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# POWER MANAGEMENT SCHEME FOR PV-BATTERY-BASED HYBRID MICROGRIDS FOR GRID-CONNECTED AND ISLANDED MODES

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## ABSTRACT

Distributed Generation (DG) is an effective way of integrating renewable energy sources Microgrid, which improves the reliability and efficiency of power systems. Photovoltaic (PV) systems are ideal DGs with attractive benefits, such as availability of solar energy and low installation costs. Storage Batteries (SB) are used in PV systems to balance the power flows and eliminate power fluctuations due to change of operating condition, e.g., irradiance and temperature variation. In an attempt to effectively manage the power flows, this project presents a novel power control and management system for PV-Battery systems based Microgrid in both grid connected and islanded mode. The proposed system realizes the maximum power point tracking (MPPT) of the PV panels, balance among the power flows, and quick response of both active and reactive power demands. the proposed method performance is carried out using MATLAB/Simulink Simulationsoftware and the same is verified with hardware.

## INTRODUCTION

Manypowerutilitiesaroundtheworldhavebeenforcedtochangetheirwayofoperationforbringingcompetitionamongutility companies, new choicesforcustomers,andeconomicbenefits.Competition bringsinnovation, higher efficiency andlower costs, whichis a win-win situation for both suppliers and consumers.The twomajor driving forces:deregulation andenvironmental concerns,bring interestindistributedgeneration(DG).DGisdefined asasmallsizeelectricpower sourceconnecteddirectlytothedistributionnetwork oronthecustomersiteofthemeter.Compared totheconventionalcentralizedpowerplants,DGsare sustainable,are smaller,andcanbeinstalledclosertocustomers.ManyDGscanbeinstalledonorclose tothecustomers todeliverpowerratherthantheconventional way oftransmittingpower fromcentralizedpowerplantsovertransmission anddistribution lines.Duetosteady progress in powerindustry deregulation, and tight constraints imposed on the constructionofnewtransmission linesforlongdistancepowertransmission, DGsare expectedtoincreaseinthefuture.

DGs with controllable energy resources such as micro turbines, fuel cells, diesel generators andsmall hydro unitsaredispatchable, whereasDGswithuncontrollable energy resources, suchasrenewableenergysources likewindandPVarenon- dispatchable.Many DGsareflexibleinseveralaspects:operation,sizeand expandability.However,non-dispatchableDGsrequireapropercontrolstrategyto cope withallattractivefeaturesofDGssuchaspeakpowersaving,reliabilityandpower qualityimprovement,alternativeto expansionofthegridnetworkandgrid support.Non-dispatchableDGs,suchaswindandPV,arerenewableenergybasedsourceswhich inherentlylackthecapabilityofdispatchingduetothe weatherdependency.However, thepenetrationsofthesesourceshaveincreased drasticallyinthelastfewdecadesdueto advancementsintechnology,freecostofenergy,increasingenergy consumption,soaring cost,exhaustiblenatureoffossilfuel,andcostreduction.

ThePVsource isthedominantrenewableenergysource(RES)comparedtoWindaroundthe world. These RES based DGs can be used in different structures under different control strategies.Somenon-dispatchable DGscanbeusedasastandaloneorahybridsystem, whichiseithergridconnectedorislanded.Astandalonepowersystemisdefinedasan off-grid system,whichoperatesindependently withoutagridsupport.Similarly,a standalone RESisdefinedinthisthesisasasinglesourcewhichis operatedindividually without any support systems, such as storage or back up source to

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counteract the stochasticnatureorweatherdependency.

DuetotheintermittentnatureofRESs,thestandalonewindandPVnormally require energy storagedevicessuchasbattery,super-capacitor, supermagneticenergy storage (SMES), flywheel,andsoon. Alocal grid consistsof dispersed loads and different DGs: dispatchableand non-dispatchable,alongwithorwithoutenergystorageisreferredasa‘microgrid’,which mayoperateinagridconnectedorIslandedforsmallcommunities.

Insummary,thederegulation ofpowerindustry,advancement intechnologies,constraint intheconstructionofnewtransmission lines,customerdemandforstableandhighly reliablepowerandenvironmentalconcernsencouragetousecleanandRESs,suchas PVindifferentstructuressuchasastandalone system,hybridsystemand microgrideitherinislandedorgridconnectedmode. Theintermittentnatureofthese RESsandnon-specified standardinahybridandmicrogridsystemrequireproperpower managementcontrolstrategiestomeettheloaddemandwithstableandreliablepower.

