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A Hybrid Storage System For Power Management Of Virtual Synchronous Generators

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***Abstract* - Renewable energy sources (RESs) have been extensively integrated into modern power systems to meet the increasing worldwide energy demand as well as reduce greenhouse gas emission. As a result, the task of frequency regulation previously provided by synchronous generators is gradually taken over by power converters, which serve as the interface between the power grid and RESs. By regulating power converters as virtual synchronous generators (VSGs), they can exhibit similar frequency dynamic response. However, unlike synchronous generators, power converters are incapable of absorbing/delivering any kinetic energy, which necessitates extra energy storage systems (ESSs). Nonetheless, the implementation and coordination control of ESSs in VSGs. To fill this research gap, this paper proposes a hybrid ESS (HESS) consisting of a battery and an ultra-capacitor to achieve the power management of VSGs. Through proper control, the ultra-capacitor automatically tackles the fast-varying power introduced by inertia emulation while the battery implements the remaining parts of a VSG and only compensates for relatively long-term power fluctuations with slow dynamics. In this way, the proposed HESS allows reduction of the battery power fluctuations along with its changing rate.**

***keywords* - Synchronous generators, Hybrid storage systems, power management, Energy storage**

INTRODUCTION

The increasing penetration of renewable energy sources (RESs) has changed the paradigm of modern power systems. Nowadays, synchronous generators are responsible for frequency regulation. When frequency events occur, they perform inertial response, which can slow down the frequency dynamics by absorbing or delivering the kinetic energy stored in the rotors of synchronous generators and turbines. In the future, the task of frequency regulation will be taken over by grid-connected power converters. At present, most of the grid-connected power converters are operated to extract the maximum power from RESs without providing any frequency regulation capability.

An emerging concept for power converters to implement frequency regulation is known as virtual synchronous generators (VSGs) or virtual synchronous machines (VSMs). The basic idea behind this concept lies in the emulation of synchronous generators. However, previous research works only concentrate on VSG control and rarely discuss the practical implementation of VSGs [1]. Here, the VSG is simply implemented as an inverter fed by an ideal DC power supply. All the control loops in the VSG, e.g. inertia and speed governor, are realized by the ideal DC voltage source, which is obviously not the real case. In fact, energy storage systems (ESSs) must be involved in VSGs to achieve frequency regulation, and the implementation and coordination control of ESSs in VSGs have not been investigated in the literature.

For selection of energy storage units in an ESS, it would be desirable that high energy density units and high power density units are used together so as to increase the system operating efficiency and/or lifetime as well as reduce system costs. One example is the hybrid ESS (HESS) composed of a battery and an ultra-capacitor, where the battery is used for compensation of low frequency power fluctuations and the ultra-capacitor is used for compensation of high frequency power fluctuations. To fully exploit the advantages of different energy storage units, low/high pass filters are normally employed to extract low/high frequency power fluctuations in the system.

However, there is no guideline on how to design the cut-off frequency of such filters and it is typically determined through trial and error. In view of the aforementioned issues, a battery/ultra-capacitor HESS applied to VSGs is proposed in this paper. Specifically, the ultra-capacitor is used to emulate the inertia of a VSG, as this part of the VSG is designed to cope with high frequency power fluctuations. The remaining parts of the VSG, e.g. droop control and turbine model, are emulated by the battery, as they are tasked at compensating for relatively long-term power fluctuations with slow dynamics. In this way, one can fully utilize the advantages of the ultra-capacitor and battery to realize a practical VSG system.

The power references of the ultra-capacitor and battery are respectively derived from the virtual inertia emulation and the remaining parts of the VSG control rather than conventional low/high pass filters. Moreover, since the HESS is used to emulate frequency regulation implemented by conventional frequency regulators, the control parameters for the HESS can easily be designed based on the VSG model.

Existing model will mainly discuss about the interconnection of Distributed Generators to grid with the help of Power Electronics Converters. The model with small energy buffer to emulate the rotor inertia. Power Electronic converters are incapable of storing the energy in case of fluctuations and due to this consumer loads may be effected. The building of Virtual Synchronous Generator is mainly focused in the Existing System.

In all the existing techniques the main concern is only about system stability and few features of synchronous generation. The Schematic Diagram of the Existing System is shown in Fig.1.

