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A power management strategy for PV and hybrid energy storage system

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Abstract. Renewable energy sources are sporadic in nature, they supplement conventional energy sources. The stability of the distribution system is impacted by the inclusion of these traditional sources. The power quality of the system is also impacted by random fluctuations. Systems for storing energy are therefore created. Therefore, a battery and capacitor integrated power management method for grid-connected photovoltaic systems is devised. Battery and supercapacitor work together to stabilize the system by grabbing both steady and sporadic power and regulating the DC link voltage. The purpose of supercapacitor is to reduce battery's current stress.

1 Introduction

Now-a-days the fast-growing technologies makes the renewable energy sources to penetrate into the power system with ease and efficiency. As these sources are easily available to reduce the cost of production to the great extent but the challenges are, these are intermittent in nature to avoid these challenges we use some control techniques that is we integrate these sources with the grid and other generating units, in order to achieve high efficiency, flexibility, low maintenance. Efficient renewable source is photovoltaic energy which is highly reliable, efficient and sustainable it requires less maintenance and solar energy is available with no cost [1].

Environmental conditions like temperature, partial shading, irradiance and percentage of humidity effects the PV generation so it consequently effects the stability of the system.

Aiding PV generation with energy storage system overcomes its challenges with intermittent power system characteristics [2]. Enhancing storage systems with PV generation so that it provides continuous power to batteries which are used as primary energy storage element as it has high energy density. Helping the supercapacitor, which has a high-power density and a low energy density, to aid the battery enhances the power density and energy

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density of the entire energy system. Although the super capacitor has a high energy density, it cannot manage transients, meaning that its power density is reduced. Hence creating the Hybrid Energy Storage System [3].

Supercapacitor power factor decreases the stress on the batteries and increases its lifespan. Power management during dynamic load conditions are handled by HESS and PV cell and the Power fluctuations are compensated by HESS.

The Hybrid microgrid needs a comprehensive power supervision plan in order to function efficiently. The proposed strategy should encompass the following functions. Such as controlling the terminal power of individual distributor monitoring voltage and frequency within the system. Maintaining power balance between generator and demand. Different hybrid microgrid power management strategies have been covered in a number of studies. Making use of a centralized control approach to manage power transfer between loads, producing sources, and the utility grid in an efficient and seamless manner. This control technique is applied in both isolated and grid-interactive modes in a photovoltaic battery system. The issues related to power quality are not considered. The goal of this optimization method is to guarantee the effectiveness of the system's power management and voltage regulation [4-5]. Under severe circumstances, one diesel generator serves as a backup for storage devices and renewable energy sources. Problems such as irregular loading, delayed startup, and frequent switching.

By using this method, the supercapacitor unit receives the uncompensated battery current, hence minimizing the battery's stress. Energy management system with a supercapacitor and battery that allows HESS to function in both grid-interactive and islanded modes. Reactive power support, improved power factor, and fewer current harmonics are additional advantages of this technology. For PV-battery super capacitor hybrid systems, a coordinated control method is advised [6]. Model predictive control is a technique used by voltage source converter control in both isolated and grid-connected modes to guarantee consistent bus voltage and enable grid synchronization. A multi-segment adaptive droop control-based power management strategy is recommended for a PV and battery-connected system [7]. Voltage source converter control and model predictive control are employed. A multi-segment adaptive droop control power management strategy is recommended for a PV and battery-connected system [8].

2 Architecture of PV-Grid-HESS integrated system

As shown in Fig 1, it comprises of PV generating unit, Quadratic boost converter consists of inductors, capacitors and diodes L1, L2, C1, C2, D1, D2, and D3, respectively.
C_b -capacitor of battery, C_{db} – capacitor of bidirectional converter, C_{sc} – capacitance of super capacitor, L_f- inductance, R_f- resistance, C_f- capacitance of LC Filters, S1, S2, S3, S4 are switches of quadratic boost converter.
S_{b1} and S_{b2} are the switches of battery bidirectional converter.
R_{nl} and L_{nl} are resistor and inductor of bridge rectifier.
Rl_{ac} and Rl_{dc} are ac and DC loads respectively. V_g, V_{dc}, V_b and V_{sc} are grid voltage, DC bus voltage, battery voltage and supercapacitor votlage. S_{s1} and S_{s2} are the switches of super capacitor.