**MOTIVATION AND BACKGROUND**

Thenon-dispatchableDGssuchasPVisutilizing broadlynowadaysdue to the advancementin technology,free ofenergycost, less dependence onfossilfuels,andcostreductions inlastfewyears. However, thepower managementcontrolstrategy forRESsisstillchallenging duetotheirweather dependency,highstabilityandreliablepowerdemandandgridrequirements. The advancementinpowerelectronicsprovidesflexibility incontrol,whereasincreasing penetrationofRESsbringsissuesinagrid.Similarly,increasing islanded(off-grid) applicationsofRESsespeciallywitharapidlygrowing DCsystemrealizeschallengesin power management.TheRESs arestill costly incomparisontoconventionalenergysources,suchasgas,anddiesel.Therefore, theRESsdemandthecosteffectivesystemstructureandcontrolstrategy toreducethe overallcost.

**PROPOSED SYSTEM**

A typical configuration of PV-battery system is illustrated in figure 1.2 which is a hybrid micro grid system consisting of a PV array that contains a number of PV panels, battery bank for power storage, and a centralized bidirectional inverter that interfaces the DC to AC power system.

A unidirectional DC/DC converter is installed to control the power of PV arrays, while the battery bank is charged/discharged by controlling a bidirectional converter that bridges the battery and the DC bus. DC loads are supplied through direct connection to the DC bus and AC loads and the point of common coupling (PCC) is located on the AC side. Before connecting to the utility grid, a transformer is employed to step up the AC voltage to that of the grid.

The PV-battery system can be working in either grid-connected or islanded modes. Since PV output power and load demand may change constantly during a day, the power management algorithms for PV-battery system are required to manage the power flow between power productions and consumptions. Furthermore, both DC bus and AC bus voltages must be stabilized regardless of changes in the system to ensure a reliable power supply.

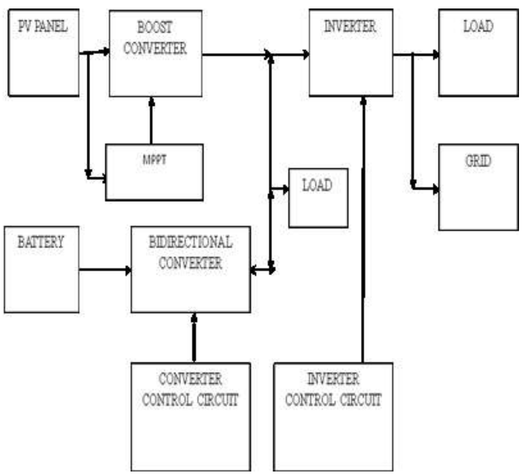


**Fig 1Overall Block Diagram**

**1.3 THE BENEFITSOFSOLAR ELECTRICITY**

i. Cutyourelectricitybills:sunlightisfree,so onceyou'vepaidfortheinitialinstallationyour electricitycostswillbe reduced.
ii. Getpaidfortheelectricityyougenerate:the government’sFeed-InTariffspayyouforthe electricity

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yougenerate,even ifyou useit.

iii. Sellelectricitybacktothegrid:ifyoursystemisproducing moreelectricity thanyouneed,or whenyou can't useit,you can sell thesurplus back to thegrid.

iv. Cutyourcarbonfootprint:solarelectricityisgreen,renewableenergyanddoesn'trelease any harmfulcarbondioxide orotherpollutants.AtypicalhomesolarPV systemcouldsave over atone of carbondioxide peryear– that's morethan 30 tones over its lifetime.

## SYSTEM DESIGN

A power management strategy for a PV-battery unit is discussed in based on droop control for load sharing between the PV-battery unit and another power source. An improved version, which considers multiple power units, has been presented in this project. Although these strategies successfully manage the power demand and production, both of them mainly focus on the power management between the PV-battery unit and other generation units. Additionally, these methods do not consider systems with DC bus and loads.A hierarchical control algorithm for a PV-battery-grid system regulates the AC bus voltage and manages the active and reactive power by the PV-battery unit. A decentralized method for islanded PV-battery systems is presented in some references. This method aims at solving load sharing in system configurations with multiple PV and battery units based on 24-hour forecasted data for a grid-connected PV-battery system. The topology of the proposed system, where PV and battery bank are interfaced with the grid using decentralized inverters, is different from the system existing configuration.