The basic idea behind this concept lies in the emulation of synchronous generators. However, previous research works only concentrate on VSG control and rarely discuss the practical implementation of VSGs. Here, the VSG is simply implemented as an inverter fed by an ideal DC power supply. All the control loops in the VSG, e.g. inertia and speed governor, are realized by the ideal DC voltage source, which is obviously not the real case

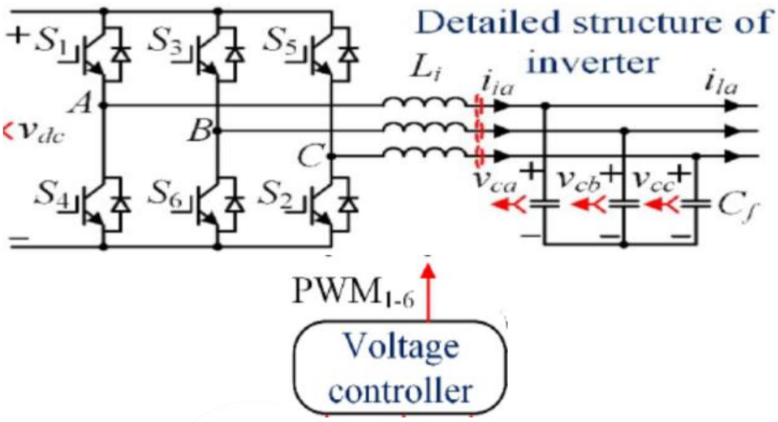

Fig. 1 The schematic diagram of the existing system [1]

2 VSG MODELLING

The character of all small RES and DER up to now is of a "following nature". This means that all the available power of the source is delivered to the electricity grid, irrespective of the voltage level or power flow in the grid. Mostly all new DER makes use of electronic power converter for the grid coupling. The adaptation of an electronic converter to mimic the character of a Virtual Synchronous Generator for short periods, including inertia, may be a major improvement for the dynamic properties. The system needs a small electrical storage, the first and most important step to intentionally islanding and true micro grid operation is also set.

The following characteristics can be implemented:

1) Prevent electricity grid instability and blackouts due to large frequency variations caused by decentralized generation, and the subsequent social chaos.
2) Retain safety in fault situations of an electricity grid with any given share of decentralized generation.
3) Laydown a basis for intentionally islanding of low voltage area's with decentralized generation, in order to keep functioning the social structures in these areas.

A beneficial point is that this new VSG technology even can let DER work autonomously for short during network failures. In electricity grids the frequency of the generated voltage is stabilized by a combination of the rotational inertia (rotating mass) of synchronous power generators in the grid and a control algorithm acting on the rotational speed of a number of major synchronous power generators.

This works because the rotating masses of all synchronous generators are coupled electromechanically through their grid connections and as a consequence run at exactly the same electrical frequency. When in future decentralized non-synchronous generation units replace a significant part of the synchronous power generation capacity, the total rotational inertia of the synchronous generators is decreased significantly [3]. As a consequence the variation in the rotational speed of the synchronous generators due to changes in their net load will become much higher than at present. This causes large electrical frequency variations that can end up in an unstable grid.

3 PROPOSED MODEL

Renewable energy sources have been extensively integrated into modern power systems to meet the increasing worldwide energy demand. The task of frequency regulation previously provided by synchronous generators is gradually taken over by power converters, which serve as the interface between the power grid and RESs. By regulating power converters as virtual synchronous generators, they can exhibit similar frequency dynamic response. However, unlike synchronous generators, power converters are incapable of absorbing / delivering any kinetic energy.

Proposes a hybrid ESS consisting of a battery and an ultra-capacitor to achieve the power management of VSGs. Through proper control, the ultra-capacitor automatically tackles the fast-varying power introduced by inertia emulation while the battery implements the remaining parts of a VSG and only compensates for relatively long-term power fluctuations with slow dynamics. In this way, the proposed HESS allows reduction of the battery power fluctuations along with its changing rate.

