used in this work. A battery stores energy when excess power is generated compared to grid demand, and it discharges when the system has low power generation.

SUPERVISORY CONTROLLER

The supervisory controller's primary purpose is to compensate for the mismatch between the main power transferred from or to the grid. The supervisory controller only modifies the reference set point for the battery. To perform this task, it needs information from the grid demand.

This work's main motive is to meet the load demand in short distance distribution systems irrespective of renewable energy power.

SIMULATION AND RESULTS

The performance of the proposed MVDC-ESS configuration is evaluated under variable wind speed and irradiance conditions. Thus the generation is dynamic. The generated voltage and current from Windfarm and Solar plants are shown in Figures 4 and 5.

The generated AC power is converted into DC power by Thyristor controlled rectifier. The current and voltage waveforms observed at the Rectifier end are observed in Figures 6 and 7. For wind energy, the current rectifier end is significantly less, and the current changes are not visible. However, for solar energy, the current at the rectifier end is very low compared to wind energy, but it is frequently varying for the entire simulation. The voltage at the rectifier end for wind energy is instantly increased to its maximum values for the first few μs of simulation. Later it is slightly decreased and maintained as almost constant up to the end of the simulation. The voltage at the rectifier end for solar energy is quite different from wind energy and low in value. For the first 0.8s of simulation, the voltage is the minimum value, and then it is raised to its maximum value for the total 2s of simulation.

The converted dc power is transmitted through the dc link to the inverter. At this end of the inverter, the current and voltages are crucial to analyse the total proposed system performance. Since, at this end, the ESS configuration is also connected to dc-link, as shown in Figures 1 and 2. For wind energy and solar energy, the current is almost zero, and it is similar to the rectifier end current. The voltage at this grid-connected converter is also identical to the rectifier end voltage. However, the difference in voltage and currents at both the ends of dc-link is that the inverter end waveforms have more fluctuations. These changes of current and voltage waveforms at gird connected converter are observed in Figures 8 and 9. Thus MVDC voltage is maintained at a constant irrespective of the generation.

Table 1: Simulation Parameters

DC line (π model)		Phase reactors	
$Rline$	9.5 mΩ/km	R	90 mΩ
$Lline$	0.53mH/km	L	8.6 mH
$Cline$	0.21 μF/km	Filter	
Length	8 km	$Cfilter$	0.2 mF
Control loops		DC Grounding capacitors	
kp, ki	1.9, 0.06	C	333 μF

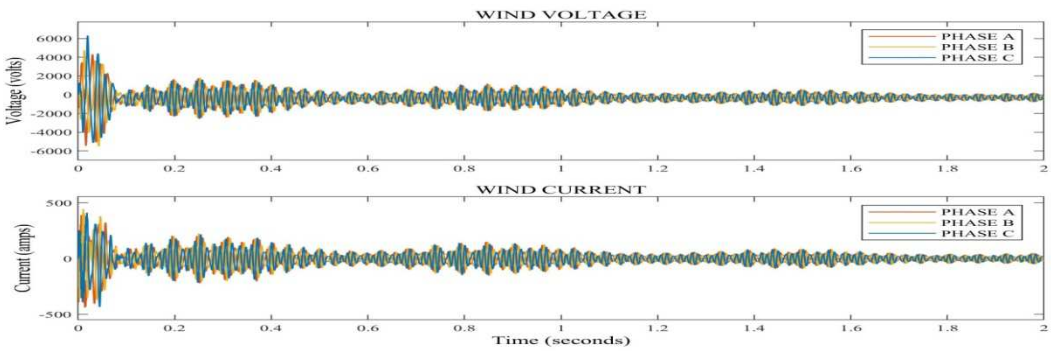

Figure 4: Generated Voltage and Current from Wind Farm.

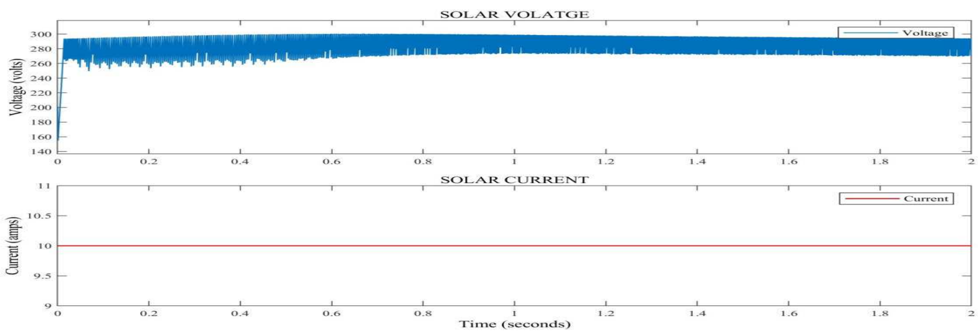

Figure 5: Generated Voltage and Current from Solar Plant.

