B. TECH. PROJECT REPORT

On

Grid integrated PV Based Single Phase Power Generating Unit

BY

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DISCIPLINE OF ELECTRICAL ENGINEERING

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Grid integrated PV Based Single Phase Power Generating Unit

A PROJECT REPORT

Submitted in partial fulfillment of the requirements for the award of the degrees

of
BACHELOR OF TECHNOLOGY
in

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DEC 2016

CANDIDATE'S DECLARATION

We hereby declare that the project entitled **"Grid integrated PV Based Single Phase Power Generating Unit "** submitted in partial fulfillment for the award of the degree of Bachelor of Technology in 'Electrical Engineering' completed under the supervision of **Dr. Amod C. Umarikar, Associate Professor , Electrical Engineering ,**IIT Indore and **Dr. Dipankar Debnath , Assistant Professor , Electrical Engineering** , IIT Indore is an authentic work.

Further, we declare that we have not submitted this work for the award of any other degree elsewhere.

Signature and name of the students with date

CERTIFICATE by BTP Guide(s)

It is certified that the above statement made by the students is correct to the best of my/our knowledge.

Signature of BTP Guide(s) with dates and their designation

Preface

This report on “Grid integrated PV Based Single Phase Power Generating Unit ” is prepared under the guidance of Dr. Amod C. Umarikar and Dr. Dipankar Debnath.

Through this report we have tried to give a detailed design of a power electronic interface capable of integrating PV with Grid power supply and try to cover every aspect of the new design, so as to make usage of Solar energy more widespread and economic .

We have tried to the best of our abilities and knowledge to explain the content in a lucid manner. We have also added graphs and pictures of Hardware prototype to make it more illustrative.

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I would also want to use this opportunity to thank Mr. Raghvendra Hanswal ,Deputy Manager , Electrical Lab , IIT Indore for giving us valuable insights from time to time with operation of lab equipments and giving us moral support for the duration of the project .

Last but not the least , We would like to thank our parents for their unwavering support and encouragement .

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Abstract

Aim of this project is to implement a reliable, efficient Grid integrated PV Based Single Phase Power Generating Unit for Urban Household Application with a battery as an energy storage element . In this project a power electronic interface has been proposed capable of extracting maximum possible power from Solar Panel , supplement the need or feed excess power to Grid power supply , store energy in battery for emergency need and feed normal household loads .

To design such scheme three major steps are carried out: first, a standalone scheme which can feed the household loads in absence of grid power supply is developed. In second step, a grid integrated scheme is developed which doesn't make use of batteries . These two schemes are combined together in third step to make the final product.

Control schemes have been proposed for both the topologies for controlling output voltage, inverter dc link voltage, MPPT of PV and battery charging/discharging current , unity power factor operation of grid . Both the schemes have been validated by performing detailed simulation studies. A laboratory prototype has been built to validate the control scheme performed in simulation studies. The control scheme and hardware operation has been performed using a TMS320F28377S DSP .

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Chapter1

Introduction

It is a well known fact that energy supplied by sun in form of light is far higher than our today's total energy need . Also we have technology to harness solar energy but still its use is not so widespread and economic . A user having access to grid power supply doesn't even think of using solar energy because grid power supply is relatively cheap and has less maintenance cost . Due to lack of consumer oriented products solar energy's potential is still unexplored .

1.1 Requirement of PV system

PV systems meant for acting as a power supply require an auxiliary power source in form of battery, super capacitor, fuel cell or maybe grid, if possible. Output power of PV modules vary widely with changes in solar irradiation and temperature. PV systems meant for small or low power applications generally exhibit relatively high power capacity at high level of irradiation and very low power capacity at low level of irradiation. So an economic designing of a PV based power generation system require an energy storage element in the form of battery . Normal Household applications generally involve ac power driven appliances while output power of PV or battery is dc in nature. Hence, there is a need for efficient and reliable electrical power conversion system . For designing a PV system with battery requires an effective battery charging and discharging control so as not to affect battery life and health. Battery life and health deteriorates if unregulated current is drawn from or supplied to the battery. For integrating a PV system with grid we need to ensure unity power factor operation of grid .

