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ENHANCING THE TRANSIENT RESPONSE OF HESS FOR VOLTAGE STABILITY IN DC MICRO GRIDS USING AN AUTONOMOUS CONTROL STRATEGY

Maddala Sandya Rani, PG Scholar, Sree Vahini Institute of Science and Technology, Tiruvuru
Dr. K. Kiran Kumar, Assoc. Professor, Sree Vahini Institute of Science and Technology, Tiruvuru

ABSTRACT :

To stabilize the system and compensate for the demand-generation mismatch, energy storage systems (ESS) play a crucial role in renewable microgrid systems. An essential and game-changing part is the energy storage system that uses batteries. Nevertheless, the lifespan of BESS is noticeably diminished by high current stress, particularly during sudden or transient power fluctuations, because of its poor power density and, as a result, delayed dynamic response. The result is a storage system that is hybridized with super capacitors. In order to compensate for the system's transient demand, controllers developed for energy storage systems need also react considerably. Super capacitors and batteries may be controlled independently using k-Type compensators and a nonlinear PI controller (NPIC), respectively, as suggested in this article. The voltage regulation capabilities of the developed control scheme are evaluated in a self-contained microgrid. In addition, a benchmark controller based on a low-pass filter (LPF) is compared. According to the findings, the suggested control method has better voltage regulation capabilities and a quicker reaction time. The suggested approach maintains a considerably decreased voltage variation between 47 V - 51 V for the test system regulated at 48 V for different abrupt load-generation case studies, in contrast to the 45 V - 56 V seen in the LPF methodology. In addition, the control method is less complicated and requires fewer sensors, which decreases the negative impact on the ESS response under transient conditions, compared to LPF-based control strategies.

INTRODUCTION :

Limited fossil fuel resources, incremental electric power consumption, global climate change, legislation for integrating renewable energy sources (RES), and the stochastic properties of RES and their associated challenges are just a few of the reasons that electric power generation, transmission, and distribution will be a top priority in the years to come [1]. Researchers and businesses alike have taken an interest in microgrids (MGs) as a potential new way to enhance power quality and generate transitive energy via the use of renewable energy sources (RES) [2]. MGs are dynamic distribution networks that use RES and other distributed energy resources to power linked loads. Fig. 1 shows that these MGs can switch between grid-connected and island modes of operation. The proximity of the power production and the load makes the power supply more dependable, with lower power losses and increased power quality. This allows it to meet a range of load needs all at once [3]. In addition, MG offers a relevant and practical strategy for the long-term electrification of rural areas, which are often sparsely inhabited, geographically dispersed, and not connected to the main grid [4].

It is challenging to electrify these regions using standard transmission and distribution technologies due to techno-economic restrictions. A more efficient solution in these instances is standalone RES based MGs [5]. Due to its low cost, ease of installation, adaptability, and technical maturity, PV has become one of the most prominent RES technologies in the last ten years [6]. However, because to their reliance on weather, changing environmental elements, and/or time constraints, the majority of RES systems are intermittent. Since this is the main cause of demand-generation mismatch, it lowers the dependability of the power network [9], affects the voltage and frequency of the network negatively [7], and unintentionally makes it harder to implement RES [10]. Energy storage systems (ESS) serve as a power balancing medium and can alleviate a number of issues related to renewable energy sources (RES), such as low power quality, inadequate load following, generation-load mismatch, voltage instability, frequency deviation, and intermittent output power [11]. Typically, BESS are chosen because of their high energy density. On the other hand, BESSs (lead-acid, lithium-ion, nickel-Cadmium, nickel-Metal hydride, redox-flow, etc.) are only applicable to steady-state dynamics. Because BESSs have a poor power density, compensating for significant fluctuations shortens their lifespan and necessitates frequent replacement, cutting into their profit margin. For an economically dependent power network to efficiently adjust for disruptions caused by RES, ESS ideally has an optimum operating period, high power density, energy density, and response time [12]. The increased efficiency and energy density of BESS make them the go-to option most of the time [13]. Nevertheless, its technical error impedes adequate adjustment for brief or abrupt power variations, which severely affects the BESS life cycle [14]. At the same time, we should expect BESS degradation to speed up under these conditions [15], and their economic importance to plummet as a result [16]. Additionally, as these features are unlikely to be delivered by a single ESS, the flexibility to harness desired attributes from each ESS may be achieved by hybridization of diverse energy storage systems. The combination of BESS and SCSS is one example of an ESS that has several uses. Here, SCSS's low energy density, high power density, practically infinite life cycle, short reaction time, and high self-discharge are technologically complementary to BESS's technical features, which include a limited life cycle, high energy density, low power density, a relatively low self-discharge, and a short reaction time. So, the end product, a hybrid energy storage system (HESS), is feasible from an economic perspective, has a reasonably quick dynamic reaction, an optimized life cycle, and a high power density [17]– [21]. Thus, it is essential that the HESS controller mostly provide a seamless transition and power distribution to make the most of the prominent technological features of BESS and SCSS. Here, we propose and implement a controller to enhance SCSS's transient responsiveness. In a microgrid powered by renewable energy sources, the idea is to build a decoupled control system that uses the strengths of BESS and SCSS to regulate voltage. The controller for BESS is based on Type II compensators, whereas the controller for SCSS is NPIC, or non-linear PI controller. A sufficient reference current is created for the BESS using the error signal measured at the DC bus and the appropriate location of the poles and zero. The BESS then operates in line with its slow dynamics, aiming to meet the average energy demand of the microgrid. In a similar vein, the NPIC controller operates the PI controller and generates the necessary SCSS reference current based on the needed transient response towards DC bus voltage regulation using a look-up table (LUT).

