Journal of Solar Energy Research (JSER)

Journal homepage: www.jser.ut.ac.ir

Grid Connected Photovoltaic and Hybrid Energy Storage Based Microgrid System Power Management Analysis Using Power Management Techniques

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ARTICLE INFO

Article Type:

Research Article

Received:2025.12.09
Accepted in revised form:2026.04.10

Keywords:
Photovoltaic; Hybrid Energy Storage System; Power Management Techniques; Modified Power Management Algorithm; Proportional Integral Controller; Microgrid

ABSTRACT

In this research, a newly designed Grid-connected Photovoltaic (PV), HES based microgrid system is developed and a suitable Power Management Technique (PMT) is suggested with a Modified Power Management Algorithm (MPMA) to enhance system efficiency and reliability. The suggested PMT effectively regulate the DC voltage during the variation of PV generation, manage the power flow and power quality. The developed MG system component is interconnected to the DC bus through suitable controlled converters. PMT is used to generate the accurate reference signal using the MPMA which strengthens the accuracy level of the pulse of the converters and hence results quick adjustment of the DC-Link voltage and smoothly manage the power flow among various sources and improve the power quality by bringing the Total Harmonics Distortion (THD) level to 2.96% recommended under IEEE 519 standard. It also provides encouraging results of settling time of 0.2 sec and peak over shoot of only 2.80%. Battery and Super capacitor are used to enhance stability and continuity of smooth operation, in addition, super capacitor provides backup and also reduces the strain of the battery during transient condition. The effectiveness of the developed PMT with the designed microgrid is verified with MATLAB/SIMULINK Platform.

1. Introduction

The increased demand of electricity in the last few years has caused shortage of fossil fuel, attracted more and more renewable based energy sources (RES) for the generation of electricity. The use of RES is not only to full fill the future demand but also be able to provide clean energy which will overcome the environmental problem. The newly developed integrate technology makes the RES to

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Cite this article: P, S. and Naidu, I. (2026). Grid Connected Photovoltaic and Hybrid Energy Storage Based Microgrid System Power Management Analysis Using Power Management Techniques. Journal of Solar Energy Research, 11(2), 3041-3054. doi: 10.22059/jser.2026.407799.1685

DOI: 10.22059/jser.2026.407799.1685

integrate with grid easily, this results the concept of microgrid (MG). The MG system makes the modern power system more reliable and flexible [1-3]

Several works and researches were done in the last few years to investigate the perfomance, operation and control of different MG architecture system. Katiraei, F et al, Liu, X et al, Narsa., R T et al. [1-3] have provided and discussed the suitability and advantage of PV integrated MG system in comparison to other RES based MG system such as wind, photovoltaic, hydropower, geothermal, and biomass. PV has major contribution due to its low cost of installation, maintenance and simple grid integration, they also analysed the changing of environmental condition affects the generation and stability of the PV integrated system and provided the idea of battery backup a to make the system more stable, reliable and safe.

Liu, X et al, Narsa., R T et al. [2-3] have reviewed and observed, the characteristics of rate of change of charging and discharging quality of the battery and found it leads to make the MG system unstable during transient period even though the battery possess high energy density. They have suggested to add a super capacitor to overcome the problem during any transient period. The suggested super capacitor reduces the battery burden and enhances the utilization capacity

Narsa., R T et al, Bharatee, P., et al, Kotra and Mishra, Manandhar, M. et al. [3-6] have proposed PV integrated grid with HESS which included both battery and super capacitor as energy storage devices. They have carried out many critical analyses by implementing different power management scheme (PMS).

Kotra and Mishra, Manandhar, M. et al, Ye, C., Miao et al, Kuldeep, K. et al, [5-8] have investigated the importance of power balancing between generation and demand through power monitoring plan in a MG system. Badmus, E. O. et al, Pannala, S., et al. [9-10] have developed advanced PMS to manage active power flow in PV integrated MG system with HESS. critical analysis of control techniques had been carried out to distribute power among various generation units to load effectively keeping the DC voltage constant.

Lee H et al. [11] have carried out the performance investigation of a centralized controller with the association of a multilevel inverter without any additional controller in a DC microgrid system, and later Patel, S et al. [12] have proposed a neural network-based model predictive controller (MPC) technique, which is used to generate the appropriate training results during variation of load. The proposed techniques maintain smooth regulation of frequency and DC link voltage.

Abulanwar, S et al. [13] have critically analysed the harmonic contents and its mitigation with the implementation of a digital proportional resonant (PR) and PR with synchronous current controller in the converters in a standalone hybrid AC/DC MG system, symmetrical and unsymmetrical fault analysis had also been demonstrated. Jasim AM et al. [14] have suggested an intelligent online monitoring technique and the importance of ANN control to maintain the system stability without considering the performance of super capacitor both in grid and islanded condition. Mahmood, H et al, Sandeep, S.D et al. [15-16] have investigated the effectiveness of power management strategy using multi loop controller, they also suggested the autonomous adjustment of load with respect to the PV operating point technique.

The phase-locked loops (PLLs) techniques were used for synchronization Kotra and Mishra, Manandhar, M. et al, Ye, C., Miao et al, Kuldeep, K. et al, [5-8], however during unbalanced and distorted grid voltage, this technique were failed to estimate the phase and frequency accurately. To overcome the problem of accurate estimation of both phase and frequency parameter, moving average filter had been suggested by Narsa., R T et al, Bharatee, P., et al. [3-4], and Sandeep, S.D et al. [16]. For further improvement of the performance of estimation, MAF with PLL had been suggested by P Golestan, S., et al. [17] and Habibullah, Al et al. [18]. Addition of PI and PID with adaptive droop controller suitably managed the voltage and power flow in DCMG system consist of utility grid (UG), energy storage device (ESD), distributed generator (DG) and Electric Vehicle (EV).

Shayeghi, H. et al. [19] have proposed a Fuzzy Logic with distributed control system based active power management technique with the hybrid energy storage and wind-diesel system.

Kim, S. T et al. [20.] have suggested Superconducting magnetic energy storage (SMES) based PV connected grid distribution system for effective power management.

Singh, D. [21] has analysed the power quality issues and suggested IPRT and PMT to solve the issues in a MG system.

Kuppusamy, A. et al. [22] have developed parallel-connected quadratic boost converters with a novel controller which is used to efficiently convert electrical power from PV and wind systems. They observed, these converters work well for DC-DC boosting in battery storage systems, and DC microgrids.
Ndeke, C.B et al, Sathishkumar, S. K et al. [23-24] have suggested an energy management scheme with advanced features in MG system. The proper integration of RES and HESS with the DC bus depends upon the design and control techniques of the converters.
Sarvi, M et al. [25] have designed a high step-up DC-DC converter with an interleaving technique at the converter's input to boost voltage gain and decrease input current ripple.
Haghshenas, M et al. [26] have suggested proper coordinated control between various energy sources and the load to enhance the system ability to manage the power flow, which improves the grid resilience and power quality.