The General representation of the proposed model is shown in Fig. 2. Moreover, since the HESS is used to emulate frequency regulation implemented by conventional frequency regulators, the control parameters for the HESS can easily be designed based on the VSG model. The power references of the ultra-capacitor and battery are respectively derived from the virtual inertia emulation and the remaining parts of the VSG control rather than conventional low/high pass filters. Moreover, since the HESS is used to emulate frequency regulation implemented by conventional frequency regulators, the control parameters for the HESS can easily be designed based on the VSG model.

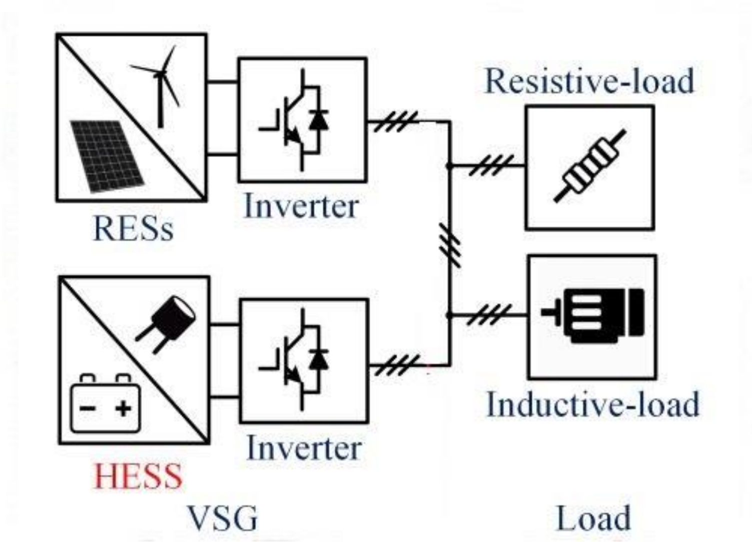

Fig. 2 Proposed model [1]

For selection of energy storage units in an ESS, it would be desirable that high energy density units and high power density units are used together so as to increase the system operating efficiency and/or lifetime as well as reduce system costs. All the control loops in the VSG, e.g. inertia and speed governor, are realized by the ideal DC voltage source, which is obviously not the real case. In fact, energy storage systems (ESSs) must be involved in VSGs to achieve frequency regulation, and the implementation and coordination control of ESSs in VSGs have not been investigated in the literature [2][3].

4 SIMULINK MODELING

4.1 SIMULINK MODEL FOR VSG

The entire Simulink model of the Virtual Synchronous Generator system is shown in Fig. 3, consisting of Inverter, AC voltage controllers along with LC filters. The Inverter acts as interface between grid and Solar system [4]. The inverter output with nominal frequency of 50Hz is fed to the load of 4KW. The network parameters including the ratings and impedances of proposed model components for simulation analysis is given in Table 1.

Table 1. System Parameters

Parameters	Value
Grid Voltage	600 V
Fundamental Frequency	50 Hz
Switching Frequency	4 KHz
Filter Design Parameters: Inductance Capacitance	 350 μH 330 μF
Load 1	9 KW
Load 2	4KW

Considering these parameters grid connected PV based system with Double Synchronous Controller is designed as shown in Fig. 3.

