

Improving Power Quality and Managing Power in a PV-HESS Based Grid-Tied Microgrid with a Model Predictive Control Method

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Abstract - Renewable energy sources are infamously unstable when it comes to producing constant power because they rely on weather conditions, and power electronics devices can decrease power quality by introducing harmonics into grid interaction systems at the point of common coupling (PCC). This research presents a PV system that is connected to the grid and uses a hybrid energy storage system (HESS) to solve these problems. In addition to facilitating the smooth transfer of power from generation to storage and consumption, this article primarily aims at ensuring a consistent and high-quality power supply to the loads. By regulating the power converters with a finite control set-model predictive control (FCS-MPC) method, the power management system is optimised. Further, the three-phase voltage source converter (VSC) is subjected to a modified leaky least mean square (MLLMS) method. By enhancing the system's capacity to isolate the relevant components of the load current, this algorithm reduces harmonic distortion and allows for faster adaptability to changing operational conditions. The DC-DC converters of the hybrid energy storage system are actively adjusted to guarantee peak performance. Levels of the States of Charge (SoC) of the available storage devices are taken into account by the technique. This system's versatility was demonstrated using MATLAB/Simulink modelling and simulations that took into account different load and PV generating scenarios. Modern grid-interactive microgrids rely on improved power quality and efficient energy management.

Key Words: Photovoltaic, hybrid energy storage (HES), model predictive control, modified leaky least mean square (MLLMS), voltage source converter, power management.

1.INTRODUCTION

In order to address the increasing need for clean energy while simultaneously reducing dependency on fossil fuels and protecting the environment from their adverse consequences, microgrids powered by solar panels have lately evolved as a viable option [1]. An integrated photovoltaic (PV) system, energy storage devices, loads, and other DERs are all part of a microgrid, which is a localised energy system. Its flexibility to function in either grid-connected or island mode improves energy management and resilience. The generation output of the photovoltaic system is, however, highly unpredictable

due to its intermittent nature. A solution to this problem is being sought for through research on hybrid energy storage systems. Instability when linked to the grid is a potential issue for microgrids that depend significantly on RES. Because of the storage system, microgrid resilience is increased and these problems are reduced. Because of its unpredictable output, the ability to get the most out of renewable energy sources (RES) needs to be carefully considered while constructing a PV-based system. Several maximum power point tracking (MPPT) algorithms were discussed in references 2, 3, and 4. The incremental conductance (InC) method, renowned for its high accuracy and low processing overhead, is employed by this system to optimise power distribution to the microgrid [5]. When using renewable energy sources like photovoltaic systems, which have intermittent output, microgrids depend significantly on energy storage systems (ESS) to keep the power flowing continuously. To control the flow of electricity, energy storage devices are essential. A microgrid equipped with an energy storage device can be used as a buffer to ensure a steady flow of power throughout the system. When it comes to energy storage, photovoltaic systems (PV) are most commonly paired with batteries. The high energy density of the BES makes it an ideal candidate for long-term energy storage.

The slow response time of BES causes it to have slow charging and discharging speeds. This means they aren't the ideal pick for situations where there is an abrupt shift of authority. But supercapacitors are different in that they can store a lot of power in a small package and respond quickly. Because their energy density is lower than that of BES, they are inadequate for large-scale energy storage. The Ragone graphic [6] shows the relationship between the energy density and power density of several storage technologies in Figure 1. Combining these two energy storage devices has many benefits, including extending battery life and making microgrid power management easier [7]. Power injection into the grid also has a major effect on the grid-interactive photovoltaic system's reliability of control. To achieve these objectives, a trustworthy control approach is applied to the power converters.