1.2 Proposed scheme

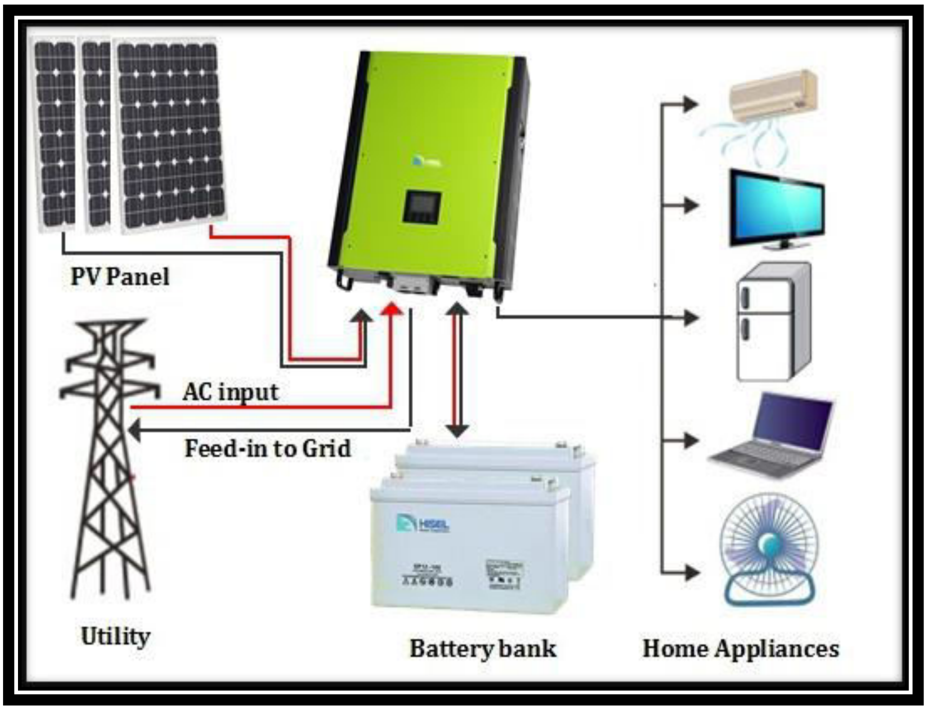


Figure 1.1 General Block Diagram of Proposed Product

Existing schemes solely depend on battery bank in absence or deficit of solar energy , thus requiring a large battery bank . Large battery Bank comes with high maintenance cost and space requirement . Proposed topology also uses grid power supply in absence or deficit of solar energy , thus requiring a much small battery bank resulting in much less maintenance cost and space requirement .

The scope of the project work tries to overcome these drawbacks by proposing a power electronic interface capable of extracting maximum possible power from Solar Panel , supplement the need or feed excess power to Grid power supply , store energy in battery for emergency need and feed normal household loads . As this reduces grid power usage, thus it cuts down the electricity bill which serves as motivation to user to use solar energy .

Chapter 2

Proposed Scheme configuration

As stated in previous chapter , complete problem is segregated in two parts . Combining both these schemes will result into final product .