## PROPOSED POWER MANAGEMENT SYSTEM

A typical PV-battery system with the proposed power management system (PMS)is shown in figure 4.1. In this topology, the PV array is interfaced with the DC bus by a DC/DC boost converter while the battery bank uses a bidirectional DC/DC converter to control the charging and discharging processes. A centralized inverter is installed to interconnect the DC and AC networks. DC load block generally represents the loads that are connecting at the DC bus, which can be multiple types of loads such as electric vehicles or office buildings. There are also AC loads consuming power at the AC bus.

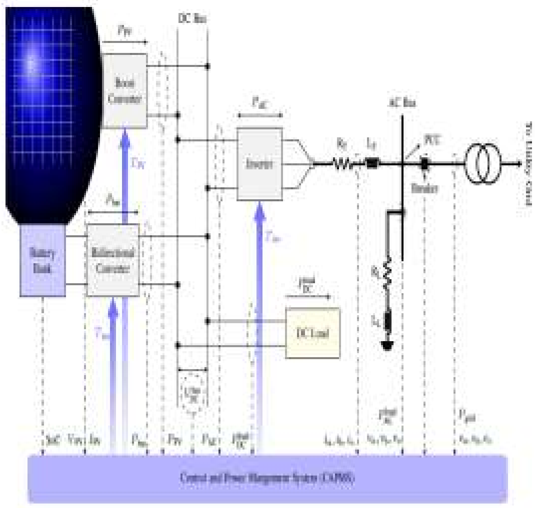


**Fig. 2 Circuit diagram of the proposed topology**

Therefore, power flows in the hybrid microgrid are always balanced. With well-balanced power and regulated voltages, PMS ensures an uninterrupted power on both DC and AC buses and allows loads to plug and play in the PV-battery system, regardless of disturbances from switching operating modes. Additionally, since the DC bus voltage is controlled, as long as voltage level matches, DC loads will be able to connect to the DC bus without additional converters. When necessary, the PV-battery system can also provide reactive power to the grid.

### Boost Converter

This is a converter whose output voltage is larger than the input voltage and output current is smaller than the input current.

- When the switch S1 is ON: Diode (S2)is reversed biased. Output circuit is thus isolated, inductor is charged.
- When the switch S1 is OFF: The output stage received energy from the inductor as well as from the input. Filter capacitor is very large to ensure constant output voltage as in fig.4.2.

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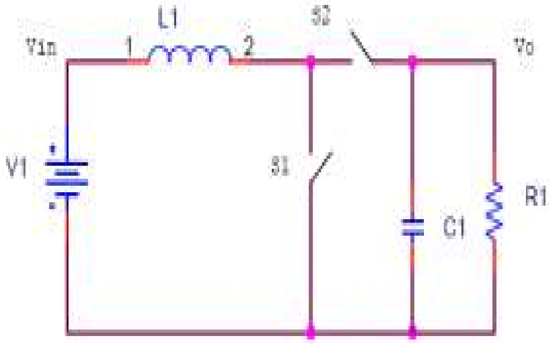


**Fig. 3 Boost converter**

**MPPT**

The PV array converts solar energy into DC power, and is connected to the DC bus via a boost DC/DC converter. However, due to nonlinear characteristics of PV panels and the stochastic fluctuations of solar irradiance, there is always a maximum power point (MPP) for every specific operating situation of a PV array. Therefore, maximum power point tracking (MPPT) algorithms are typically implemented in PV system to extract the maximum power a PV array can provide. The proposed PMS employs one of the most popular methods, which provides a reference voltage V that the PV array will track to produce the maximum power under various operation conditions (different combinations of irradiance and temperature). There are three possible control schemes for the PV array, MPPT control, power-reference control, and DC bus voltage control, depending on the situation of the PV-battery system. For example, in islanded mode, when PV is greater than the total load demand (DC and AC), and the battery is fully charged or the charging rate P reaches its upper limit, the PMS will generate control commands to set the PV array to work the DC/DC converter accordingly. In this case, to balance the power flows, PMS will decide proper power references for the PV array.

**Bidirectional converter**

The below Figure 4.3 shows the boost mode operation. As shown in the figure, boost mode operation is affected by the $S_2$. Switch$S_1$ should be always turned on at this mode, and $S_3$ should be complementarily operated FM $S_2$.The voltage gain of the boost mode is obtained by the following equations.

$$D_{boost} = 1 - \frac{V_{bat}}{V_{dc}} = 1 - \frac{I_{dc}}{I_{bat}} \quad (V_{dc} > V_{bat})$$