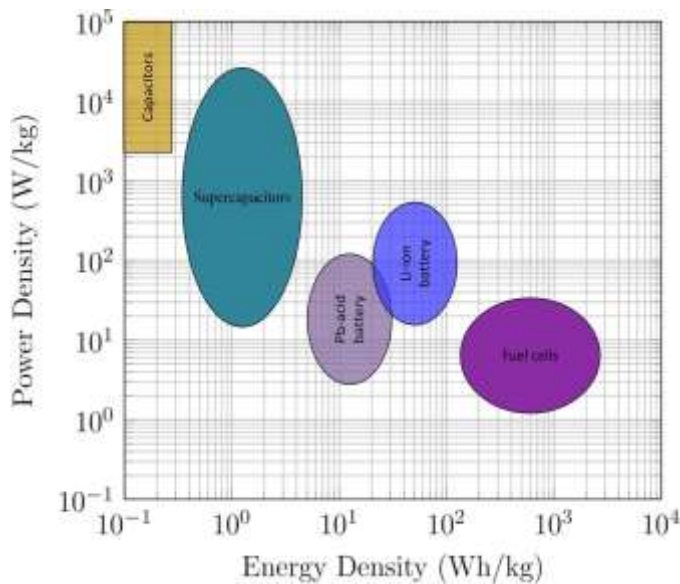


Fig. 1.Ragone plot for various storage devices.

An efficient power supervision system is essential in a microgrid setting with several distributed generation (DG) sources to keep the power supply and demand in balance, regulate the voltage and frequency, and supply electrical power. Furthermore, it aids in keeping the energy storage devices' state of charge (SoC) levels. In literature, numerous methods for distributing power have been proposed. Based on the levels of the system of components in a microgrid that operates independently of the grid, a power management strategy is suggested in [8]. An energy distribution strategy that is based on DC-link signalling is described in [9]. There is more strain on the battery because it is the sole energy storage source for the system. In order to control the voltage of the grid-tied PV system, an adaptive neuro-FIS based power sharing method is presented in [10].

The HESS control method described in [11] makes use of a CCSNN-based energy supervision strategy, which combines cuckoo search with neural networks. The production of solar energy is highly susceptible to variations in irradiance as a result of the many weather conditions that can occur. Voltage sags, swells, and flickers can be observed at the PCC as a consequence of voltage instability and frequency deviation caused by these variations [12]. To generate the switching signals needed for reliable operation when integrating PV-based microgrids to the grid via DC-AC voltage source converters (VSCs), an efficient control method is required. When nonlinear loads are connected at the power electronic converter (PEC), the use of the converter for DC-AC conversion results in a system with high harmonic distortion [13]. Managing system harmonics and achieving power distribution between the load and the source are the primary goals of VSC control [14]. The literature is replete with control approaches that aim to robustly regulate the VSC. In [15], the standard dq0 base controller is used. Under all kinds of weird circumstances, the PLL block performed

poorly. The integral sliding mode technique is discussed in reference [16]. When taking imbalanced loading or variations in load into account, the least mean square-based controller still manages to produce satisfactory performances [17]. One example of a control mechanism is the leaky least mean logarithm (LML) in [18]. Reducing the weight factor's oscillations is the goal of the modified variable step size LMS that is shown in [19]. In [20], a leaky least mean control approach is utilised, with a changeable step size. Problems with drifting in the LLMS and LLMF algorithms can lead to an unlimited estimate of the weight factor. By including a leakage factor, the Modified Leaky LMS solves the LMS algorithm's drifting problem [21]. In addition to the benefits already discussed, the MLLMS algorithm is a good fit for extracting essential components because it is easy to apply and requires minimal processing.