LITERATURE SURVEY :

In "A comprehensive review on renewable energy development, challenges, and policies of leading Indian states with an international perspective," J. B. Holm-Nielsen, L. Mihet-Popa, A. Annam, N. M. Kumar, S. Padmanaban, G. M. Shafiullah, and S. Padmanaban wrote the following:A number of factors, including finite fossil fuel supplies, rising electric power consumption, changing global climate, laws requiring the integration of renewable energy sources (RES), and the stochastic characteristics of RES along with their associated problems, will make electric power generation, transmission, and distribution the top priority in the years to come. Researchers and industry professionals have taken an interest in microgrids (MGs) as a potential new way to enhance power quality and generate transactive energy via the use of renewable energy sources (RES). MGs are dynamic distribution networks that use RES and other distributed energy resources to power linked loads.

"Sizing a hybrid energy storage system for maintaining power balance of an isolated system with high penetration of wind 4 generation," co-authored by Y. Liu, W. Du, L. Xiao, H. Wang, S. Bu, and J. Cao, published inHowever, because to their reliance on weather, changing environmental elements, and/or time constraints, the majority of RES systems are intermittent. In particular, this causes a demand-generation mismatch, which lowers the power network's stability by altering its voltage and frequency and thus restricts the practicality of RES penetration. Using an energy buffer, such as an energy storage system (ESS), which acts as a medium for balancing power, can solve many issues related to renewable energy sources (RES), such as low power quality, inadequate load following, generation-load mismatch, voltage instability, frequency deviation, and intermittent output power. Typically, BESS are chosen because of their high energy density. On the other hand, BESSs (lead-acid, lithium-ion, nickel-Cadmium, nickel-Metal hydride, redox-flow, etc.) are only applicable to steady-state dynamics. Because BESSs have a poor power density, compensating for significant fluctuations shortens their lifespan and necessitates frequent replacement, cutting into their profit margin.

As stated in the article "Implementation of optimization-based power management for all-electric hybrid vessels" by L. W. Y. Chua, T. Tjahjo Widodo, G. G. L. Seet, and R. Chan,The combination of BESS and SCSS is one example of an ESS that has several uses. Here, SCSS's low energy density, high power density, practically infinite life cycle, short reaction time, and high self-discharge are technologically complementary to BESS's technical characteristics, which include a limited life cycle, high self-discharge, low energy density, and a limited life cycle. Consequently, the final hybrid energy storage system (HESS) is economically viable, has a considerably quicker dynamic reaction, an optimized life cycle, and a high power density. Thus, it is essential that the HESS controller mostly provide a seamless transition and power distribution to make the most of the prominent technological features of BESS and SCSS. Here, we propose and implement a controller to enhance SCSS's transient responsiveness.

METHODOLOGY:

For batteries, we provide a decoupled control technique that makes use of k-Type compensators; for super capacitors, we suggest a nonlinear PI controller (NPIC). The voltage regulation capabilities of the developed control scheme are evaluated in a self-contained microgrid. In addition, a benchmark controller based on a low-pass filter (LPF) is compared. According to the findings, the suggested control method has better voltage regulation capabilities and a quicker reaction time. In comparison to the LPF methodology's 45 V - 56 V voltage deviation, the suggested approach maintains a substantially lower voltage deviation between 47 V - 51 V for the test system regulated at 48 V during several sudden load generating case studies.

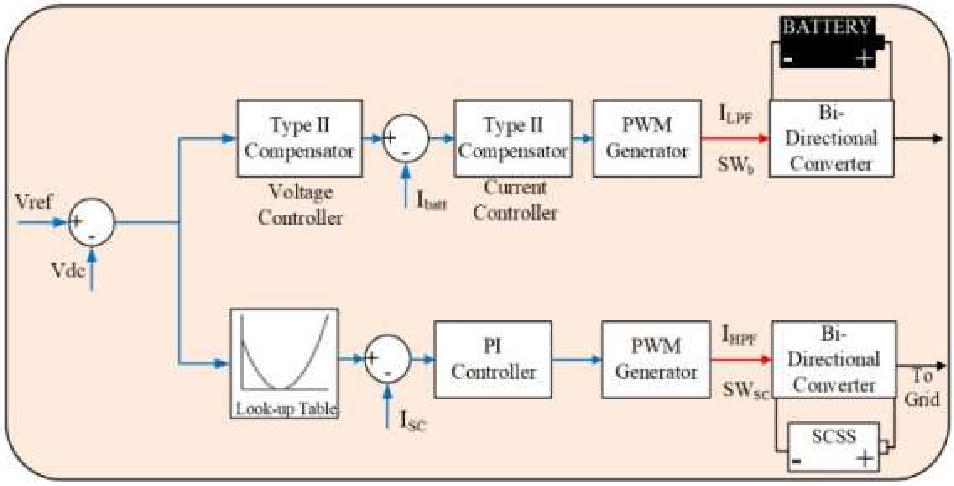

Fig. 1 Proposed controller design for power management between BESS and SCSS.