To integrate a low-voltage photovoltaic system with the distribution system and acquire the required DC-link voltage system, the output voltage of the DC-DC converter should be adequate. When combined with a photovoltaic system, a quadratic boost converter provides high conversion efficiency over a broad voltage range. Supercapacitors and batteries are used for energy storage in conjunction with the bi-directional boost DC-DC converter to control power flow between the grid and the energy storage systems. A variable speed converter, which may function as either a rectifier or an inverter depending on the mode of operation, connects the DC microgrid to the AC utility grid.

The LC filter gives the smooth voltages and currents and also reduces the ripples on Ac side. Linear and nonlinear loads are connected to analyse under different operating modes. The generation of reference current, a power management algorithm, and control over various current converters are the main parts of this power management system. The recommended power management configuration for a system linked to the grid is shown in Fig. 2. The average and transient power needs for photovoltaics are represented by PR_{avg} and Pr_{trans}, respectively, whereas the reference PV current is represented by i_{pvr}.

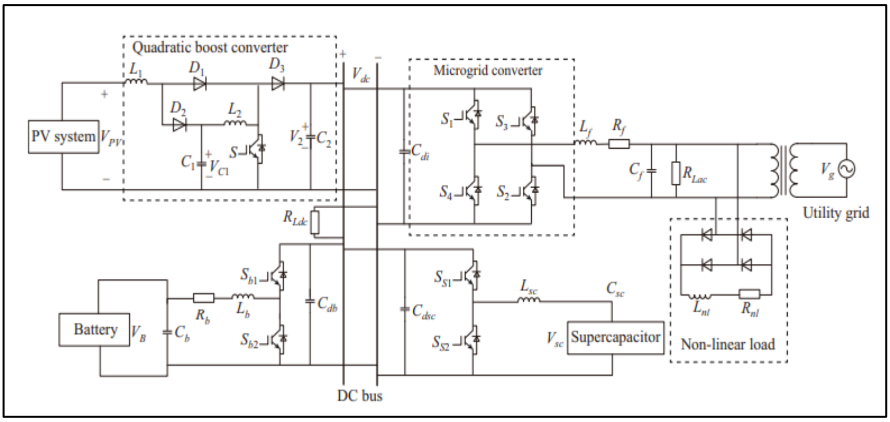

Fig. 1. Architecture of PV integrated with HESS

3 Power management Control Structure

Generated power and demands should be balanced to attain power equilibrium state. Reference currents are generated based on the battery power, grid power, PV power, supercapacitor power.

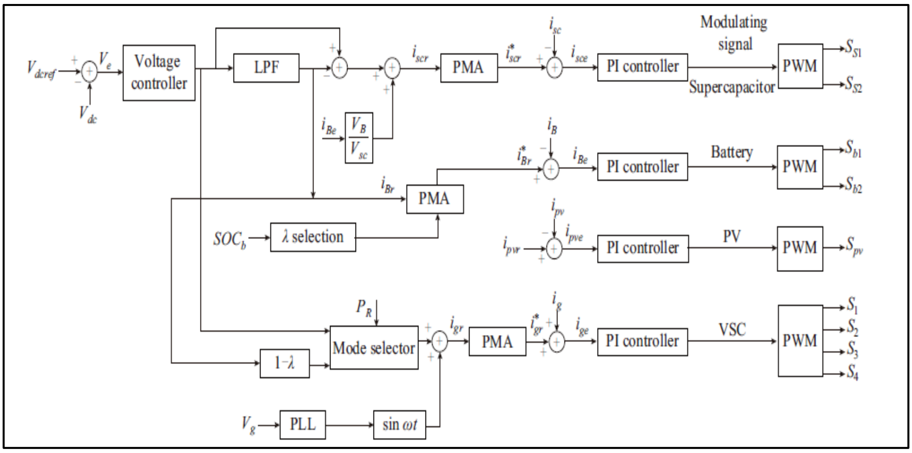

Fig. 2. Control structure of PV system

Power balance equation is:

$$P_g(t) + P_{pv}(t) + P_B(t) + P_{sc}(t) - P_l(t) = P_t(t) \qquad (1)$$

Power sharing between generation and load consumption should be balanced according to eq(1)
Where $P_l(t)$ is the load power, total power required is represented as $P_t(t)$ and it has two components, average power component is represented as $\bar{P}_t(t)$ and transient component is represented as $P^*_t(t)$

$$\bar{P}_t(t) + P_t'(t) = V_{dc} i_t(t) \qquad (2)$$

$$i_t(t) = \frac{\bar{P}_t(t)}{V_{dc}} + \frac{P_t'(t)}{V_{dc}} = \bar{\iota}_t(r) + i_t'(t) \qquad (3)$$

The surplus power in eq (2) is supplied to the grid and grid current eq (3) is generated from eq(2)
Average component eq (4) of total currents is extracted by LPF. Transient currents eq(5) are obtained from super capacitor and it is given by:

$$\bar{\iota}_t(S) = \frac{\omega_c}{S+\omega_C} i_t(S) \qquad (4)$$

$$i_t'(S) = \left(1 - \frac{\omega c}{S+\omega_c}\right) i_t(S) \qquad (5)$$

This controlling architecture consists of power management architecture, for the production of reference currents and for the selection of power-sharing coefficient based on the state of charge of battery according to the table 1.
Based on the values we have given conditions in matlab simulation.

Table 1. Logic for power sharing coefficient .[1]

SOC_b (t)	λ	1-λ
$0.7<SOC_b<U$	1.0	0
$0.5<SOC_b<0.7$	0.6	0.4
$0.1<SOC_b<0.5$	0.3	0.7
$SOC_b<L$	0	1.0

Table 2. Parameters.

Specifications	**Parameter**	**Value**
PV array	V_{Pv}	40 V
	i_{Pv}	20 A
Supercapacitor	V_{sc}	16.2 V
	i_P	200 A
	C_{sc}	58 F
	i_{mc}	19 A
VSC	L_f	10 mH
	C_f	1 µF
	C_{di}	2200 µF
Supercapacitor BDDC	L_{sc}	5 mH
	C_{dsc}	220 µF
Battery	C_B	14 Ah

	V_B	12 V
Battery BDDC	R_b	0.5 Ω
	L_b	5 mH
	C_b	220 µF
	C_{db}	220 µF
Quadratic boost PV converter	$L_1 = L_2$	5 mH
	C_1	110 µF
	C_2	220 µF
Linear and non-linear load parameters	R_{Ldc}	50 Ω
	R_{Lac}	10 Ω
	R_{nl}	30 Ω
	L_{nl}	1 mH
Utility grid	V_g	230 V
	f	50 Hz
DC bus voltage	V_{dc}	100 V
MAF	f_{MAF}	100 Hz
LPF	f_{LPF}	1 Hz

