A Unified Power Management Strategy for a Grid Connected PV Hybrid Energy Storage System

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***Abstract** - The Advancement of energy management tools for next generation is Photovoltaic (PV) installations, including storage units, maintain flexibility to distribution system operators. In this project deals with the hybrid power system consisting of renewable energy sources to supply the isolated sites without interruption which represent a viable and sustainable solution. The HESS is composed of a two Energy Storage devices (ESD), Super-capacitor (SC) and a battery. A single phase grid interactive voltage source converter performs the main function of real power transfer along with ancillary services like current harmonics mitigation, reactive power support and power factor improvement at the point of common coupling (PCC).Active participation of super capacitor/battery control to handle sudden/average changes in power surges results in fast DC link voltage regulation, efficient energy management and reduced current stress on battery.*

***Index Terms*—Battery, power quality features, renewable grid integration, super-capacitor, voltage source inverter.**

1. INTRODUCTION

Renewable sources based microgrids are gaining popularity due to depleting fossil fuels and increasing demand for high reliability supply. To supply electronics, LED lighting and variable speed drive loads from solar photovoltaics (PV), dc system offers high efficiency as compared to ac system. Efficiency is expected to be 10-22% higher in case of dc system Further, dc system offers higher reliability due to less power conversion stages. Other key advantage of dc system is high utilization of cables due to absence of reactive power flow. Operation of all sources and storage elements should be controlled to ensure uninterrupted supply of power to loads. Following are the key control objectives of this system:

- Uninterrupted power to loads
- Optimal utilization of solar PV
- Minimum use of power from ac and dc grids
- Extended life of operation of battery and super capacitor

ULTRACAPACITOR are increasingly interesting because of their high-energy density and high-power density. Ultracapacitor applications in power distribution systems and in utility electronic device have described improvements in power quality, uninterrupted power supply (UPS), and memory backup. Major efforts have been invested to exploit the huge-power capability of ultra capacitor hybrids with batteries or fuel cells in pulsed operating modes, which are of appropriate interest to portable power systems, electric vehicles and digital telecommunication systems. On the other hand, parallel hybrid power sources that combine advanced batteries with ultra capacitors can overcome the power deficiency at lower monetary, volumetric, or weight cost. Such systems have been experimentally exhibit longer operating times compared to systems without ultra capacitors. The present paper is propose to fill out that void by providing a method and analytic results for a simplified model of the battery–ultra capacitor system operating under pulsed position. The analysis focuses on the interrelations between battery, ultra-capacitor and load in terms of their power and energy barrier, so that the potential gains in peak power, reduction of internal losses and expansion of discharge life can be revealed and evaluated.

On the PV source side, a dc–dc converter with a huge voltage gain is necessary for converting the low PV panel voltage into the high dc-link voltage. There are many high-gain converter that comprise of diodes and capacitors to increase the steady state voltage gain. Obtain high gain requires more number of components that result in reduced converter capability. A bidirectional dc–dc converter at the dc link enables power flow into and from the energy storage elements. Distinct control strategies have been proposed for bidirectional dc–dc converters that include use of neural networks to fuzzy logic optimal control and model-predictive control (MPC). It is well known that any change in the load/renewable power affects the dc-link voltage straightly. The sudden decrease/increase of load/renewable power would result in an increase in the dc-link voltage above the reference value, whereas a rapid increase/decrease in load/renewable power would reduce the dc-link voltage below its reference value.

Energy management schemes are proposed for a hybrid battery/super capacitor energy storage system that calls for large memory for its implementation. The method reported in is based on the classical model predictive control (MPC) that relies on a discrete model of the control system and a cost function making it computationally intensive which is the main drawback. Keeping the above perspective and issues, The main concerns in the hybrid micro grid environment under large changes in the DC link voltage include, (a) the operating point shifting from maximum power point (MPP) on the renewable sources side, (b) inability to achieve effective power management at the DC link and (c) degradation of compensation performance of the grid side VSC. Power quality is another important aspect that needs to be addressed for renewable grid integrated hybrid system. In addition to the above, the energy management schemes should achieve the main function of real power transfer along with the additional power quality features such as current harmonic remuneration, reactive power support and unity power factor operation at the point of common coupling.