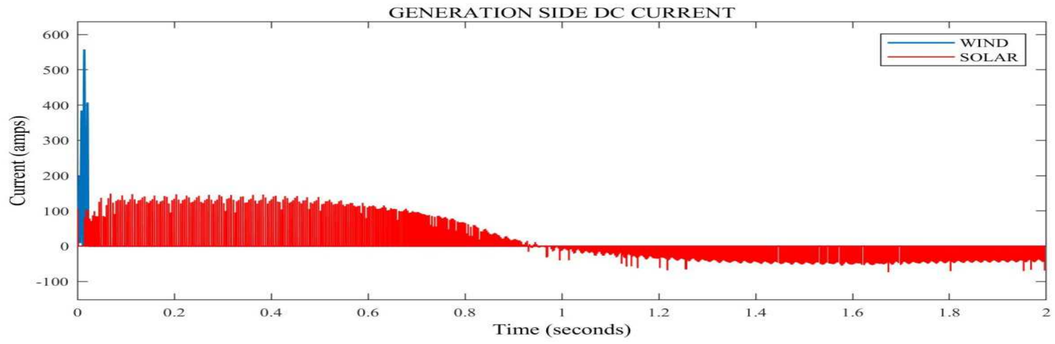

Figure 6: MVDC Current at Generation side Converter.

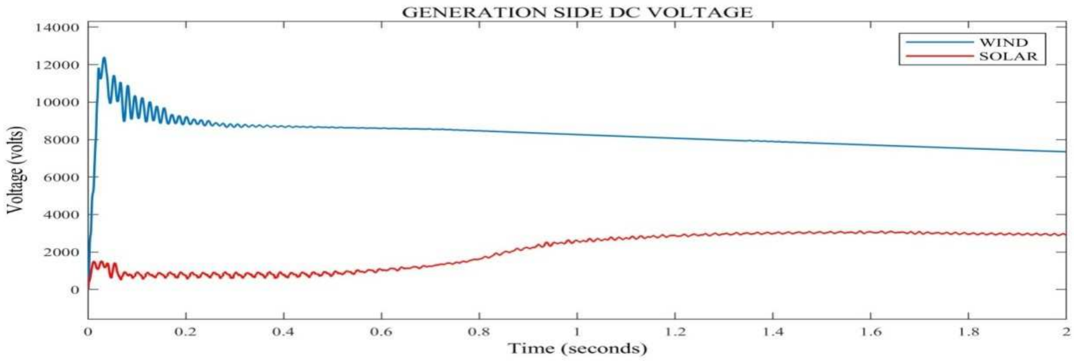

Figure 7: MVDC Voltage at Generation side Converter.

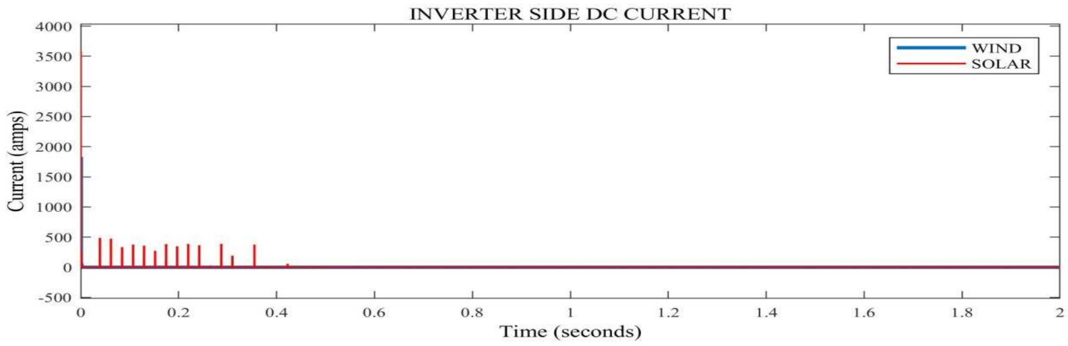

Figure 8: MVDC Current at Grid Side Converter.

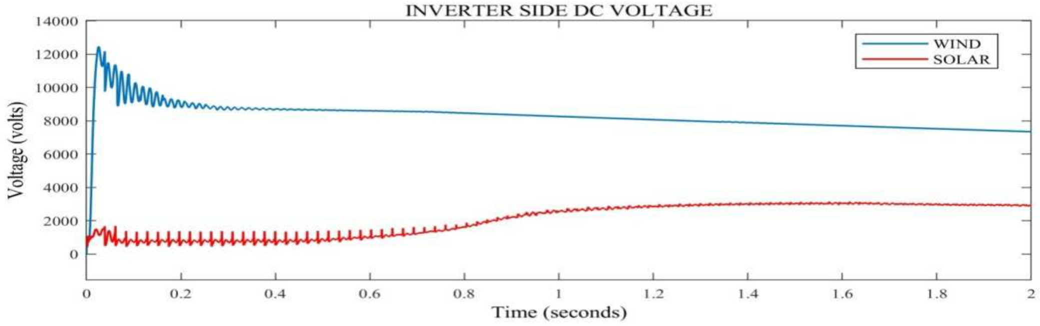

Figure 9: MVDC Voltage at Grid Side Converter.