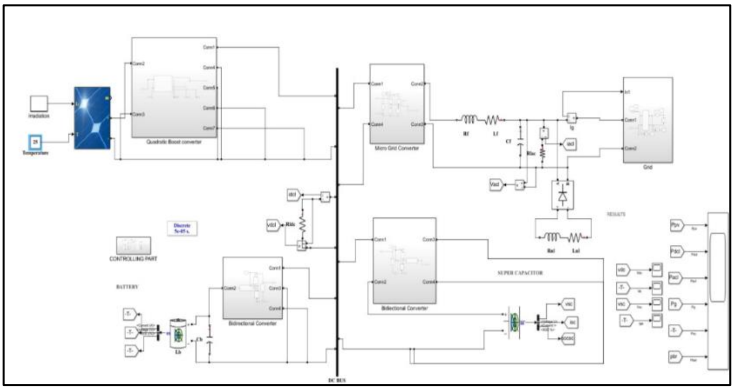

Fig. 3. Simulation model of pv connected grid integrated with HESS

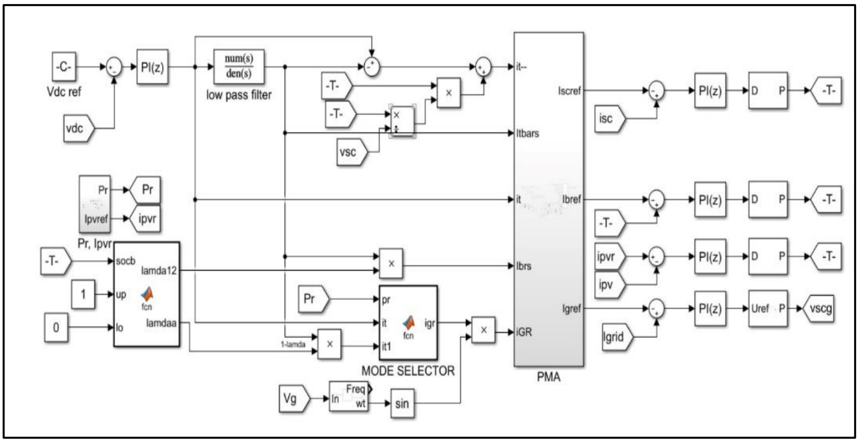

Fig. 4. Current algorithm with PWM technique.

The developed system consist of PV generation buck boost converter to step up DC voltage and hybrid storage systems, battery aiding with supercapacitor to avoid intermittent power supply problem and surplus energy is provided to grid through microgrid converter fig.3 and mode of operation are implemented according to the proposed power management controlled scheme fig.4.
Based on the power, modes are defined as:
1) Variation in power.
2) Variation in load
3) IPM: $P_R>0$.

1)Variation in PV power:

To adjust the PV generated power, the irradiance is changed from 1000 to 600W/m^2 at t=2sec. The DC bus voltage returns to equilibrium after 0.15 seconds with a 1 volt undershoot. To get the DC link voltage back to a constant level, the batteries and grid adjust for average components. A supercapacitor attached to the battery reduces the PV power variation's . The PV power is generated is 200Watts, aiding with battery(P_{bat}), super capacitor (P_{sc}) supplies the DC load (Pd_{cl}), AC load(Pa_{cl}) and excessive power transfers to the grid fig .5.

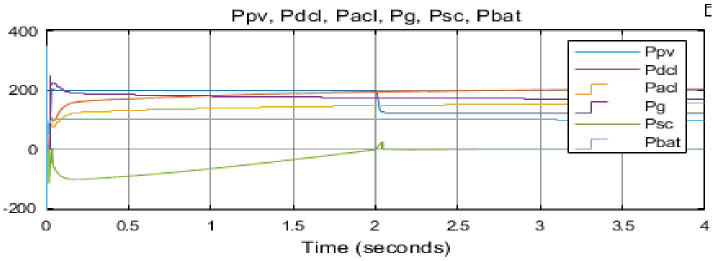

Fig. 5. Outputs of PV power

2)Variation in Load:

This falls under the circumstances of insufficient power at t=2 seconds. Batteries and grid handle the increased average power demand to maintain DC bus voltage constant. The supercapacitor manages transient powers with a voltage dip of 2 volts and regains constant voltage within 0.2 seconds by controlling the conduction time of the IGBTs by generating the necessary current-controlled pulses to achieve power balance fig .6. The DC load of 50 ohms is varied around 25 ohms. Transients cause a frequency deviation of + or -0.01, but the frequency quickly returns to its original value. In order to preserve the system's efficiency and power factor, the frequency must be kept constant or within acceptable bounds [3]. The graphs show that when the DC load grows, so does the power consumption, which raises the average power demand. The grid, battery, and supercapacitor handle the transients, which are caused by abrupt variations for load, respectively.