The BESS may be charged or discharged according to the grid's power needs, whether there is an excess or deficit, since it is a dispatchable energy source. The BESS is depicted in the above picture operating in voltage-controlled mode for DC bus voltage regulation. It is regulated using an outer loop for current and an inner loop for voltage.

We use a type II controller for the voltage and current feedback loops to ensure that the BESS responds appropriately to voltage regulation, taking into account the technical power density constraints of the BESS. For more reliable and effective grid regulation, look no farther than type II controllers, which are a subset of lead compensators. Proper shape of the control loops is provided by the combination of zeros and poles. The gain and phase parameters of the open-loop frequency response are adjusted to accomplish this. With the right adjustments, you may obtain a zero steady-state error with quicker response and minimal overshoot, compensating from 0◦ to 90◦.

The needed value of the gain is denoted by υ, while wz and wp are the controller's poles and zeros in the frequency domain, respectively. Consequently, these controllers are designed using the k-factor technique Because BESS has a delayed dynamic reaction during generation and or load changes, its stability and responsiveness are achieved by constructing the voltage and current control loops using the k-factor technique. When considering the design of these controllers, limited bandwidth is taken into account. Therefore, BESS contributes to the BESS's extended life owing to decrease in current level by compensating just the average long-term power consumption of the system with a smooth transition. such, the blue lines in Figure indicate how to operate BESS such that it supports the DC bus with a constant steady-state voltage. Then, SCSS may be constructed to use them based on their main operating features. Because SCSS have a low energy density, using them under steady-state voltage variation reduces their useful life and technical impact. Following the transition from a transient to a steady-state demand for the bus voltage, SCSS functioning should quickly reach zero value. Second, unexpected changes in power need a quick dynamic reaction.

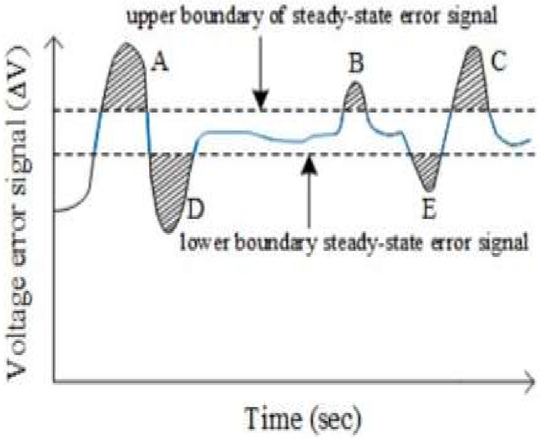

Fig.2 Allocation of power between BESS and SCSS based on voltage deviation at the DC bus.

So, as seen in Fig. 2 we develop a non-linear PI controller architecture that is controlled by a 1-D LUT in order to create this non-linear function and to restrict the functioning of the SCSS during steady-state voltage variation. the DC bus voltage, and the primary goal of this approach is to determine two acceptable bounds: the lower and higher borders. Therefore, the controller is programmed to prevent SCSS from operating by regulating under-voltage and over-voltage conditions, limiting power absorption and injection, and defining its lower and upper boundary limits, respectively, based on observations of the error signals generated by Vref and Vdc at the DC link. Because of this, the SCSS controller will have constraints and cannot function in the BESS-compensated steady-state zone.