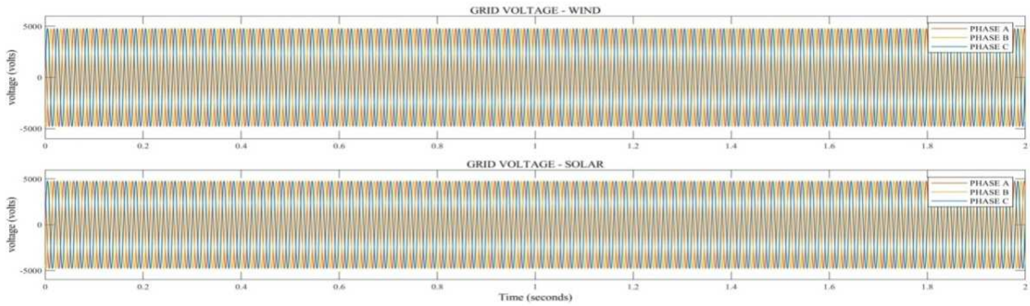

Figure 10: Grid Voltage.

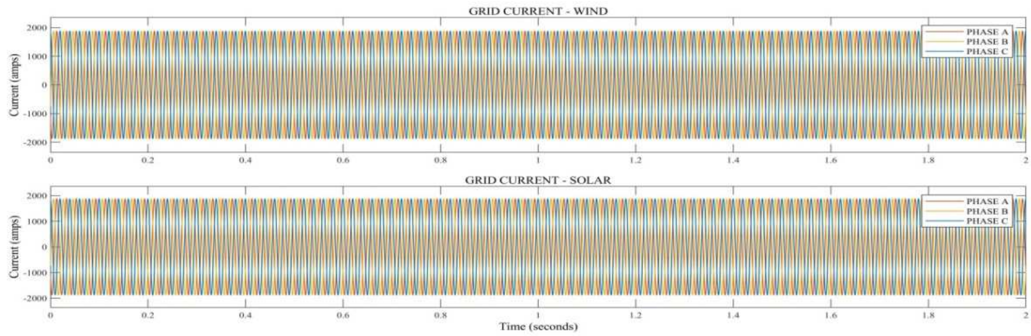

Figure 11: Grid Current.

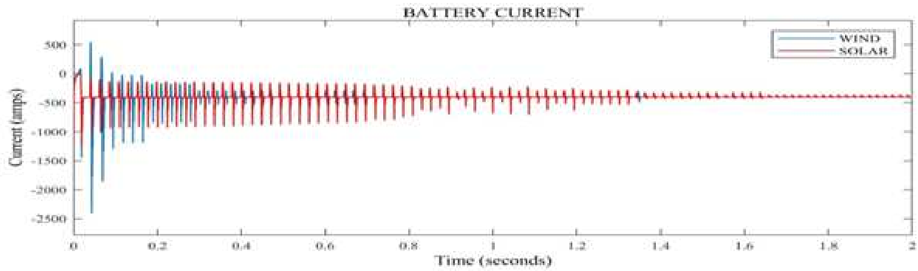

Figure 12: Battery Current.

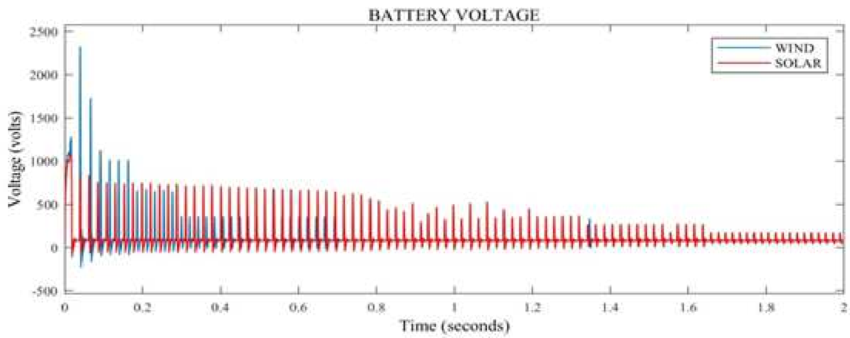

Figure 13: Battery Voltage.

The final outputs of the proposed configuration for both energies are shown in Figures 10 and 11 respectively. The result of the entire system is dependent on the performance of the ESS. The battery and supervisory controllers are responsible for the total controlled operation of the circuits. The supervisory controller receives the grid and generation values then modifies the bi-directional dc-dc converter's set point through the battery control system. Thus the charging and discharging of the battery occurs frequently concerning the generation for the 2s of simulation. The current and voltage of the battery are shown in Figures 12 and 13.

CONCLUSIONS

In this paper, a hybrid system, including the MVDC distribution system with ESS Configuration, has been modelled and simulated. All the necessary controlling strategies are implemented. This proposed hybrid configuration can produce an uninterrupted power supply to the grid through renewable energy sources. And MVDC has enormous potential to integrate different renewable sources. The MVDC-ESS configuration is simulated for Wind and Solar energies; the performance of this MVDC-ESS configuration is analysed and compared for both the energies.

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