The SoC of super capacitor, battery, maximum power point current, transient current and average current parameter are all consider into account in the maximum paper mentioned in the literature for reference signal generation using PMT with PMA. This results in better power management and an acceptable level of power quality. However, in our proposed PMT with MPMA, we have included additional parameters along with some of the parameters in the existing technique to achieve better power quality, less settling time, and also less percentage of peak overshoot. To get better outcomes, the power sharing coefficient and converter type are also appropriately chosen along with appropriate system design.

The unique contributions of the paper are (1) Fast DC voltage restoration and proper regulation during variable PV power (2) Better power quality with THD as per IEEE 519-2019, (3) lesser settling time (4) Less percentage of peak overshot (5) simple computation and better power flow management,

The novelty presents the development of a Power Management Technique with a Modified Power Management Algorithm (MPMA) this technique decomposes the effective power demand into three components such as average, oscillatory, and transient, enabling effective sharing of power. Unlike conventional power management schemes that rely on heuristic power sharing or fixed operating rules, the proposed approach systematically assigns transient and oscillatory power components to the super capacitor while reserving average power handling for the battery and grid, resulting in the better regulation of DC link voltage under variable PV irradiance. The MPMA inherently manages or shares the power flow effectively and enhance the power quality all with low computational complexity even though more parameters are taken in to consideration discussed above in the paragraph.

The details of the paper are discussed in five sections as follows. section. 1 provides the introduction with the newness of the work, section. 2, discusses the system and its architecture with schematic presentation, section. 3 provide explanation of developed PMT with MPMA. Section. 4 and section. 5 analyses the result of simulation and conclusion respectively.

2. Proposed PV connected Grid with HESS

Figure 1 shows the block diagram of the considered system in this research work. PV source, battery, supercapacitor and grid interface with both AC and DC load are the main fundamental components of the system architecture. To control and regulate the PV output, a DC–DC converter is connected between the PV and the DC bus. Bidirectional DC–DC converters connect the battery and supercapacitor to the DC bus, allowing for regulated charging and discharging for power management. To ensure steady operation and load support under fluctuating generation and demand situations, the utility grid is connected via an AC–DC converter, which facilitates power exchange between the DC bus and the grid.
Figure 2 shows the schematic diagram of the system and it can be observed, Diodes $D_1, D_2, D_3,$ inductors L_{1PV}, L_{2PV}, capacitors, C_1, C_2 and switch S_Q are the parts of converter. V_{PV}, V_2 are the voltages across PV and voltage across the capacitor C_2, the capacitor C_2 has same voltage as DC bus. The register, inductor, two switches, two capacitors and voltage of the battery are represented by $R_B, L_B, S_{B1}, S_{B2}, C_B, C_{B1}, V_B$, all are the parts of the bidirectional converter placed between battery and DC bus. Similarly, the bidirectional converter parts placed between super capacitor and the DC bus are one inductor, one capacitor, two switches and voltage across the capacitors represented as

$L_{SC}, S_{SC1}, S_{SC2}, V_{SC}$ respectively, the grid and DC bus is connected through the converter; four IGBT switches $S_{1M}, S_{2M}, S_{3M}, S_{4M}$ register R_{f1}, inductor L_{f1}, and capacitor are the part of the converter. Grid voltage represented as V_G. Nonlinear load with diode bridge rectifier and resistor-inductor combination connected to the AC side and a simple register treated as DC load, connected to the DC bus, the components associated with the proposed system and it's quantitative magnitude are presented in Table 1.

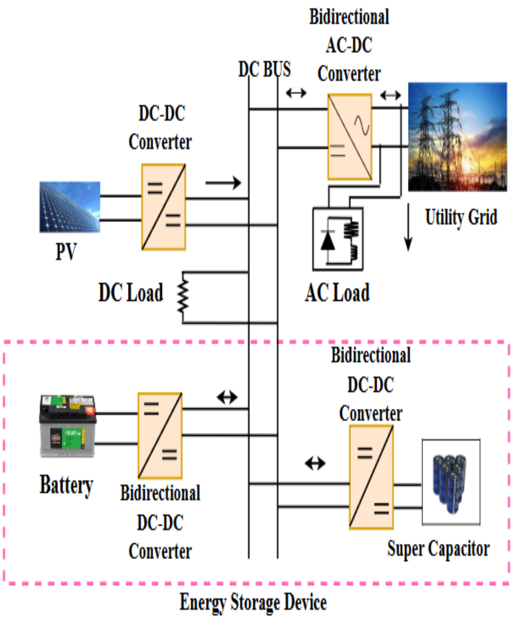

Figure 1. Grid-connected PV and HES system

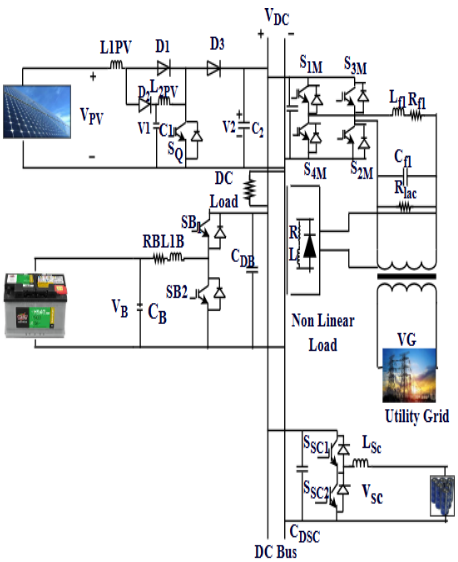

Figure 2. System schematic diagram

Table 1. The proposed system designed parameter and its values

Parameters	Values
PV voltage,current and Gains ($V_{PV}, I_{PV}, K_{PPV}, K_{IPV}$),	50V,20Amp,0.01,0.1 $440e^{-6}, 440e^{-6}, 10e^{-3}$
Boost PV converter C_1, C_2, L_1	
Battery Voltage, capacity, and Gains (V_B, I_B, K_{PB}, K_{IB})	48V,12Ah,0.03,0.65 $440e^{-6}, 440e^{-6}, 5e^{-3}$
Buck Boost converter (C_B, C_{B1}, L_B)	
Supercapacitor capacitance,voltage and gains ($C_{SC}, V_{SC}, K_{PSC}, K_{ISC}$),	58F,58V,0.043,0.65 $440e^{-6}, 440e^{-6}, 2e^{-3}$
Buck Boost converter (C_{SC1}, C_{SC2}, L_{SC})	
Grid voltage, frequency, DC bus voltage (V_G, f, V_{DC})	50V,50Hz,100V
Linear and Non linear load ($R_{LDC}, R_{LAC}, R_{NL}, L_{NL}$)	50Ω,50Ω,5.5Ω,$10e^{-5}$
PI Controller parameters	
PV module	$K_{ppv} = 0.01, K_{ipv} = 0.1$
DC Voltage	$K_{pdc} = 0.003, K_{idc} = 0.065$
Battery	$K_{pb} = 0.03, K_{ib} = 0.65$
Super capacitor	$K_{ps} = 0.043, K_{is} = 0.65$
LCL Filters	R = 6.8 ohms L = 0.9e-3 H,R = 6.8 ohms L = 1.8e-3 H,C = 10e-6F
Coupling capacitor	2200e-6 and R = 0.5 ohms

3. Proposed Power Management Technique

The proposed power management technique is associated with the modified power management algorithm and converter control technique, to generate accurate reference signal. The block schematics for the PMT and converter control are shown in Figure 3 and Figure 4, respectively. The detailed mathematical steps are provided in the paragraph below.