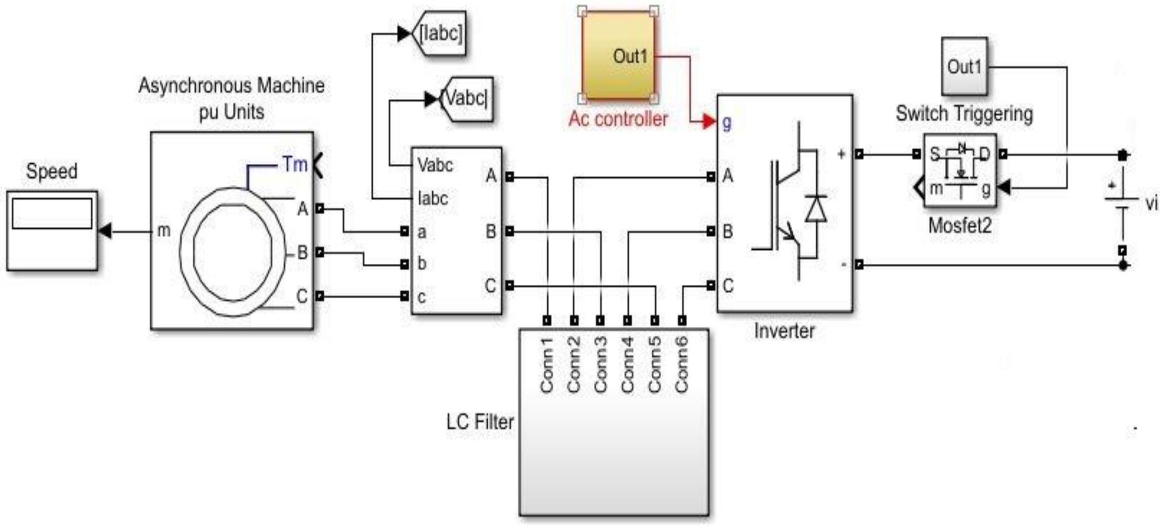

Fig. 3 Simulink model of VSG

4.2 SIMULINK MODEL OF DC VOLTAGE CONTROLLER WITH HESS

The DC Voltage Controller with Hybrid Energy Storage System is interconnected with VSG through a switching mechanism which is operated based on the input voltage. For example when the input voltage is greater than 600V the switch is in the on position then it will allow the HESS, when the input voltage is less than 600V the DC controller is isolated from main supply [5]. The corresponding Simulink model is shown in Fig. 4.