II.SYSTEM CONFIGURATION AND PROPOSED ENERGY MANAGEMENT SCHEME

1.Existing System

PV Based Micro Grid with Battery and Super Capacitor Combined Storage shown in fig.1. In this architecture, PV power is used as a major source to supply the load. The PV array output is controlled by boost converter to maintain the *dc* grid voltage at 48 *V* .The PV array is formed by connecting 32 cells in series and 8 such rows in parallel. which is the maximum power region for the considered solar array and hence, it is assumed to the maximum power tracking.

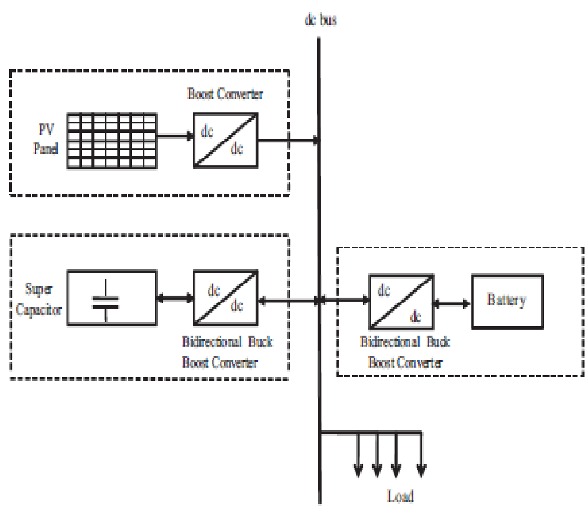

Fig. 1. Exsiting Block Diagram

2. *Proposed System*

The grid interactive hybrid micro-grid system considered in this paper is shown in Fig. 2. The emulated RES system is connected with the high gain DC-DC converter in order to mimic the unpredictable changes in the renewable energy source. Batteries and super capacitors are used as ESDs to meet the requisite the power flow in the micro-grid environment. The bidirectional buck-boost DC-DC converter topologies are used to maintain the power flow between the ESDs and utility grid. The VSC is mainly employed for real power exchange from RES to the utility grid. In addition to the above, the converter also provides additional services like current harmonic mitigation, reactive power support and power factor improvement at the point of common coupling (PCC).

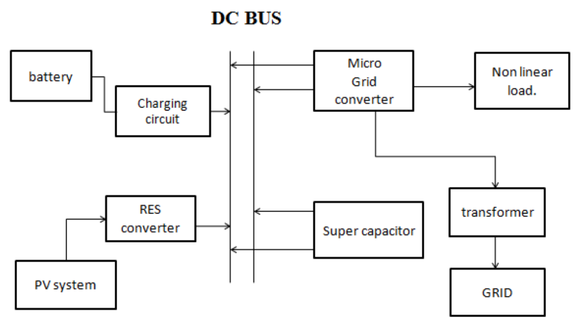

Fig. 2. Proposed Block Diagram

The proposed energy management scheme mainly consists of reference currents generation, power management algorithm, current control and switching pulse generation for various converter stages as shown in Fig. 2. The average and transient power references are generated using low pass filter and rate limiter. The average reference currents of battery unit and utility grid are generated from the low pass filter. In each power mode, based on the SoC status of ESDs, four operational objectives are formulated and then PMA generates the appropriate reference quantities for various power converter stages. The reference quantities obtained from the PMA are tracked by the current control stages and the control signals from the current control stages are used to generate the switching pulses for various power converters. To integrate the low-voltage PV panels to the distribution system, the output voltage of the intermediate dc–dc converter should be huge enough to generate the required dc-link voltage [9]. Hence, a dc–dc converter with a huge-voltage gain is necessary. The high-gain PV converter is essentially used for achieving higher voltage gains; as a result, the magnitude of the current drawn from PV side is high, and hence, the converter achieve most of the times in continuous current mode (CCM).