In this PMT, reference current generation accuracy level is enhanced using a modified PMA, in addition to some of the existing algorithm parameters like the SoC of the super capacitor, battery, maximum power point current, transient current and average current in [4-7], we have modified the PMA by suitably adding more parameters like load power and grid power. Overall power management Technique is shown in Figure 3 for developing reference signal. Figure 4 and Figure.5 shows control of converter and flow chart of the proposed algorithm. The systematic steps for the PMT in the proposed microgrid system are described step by step, for balancing the power generation must meet the demand. Power balance equation can be formed as, all mathematical equation mentioned below is from [4-6]

$$P_{pv}(t)+P_B(t)+P_{sc}(t)+P_G(t)=P_L(t)=P_{Ldc}+P_{Llac} \quad (1)$$

$P_G, P_{PV}, P_B, P_{SC},$ stand as the generation of GRID, PV, Battery, Super capacitor power respectively, P_L Stand as the load demand, It covers the need for both AC and DC electricity. The average and transient power are two primary components for balancing the power. The supply current from the two presented below

$$I_{avg} = I',$$

$$I_{tan} = I'' \quad (2)$$

$$I = I' + I'' = \frac{P' + P''}{V_{DC}}$$

Eq.2 can also be expressed in the form

$$I = I' + I'' = K_p V_{err} + K_i \int V_{err}\,.dt \quad (3)$$

Extraction of the average current is done with the connected low pass filter and after that, it distributed to all sources.

$$I'(t) = \frac{\omega_c}{s+\omega_c} * I(s) \quad (4)$$

Transient current provided by the super capacitor is presented below in eq.5

$$I''(t) = \left(1 - \frac{\omega_c}{s+\omega_c}\right) * I(s) \quad (5)$$

As, it was previously mentioned, the MPMA considers both generated and load power along with other parameters in the existing [4-7], [24] while determining the system's operational performance. The battery and super capacitor's state of charge is determined using the coulomb counting method [4]. Two modes of operation, such as DPM and EPM have been shown in the study to demonstrate the effectiveness of the modified PMA based on PV power generation with changes in irradiance level and demand. In DPM $P_R < 0$, and in EPM $P_R > 0$, where the parameter P_R is the required power and it is the difference of PV generation and the load of the system, $P_R = P_{PV} - P_{Load}$, Table 2 presents the chosen value of $\lambda = \text{sharing coefficent}$, the logic for sharing coefficient in DPM where H-stands for high value of SoC, M-H stands for medium and high, L-M stands for lower and medium and V-L stands for very low value.

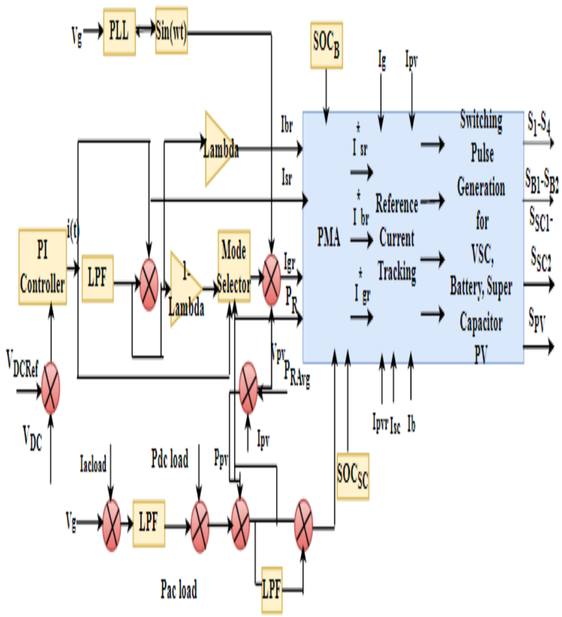

Figure 3. Proposed power management technique

Table 2. Chosen sharing coefficient parameter

Battery SOC	Description	λ	$1-\lambda$
$0.7 < SOC_b < 0.9$	H-SoC	1.0	0
$0.5 < SOC_b < 0.9$	M-H-SoC	0.6	0.4
$0.1 < SOC_b < 0.5$	L-M- SoC	0.3	0.7
$0 < SOC_b < 0.1$	V-L SoC	0	1

he Power Modes that are being studied and their descriptions are shown in Table 3. In DPM, the battery, PV, and main grid control the average shortfall power requirement until the battery's SOC is inside the bounds, while the super capacitor manages the transient power component until it reaches its lower SOC boundary. Battery and super capacitor are charged with additional power until they reach their maximum SOC limits in EPM, and Table 4 DPM functional analysis corresponds to the SoC level is shown. Every time the battery and super capacitor are fully charged or reach their higher SOC constraints, the extra power is transferred to the main grid via VSC. The functional description of EPM is given in Table 5.

Table 3. Description of the power mode under study

Conditions	Modes	Description
$P_R > 0$	DPM	$P_{PV} < P_L$ Battery and Grid active and provides power
$P_R < 0$	EPM	$P_{PV} > P_L$ Battery and Super capacitor will store

Table 4. Functional Design of DPM

Chosen Condition	Battery current	SC current	Grid Current
$SOC_b > LL, SOC_{sc} > LI$	$I_{br} = \lambda >$	$I_{sc} = I_{tra}$	$I_{gr} = (1-\lambda) \times I_{avg}$
$SOC_b < LL, SOC_{sc} > LI$	$I_{br} \cong 0$	$I_{sc} = I_{tra}$	$I_{gr} = I_{avg}$
$SOC_b > LL, SOC_{sc} < LI$	$I_{br} = \lambda >$	$I_{sc} \cong 0$	$I_{gr} = (1-\lambda) \times I_{efa} + I_{eft}$
$SOC_b \le LL, SOC_{sc} \le LI$	$I_{br} \cong 0$	$I_{sc} \cong 0$	$I_{gr} = I_{iavg}$