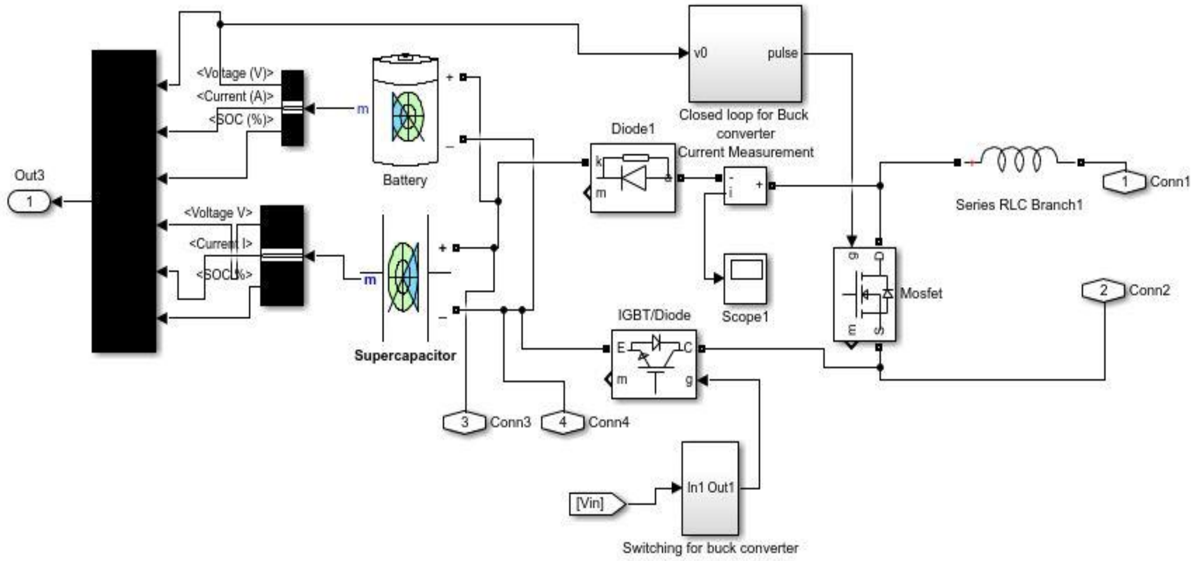

Fig. 4 Simulink model of DC voltage controller

The control logic Simulink model is shown in Fig. 5 for switching operation

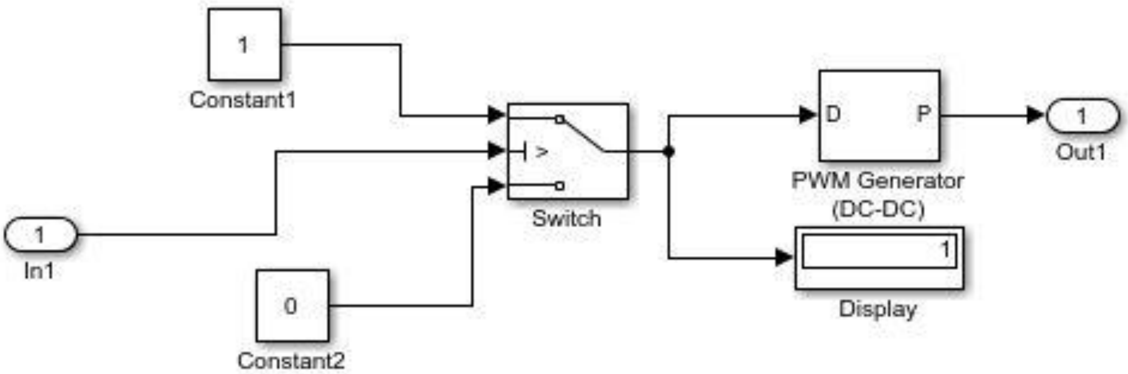

Fig. 5 Simulink model of control logic

4.3 OPERATION

Conventionally, the VSG system is simply implemented by an ideal DC voltage source connected to an inverter. By controlling the inverter based on the output voltage generated by it through the closed loop AC voltage controlled the objective of the frequency regulation can be achieved. The frequency regulation is implemented by the Battery/super-capacitor. The battery connected to the super-capacitor through DC/DC converter and an LC filtered three phase inverter is employed as the interface between the super-capacitor and Load. The voltage controller is dictated to follow the voltage references of output voltages.

The voltage controller consists of two parts i.e., an AC voltage controller performs the regulation of three phase AC output voltages and DC controller will performs the charging of the Hybrid energy storage system based on the logic control switches based on input value from the PV system. The main function of controller is to manage the power between the load and HESS [6].

When the power generated by the PV module is equal to the power drawn by the load then the DC controller will be off position so the no charging of HESS. If the power of the PV module is greater than the load consumption then DC controller logic switch is on and the HESS will start charging up to the SOC levels. In the HESS system during high fluctuating loads the super capacitor will charge according to the variations and in the normal charges with time the battery will get charged up to the rated value [7][8].

5 SIMULATION RESULTS

The input voltage for the system is 600V and the output voltage at load end from the Inverter is shown in Fig. 6. The output current waveforms for given input of 600V for given load is shown in the Fig. 7.