III.POWER MANAGEMENT ALGORITHM

The "power algorithm" level compose the MPPT algorithm [12], the power-balancing algorithm and the battery current-tracking algorithm. The battery current-tracking algorithm will be given. Storage units are used to implement the inner power balancing; the corresponding algorithm is now detailed. By assuming a generating operation of batteries and super capacitors and by ignoring losses in the power electronic converters, battery power Pbat and super capacitor power Psc appear directly to the dc bus and are added to PV power Ppv. A part of this power is exchanged inside a c-bus capacitor Pdc. Some power is lost in choke *L*filter, and then, the power is sent to grid Pg. In the conversion chain studied, possibilities endure to store energy or to boost it by managing the exchanged power with batteries Pbat and with super capacitors *p*sc [25].

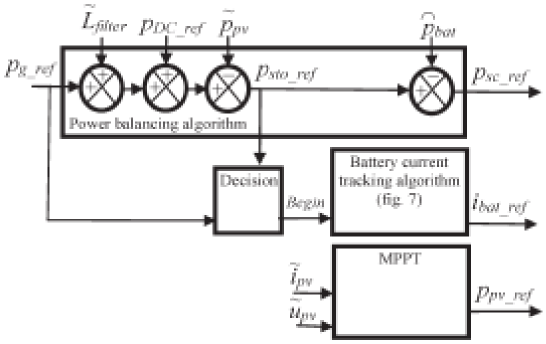

Fig. 3. power algorithm

IV.CURRENT CONTROL

A.Supercapacitor, battery and converter control

The battery energy management scheme is mainly used to adjust the power balance in the dc grid. Many control schemes are described in the literature to control the battery current in various operation. Among them, a unified current-mode control [22] for hybrid vehicles and for renewable power system [23] is reported.The main drawbacks of this scheme are hard compensator design and low efficiency at light-load conditions. To avoid these issues, a fast acting dc-link voltage-based energy management scheme is suggested for battery current control.

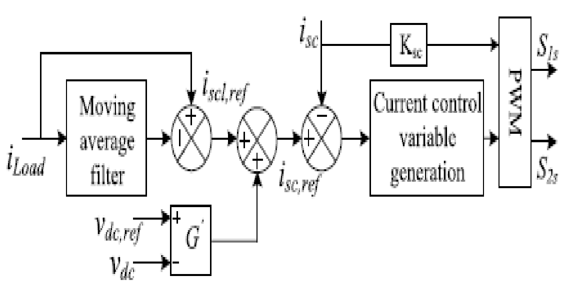

Fig. 4. Current control loop

The proposed scheme mainly consists of battery SoC evaluation, battery reference current generation, and generation of control variable (δB). The bidirectional converter switches are operated in complementary mode. Therefore, it is enough to find out the control case in the boost mode of operation. Upon simplification of (8), the control variable (δB) is derived as

$$\delta_B(t) = \frac{v_{\mathrm{dc}} - v_B}{v_{\mathrm{dc}}} + \frac{L_B}{v_{\mathrm{dc}}}\frac{di_B}{dt}.$$

In (9), the first part is the feed forward term, which improves the dc-link voltage regulation across battery voltage changes. The second part is the anticipating term and the coefficients of these parts are not stable. These coefficients are changing with the dc-link voltage, and hence, the dynamics of the dc-link voltage is quicker. The reference current of the battery converter (*iB*,ref) is generated by a simple voltage compensator [*Gcv* (*z*)] in the outer dc-link voltage loop. This *Gcv* (*z*) is responsible for regulation of the dc-link voltage. In order to further develop the transient feedback of the dc-link voltage, a term proportional to the voltage error.