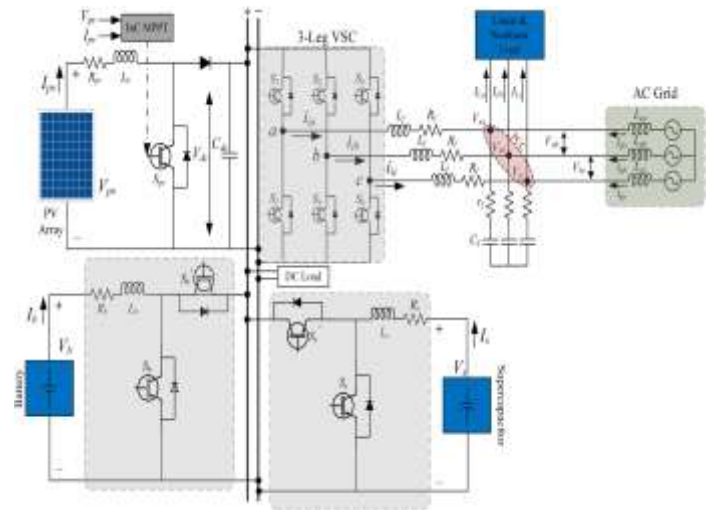


Fig. 2.PV-HESS based system framework

Typically, linear cascaded control loops and pulse width modulation are employed for switching pulse production in converters. It is also common practice to employ hysteresis control. Despite their widespread use, these approaches have a number of downsides that affect the converter control process. If you modify any of the system parameters, you'll have to re-tune the controller because the control loops don't take the non-linear dynamics into account [22]. The utilisation of model predictive control (MPC) is on the rise due to the increased computing capability of microprocessors. It takes into account all the nonentities in the system and offers a basic methodology. Control variable step-ahead predictions are made possible by the finite control set-model predictive control by means of the converters' specified switching combinations. The optimal switching state is chosen by comparing it with the reference value. In order to finish the control operation, the converters are fed these switching signals. An isolated DC micro-grid with a cascaded energy storage system linked via a DC-DC bidirectional converter was used in conjunction with FCS-MPC and a power balancing strategy based on

systems on chips in [23]. The FCS-MPC and a power flow control method have been employed by [24] to manage a PV microgrid that is connected to the grid. The MPC for power converters in an AC microgrid with an LC filter has been used for rapid capacitor voltage tracking in [25]. Additionally, it demonstrated the mpc's resilience in comparison to the traditional PWM. This work uses a single step prediction horizon to achieve quick control action without putting too much computational weight on the system.

2. Proposed System Control Schem

Fig. 2 illustrates the configuration of a three-phase Photovoltaic-HESS fed grid-interactive system. The photovoltaic system's connection to the three-phase grid is designed in a two-stage architecture. In order to maximise the power output of the CMPPT algorithm, the PV system makes use of the DC-DC converter to raise the voltage. The DC bus capacitor (C_d) is connected to the SC and batteries using a DC-DC bidirectional converter. The LV sides of the bidirectional converters are connected to the HESS via indicators (L_b, L_s) having internal resistance (R_b, R_s). The three-phase dc-ac VSC is tied to the PCC through interfacing indicators (L_f) with resistance (R_f). The switching ripple filters (C_f, r_f) are also used at the PCC for eliminating the switching disturbances. Non-linear loads are connected at the PCC using diode bridge rectifier.

Algorithm for Power Sharing (APS)

The algorithm for power sharing decides the microgrid operating condition depending upon the power generated by Photovoltaic system and the load requirement. Three operating condition are devised by APS as follows 1) Sufficient Power Generation (SPG), ($PPV > PL$). 2) Insufficient Power Generation (IPG), ($PPV < PL$). 3) Balanced Power Generation (BPG), ($PPV = PL$). However, the BPG mode of operation is included in the IPG mode because in both the modes the storage units are operated in discharging condition. Depending on the Soc levels of HESS and the operating mode the reference values are assigned accordingly. 1) SPG: In this mode of operation, the generated PV power is higher than that of load demand. Thus the excess power is absorbed by the battery and SC to attain there SoC upper limit. After the battery reaches there SoC uper limit the charging are stopped. At this condition the battery becomes ideal and only

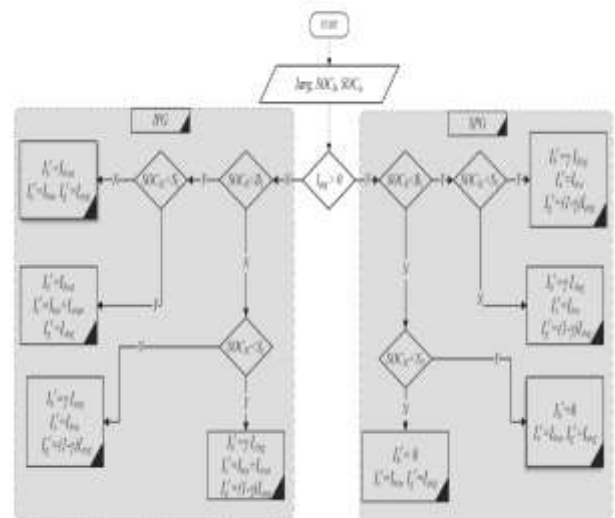


Fig. 3. Algorithm for Power Sharing.