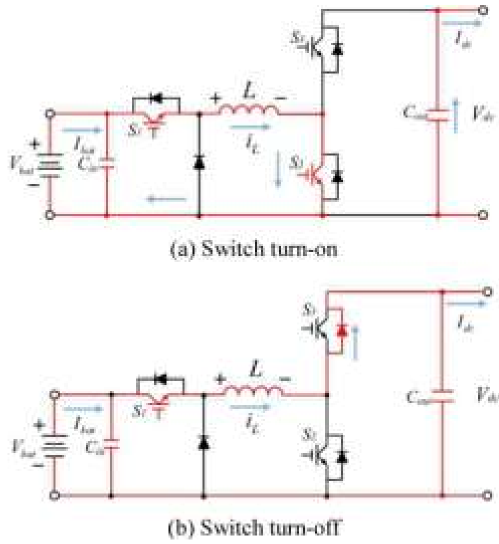


Fig. 4 Bidirectional converter- Boost mode

The below Figure 4.4 shows the buck-mode operation of the bidirectional DC-DC converter. Switch $S_1$ is turned on and off for the general operation of the buck converter topology. In this mode, $S_3$ is always turned on and $S_2$ is always turned off. The voltage gain of buck-mode is described as follows according to the duty of $S_1$

$$D_{buck} = \frac{V_{dc}}{V_{bat}} = \frac{I_{bat}}{I_{dc}} \quad (V_{dc} < V_{bat})$$

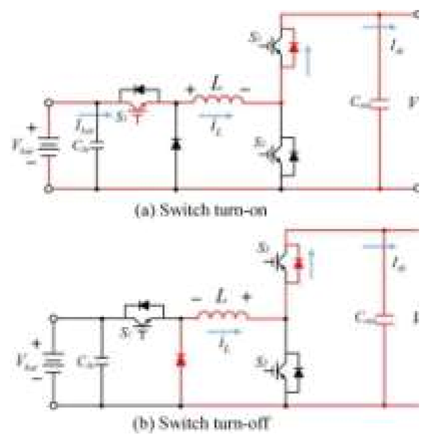


**Fig. 5 Bidirectional converter- Buck mode**

**Three phase inverter**

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A three-phase inverter is used to convert DC to AC power, interfacing the DC and AC sides. Similar to the converters discussed above, the control scheme of inverter depends on the operating (grid-connected or islanded) mode of the system as illustrated in Fig. 4.5. Depending on the operating mode, the controller selects different sets of variables to be controlled. Three phase inverters are normally used for high power applications. The advantages of a three phase inverter are:

- The frequency of the output voltage waveform depends on the switching rate of the switches and hence can be varied over a wide range.
- The ac output voltage can be controlled by varying the dc link voltage.