A.SUPERCAPACITOR

The supercapacitor energy management scheme plays a important role for achieving fast dc-link voltage dynamics. The proposed system mainly contains the generation of supercapacitor reference current (*i*sc,ref) and fast acting current control loop. A moving average filter (MAF) is used to adjust the average load demand. The supercapacitor current control is attain by a fast acting direct current feedback and generation of control variable (*δsc*) based on error current dynamics as illustrated in Fig. 6 The supercapacitor current using MAF is obtained as

$$i_{\mathrm{sc,ref}} = i_{\mathrm{Load}}(t) - \frac{1}{T}\int_{t_o}^{t_o+T} i_{\mathrm{Load}}(t)\,dt + G'(v_{\mathrm{dc,ref}} - v_{\mathrm{dc}})$$

where *G_* is the gain of the dc-link voltage dynamics estimates.The main feature of this controller compared to the conventional one is that the gain values of the corresponding and derivative coefficients of supercapacitor error currents are not constant.

V.VSC CURRENT CONTROL

The required battery and ultracapacitor currents *i*batt req and *i*cap req are enforced using PI current controllers. The PI current controllers are designed using the procedure described in .

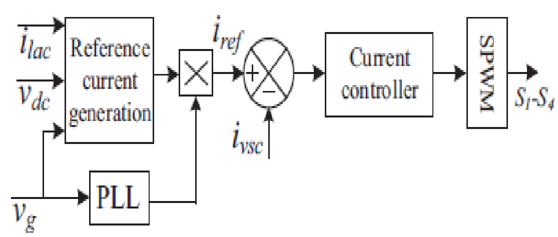

Fig. 5. VSC control structure

The VSC control mainly consists of reference current generation, computation of voltage template and current control part as shown in Fig. 5. The reference current for the VSC is generated based on the bidirectional power flow (inverter or rectifier) from the AC grid to the DC link or vice versa. In EPM, the excess power is primarily used to charge the batteries and supercapacitors. Once the energy storage devices reach to their high SoC limits, then the remaining excess power is injected into the utility grid via VSC. In this mode, the VSC operates as inverter.

A.CONVERTER CONTROL

The battery and super capacitor is controlled by bidirectional buck boost converter. The control circuit associated with the bifractional converter for battery and super capacitor. The variation in the *dc* grid voltage that arise due to imbalance power is used to generate the current reference.

TABLE I SYSTEM PARAMETERS

Supercapacitor parameter	Values
Terminal voltage(Vsc)	16.2V
Max.peak current(Ip)	200A
Capacitance/pack(Csc)	58F
Battery specification	Values
Battery capacity	14Ah
Terminal voltage	12V
Battery in series	4
Battery converter parameter	Lb=1mH, Cb=220μF Cdb=220 μF
Supercapacitor converter parameter	Lsc=1mH, Cdsc=220 μF
PI controller parameter	Values
Supercapacitor	Kp,sc=0.4
Battery	Kp,b=0.15
RES converter	Kp,res=3
DC voltage	Kpvd=0.1
Grid and DC link voltage	Vg=230, V=50Hz, Vdc=80V

From this fluctuant total reference current, the *dc* component is derived using filter and it is made as a reference current for the battery. The difference between the fluctuant total reference current and the *dc* component is the reference current for super capacitor. This is the current which is responsible for reduction in *SOC* and increase in stress on the battery. Thus, the steady *dc* current is drawn by battery and the quick fluctuations are bypassed to super capacitors which can best handle them.