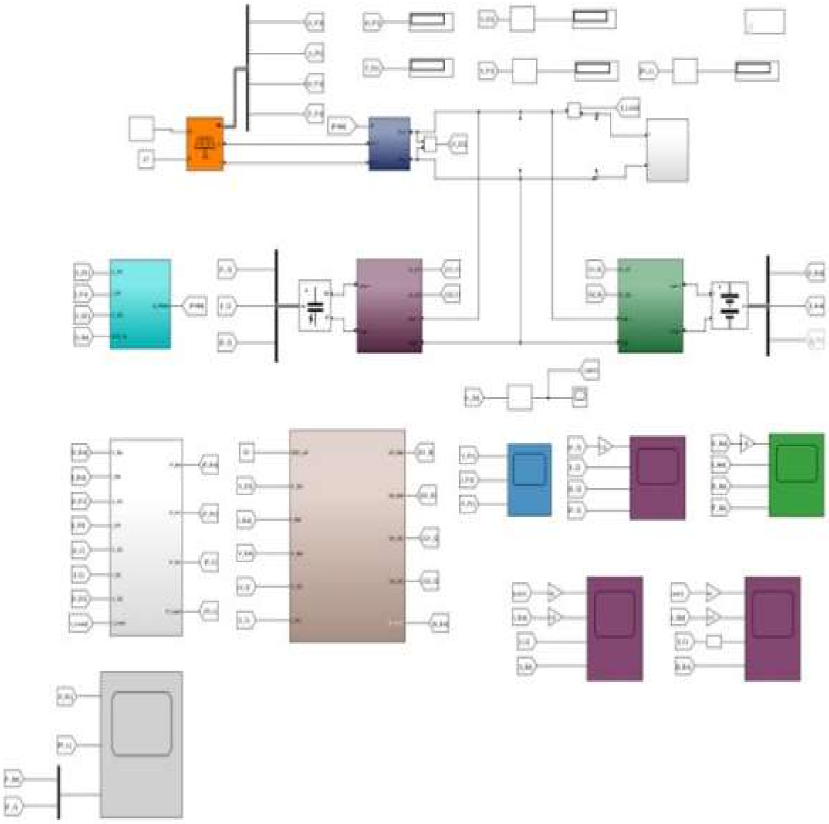

Fig. 3 Simulink design for proposed controller design for power management between BESS and SCSS.

The SCSS is charged in regions A, B, and C during the dynamic load shifting process in order to absorb superfluous energy and control the voltage below the upper boundary area. In the same way, the voltage is controlled in regions D and E, which are above the lower border zone, by immediately discharging the SCSS and providing the power that is lacking. This approach also permits the limitation of power transition during steady-state mistakes by means of the appropriate model-based regression approaches that are necessary.

A DC microgrid system is used to study and compare different control strategies. The system includes an independent 480W- PV power source and a desired reference voltage level (Vref) of 48 V. The study is conducted for different changes in microgrid load-energy, and the nominal system characteristics are listed in Table 2. In line with this, the suggested control strategy's robustness is marked by comparing the regulation of DC bus size with its degree of deviations. The effectiveness of the suggested controller in lowering the BESS stress current and increasing its life cycle is further evaluated by comparing it to the BESS SOC.

RESULTS :

INCREMENT IN LOAD DEMAND

Here, the solar PV panel is operating at a temperature of 25 °C and an irradiation of 509 W/m2; the initial load resistance setting was RL D 4.8, which predicted a load need of 10 A.