The VSC control for the microgrid requires to generate the three-phase grid reference current. Three components are needed for the calculation of the reference current, i.e. PV feed forward component which accommodates the varying condition of solar irradiance, loss component and the extraction of fundamental active and reactive weight of load current. The fundamental component is extracted using the Modified Leaky LMS (MLLMS) based adaptive control is implemented. The fundamental component calculation depends upon the PCC line voltage (v_{gab}, v_{gbc}) and the load current (I_{La}, I_{Lb}, I_{Lc}). The three phase voltages at PCC are evaluated from the line voltages as in (7) [26].

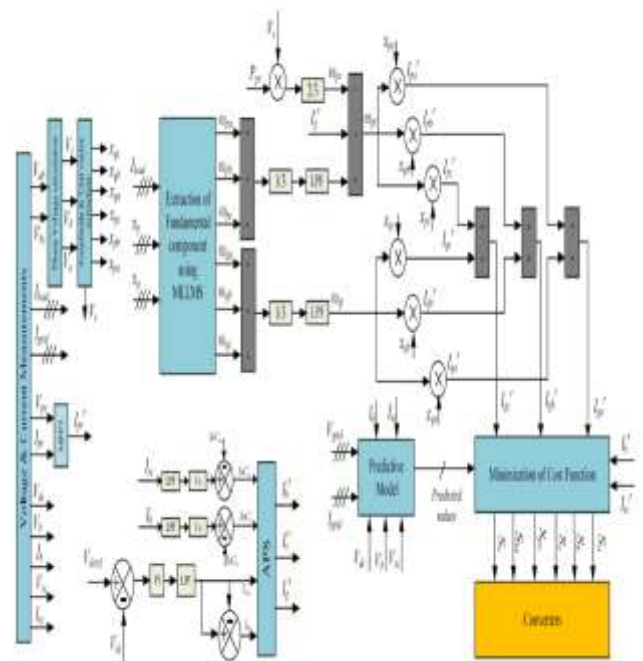


Fig. 4. Layout of MLLMS based MPC control

VSC Control: Having two switches in each legs of the VSC we have a total of eight switching states.

Correspondingly we will have eight voltage vectors for the converter. For each of these voltage vectors the values of current sample is computed for the future sampling time. The mathematical model for the VSC is demonstrated

3.Results and Discussion

The power management system and controller based on MLLMS-MPC are modelled and studied under different operating scenarios using the MATLAB/Simulink environment. The section delves into the system's simulated outcomes under these different operational conditions. The non-linear loads are taken into consideration using a diode bridge rectifier, an indicator, and a series resistor.