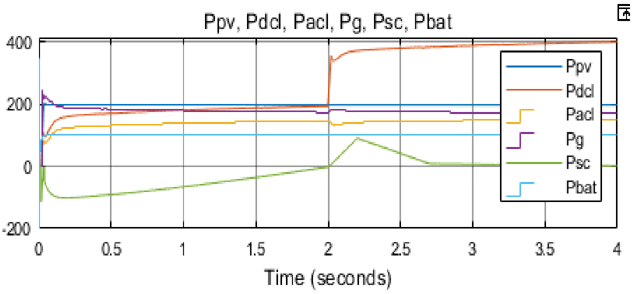

Fig. 6. Outputs of variation in load

3)IPM:

There are four states in this mode that takes SoC into account. State 1 is defined as $SOC_b < U$ and $SOC_{sc} < U$, indicating that the battery and supercapacitor are charged at t = 0–2s. The electrical grid receives the leftover surplus power. State 2 is defined as $SOC_b < L$ and $SOC_{sc} > L$ at t = 2-4s. The power grid manages the entire power. Temporary power is supplied by the supercapacitor. The battery runs flat. State variables at t = 4-6s are $SOC_b > L$ and $SOC_{sc} < L$. 3. The battery and power grid split the total power. Supercapacitor inactivity occurs. State 4 is defined as $SOC_b < L$ and $SOC_{sc} < L$ at t = 6–8 s. The power grid controls the overall power. Both the supercapacitor and the battery deactivate. Thus, average power is handled by the battery grid and PV generation based on the battery's state of charge and the supercapacitor's needed amount fig .7.The supercapacitor then compensates for the transient power, which helps the system become more stable and efficient.

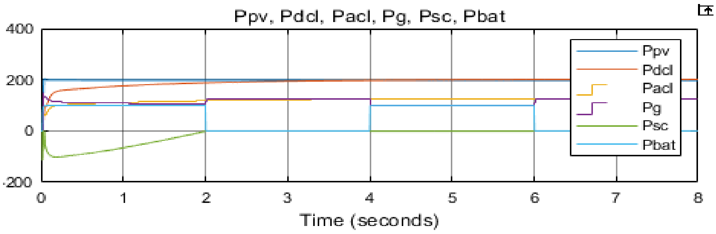

Fig. 7. Output powers in IPM

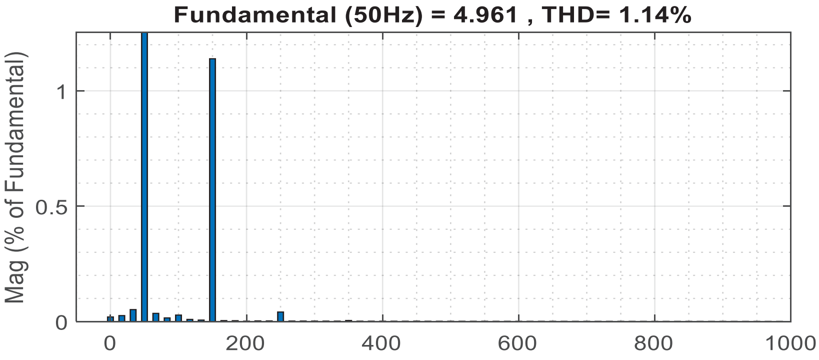

Fig. 8. Total harmonic distortion

4 Conclusion

The proposed power management ensures the power balance between the PV generation, DC and AC loads, storage system and utility grid these can be achieved by controlling the pulses given to the IGBT i.e., by calculating the reference currents and comparing it with real time battery current. It consist of two modes variation in power and variation in load. When power, load changes there is sudden dip in the DC bus voltage however proposed scheme ensures the voltage stability in 2 sec and there is + or – 0.01 frequency deviation and it will also become stable within 2 secs.The grid currents have a total harmonic distortion of 1.14% which are acceptable limits .The objectives of the pro- posed scheme, e. g., faster DC voltage regulation, voltage and frequency regulation, maintenance of power quality is- sues, are justified through simulation results.

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