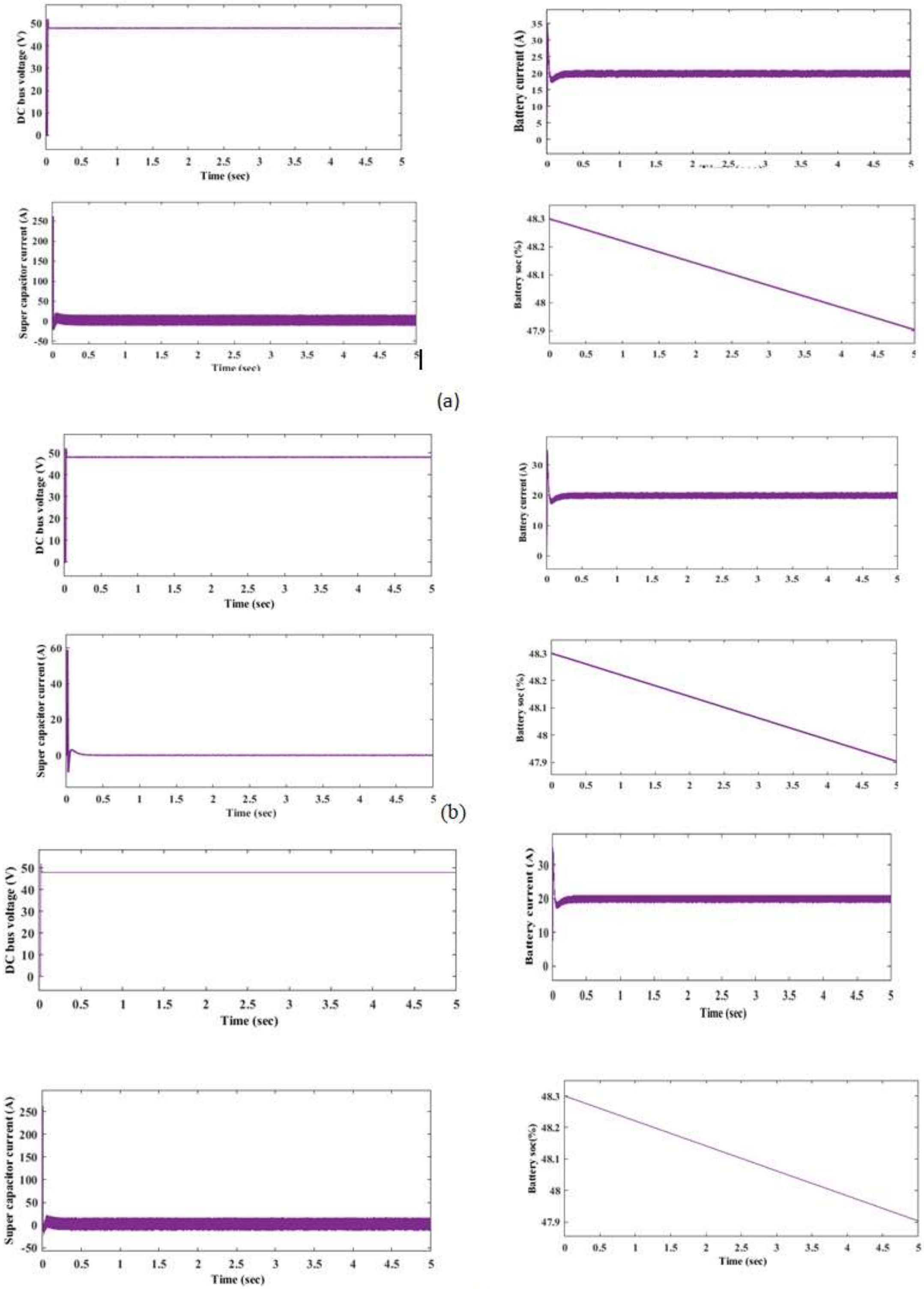

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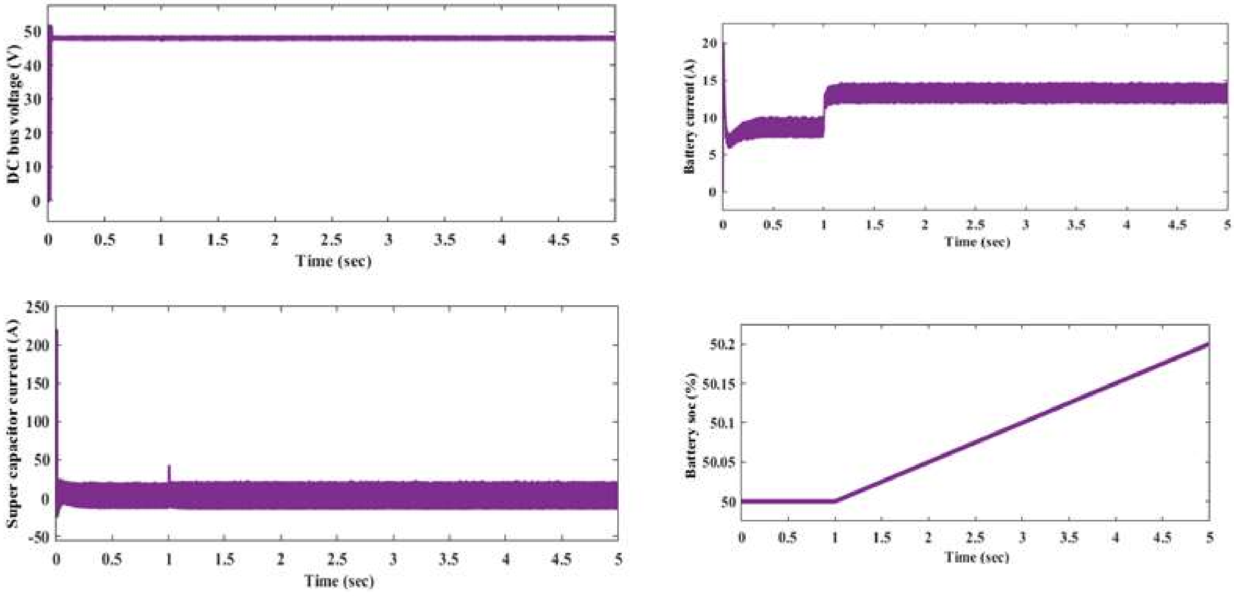
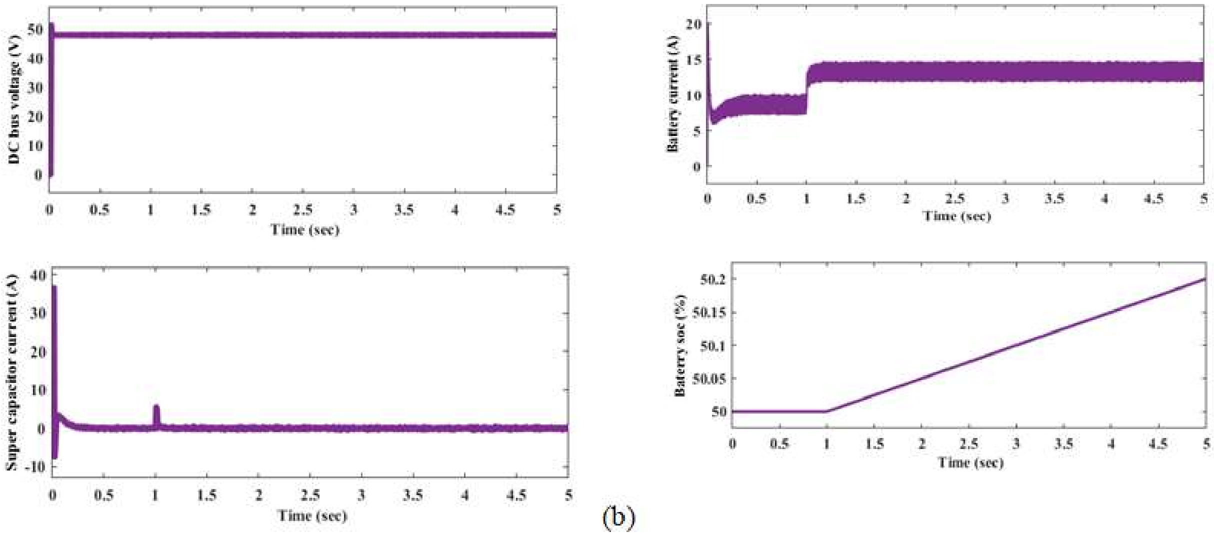
Fig. 4 Results obtained with abrupt load increase in microgrid. a) LPF control strategy; b) a decoupled control strategy for batteries and super capacitors based on k - Type compensators c) Fuzzy Logic Controller