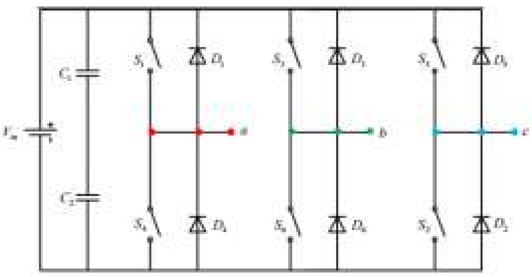


**Fig. 6 a Three Phase inverter**

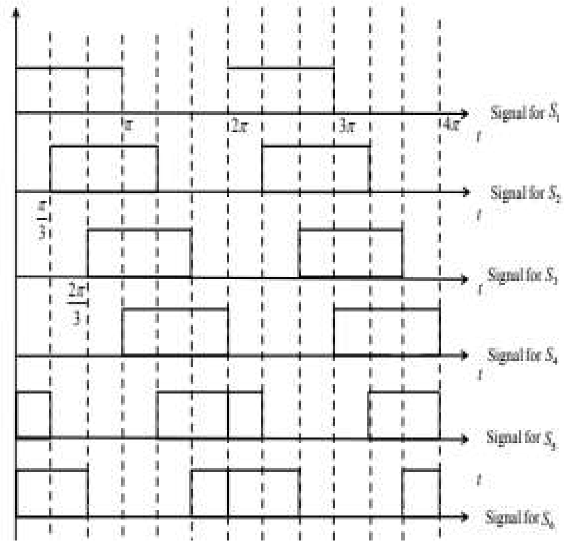
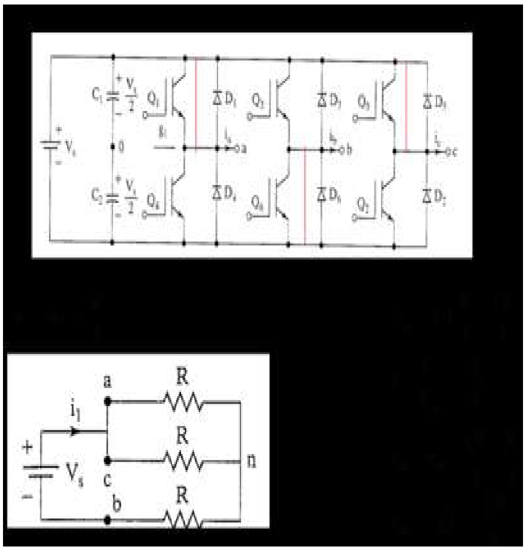
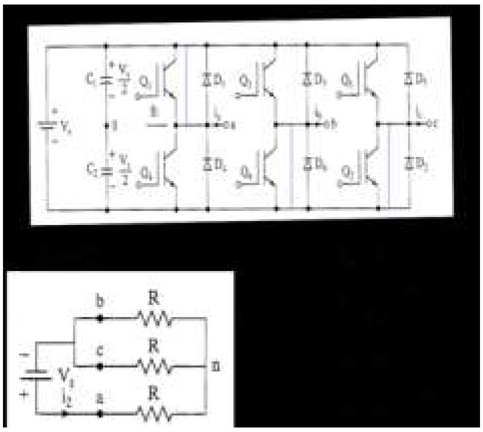
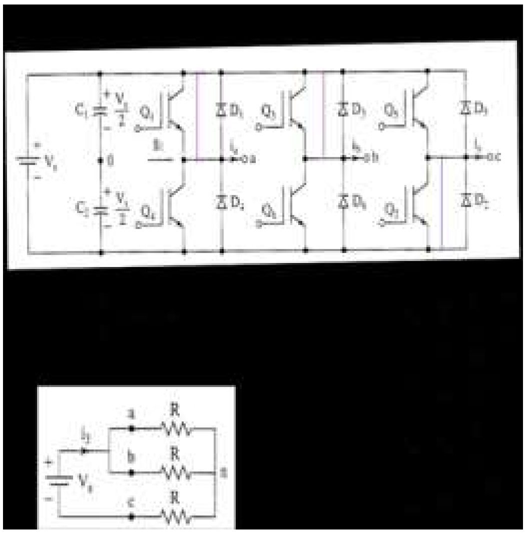



**Fig. 6 b Switching sequence**

The Fig. 4.5 (a) and (b) depicts the basic configuration and switching sequences for the below modes of operation i.e., mode 1, mode 2 and mode 3.







**Filters**

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Since we know the order of characteristic harmonics, it can be eliminated using passive tuned filters, whereas for elimination of non-characteristic type, we need LC type filtering scheme.

## SIMULATION

### SIMULINK

When a new inverter circuit is developed or a control strategy of a inverter, it is often convenient to study the system performance by simulation before building the breadboard or prototype. Fortunately larger number of user friendly digital programs is available for the study of power electronics system. Example SIMULINK, PSPICE, EMTP etc, out of this SIMULINK is user friendly and most suitable for power electronics and drives.The single phase boost inverter has been simulated using MATLAB/SIMULINK 2014a. MATLAB is a software package for high performance numerical computation and visualization. It provides an interactive environment with hundreds of built in functions for technical computation, graphics and animation.

MATLAB stands for MatrixLaboratory. MATLAB built-in functions provide excellent tools for linear algebra computations, data analysis, signal processing, optimization, and numerical simulation of ordinary differential equations, quadrature, and many other types of scientific computations. Most of these functions use state of the art algorithm. It is very easy to learn and use.

### SIMULATION DIAGRAM

### Existing Topology Simulation

The existing single phase PV hybrid management system simulation diagram is shown in the figure 5.1 consists of PV-Battery based power supply generations, PWM based controller circuits and load. The output of the circuit is taken across the single phase load.

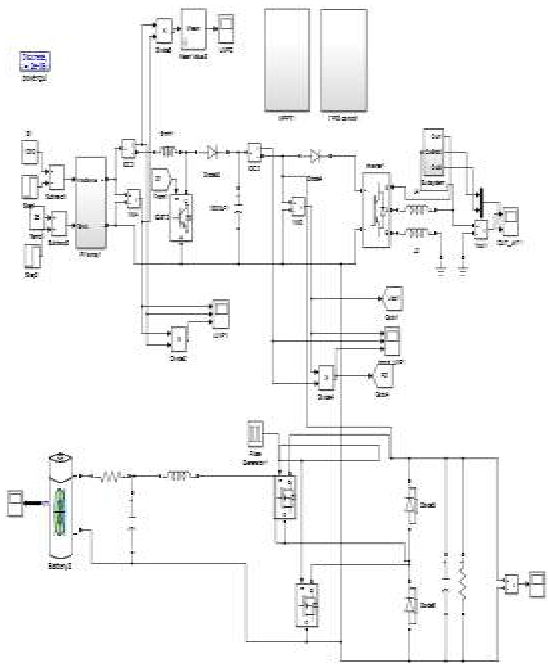

**Fig. 8 Existing System Simulation diagram**

In this circuit the Power handled in the microgrid is not reliable and efficient one. So we are in need of three phase systems with MPPT controller circuit as in the proposed system simulation diagram.