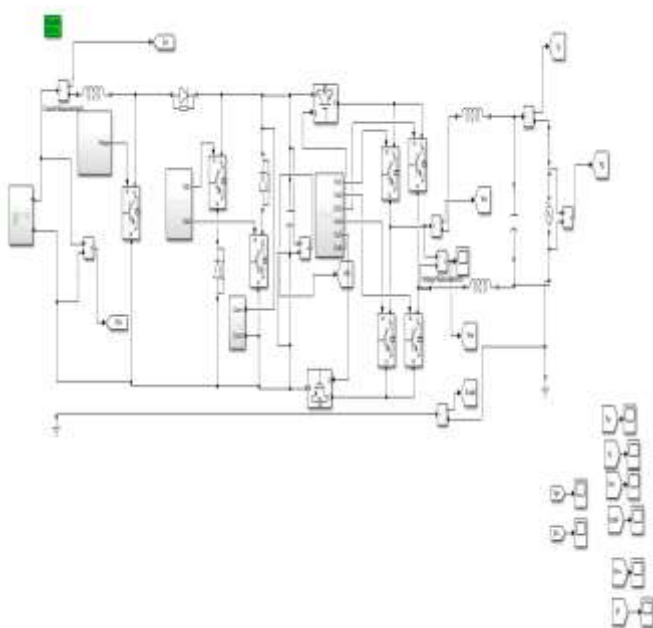


Fig. 5. Simulation diagram of the proposed system

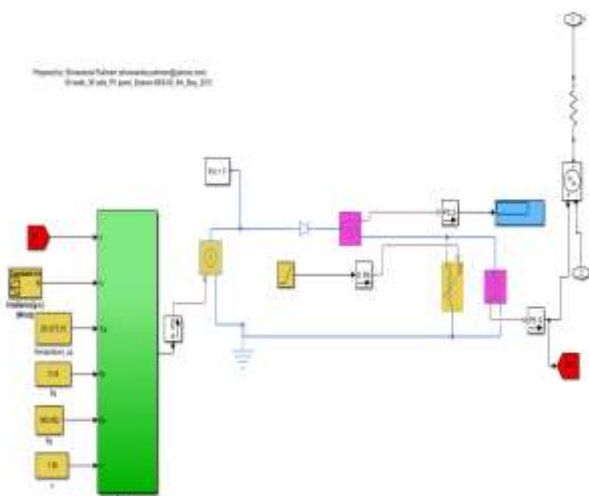


Fig.6. PV Module

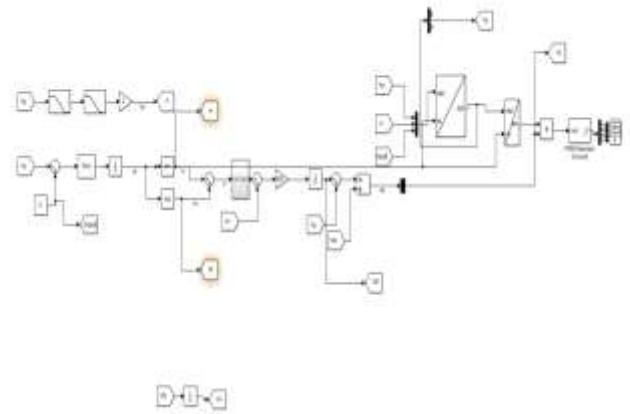


Fig.7. Control strategy

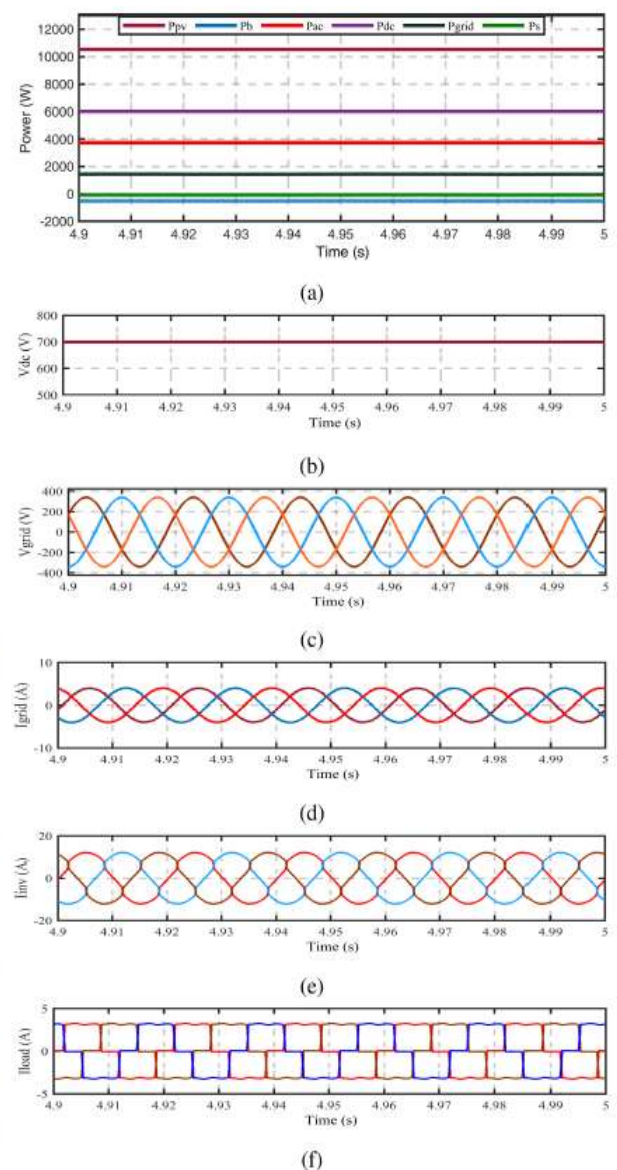


Fig. 8. System response under non-linear load (a) Power variation (b) DC bus voltage (c) Grid voltage (d) Grid current (e) Inverter current (f) Non-linear load current.

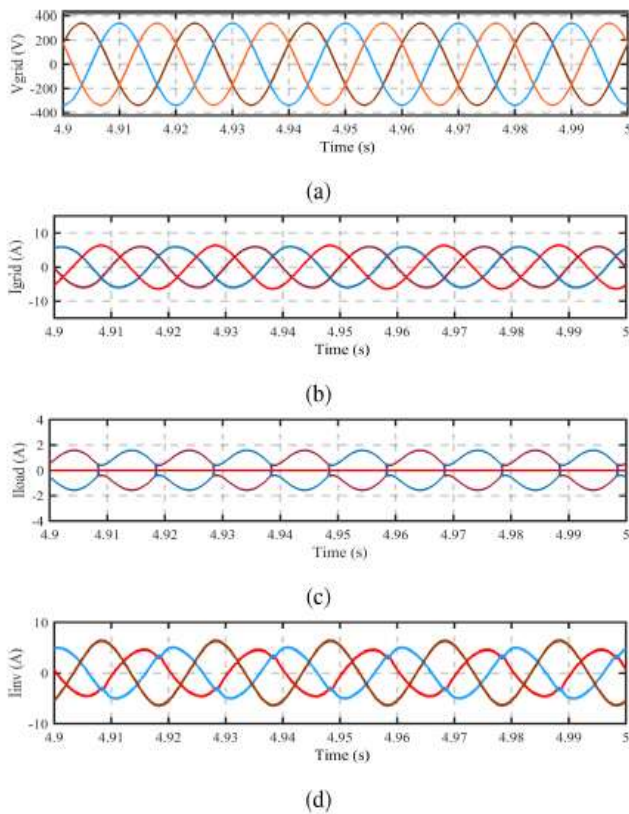


Fig. 9. System response under unbalanced loading (a) Grid voltage (b) grid current (c) Load current (d) Inverter current