DECREMENT IN LOAD DEMAND :

The solar PV panel is set to run at SD509W=m2 and TD25_C in this instance. When the starting load requirement (RL) is set at 4.8, the resulting Pspv is 480Wat MPPT, which forecasts a load demand of 10 A. Vdc is 48 V at this early stage. Increasing RL to 9.6 during the operating time causes a sudden drop in load demand from 10 A to 5 A. This drop occurs at t D 0:1 sec. Consequently, at this same moment, Vdc is rising, and in order to keep the voltage at 48 V, the HESS components must be charged with the excess generated. As seen in Figure 4.2 (a), the BESS achieves a steady-state 58 charge current of 10 A at time D 1:15 sec with an initial current overshoot in the LPF control method, which accounts for the average power differential (240 W) caused by the reduction in load demand. Consequently, in order to control the DC bus voltage, SCSS makes up for the transient high-frequency component.



(a)



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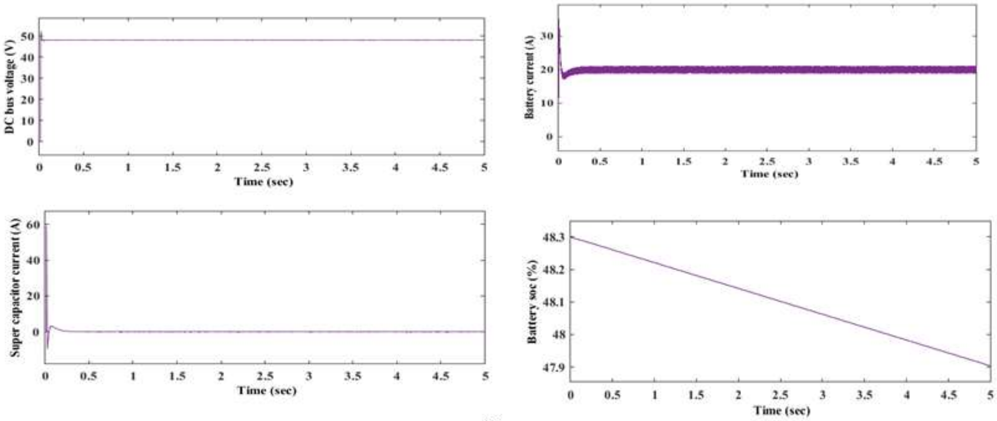
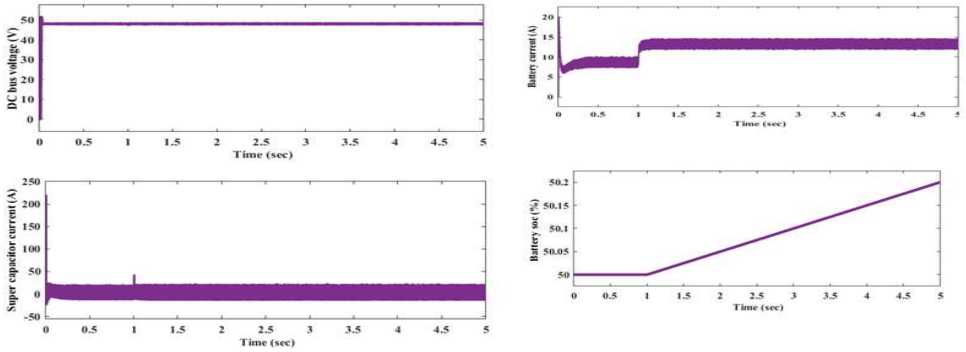


(c)

Fig. 5 Results obtained with abrupt load increase in microgrid. a) LPF control strategy; b) a decoupled control strategy for batteries and super capacitors based on k - Type compensators c) Fuzzy Logic Controller

INCREMENT IN SOLAR PV GENERATION :

In this scenario, the operational analysis assumes a 10 A load demand with a constant load resistance of RL D 4.8. From the start, the solar PV panel gets SD509W=m2 at a constant temperature of TD25_C. At time D 1 sec, the irradiance is suddenly raised to 990W=m2 for the operating period. Consequently, while operating in MPPT mode, the produced power (Pspv) rises from 480 W to 960 W. At this time, the PV system has produced an excess of 480 W=m2, which causes a load-generation mismatch. Consequently, the DC bus voltage is affected by an increase in voltage, which has to be controlled by rerouting this excess power production and charging the HESS.