### Proposed Topology Simulation

The Proposed Three phase PV hybrid management system simulation diagram is shown in the figure 5.2 consists of PV-Battery based power supply generations, PWM based controller circuits and load. The output of the circuit is taken across the three phaseload.

In this circuit the simulation results are taken from the input side and output side for the verification of the circuit

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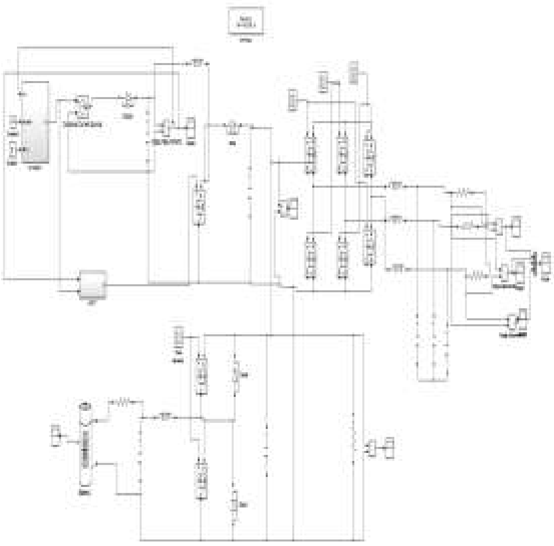

**Fig. 9 Proposed Simulation circuit**

The simulation parameters used in the circuit are mention in the simulation figure 5.2 as shown PV voltage, Battery voltage, Converter Voltage, Dc link voltage and AC Output voltage.

**SIMULATION OUTPUT**

The Simulation outputs in the input sides are obtained and is shown in the figure 5.3(a) to 5.3(e), similarly the output voltage at the inverter side is shown in the figure 5.4 for the verification of the proposed topology.