Table 5. Functional Design of EPM

Chosen Condition	Battery Current	SC current	Grid Current
$SOC_b > UL, SOC_{sc} > UI$	$I_{br} =$	$I_{sc} = I_{tra}$	$I_{gr} = (1-\lambda) \times I_{avg}$
$SOC_b < UL, SOC_{sc} > UI$	$I_{br} \cong$	$I_{sc} = I_{tra}$	$I_{gr} = I_{avg}$
$SOC_b > UL, SOC_{sc} < UI$	$I_{br} =$	$I_{sc} \cong 0$	$I_{gr} = (1-\lambda) \times I_{efa} + I_{eft}$
$SOC_b \le UL, SOC_{sc} \le UI$	$I_{br} \cong$	$I_{sc} \cong 0$	$I_{gr} = I_{iavg}$

In converter control description below paragraphs highlights the work in a systematic way as follows, Figure.4 and Figure.5, presents the block diagram of converter control and the corresponding flowchart of the MPMA. This converter control method block diagram shows different input parameters which are responsible for switching action. The proportional integral (PI) is also a component for the final reference signal. We have used the conventional PI controller mechanism to produce precise converter pulses used in the MG system. Both an inner and an outer control loop forms the control structure. The PI-based inner loop is the current control loop and it responsible for tracking reference signal, after MPMA, while the PI-based voltage control loop is the outer loop and regulates the DC bus voltage. PI-controlled battery converters regulate the charging and discharging current of battery by taking SoC level in to consideration and make the power balance. PI-controlled super capacitors regulate fast-changing power using super capacitor reference current, PI-controlled grid-side converters regulate grid current and synchronize with the grid using PLL, and PI-controlled PV controllers regulate PV output using reference PV current generated by MPMA. Voltage control loop gains are acting slowly than current to maintain stability, and PI gains are selected using the traditional technique. For PV, batteries, and super capacitors employ the same control structure that modifies the gain values according to the power rating. The selected values of proportional gain and integral gain are given in the last row of Table 1 in system parameters values and these values are chosen based on the designed specification and ratings of the converters, other components such as DC bus capacitance, and switching frequency.

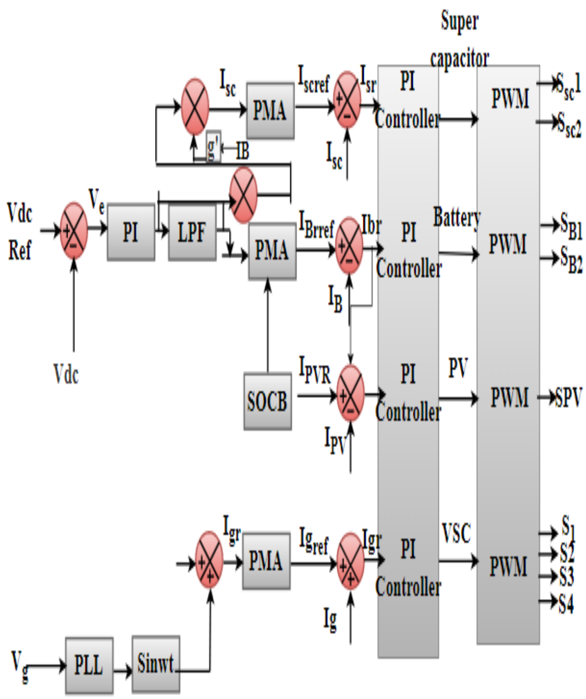

Figure 4. Converter control technique

The modulating signal produced by each PI's output is fed into a PWM block to produce a pulse. Let us discuss the steps

The controlling signal of the PV is represented in

Equ. 6

$$\delta_{cpv} = K_{ppv} I_{pv}(t) + \frac{K_{ipv}}{T_{cpv}} \int_{t-T_{pv}}^{t} I_{pve}(t)dt \quad (6)$$

Where $I_{pve}(t), T_{cpv}, K_{ppv}, K_{ipv}$ represents the PI controller's error for the PV current, window length, proportional, and integral coefficients, respectively. The control action of the voltage source converter depends on the reference current generated using the bidirectional power flow, the produced reference signal is represented by the equ.7, ω, λ stands for angular frequency of the grid and sharing coefficient

$$I_{gr} = \begin{cases} (1-\lambda)\overline{I_t} \sin \omega t, P_{RP} > 0 \\ \overline{I_t} \sin \omega t, P_{RP} < 0 \end{cases} \quad (7)$$

The hybrid energy storage converter operation control produced the battery reference current followed by eq. 8 and the corresponding modulating signal by eq.9

$$I_{Bref}(t) = f_{BP} \lambda \frac{1}{T_B} \int_{t_0-t_B}^{t_0} I(t).dt \quad (8)$$

$$\delta_b = KpbI_B(t) + \frac{K_{ib}}{T_B} \int_{t-T_B}^{t} I_B(t).dt \quad (9)$$

The main components of the supercapacitor control structure are bidirectional DC-DC converter control, a power management algorithm, and reference current generation, as shown in the control diagram in Figure 4. The high frequency momentary component of the total operating current at the DC connection is managed by the supercapacitor using an LPF, which is supplied by, after which eq. 10

$$I_{sc}(s) = I_t(s) - \frac{\omega_c}{S + \omega_c} I_t(s) + g' I_B(s) \quad (10)$$

Where $g' = \frac{V_B}{V_{Sc}}$, the additional compensator shown in Fig.4

The PMA receives the reference current that was calculated by eq.10. By considering the other input variable MPMA decides the working mode. The switching pulses for the super capacitor converter are then obtained by passing the reference current produced by the MPMA via the current regulator. The super capacitor current reference is determined by eq.11

$$I_{Scref}(t) = f_{scp} I_{Sc}(t) \quad (11)$$

The systematic flowchart of the power management scheme with the MPMA is shown in the Figure.5

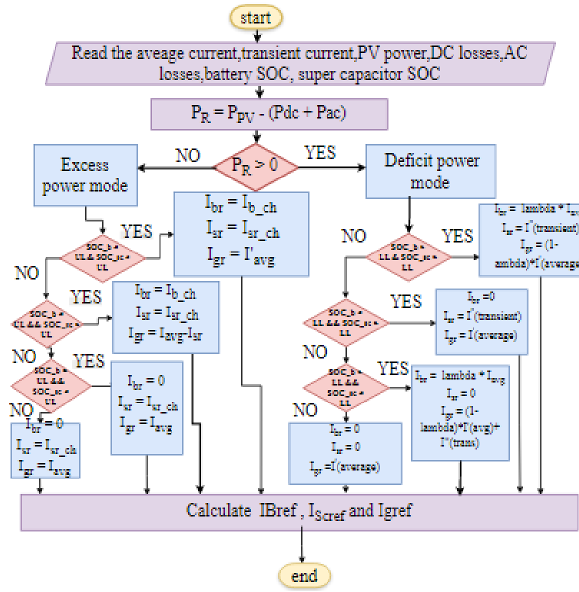

Figure 5. Flowchart of the MPMA

4. Simulation Results and Analysis

The MATLAB/Simulink platform is used to conduct the research work. The model is designed, developed and then PMT is implemented with MPMA in accordance to the parameter specifications listed in Table 1. EPM and DFM are taken into account to confirm the efficacy of the suggested technique.