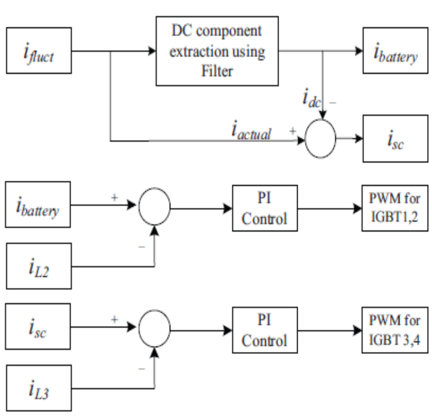

Fig. 6. Control loop for battery and supercapacitor

Both battery and super capacitor charges and discharges according to the load condition to maintain the *dc* grid voltage. The initial *SOC* of the battery and super capacitor is set as 50%. The terminal voltage and *SOC* of the battery and super capacitor will vary depends on the power imbalance nature.The operation of super capacitors under connected energy storage mode is given in the Fig. 13. The high frequency fluctuation present in the reference current is absorbed by the super capacitors. The super capacitor discharges at a faster rate during the period from 2−4*s* when compared to the period of 1 − 2 *s*, as the fluctuations are severe in that zone. Thus, the current increases to 7 *A* suddenly at 2 *s* to relieve the stress on the battery.

VI.RESULT AND DISCUSSION

A.SIMULATION STUDIES

Specific simulation studies are carried out using MATLAB/ Simulink software in order to verify the validity of the proposed energy management scheme. The system parameters used for the simulation study are presented in Table II. The steady state and dynamic performance of the expected energy management scheme are presented in this section under various operating modes. Four sub-states are possible in each power mode based on SoC status of energy storage devices.In this project it can consist of renewable sources with energy storage devices that can connected to the DC bus and the other side it have an inverter that connected to the non linear load and the grid. The inverter input is the voltage of DC bus system.

PV with MPPT controller

The PV array has been designed taken into consideration its dependence upon the irradiance, temperature, number of PV cells connected in series and parallel. The PV array is interfaced across the boost converter. In this algorithm the operating voltage of the PV module is bothered by a small increment, and the resulting change of power, P is analysed. If the P is positive, then it is supposed that it has moved the operating point closer to the MPPT. Thus, further voltage perturbations in the exact direction should move the operating point toward the MPPT. If the P is negative, the operating point has moved away from the MPP, and the direction of perturbation should be reversed to lifted back toward the MPPT.

B.BATTERY SYSTEM

A battery is used as energy storage to boost the power necessary to meet the load when weather conditions are not optimal. The battery is modeled in such a way that when there is deficient in power the battery supports the source and when there is excess power it is utilized by the battery.The rating of the battery is 12.7V but the DC bus voltage is 80V hence during charging condition of battery the voltage is bucked using buck converter and during discharging condition the voltage is boosted using boost converter. Necessary breaker is provided to connect either buck or boost converter based on the condition

C.SUPERCAPACITOR

They combine the best features of EDLCs and pseudo capacitors together into a unified super capacitor although hybrid capacitors have been explored less than EDLCs or pseudo capacitors; the research that is available suggests that they may be able to outperform comparable EDLCs and pseudo capacitors. As a result, R&D efforts concerning the fabrication of enhanced hybrid capacitors and the development of more accurate quantitative models of hybrid capacitors have continued to expand Along with the increasing interest in developing high cycle life, high-energy super capacitors, the tremendous change in tuning the design and performance of hybrid capacitors is leading them to surpass EDLCs as the most promising class of super capacitors. Supercapacitor is charged, if extra power is available in the DC bus. If Fuel-cell did not meet the load demand, it will discharge.

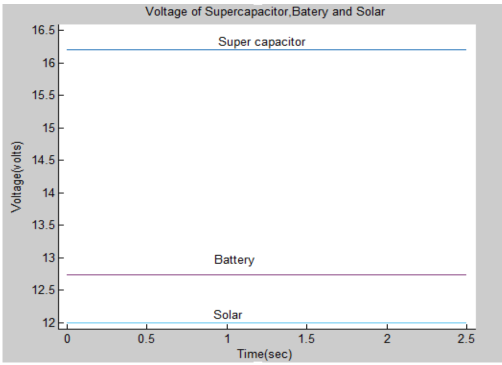

Fig. 7. Output Voltage of PV Battery Supercapacitor

The DC bus link should have the value of 80V. The input voltage is applied from sources like PV panel, battery and Supercapacitor, all that are connected to DC bus to get the bus link voltage of 80V that shown in figure 8.