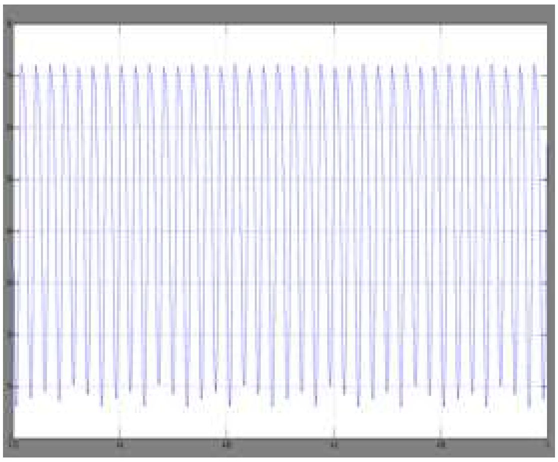

**Fig. 10 (a)PV Panel Input**

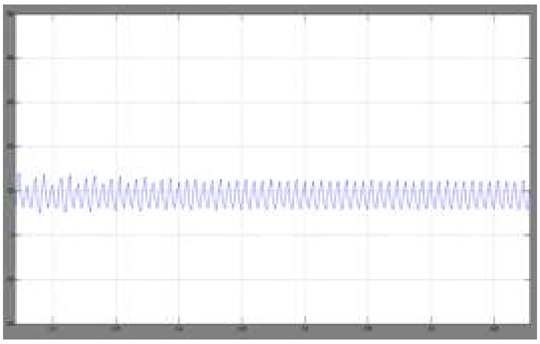

**Fig. 10 (b) Boosted DC voltage**

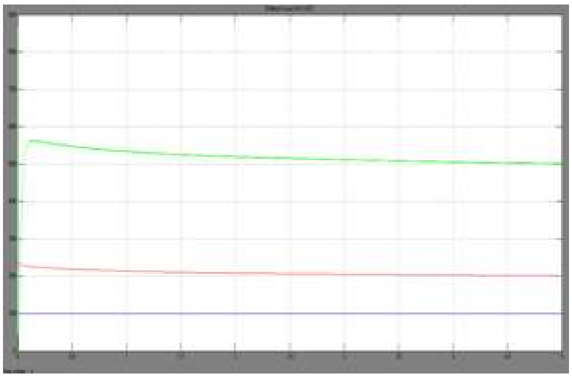

**Fig. 10 (c) Battery Input Voltage**

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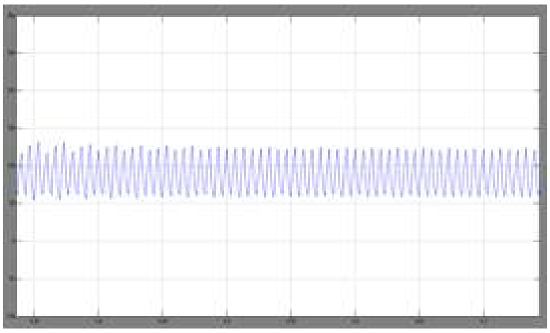


**Fig. 10 (d) Bi directional converter output voltage**

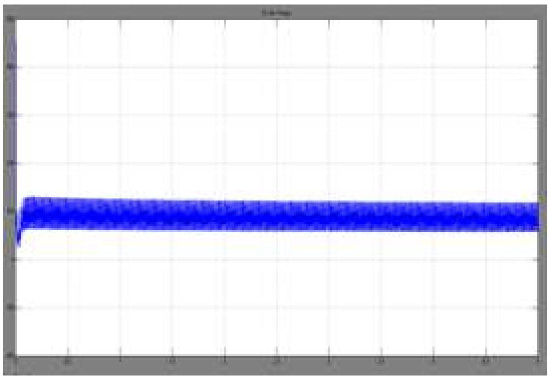


**Fig. 10 (e) DC link voltage**

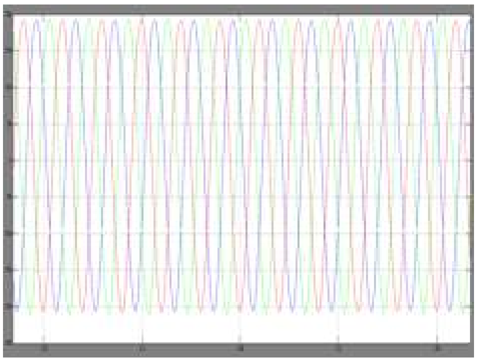
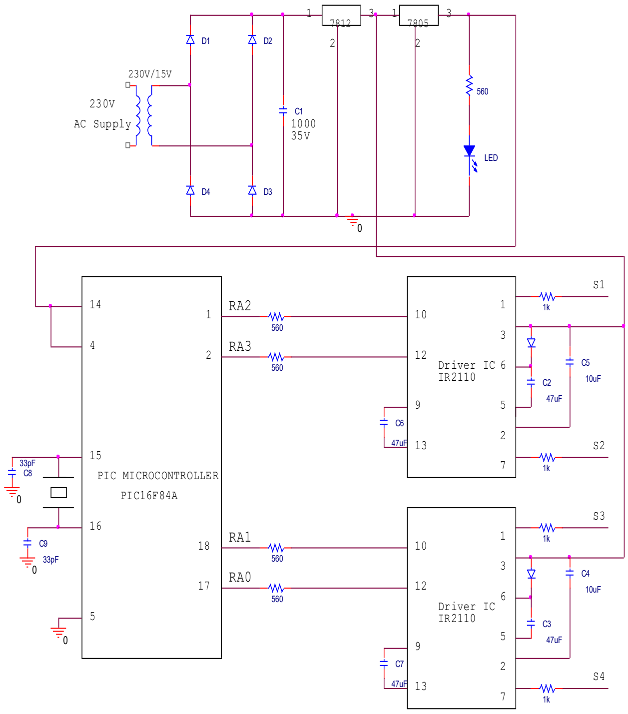


**Fig. 10(f) AC Output Voltage**

Thus from the above output waveform of it is clear that the proposed topology is able to supply power to the load when the islanded mode exists with the help of the controller circuit and is proved through the MATLAB simulation software

**HARDWARE OUTPUT**

Thus the power management system was simulated and the hardware was implemented for the solar based power generation with bidirectional power management proposed system and the results are shown in figure 6.9, 6.10, 6.11, 6.12, 6.13and 6.14




respectively for the verification of the concept.