4.1. Variation of PV irradiance and its associated outputs

The above two condition such as EPM and DPM are shown in Figure. 6 At first, EPM has been observed till 1 second, after that it gradually decreases and required power increases which leads to DPM. But the DC power remains constant. After, analyzing the two modes, then we have to observe the behavior of PV, battery and super capacitor performance in the different cases, PV parameters simulation results with different irradiance level are presented in Figure 7 (a)-(d), It demonstrates the active operation of the techniques with variable PV power generation. The system's irradiance is changed from 1000 to 800, 600 and 400 respectively in order to alter the PV power generation at t = 1s, 2s, 3s and 4s respectively. Figure 7 (a) shows the decrease in PV irradiance at every instant, corresponding PV voltage, current and power are presented from Figure7 (b)-Figure 7 (d). shows the PV generation is fluctuating as the PV irradiance changing. however, the PV voltage remains constant but initially small overshoot is observed and it is compensated with the help of energy storage devices

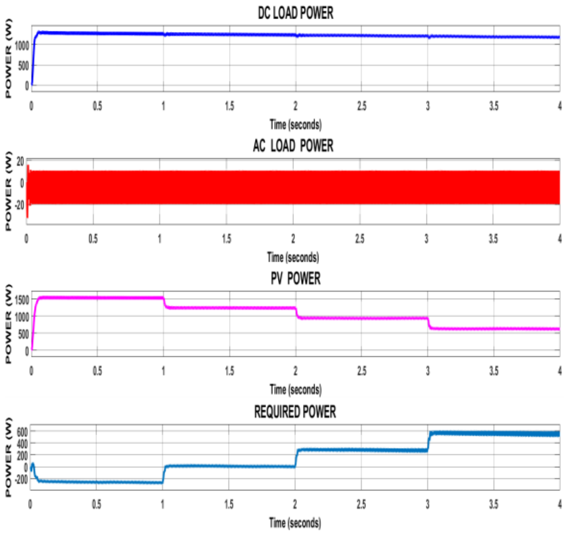

Figure 6. (a)-(d) Simulation of DC bus power, AC power, EPM and Required power (DPM)

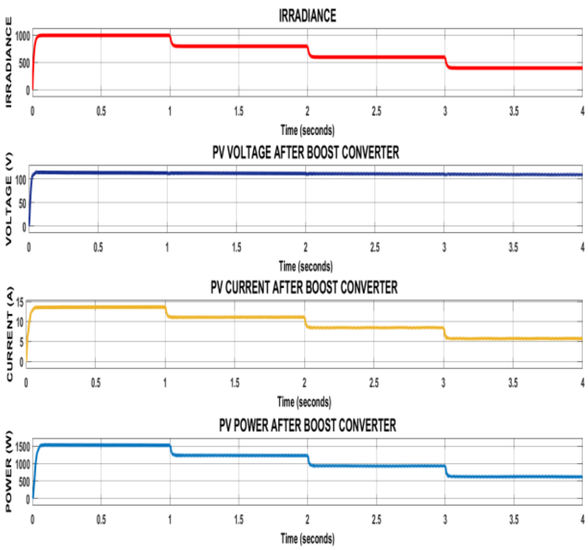

Figure 7. (a)-(d) PV parameters simulation results with different irradiance, PV voltage after boost converter, PV current and PV Power

4.2 Performance of Battery Parameter during this period

Corresponding to the PV power variation discussed above in 4.1, the battery parameters such as battery voltage after boost converter, battery current and battery power are presented in Figure 8 (a)-(c), It is observed that even though battery current and power deviates, the battery voltage remains constant with less overshoot and less fluctuation at every instant of changing irradiance. The battery is gradually charging and power delivered to the load by the battery is also gradually increasing, this shows the contribution of power to the load

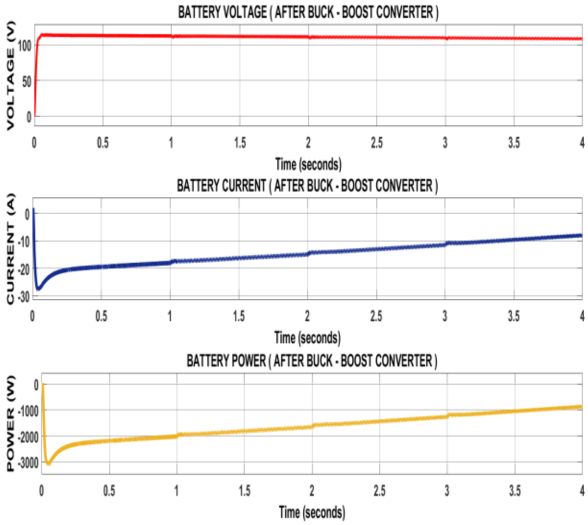

Figure 8. (a)-(c) Simulation parameters of Battery Voltage, Battery Current and Battery Power values with respect to the different PV power generation

4.3. Performance of Super Capacitor Parameter during PV Power Variation

Corresponding to the PV power variation, the super capacitor parameters such as super capacitor voltage after boost converter, battery current and battery power are presented in Fig.9(a)-(c), it is observed that even though super capacitor current and power deviate, the super capacitor voltage remains constant with very less overshoot. The super capacitor is highly charged initially in order to eliminate the transient effect of the battery.

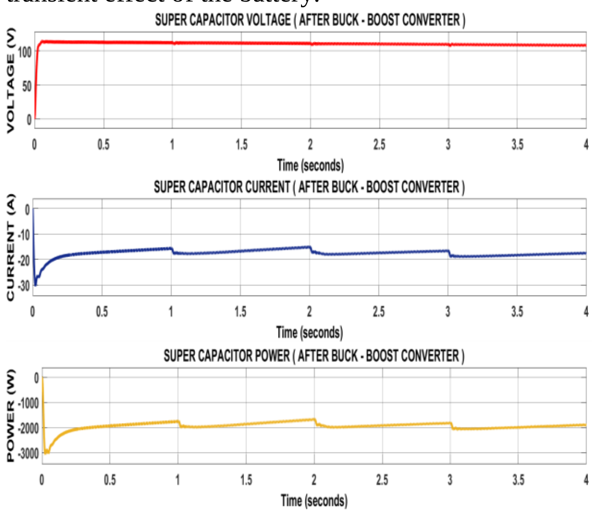

Figure 9. (a)-(c) Simulation parameters of Super Capacitor Voltage, current and Power values with respect to the different PV power generation

4.4. DC BUS Parameter during PV Power Variation

Corresponding to the PV power variation, further various DC bus parameter performance is observed and presented in Figure 10 (a)-(c), it shows the DC bus voltage, current and power remain constant in the variable generation, the close observation shows there is very less disturbance and it settles within a fraction of second.