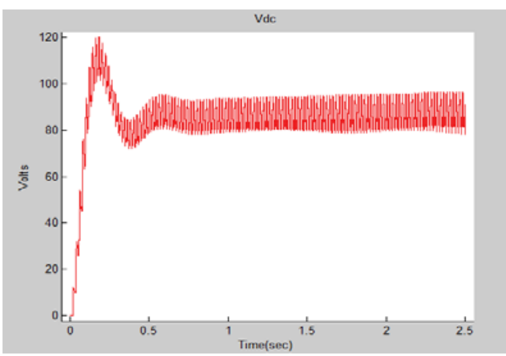

Fig. 8. DC Voltage Output

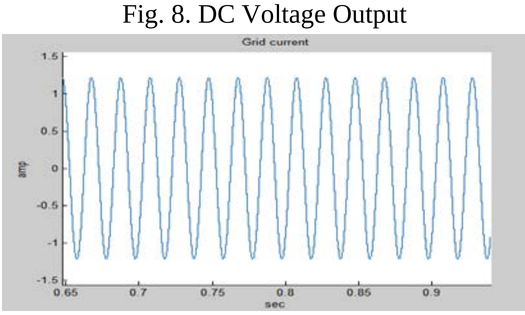

Fig. 10. Grid Current

The input voltage from the DC link that achieve with the inverter circuit as a input and they convert to the AC waveform to the utility grid, at the voltage of 230V. The output grid voltage is shown in figure 9.

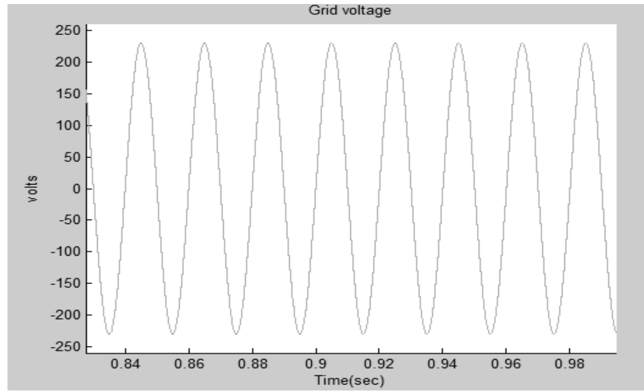

Fig. 9. Grid voltage

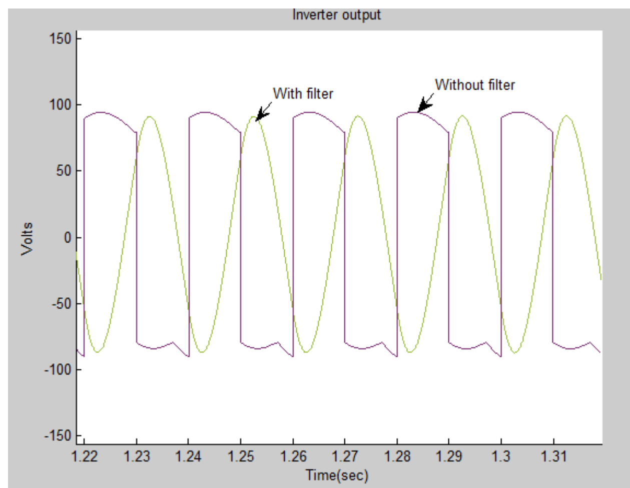

Figure 11.Inverter Output With and Without Filter

This is the grid current that placed along with the grid voltage. The grid voltage is shown in figure 9 and the grid current is above 1.5amps is shown in figure 10. The grid can be maintain attherating.

D.INVERTER SYSTEM

A DC/AC is used to generate AC waveform from the DC signal. Some harmonics have been found in the output of the inverter which has been eliminated using necessary filters.DC bus voltage is converted into AC, again filter is used to eliminate harmonics in order to obtain pure harmonics as shown in figure 11. In this level, with and without filter is used to get the pure AC on the inverter.

