International Journal of Trend in Scientific Research and Development (IJTSRD)
Volume 4 Issue 4, June 2020 Available Online: www.ijtsrd.com e-ISSN: 2456 – 6470

Control and Power Management in HRES System

Majid Hussain

M. Tech Scholar, Electrical Engineering,
GRD Institute of Management and Technology Dehradun, Dehradun, Uttarakhand, India

ABSTRACT

A novel energy control strategy for a battery/super capacitor in HRES, which is designed to be tunable to achieve different goals, is described. Two possible goals for adding a pack of super capacitors are examined for a test micro grid using lead-acid batteries: 1) improving the microgrid'sefficiency and range and 2) reducing the peak currents in the battery pack to increase battery life. The benefits of hybridization are compared with those achievable by increasing the size of the battery pack by a comparable mass to the super capacitors. The availability of energy from regenerative braking and the characteristics of the super capacitors are considered as impact factors. Super capacitors were found to be effective at reducing peak battery currents; however, the benefits to range extension were found to be limited. A battery life extension of at least 50% is necessary to make super capacitors cost effective for the test vehicle at current prices.

How to cite this paper: Majid Hussain "Control and Power Management in HRES System" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-4 | Issue-4, June 2020, pp.609-614, URL: www.ijtsrd.com/papers/ijtsrd31150.pdf

IJTSRD31150

I. INTRODUCTION

Todays also there are very large area of world especially in rural area still not have the access of electricity from the grid partly due to high cost and partly due to their remote location. In those areas, the electricity needs of the residents are generally fulfilled by diesel engine generators which is not a viable option as the remote areas are full of RERs potential. Recently, hybrid renewable energy systems (HRESs), combination of different types of renewable energy resources (RERs) along with the storage devices of different characteristics come into play for providing electricity for the areas where grid electricity is not available [1]–[4]. Almost all the RERs are freely available and have advantages like environment friendliness, and available in abundance. The RERs can be used in combinations where the different RERs are so selected that they can complement each other. Such a combination is wind-solar combination, where the shortcomings of one RER is overcome by other RER. This combination of different RERs not only can increase the reliability of the system but also reduce the overall price. [5]–[9] Also it is well documented that without the support of grid, HRES only cannot provide the enough inertia to the entire system in order to keep frequency and voltage within limits. So, ESSs are needed to overcome this problem. [10] Therefore, ESS along with major constituent of HRES also constitutes the large share of capital investment. [11]–[13] Therefore, investment in the HRES mainly dependent on the various particulars of the HRES and ESSs being the forth runner in terms of cost decides the overall cost of the HRESs and that can be limited by suitably selecting the proper sizes of the different components of HRES. This not can reduce the overall cost but also helps in increasing the operating lives of the ESSs. [14]

As per the previous literature and widespread applications, battery energy storage system (BESS) can be assumed to be most popular and mature type of ESSs available in today's scenario. [15] But, as far as single use of ESS considering BESS, can harm the operating life of BESS very significantly because of rapid charge and discharge of it due to variations in the output of RERs as well as variations in the load requirement. [16], [17] Some domestic appliances require very large amount of power only for significantly small time like water pump motor that requires almost ten times of the normal current only for 2-4 seconds. As a result, the required capacity of BESS increases and that can led to the increase in the investment cost. Consequently, larger size of BESS is needed to supply this surge in the current which again increases the overall cost of the system. By utilizing the different ESSs consequently can help in solving this problem which formulate the new concept of Hybrid energy storage system (HESS) using the ESSs in such a way that they can complement each other. [18]–[21] Depending on the requirement of energy and power by the load, ESSs are categorized in two types. One type of ESS can provide high amount of power in short time termed as high power ESS and second type can provide small amount of power but on longer time that is high energy ESS. By joining these two types of ESSs, one can fulfill the power and energy requirements of all the loads by suitably selecting the high power and high energy ESS. Currently, a lot of ESSs available possessing wide range of operational characteristics in terms of technical and economic point of view for example compressed air energy storage-battery, battery-fuel cell, battery-supercapacitor, battery-flywheel and battery-superconducting magnetic energy storage system (SMES) formulates the generally hybridized components of HESSs in HRES[22]. [23]–[29].