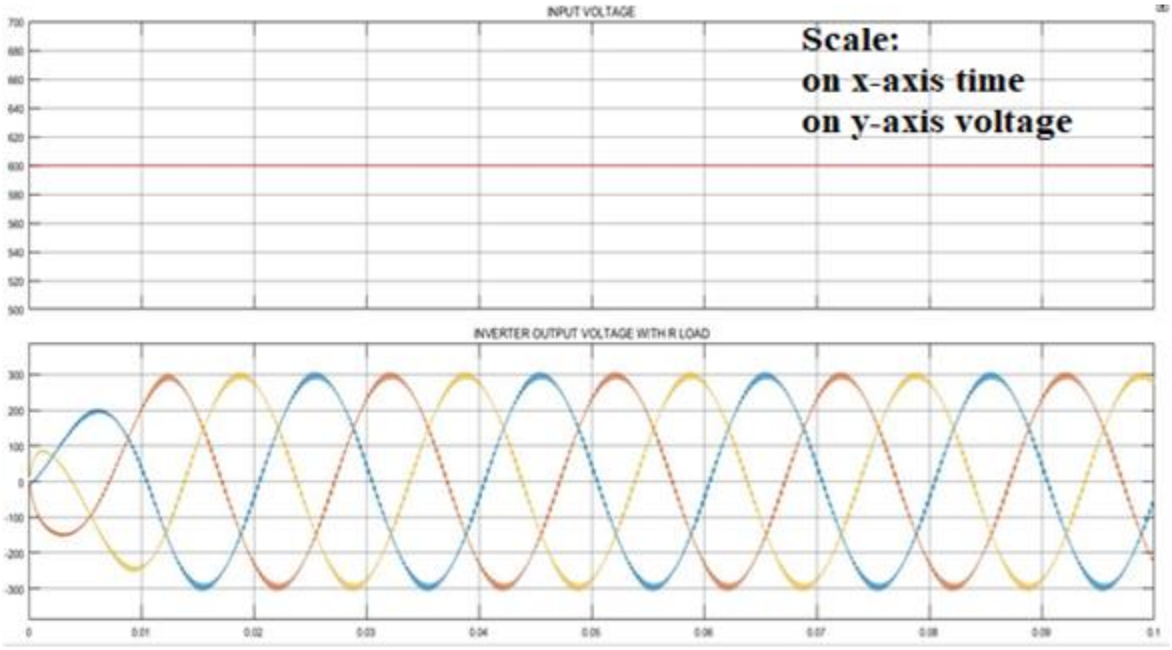

Fig. 6 Input and Output values of VSG

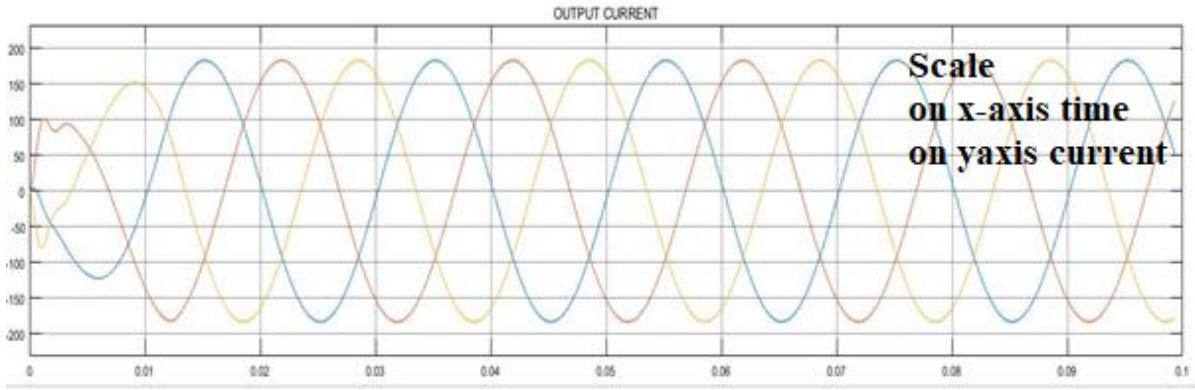

Fig. 7 Output current of VSG

Whenever the output voltage from the PV panel increases from the reference values then controllers with come into act based on the control signals and the extra power generated will be stored in battery and ultra-capacitor i.e. stored in the HESS. So that whenever the fluctuations in the load then the energy stored in the HESS will be supplied. In the HESS system during high fluctuating loads the super capacitor will charge according to the variations and in the normal charges with time the battery will get charged up to the rated value. The Power curves of the battery and Super capacitor is shown in Fig. 8. Based on the ratings i.e. SOC and initial charge of the HES systems the power at output is measured by using the scope.