E.REFERENCE CURRENT CONTROL

The Supercapacitor control loop mainly consists of reference current generation (isc;r), the current control part as shown in above.

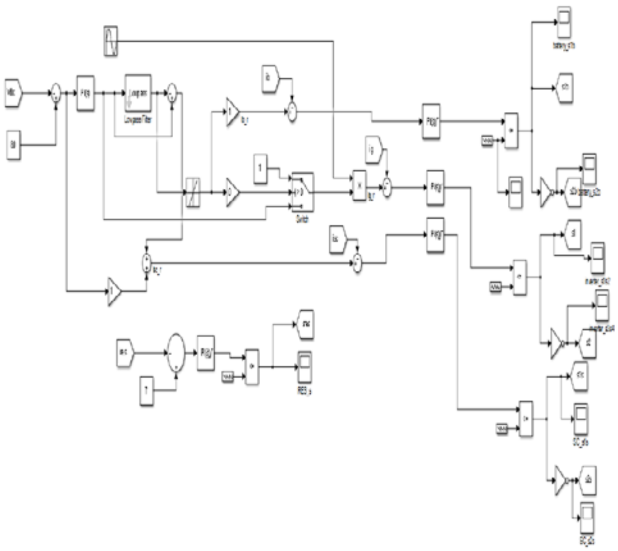

Fig. 12. Reference Current control Scheme

The reference transient and oscillatory components of ief are extracted through reference current generation block.

OVERALL SIMULATION MODEL

The developed simulation model of the renewable grid integrated hybrid energy system is shown in figure 13. It consist of PV emulator, battery, and supercapacitor unit, RES converter, voltage source control and loads. When all the storage devices and input sources are connected in the DC bus link voltage at the rating of 80V with the RES converter. The DC bus link voltage is the input voltage of the inverter circuit and they can have the controlled circuit to control the reference signals and switching circuit. It also have the filter circuit to avoid the unwanted harmonics and get the pure AC waveform at the voltage rating of 230V.