Considering the shortcomings of the various control strategies presented in the literature review, a new and enhanced control scheme is presented in this thesis work for a HRES consisting of WT and PV system. BESS and SCESS are the parts of HESS and following purposes are fulfilled by the proposed control scheme:

1. To achieve power balance in the various constituents of the hybrid renewable energy system.
2. To maintain the DC link voltage within the prescribed limits whatever be the wind speed, solar irradiance and demand in electricity.
3. To maintain the power sharing utilizing the operational characteristics BESS and SCESS in such a way that the ESS can work on to their full potential without sacrificing their operating life.
4. To maintain the frequency as well as the AC voltage within limits.

II. Control Scheme

The generated electricity by PV system and WECS put together and electricity consumed by the load is governed by HESS control scheme. Based upon that there are two modes of operation and are explained as:

1. Surplus power mode (SPM)

In SPM, the generation is more than the demand and the so available surplus power, after serving the critical and non-critical load, is used to charge the HESS until it gets charged to its upper SoC limits. This involves the separation of low and high frequency components of imbalance power and their utilization, respectively, for charging the BESS and SCESS which reduces the stress on BESS. Once the HESS gets charged to its upper SoC limits, the excess power, still available, is then diverted to the dump load to maintain the power balance.

2. Deficit power mode (DPM)

In this mode, generation is less than the demand and the deficit in the power is compensated by HESS until it touches down to its lower SoC limits. This mode also involves the separation of low and high frequency components of imbalance power and their utilization, respectively, for discharging the BESS and SCESS for the same purpose of reducing the stress on BESS. The ratings of the HESS are so selected that the supply to the critical load is ensured at all the times. But in worst case scenario, when the HESS reaches to its lower SoC limits, load shedding option of non-critical load is activated with the system serving only the critical load.

The proposed HESS control strategy is explained with the help of a block diagram as shown in Figure 1 As aforementioned, in order to achieve longer operating life of BESS, it's deep charging and discharging is avoided and allowed to operate only within its SoC limits. On the other hand, SCESS can be fully charged and discharged without any significant problems. As can be seen from the Figure 2, when the BESS is within its operating SoC limits, the error between the actual V_{DC} and reference DC link voltage (V_{DC}^*) goes as input to proportional-integral (PI) controller which in turn gives as output the total reference current (I_{DC}^*) for the HESS. The I_{DC}^* is then given as input to the LPF which filters out, as a function of LPF ($f_{LPF}(\square)$) as given by equation (1), the low frequency components ($I_{L\_freq}^*$) from I_{DC}^*:

$$I_{L\_freq}^* = f_{LPF}(I_{DC}^*) \tag{1}$$

$I_{L\_freq}^*$ current is passed from rate-limiter for achieving the BESS reference current (I_{Bat}^*) The rate for BESS charging as well as discharging is control by rate limiter and presented by the equation (2):

$$I_{Bat}^* = f_{RL}(I_{L\_freq}^*) \tag{2}$$

For reducing the error between the reference and measured currents of BES another PI controller is utilized. The PI controller feeds input to the PWM controller in order to generate the command for BESS's converter and is given by duty ratio (D_{Bat}).

The high frequency components are filtered out from the total current and given as by the equation (3).

$$I_{H\_freq}^* = I_{DC}^* - I_{L\_freq}^* \tag{3}$$

As discussed in previous chapters, the dynamics of BESS is not as fast of SCESS so reference battery current cannot tackle the fast change, So, uncompensated power (P_{B_uncomp}), as obained as per (4), is provided by SCESS and the signal for the same is formulated as per (5).

$$P_{B\_uncomp} = \left(I_{H\_freq}^* + I_{B\_err}\right) \times V_{Bat} \tag{4}$$

$$I_{SC}^* = \frac{P_{B\_uncomp}}{V_{SC}} = \left(I_{H\_freq}^* + I_{B\_err}\right) \times \frac{V_{Bat}}{V_{SC}} \tag{5}$$

Where,
V_{Bat} and V_{SC} are output voltage of the battery and supercapacitor units.

Same process is repeated for the SCESS where the error signal obtained from the f_{LPF} is utilized and PI controller generated the duty cycle for the SCESS's converter circuit and which further produce the signals for the PWM converter.

When there is excess power is available firstly utilized to increase the SoC of BESS and SCESS and when their SOC reached up to to highest level then that excess power is fed to the dump load. On the other hand when there is shortage of power exists, that shortage is overcome by HESS until their SOC drops down to their lowest limits.