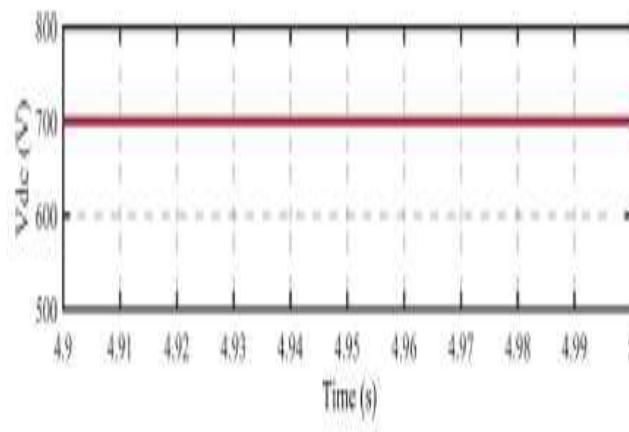


Fig.10. DC link voltage

Dynamic behaviour of the System under various PV power conditions the behaviour of the system for different settings of PV power production is shown in Fig. 11. The input irradiance is varied from 500 W/m² to 1000 W/m² at $t = 3$ seconds, changing the PV power. As shown in Figure 11(a), the system operates in deficit power generation mode for a maximum of three seconds since the PV power generation is less than the load demand at the DC bus. In this case, the BES and the grid provide the power deficiency.