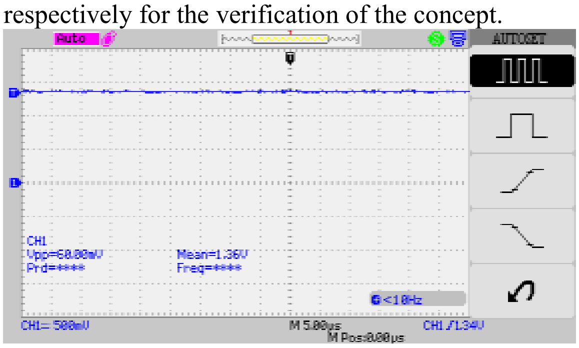



**Fig 12DC Input voltage (from solar panel 7VDC)**

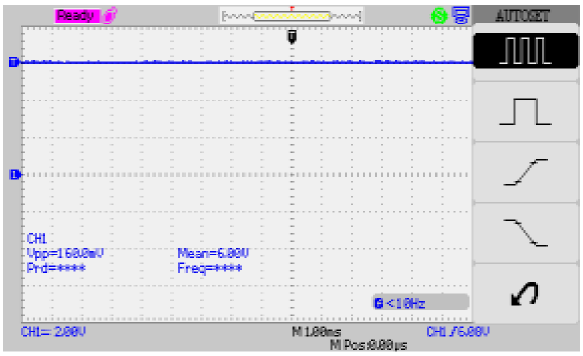



**Fig 13DC Output voltage (after dc-dc converter with MPPT-27V DC)**

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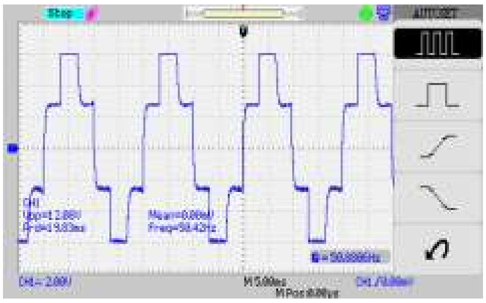


**Fig 14Inverter Output voltage-19VAC(Line-RMS)**

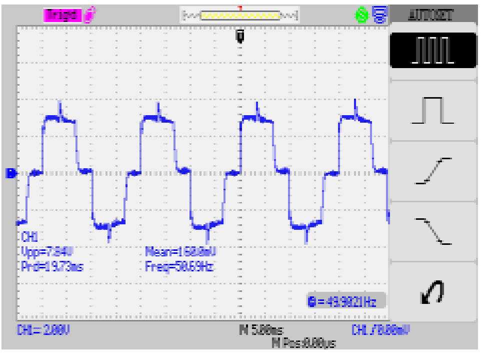


**Fig 15Inverter Output voltage-9VAC(phase-RMS)**

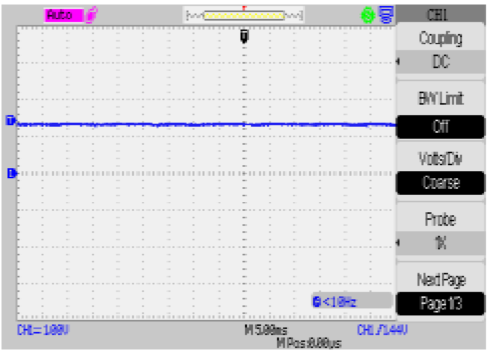


**Fig 16 Battery voltage (Biderctional)-11VDC**

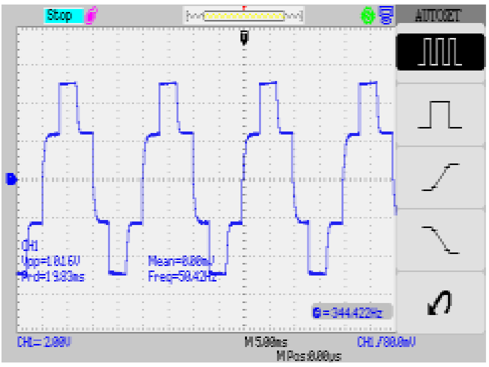


**Fig 17 AC output voltage – 5V AC**

## CONCLUSION AND FUTURE WORK

Theproposedconceptofpowermanagementstrategywithoptimumnumberof power electronicdevicesorcomponents canbeemployedinsmallandmediumsized renewablesourcesbasedACmicrogrid. Themotivation istoincreasetherevenueof therenewableenergy sourcesbyreducing thecomponentsfailurerateandthe maintenancetimeandthecosts.

The performance of the proposed concept is verified with hardware implementation validation.

In future the same concept is extended to other types of renewable energy sources with different control techniques.

A-2.1: Overall hardware image

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