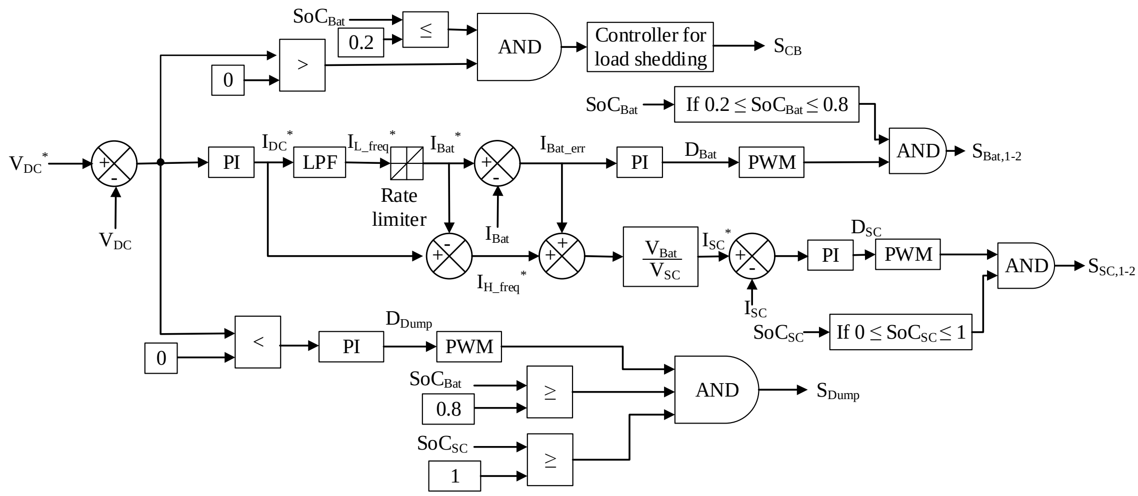


FIGURE 2 HESS control strategy

AC side inverter controller

FIGURE 3 show the inverter circuit and this is accountable to deliver command to the inverter for maintaining the frequency as well as AC voltage in the limits at the load end. Inverter controller senses output voltages at the load end and then converts these three phase components into two phase quantities (d-q). These signals of the AC voltage are equated to the two phase quantities and the resultant difference between the actual and observed values is processed through the another PI controller pair. This pair generates the signals for the inverter to maintain the voltage and frequency in the limits.

For maintaining the entire control scheme in synchronism PLL is utilized this makes the signals in tandem the operating frequency is maintained.

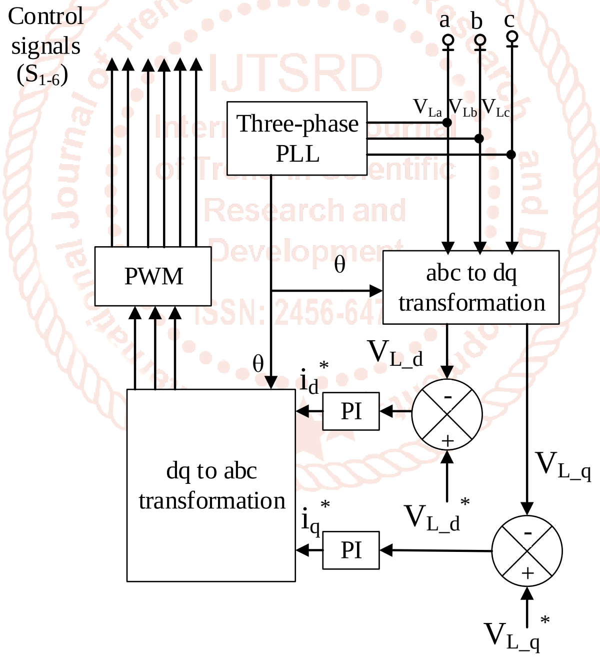


FIGURE 3 Three phase inverter controller

III. Simulations and results

As discussed earlier the generation and consumption is not same and inconstant by nature that is why the enactment of the system is examined considering changing inputs in order to mimic practical situation. The wind variations measured are presented in **FIGURE** 4 (a). Firstly it is 8 m/sec the incremented at 10 m/sec on the time being 3 sec. There is again change in the wind speed and it became 12 m/sec when time is 5 sec. Likewise, change in solar irradiance is also made and in starting it is 800 W/m^2 then increases to 1000 W/m^2 at time being 2 sec and to 1200 W/m^2 at t=4 sec, and same is depicted in **FIGURE** 4 (b). **FIGURE** 4 (c) displays variations in load current that decreases to 3 A from 9 A when time is 6 sec.