2.1 Standalone Scheme

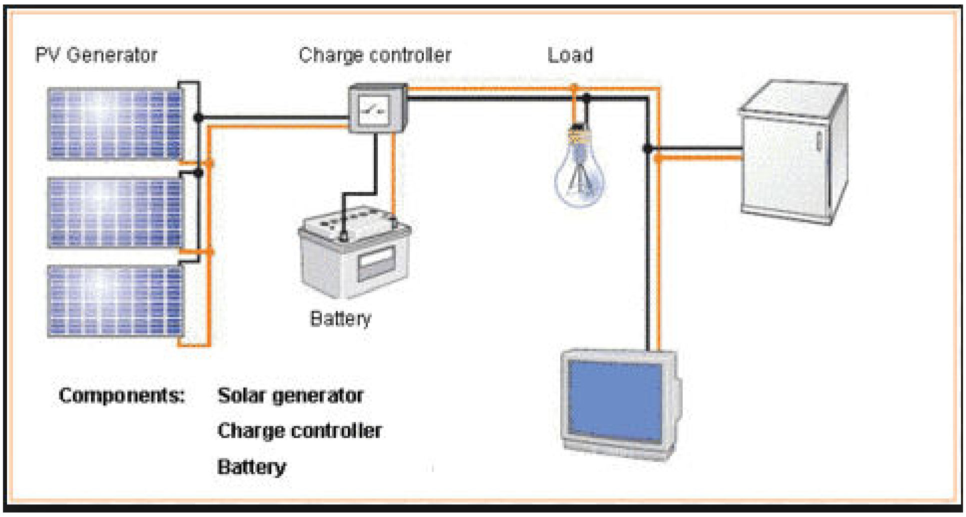


Fig. 2.1 Block diagram for Standalone Scheme

As clearly seen in picture , maximum possible power is extracted from solar panels , stored in battery for emergency need and fed to normal household loads . This scheme has solar panel as energy source and battery as energy storage element . It is an ideal product for user having no access to grid power supply (in remote areas) .Only drawback associated with this topology , is its sole dependence on Battery bank in absence or deficit of solar energy . This may not be a problem for users having no access to grid power supply but for other users it is the main problem due to which they don’t prefer to use solar energy .

Proposed Topology for this scheme is as shown below :

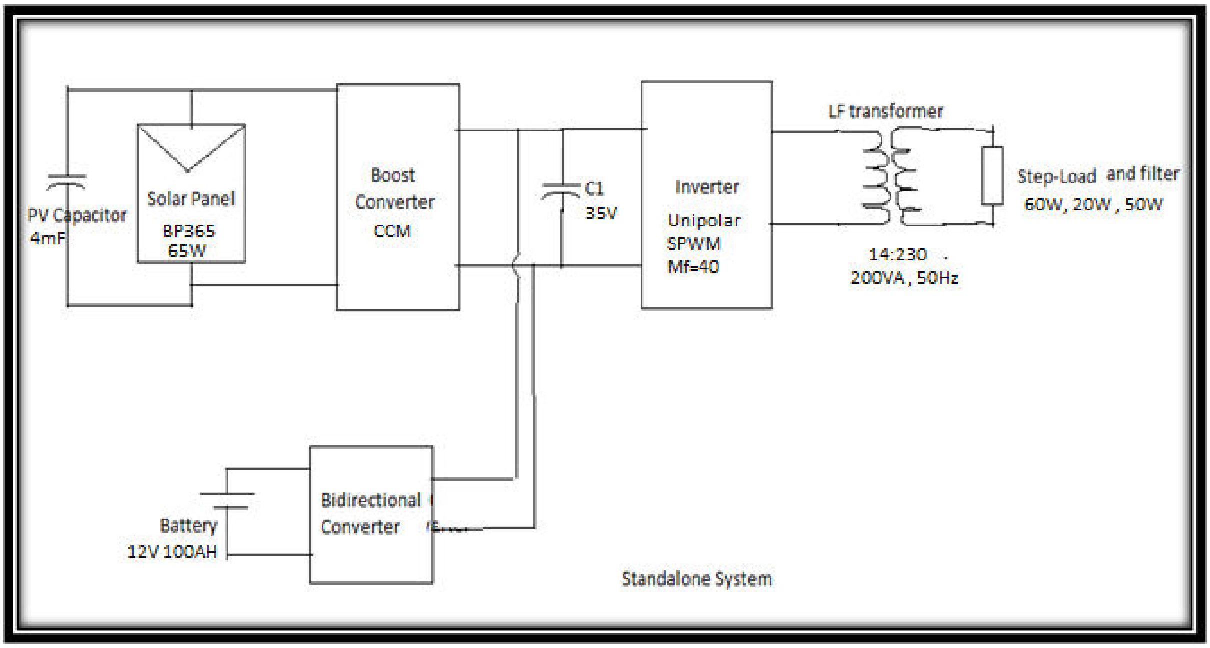


Fig. 2.2 Proposed Topology for Standalone scheme

As shown in figure , Work done under this scheme proposes a converter configuration using a boost converter to perform MPPT and control DC link voltage along with a bidirectional buck-boost dc-dc converter for the Battery charging / discharging and a single phase VSI followed by low frequency transformer for connecting to ac loads.

Subunits	**Specification**
Solar Panel	BP365(Vmp=17.6V , Pmp=65W)
PV Capacitor	4mF
DC-DC Converter	Boost Converter (CCM Vout=35V)
Inverter	SPWM Unipolar
LF Transformer	14V->230V 100VA 50Hz
Load	Step Load (60W , 20W , 55W)
Battery	12V

Table 2.1 Standalone scheme system specifications

2.1.1 Major functions to be performed by the above topology are as follows :

- Maximum power extraction from Solar panel (if can be used) .
- DC-AC Conversion with desired voltage level at output for connecting normal household loads .
- Proper Charging and discharging of battery to ensure its life and health .
- Adjusting in accordance with Atmospheric conditions and loading conditions .