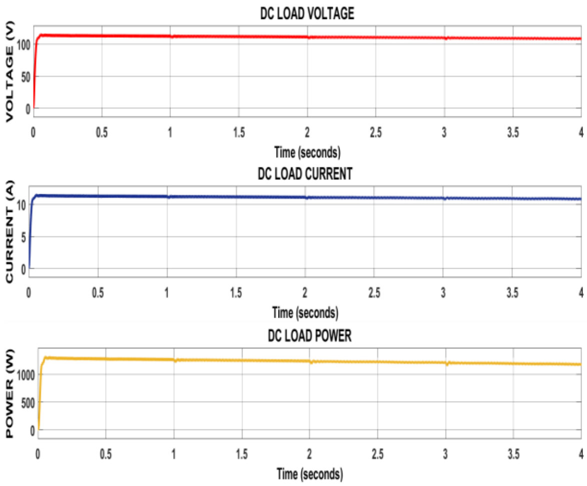

Figure 10. (a)-(c) Simulated parameter of DC-Bus Voltage, current and Power with respect to the different irrdiation

4.5. Analysis of AC LOAD Parameters, Grid Parameter

As the load is nonlinear in nature, Figure 11 (a)–(c) depicts the simulated wave form of AC load voltage and corresponding current and power during the instant of power management.

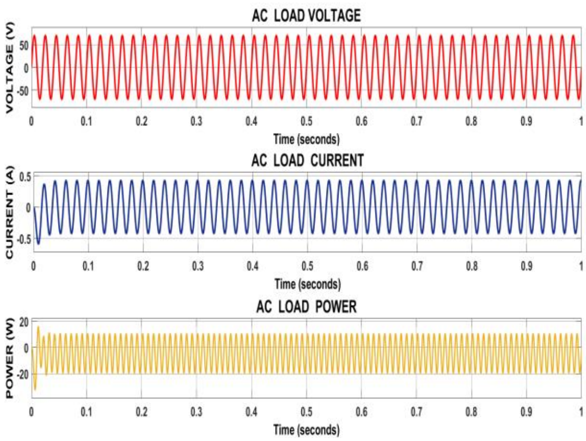

Figure 11. Simulation parameters of AC load voltage, Current and Power values with respect to the different PV power generaton

Meanwhile, Figure 12 (a–c) displays grid voltage, inverter current, and grid current, and it is evident that AC-Load current constitutes the harmonics. Lastly, Figure 13 (a–b) displays the grid's voltage and current after filtration, indicating that the current harmonics are extremely low after a few 0.033 seconds.

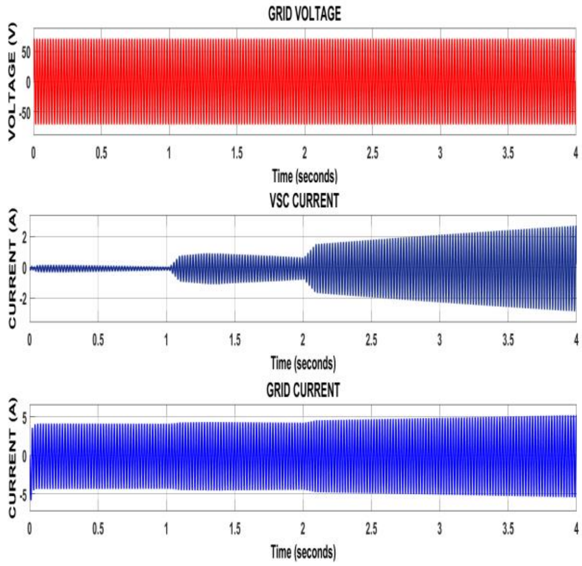

Figure 12.(a)-(c) Simulation parameters of Grid-Voltage, Inverter current, load current before and after filteration

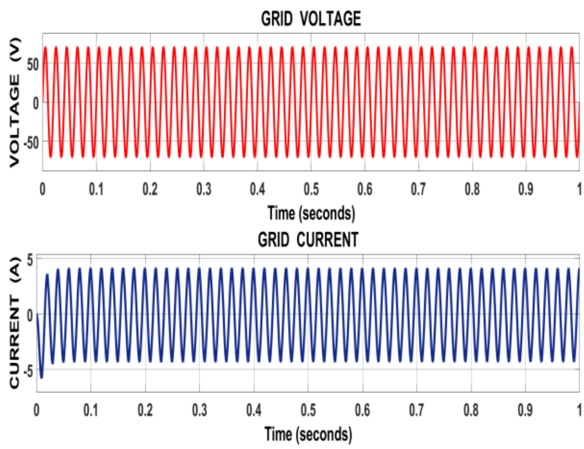

Figure 13.(a)-(b) Grid-Voltage, and source current after filteration

The Figures 7 to Figure 13 shows the performance of each individual component during the power management scheme. Figure 14 shows that, regardless of changes in PV power, the voltage remains constant and the power fluctuates less, indicating that generation and demand are balanced in the EPM. Figure 15 shows that the energy storing devices compensate for the required power, which remains constant during operation in DPM.