V_{DC} is varied at a great extend subjected to inconsistent operating circumstances and should be persistent to 640 V that is taken as the reference value for this study. **FIGURE** 4 (d) presents the shape of V_{DC} at various occasions considering change in other scenarios like wind speed etc. The results presented in various figures verified that the controller can keep the V_{DC} around the prescribed value (± 5%) in transients as well as long term situations. Upholding the V_{DC} unchanged aids to maintain AC voltage at constant level irrespective of solar irradiance and wind speed the DC voltage and corresponding AC voltage is given as [54]:

$$V_{P-N} = k\frac{1}{2\sqrt{2}}V_{DC} \qquad (6)$$

Here, phase to neutral voltage is denoted by V_{P-N} and modulation index by k.

If there are some variations in the load end as shown in **FIGURE 4** (c) then inverter controller provides adequate governor to counter these variations. By eaxmine **FIGURE** 4 (e), proposed controller can maintain the frequency almost constant and there is a little variation in frequency occurs at time 6 sec. because load is straightly linked to AC side. This is achieved by utilizing the PLL circuit that keep the frequency on track during the entire operation. **FIGURE** 4 (f) and **FIGURE** 4 (g) are showing three-phase instantaneous voltage and the phase (P-N) RMS voltage. Increased view of **FIGURE** 4 (g) now shown that displays no substantial variation in AC voltage with the change in connected load.