2.1.2 Various subunits are separately described below :

a) DC – DC Boost converter

A boost converter (step-up converter) is a DC-to-DC power converter that steps up voltage (while stepping down current) from its input (supply) to its output (load). It is a class of switched-mode power supply (SMPS) containing at least two semiconductors (a diode and a transistor) and at least one energy storage element, a capacitor, inductor, or the two in combination.

In this topology it is used to connect Solar panel to DC link . Major roles performed by this converter are MPPT and DC link voltage control , as assigned by the control scheme . As the output voltage of this converter should be load independent thus it requires to be operated in CCM (continuous conduction mode) .

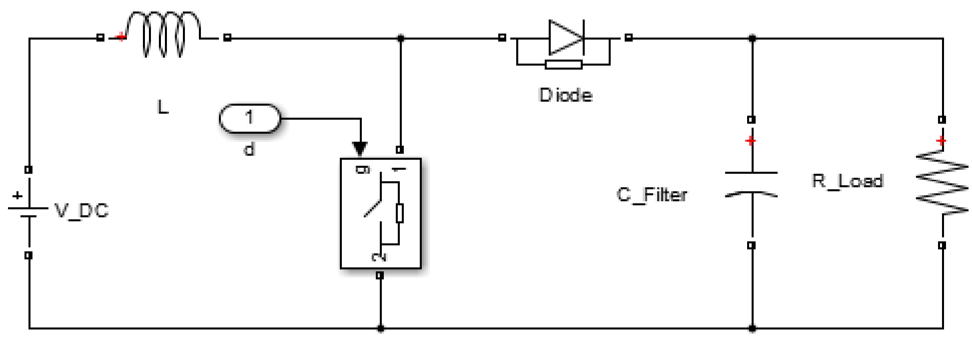


Fig 2.3 Circuit Diagram for boost converter

Input Output relation for Boost Converter in CCM is

$$\frac{V_o}{V_i} = \frac{1}{1-D}$$

Typical waveforms of currents and voltages in a converter operating in CCM mode are as shown :