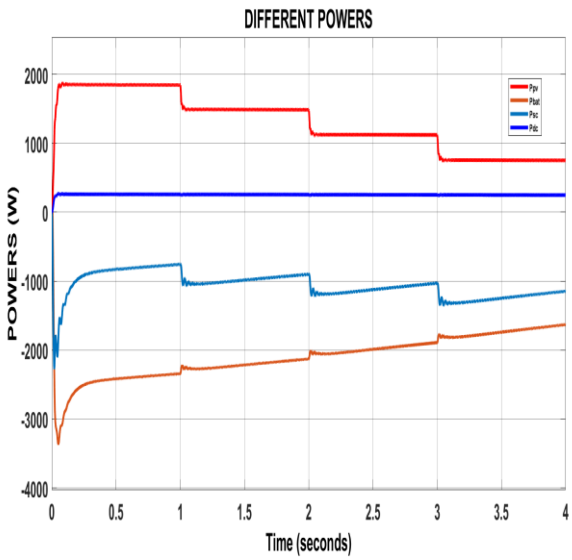

Figure 14. PV, Supercapacitor, Battery, and DC bus power in EPM

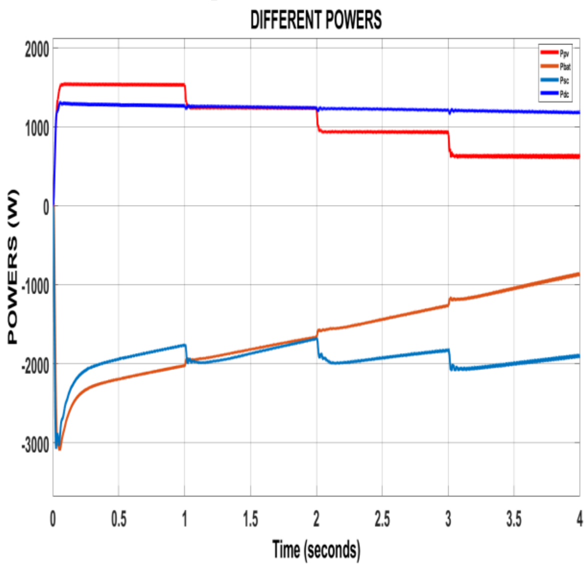

Figure 15. Power of PV, Battery, Supercapacitor and DC bus in DPM

After observation and analysis of all the obtained waveform, we did the FFT analysis, settling time and peak overshoot and present a comparative analysis with [5] .The THD obtained in the proposed technique is 2.96% and it is under IEEE 519, the THD level is shown in Figure 16.The obtained THD level in our proposed method is 2.96% and it is measured at the PCC / output of grid converter. The THD calculation considers 3rd ,5th, and 7th harmonic components based on steady-state FFT analysis of the grid current. The measurement is carried out under grid-connected operation at rated load, after system transients have settled.

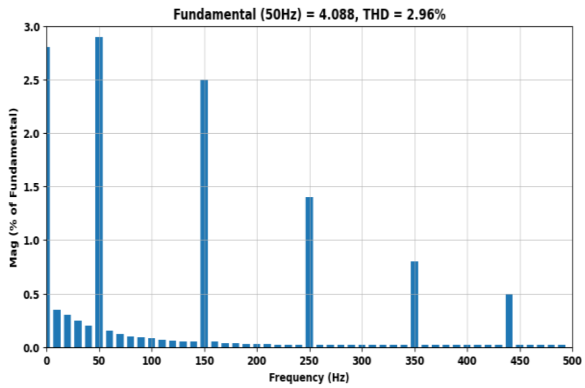

Figure 16. THD Analysis after Filteration with the proposed technique

The obtained THD is compared with Kotra, S., and Mishra.M.K. [5] paper. Figure. 17(a)-(b) and Fig. 18 present the simulated waveform of grid voltage and source current after filtration and the associated FFT analysis

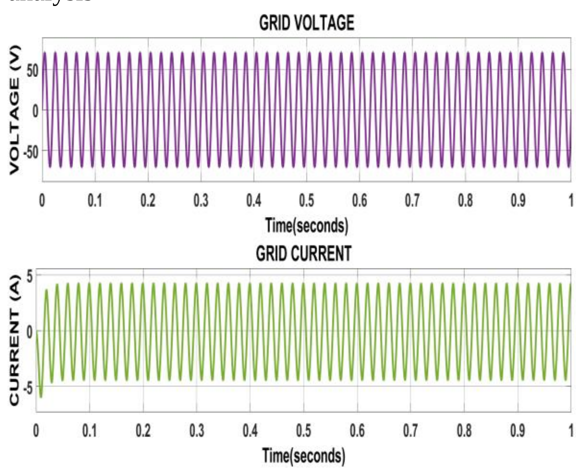

Figure 17. (a)-(b) Grid-Voltage, and source current after filtration

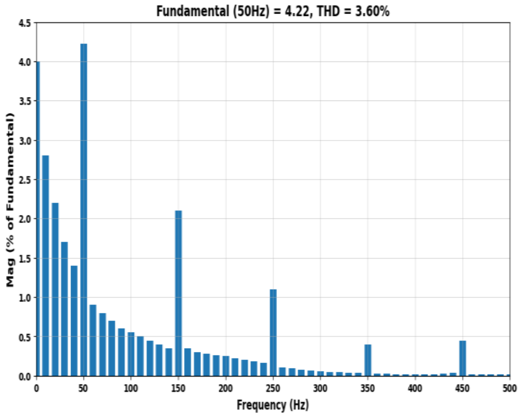

Figure 18. THD analysis after filteration followed by Figure 17 (b)

Table 6. shows the THD comparative analysis.At the same time for more clarity a bar chart is also presented in Figure 19. The comparative analysis of THD shows the Power Quality improvement and at the same time the settling time and peak over shoot also provides encouarging results in comparision to other two base papers [24],[6]. The three base papers refered utilizes most probaly all parameters as discussed in introduction section in developments of power management scheme (PMS), our algorithim takes two more parameters in to accounts and provides better results. the reference papers are investigated many conditions and experimental work, but we have done our simulation work very effectively and still work is going on to achieve better results with more critical analysis. settling time and peak over shoot analysis is presented in Table. 7 with Bar-diagram in Figure 19, Figure 20, and Figure 21

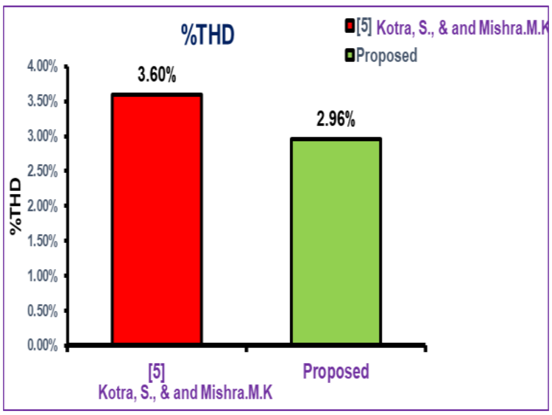

Figure 19. THD Analysis comparision

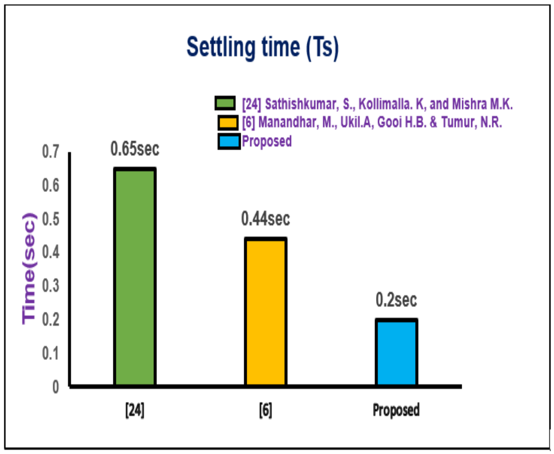

Figure 20. Settling time comparative Analysis

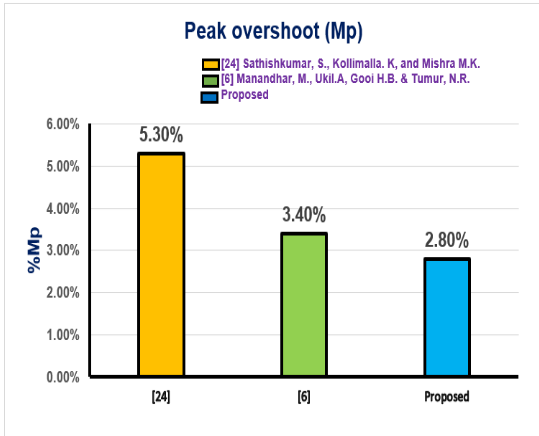

Figure 21. Peak overshoot Analysis

Table 6. THD comparative analysis with [5]