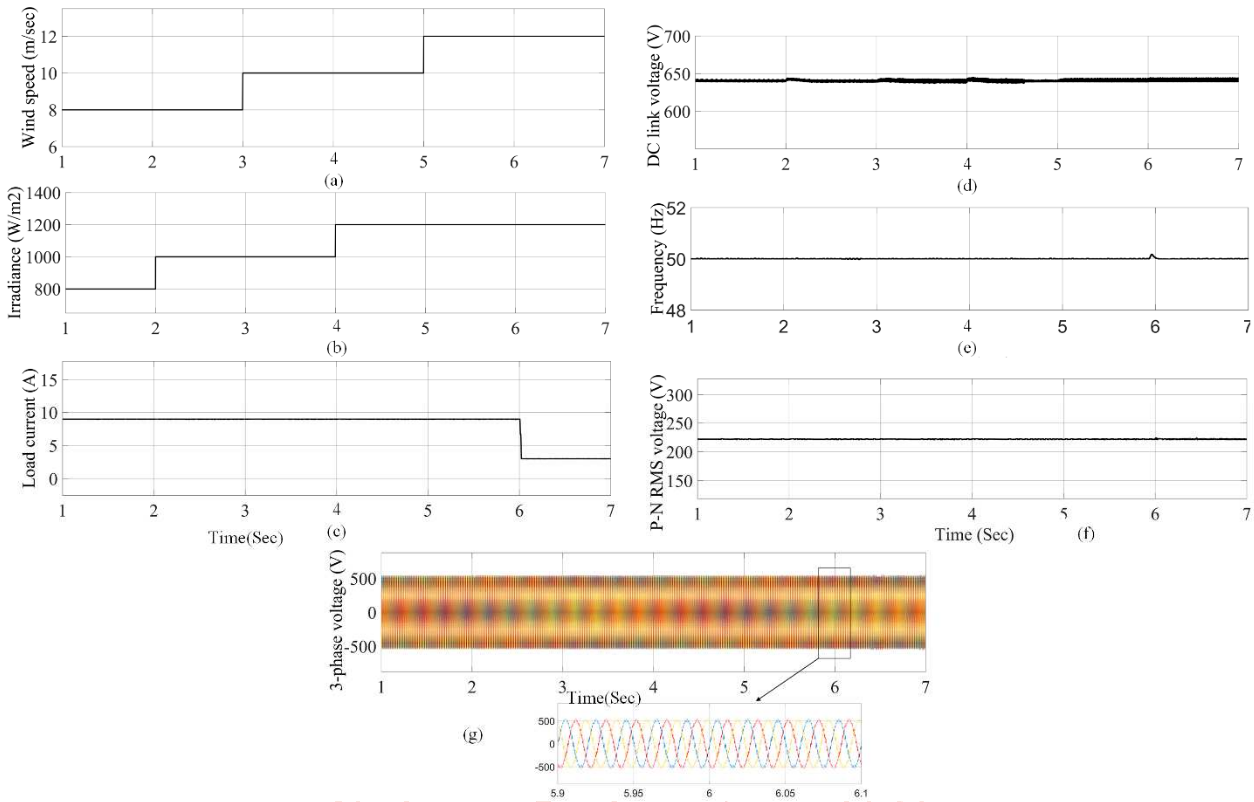
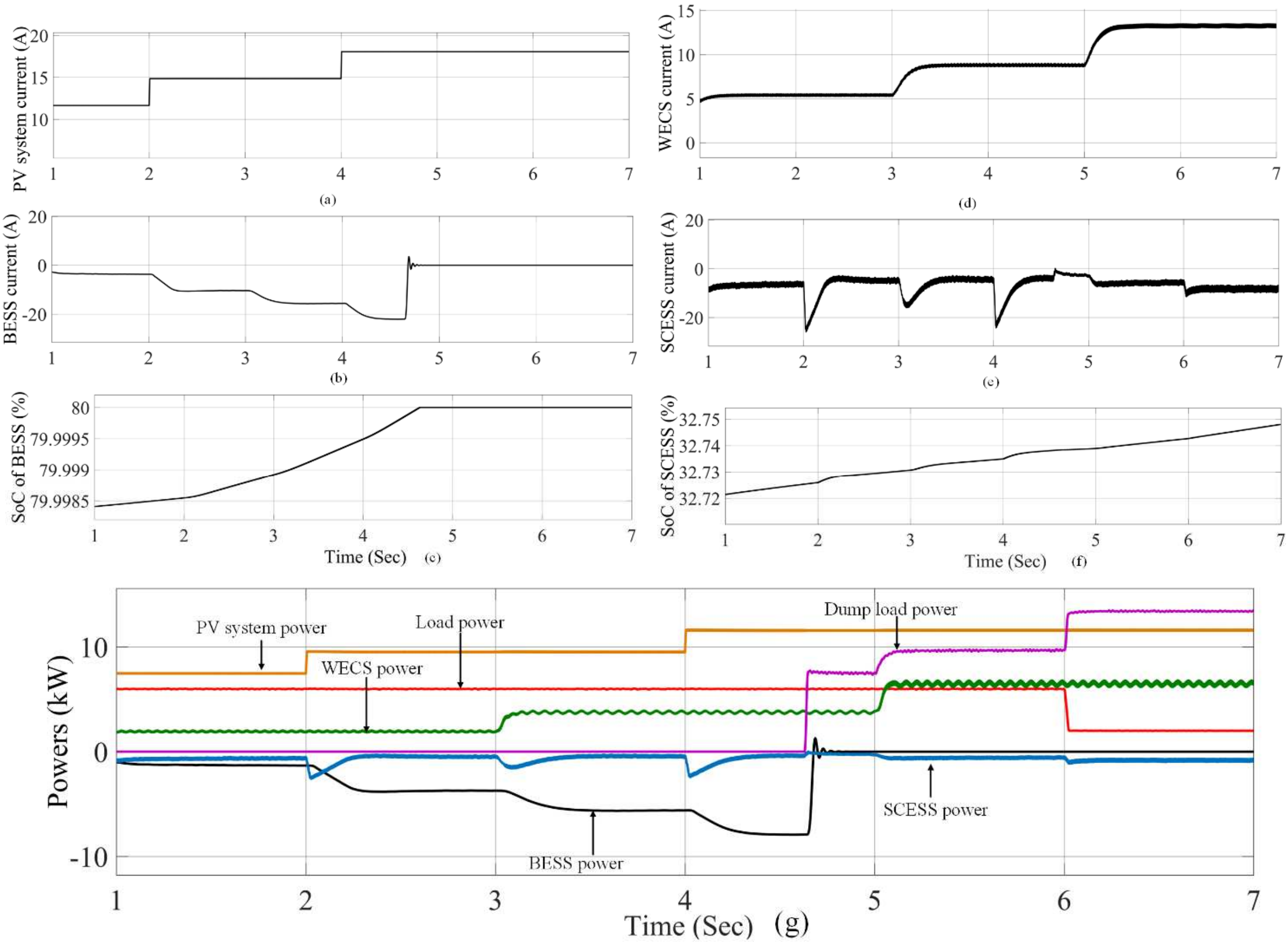