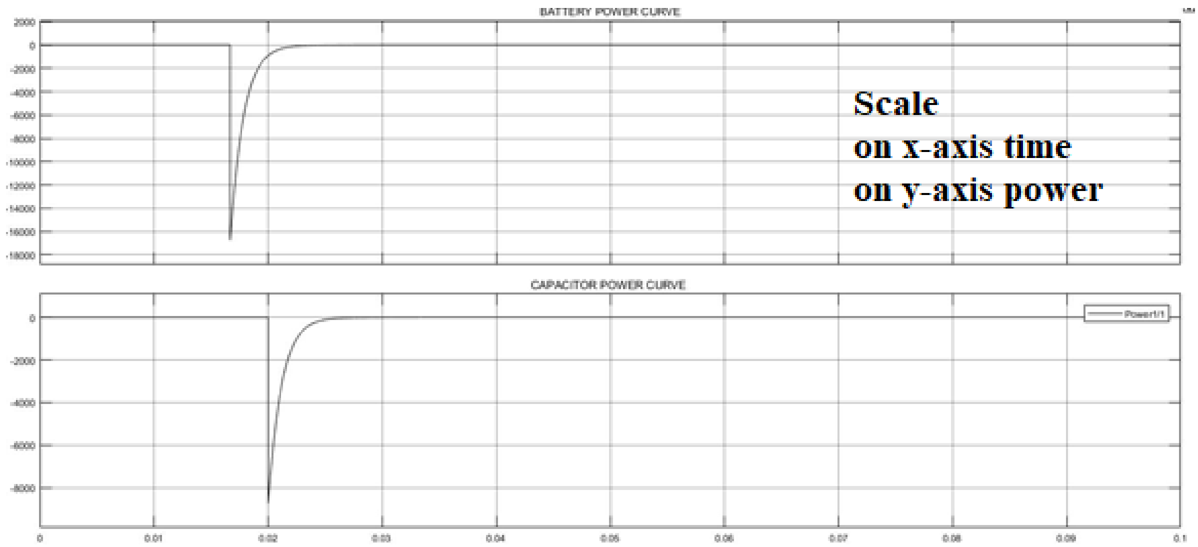

Fig. 8 Power curves of battery and super capacitor

The Voltage across the Battery and Super capacitor is shown in Fig. 9. The rated voltage across the HESS is 210V. In case any deviation in the output voltage in the load due to changes in irradiation or intensity of sun light then the controller will be act according to the changes.

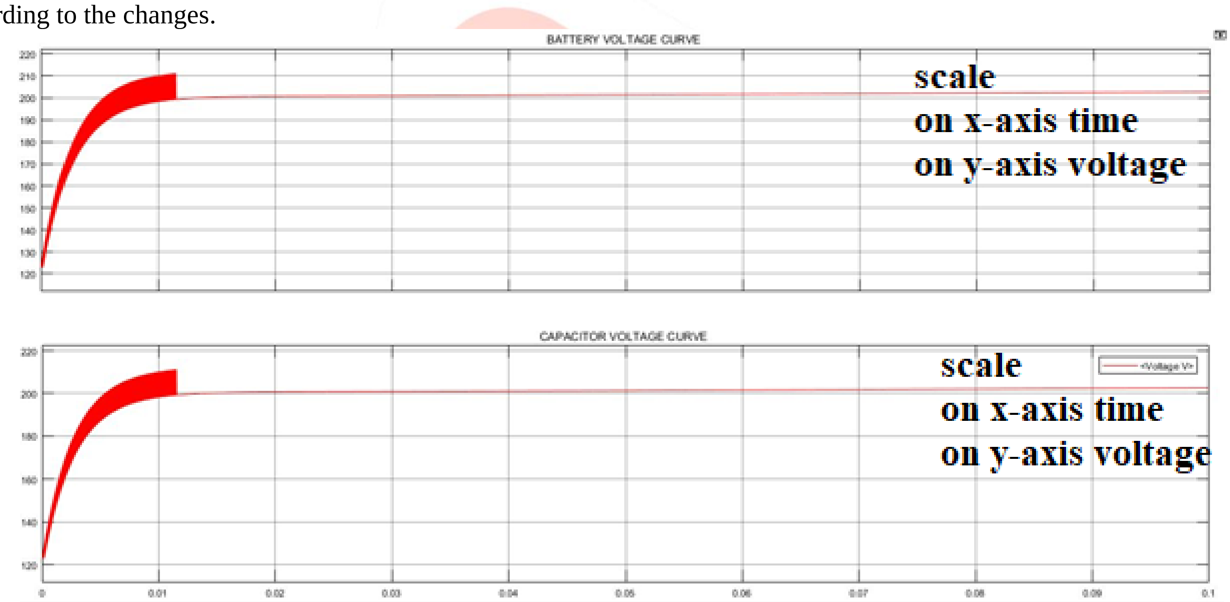

Fig. 9 Battery and super capacitor voltages

5 CONCLUSION

This paper proposes a battery/ultra-capacitor HESS to implement the VSG as different energy storage units are suitable for different control objectives in the VSG. To be specific, the ultra-capacitor is used to emulate the inertia of the VSG and cope with high frequency power fluctuations, while the battery is used to emulate the remaining parts of the VSG, e.g. droop control and turbine model, to compensate for relatively long-term power fluctuations with slow dynamics. In this way, the power fluctuations of the battery along with its changing rate can dramatically be reduced. Since the HESS is used to emulate the inertia coefficient, droop control, speed governor and turbine in a VSG model which are all well-known parameters, the controller design of the HESS is very straight forward and does not rely on the conventional low/high-pass filters. Experimental results are presented to prove the effectiveness of the proposed HESS-based VSG.

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