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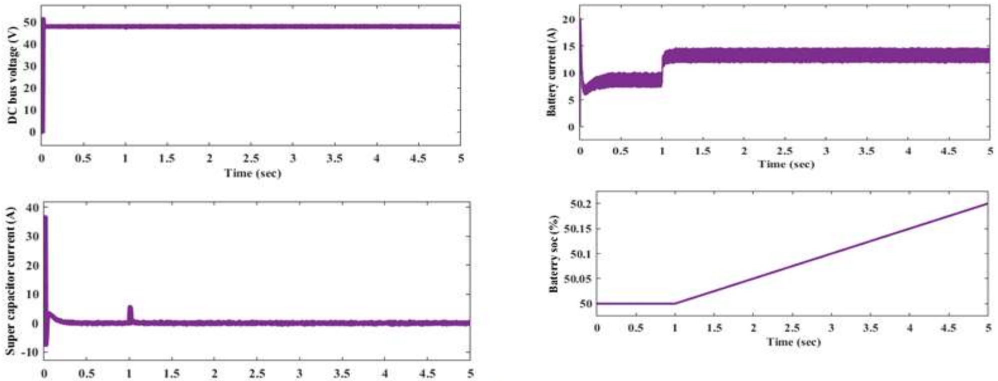

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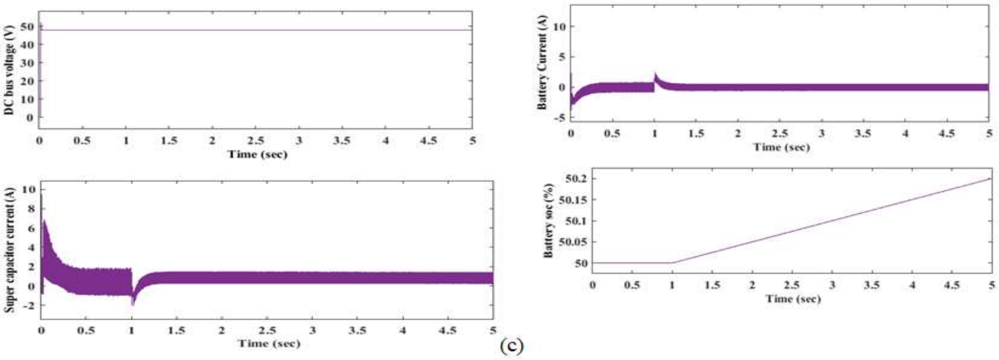
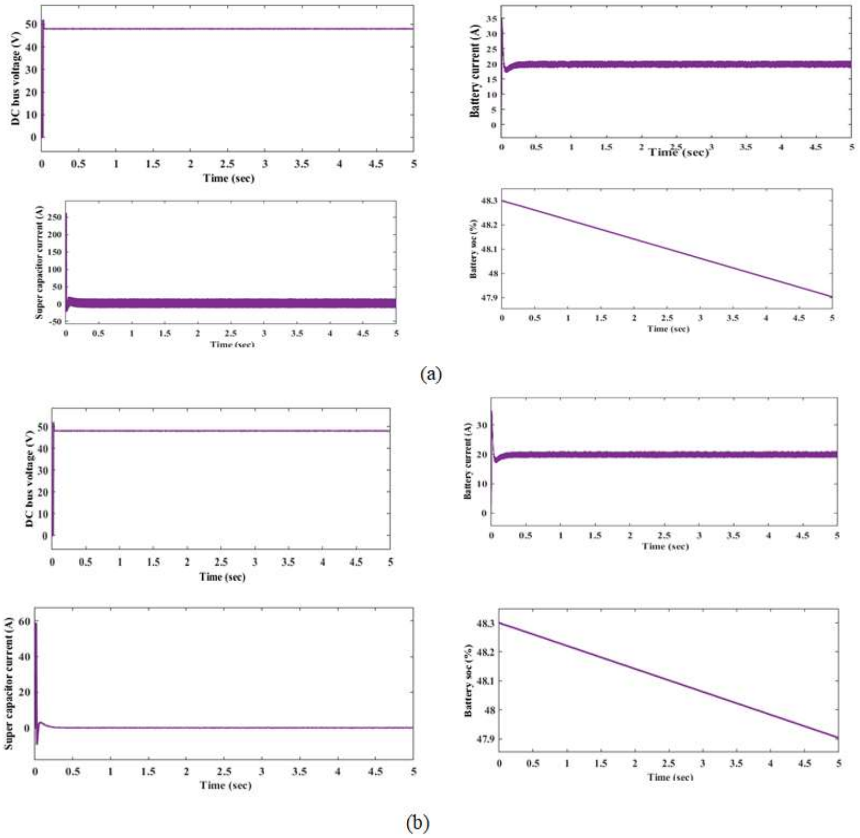