FIGURE 4 Various waveforms in surplus power mode (a) Variation in the speed of wind (m/sec), (b) Variation in the incident solar radiations (W/m²), (c) variations in the current at the load side, (d) variations in the voltage at the PCC, (e) variations in the frequency, (f) variations in the AC voltage at the load, (g) Instantaneous load voltage

The output of the PV system and WECS depends on the change in solar irradiance and wind speed as visible in Error! Reference source not found. (g). The extra power from the hybrid system is made use of in charging of the both ESS where slow transients are transferred to the battery and fast transients are transferred to the supercapacitor. The variations in the both ESSs is displayed in Error! Reference source not found. (b) which is in accordance with the variable wind speed and solar irradiance. Rapidly moving component of power mismatch is transferred to SCESS and it is shown in Error! Reference source not found. (e). At the time variation in solar power occurs when time reaches to 2 sec (Error! Reference source not found. (b)), correspondingly the current generated by the PV system also changes and by the output power of the PV system also changes and both the variations are displayed in Error! Reference source not found. (a) and Error! Reference source not found. (g). As of insignificant inertia of PV system, sharp increase in its current occurs with solar irradiance changes which subsequently effects in instantaneous rise in generated power of PV system. SCESS compensates this sudden change in the PV system output power afterwards slowly taken over by battery which helps in protection of battery from sudden charging and same thing is shown in Error! Reference source not found. (e), Error! Reference source not found. (b), and Error! Reference source not found. (g). When time reaches to 3 sec, with speed of the wind changes that also changes the output current of the WECS as shown in Error! Reference source not found. (a) and Error! Reference source not found. (d)). This helps in increment of WECS power (Error! Reference source not found. (g)). Due to this more surplus current is available for the battery as shown in Error! Reference source not found. (b)) also the power (Error! Reference source not found. (g). Another time 4 sec, increment in solar irradiance (Error! Reference source not found.**1** (b)), causes to shoot up the PV system current and corresponding power which provides more power to battery for its charging. When battery charging level reaches to it upper value which is set at 80% at time being 4.6 sec (Error! Reference source not found. (c)) battery will not take more power for its charging and power excess available is moved to dump load as displayed in Error! Reference source not found. (g). At time t=5 sec, again wind speed is increased which causes WECS output power that leads to more power to dump load (Error! Reference source not found. (g)) because battery cannot take more power because it is at its highest state of charge. After this, when connected load is reduced at time 6 sec, extra power thus presented goes to dump (Error! Reference source not found. (g)). In this entire period the SoC of supercapacitor is well under the range and when there any change in operating condition occurs SCESS goes back to charging mode after absorbing the change in operating condition. As shown in Error! Reference source not found. (f).



Error! Reference source not found. **Waveforms in surplus power mode (a) output current of PV system (A), (b) variation in current for BESS (A), (c) variations in SoC_{Bat} (%), (d) variations in output current of WECS (A), (e) variations in output current of SCESS (A), (f) variations in SoC_{SC} (%) and (g) various power waveforms (kW)**

Deficit power mode (DPM)

For examining efficacy of control strategy suggested for this work in under-generation situation the system is simulated in DPM. In DPM, shortage in power is shared by battery and supercapacitor according to their characteristics. Though the capacity of both ESSs is carefully chosen taking in to account the SoC_{Bat} cannot be below the 20% under any situation with power from PV and WECS is not available. For these types of situation the non-critical load is shedded off when SoC_{Bat} is less than the minimum value. For mimicking this situation, SoC_{Bat} is purposely considered near to 20% and battery will make its connection off from the system when its state of charge reaches to 20%.

IV. Conclusions

In this paper, a control scheme is proposed and implemented for the grid-isolated hybrid renewable energy system incorporating battery and supercapacitor. The control scheme is tested in over generation and under generation situations and worked according to expectations. By testing the system for under and over generation scenarios it is concluded that the system behaved as per the expectation and could able to maintain the frequency, difference in generation and demand, DC link voltage within the safe range when subjected to changing situations. Furthermore, gradual charging & discharging of BESS is attained with help of SCESS and giving it the fast moving transients. Along with that the controller could maintained the SoC of BESS in limits. Apart form that the three phase voltage and its frequency didn't violates the prescribed range.

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