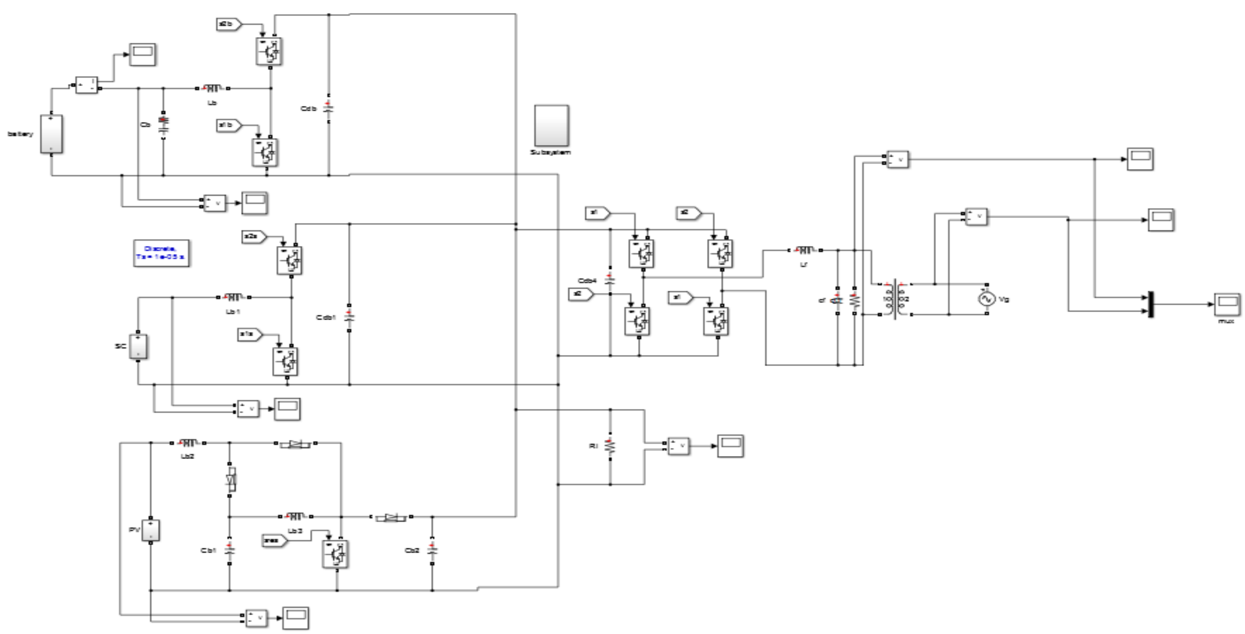

Fig. 13. Overall Simulation Model

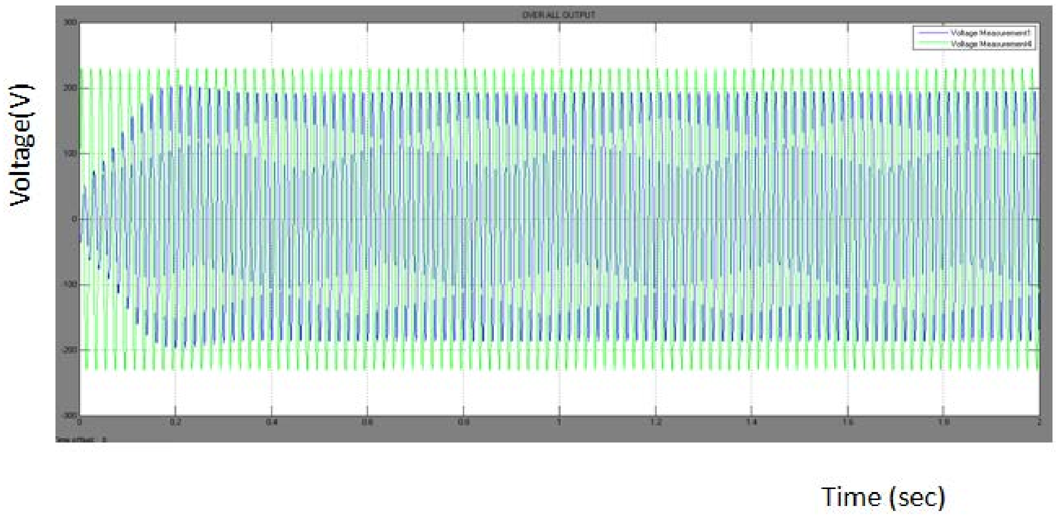

Fig. 14. Overall Simulation Output

VII.CONCLUSION

A unified power management scheme is proposed for a renewable grid integrated system with a battery-supercapacitor units as energy storage devices. It is shown that, the proposed energy management scheme performs the main function of bidirectional real power transfer along with additional power quality features at the point of common coupling. The PV/battery unit is controlled to operate as a voltage source that employs an adaptive control strategy where the PV units are controlled to operate as current controlled sources First, the hybrid unit has the ability to share the load power with other sources while storing any excess energy in the battery/supercapacitor. Second, it can track and supply the maximum PV power to the microgrid provided that there is sufficient load demand in the microgrid. Otherwise, the hybrid unit will autonomously match the available load while charging the battery/supercapacitor with the excess energy as in standalone strategies. Third, the control strategy modifies the PV operating point to follow the load when the total microgrid load is less than the available PV power and the battery/supercapacitor is fully charged. In addition, the supercapacitor may also provide the operational functions that a separate storage unit may provide in an microgrid, such as conducting voltage and frequency, and supplying the deficit power in the microgrid.

FUTURE WORK

The fast acting dc link voltage based energy management is necessary to ensure good performance of renewable system. By using fuzzy logic controller instead of PI controller,the exact values for hybrid storage device can be determined.

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