If the voltage is negative, the battery is charging. If the voltage is positive, the battery is discharging. If the grid power reading is negative, the grid is using energy. When the timer reaches three seconds, the system switches to a mode where it is generating enough power to satisfy demand and any surplus electricity is routed to the grid or the battery. The supercapacitor controls the short-term current as shown in Figure 11(b). The grid voltage variation, the grid current variation and the load current variation during PV power shift are shown in Figure 11(c), (d) and (e) respectively. The DC link voltage is presented in Fig. 11(f). It varies about 2V at $t = 3$ seconds. Figure 11(g) indicates that the BES SoC can be different.

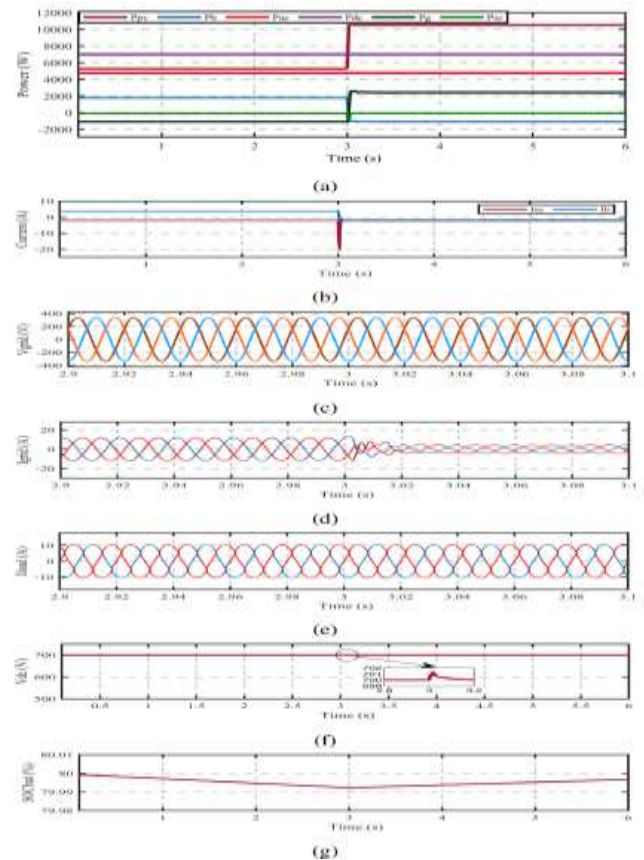


Fig. 11. System response under PV power variation (a) Power Variation (b) Battery & SC current (c) Grid voltage (d) Grid current (e) Load Current (f) DC link voltage (g) Battery SOC. Performance of the system under different load conditions

At $t = 3$ sec, an additional load of 10 kW is supplied to the DC bus and therefore the loading condition of the system is increased to 5 kW. This mechanism consumes up to three seconds of surplus electricity. The proposed system keeps the balance of power between the sources and the loads efficiently. Power is obtained from the grid and batteries proportional to the load power usage. The supercapacitor takes up this transient current, lessening the stress on the battery during this transitory.