Sl.no	Compared	THD in Percentage
1	[5]	3.6
4	Proposed	2.96

Table 7. Settling Time and percentage of peak overshoot comparative analysis with [24],[6]

Sl.no	PMS Applied	Settling Time	Peak overshoot
1	[24]	0.65	5.3
2	[6]	0.44	3.4
4	Proposed	0.2	2.8

Case 5 Analysis of SOC During the Power Management

The SOC profile of battery and supercapacitor obtained is shown in Fig. 21 and Fig.22 respectively.

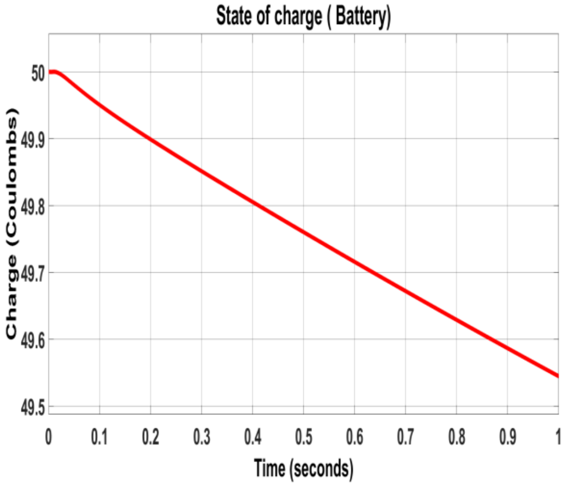

Figure 22. Soc of Battery

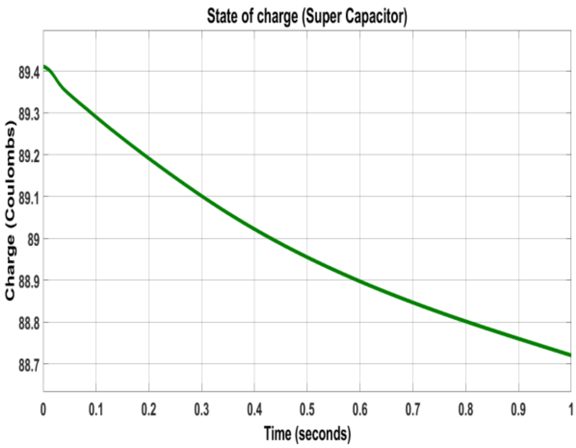

Figure 23. Soc of Super Capacitor

From Figure 22 and Figure 23, it can be observed, the battery exhibits a very gradual SOC reduction of about 0.16%, suggesting shallow depth-of-discharge operation and verifying that it is not subjected to deep or frequent cycling that hastens aging. The supercapacitor, on the other hand, exhibits a greater SOC variation of roughly around 0.7%, indicating its active participation in providing dynamic energy during transient situations and successfully divorcing short-term energy swings from the battery. The claim that the suggested battery–supercapacitor hybrid energy storage system improves battery longevity in comparison to a battery-only configuration which is quantitatively support the battery's reduced SOC swing and smoother operating conditions, significantly reduce depth-of-discharge-related stress.

The work concentrates on power management and harmonic reduction in a grid-connected PV-based hybrid energy storage system such as battery and super capacitor, under fluctuating PV irradiance with a constant demand, is the source of its constraints. Because fault ride-through and protection-oriented operation are not covered in the study, grid disturbance situations such voltage sags, frequency deviations, and islanding conditions are not examined. In terms of scalability, the suggested control technique can theoretically be expanded to larger power ratings; however, actual scalability factors like protection coordination, converter sizing, and grid code compliance have not been investigated. These elements are outside the scope of the present work and are consider as important are for future research.

5. Conclusions

In the designed Grid Connected Photovoltaic (PV) and HES Based Microgrid System, A new PMT with MPMA is proposed. This technique provides very encouraging results in terms of improvement of power quality and effective management of power due to the presence of HESS.

From the results and analysis sections, we can observe and conclude that, we have achieved our objective by reducing the THD level to 2.96% acceptable by IEEE 519, better settling time of 0.2 sec and peak over shoot of 2.8% and these obtained results are better than some of the existing PMS referred in this paper.

Fast recovery of DC bus voltage, proper regulation of voltage and frequency, improvement of power quality, less settling time, less peak over shoot percentage, efficient power management. These are the main contributed work from our research.

In referred papers, more analysis has been carried out but we have done some effective work in simulation keeping in mind more critical analysis will be carried out by us in future.

Acknowledgments

This research was supported by GITAM University. Authors appreciate colleagues of the research departme4nt.

Nomenclature

C_{sc}	Supercapactor capacitance
DPM	Deficient power mode
EPM	Excess power mode
HESS	Hybrid Energy Storage System
I_{PV}	PV current
I_B	Battery current
$I^{/}(t)$, I_{avg}	Average current
$I^{//}(t)$, I_{trn}	Transient current
I_{br}	Reference current of battery
I_{sr}	Supercapacitor reference current
Igr	Grid refenece ccurrent
K_{ppv}, K_{ipv}	Proptional and integral gain of PV
K_{pb}, K_{ib}	Proptional and integral gain of battery
K_{ps}, K_{is}	Proptional and integral of SC
K_{pdc}, K_{idc}	Proptional and integral gain of DC
Lambada	Sharing coefficent
MG	Microgrid
MPMA	Modified Power Management Algorithm
MAF	Moving average filter
P_{sc}	Supercapactor power
P_L	Load Demant
$P^{/}(t)$	Average power
$P^{//}(t)$	Transient power
P_G	Grid power
P_{PV}	PV power
P_B	Battery power
PV	Photo Voltaic
PI	Proportional-Integral
PLL	Phase-locked loop
PMS	Power management scheme
PMT	Power Management Technique
PR	Proportional resonant
PMA	Power Management Algorithm
RES	Renewable energy sources
SOC	state of charge
THD	Total Harmonics Distortion
V_{PV}	PV voltage
V_B	Battery voltage
V_{sc}	Supercapactor voltage
V_G	Grid voltage
ω_C	Cut off frequency

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