(c)

Fig. 6 Results obtained with abrupt load increase in microgrid. a) LPF control strategy; b) a decoupled control strategy for batteries and super capacitors based on k - Type compensators c) Fuzzy Logic Controller

4.4 DECREMENT IN SOLAR PV GENERATION

The efficiency based comparison between these two methods is firstly done on the basis of voltage magnitude and its degree of deviation at the DC bus (*Vdc*). As observed in Fig. 7 (a), (b) and (c), the LPF strategy is unable to optimally regulate *Vdc* during transient conditions and a transient voltage drop of 46 V is experienced, whereas in the proposed method it is 47.5V. This is mainly due to the slow dynamics of BESS that inherently curtails the required response resulting in uncompensated current that contributes to the voltage deviation and negatively impacts the BESS life cycle. Secondly, the impact on the BESS % SOC decrease in the proposed method is less as compared to the LPF method at the end of the operational analysis.



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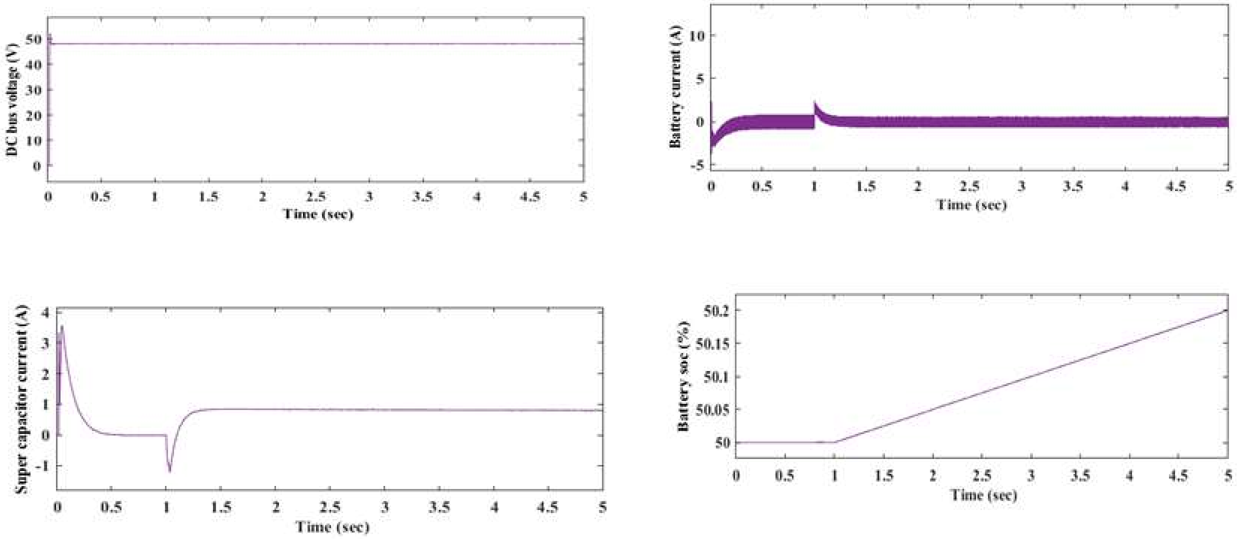

(c)

Fig. 7 Results obtained with abrupt load increase in microgrid. a) LPF control strategy; b) a decoupled control strategy for batteries and super capacitors based on k - Type compensators c) Fuzzy Logic Controller

CONCLUSION :

We provide a control technique for microgrids that can stabilize DC bus voltage and enhance power quality in the face of transient and abrupt power variations. This kind of control relies on distributing electricity across hybrid energy storage systems in the most efficient way possible. Using k-type compensators and a non-linear PI controller (NPIC), the approach separates the BESS and SCSS allocation processes. In response to several instances of power imbalance between renewable-based production and demands, the suggested control approach has been developed and rigorously tested. Better voltage control with faster BESS and SCSS responses is seen from the data. Also, a benchmark LPF control approach is rigorously compared to the findings. Using a 48 V regulated test system and a variety of abrupt load-generation case studies, the suggested methodology reduces BESS current stress and improves BESS-SoC performance, improving voltage regulation by an average of 4.4% in cases of inadequate power and 7.0% in cases of excess power. The suggested control technique greatly improves the BESS lifespan and dramatically minimizes the degree of voltage variation at the PCC during load-generation mismatch, as confirmed by this data. Consequently, the suggested controller allows for a generally quicker transient reaction with less complex modeling.

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