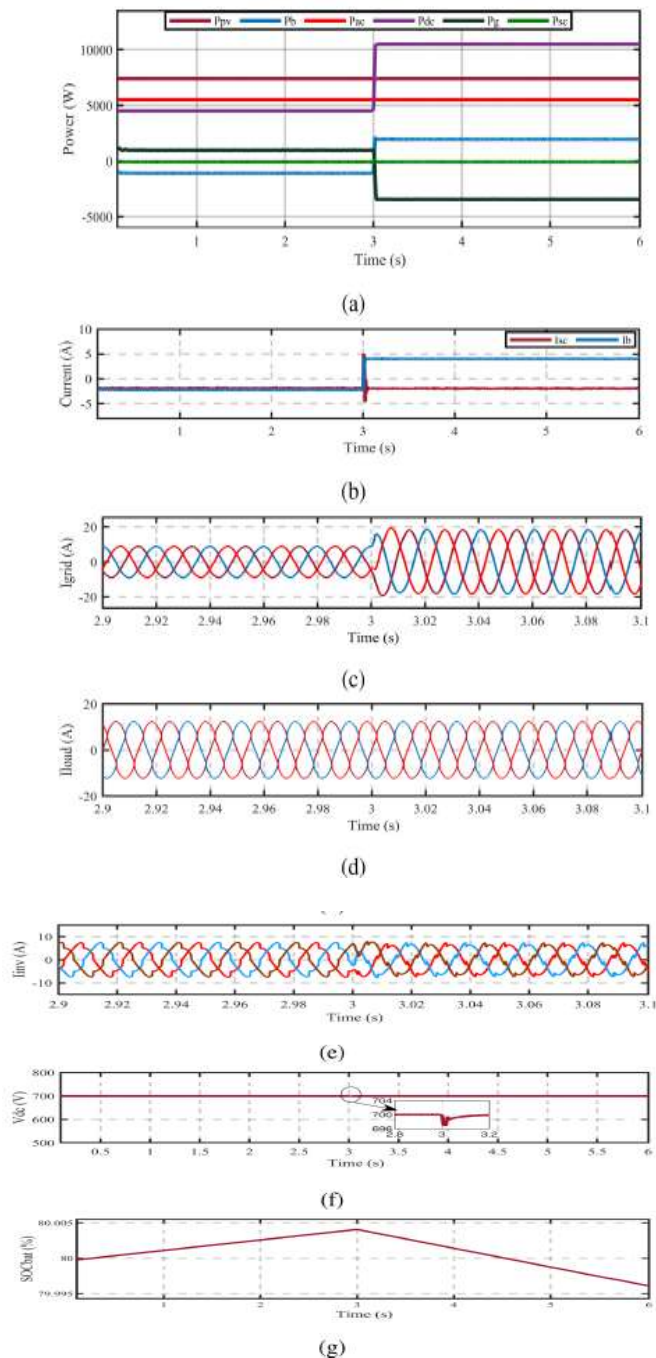


Fig. 12. System response under varying loading (a) Power variation (b) Battery and SC current (c) Grid current (d) Load Current (e) Inverter current (f) DC link voltage (g) Battery SOC.

Fig. 12. System response under varying loading (a) Power variation (b) Battery and SC current (c) Grid current (d) Load Current (e) Inverter current (f) DC link voltage (g) Battery SOC.

Fig. 12(b) shows the appropriate variations in the current. The grid current changes from power injecting mode to power drawing mode at 3 s, as demonstrated in Figure 12(c), by going through a 180° phase shift. As shown in Figure 12(f), the suggested solution keeps the DC link voltage constant even if these changes occur. At time $t = 3$ seconds, the DC link voltage deviates by

around 4.5V, as indicated in Figure 12. Figure 12(g) shows the variation of the BES's system on a chip.

4. CONCLUSIONS

For the stable operation under imbalanced loading conditions and harmonic mitigation due to nonlinear loads, a control strategy based on the Modified Leaky Least Mean Square algorithm was effectively implemented in the carried-out analysis of the investigated system. A power-sharing framework is also put in place to ensure that active power is distributed effectively. The suggested controller has strong and consistent performance over a range of challenging operating situations, in MATLAB/Simulink simulations.

The total harmonic distortion (THD) in the source current was drastically reduced by the MLLMS-based algorithm, leading to an improvement in power quality. In addition, the converter is efficiently controlled by the Finite Control Set Model Predictive Control, which accurately tracks the reference values and generates optimal switching states. The suggested control architecture guarantees high-quality power at the source, maintains stable DC-bus voltages, and offers balanced active power sharing capabilities. These findings suggest that grid-connected microgrids with hybrid energy storage systems benefit from the system's ability to enhance power management and quality.

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