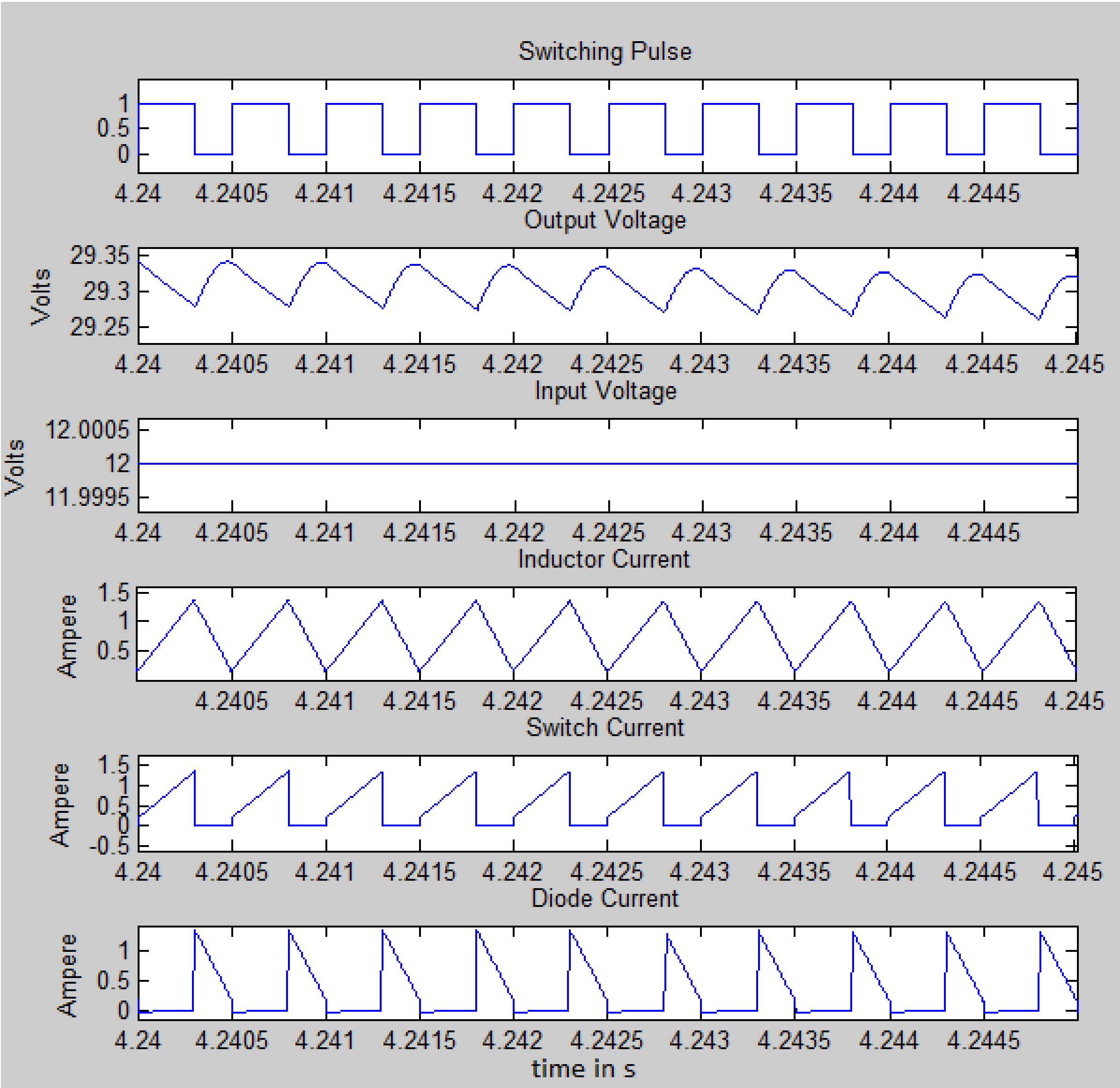


Fig.2.4 Typical Waveforms for Boost converter in CCM

b) DC – DC Bidirectional Converter

Bidirectional DC-DC converters are used in applications where bidirectional power flow may be required (here for battery charging / Discharging) .

It is a class of switched-mode power supply (SMPS) containing at least four semiconductors (two diodes and two transistors) and at least one energy storage element, a capacitor, inductor, or the two in combination. To reduce voltage ripple, filters made of capacitors are normally added to such a converter's output (load-side filter) and input (supply-side filter) .

In proposed Standalone topology it is required for controlling DC link voltage and charging / Discharging of battery . Proper Charging and discharging of battery is required to ensure its life and health .

The Schematic of configuration is shown below

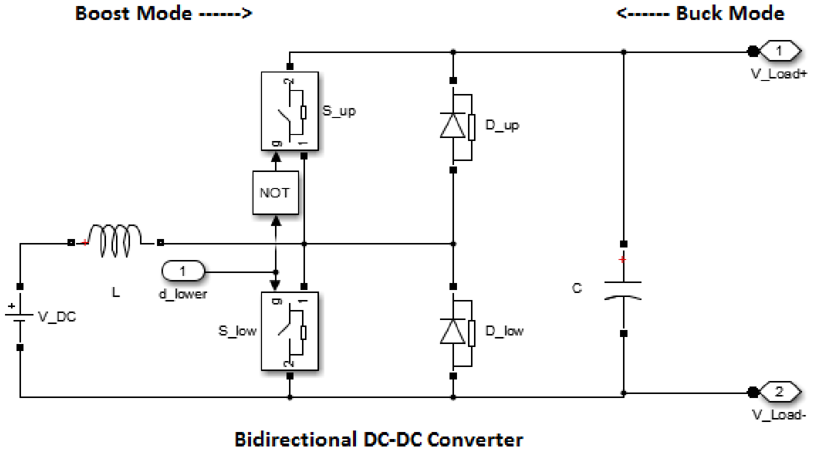


Fig 2.5

Operation of Bidirectional DC-DC converter

As seen in figure , upper and lower transistors are operated in complimentary manner . Relative duty cycle of both the switches decides the direction of net power flow i.e. whether battery will get charged or discharged .

i). Boost Mode

Lower Switch and upper diode constitutes a Boost converter . Closing of lower switch results in power flow from battery to load terminal . Thus it leads to discharging of battery .

ii).Buck Mode

Upper Switch and lower diode constitutes a Buck converter . Closing of upper switch results in power flow from load terminal to battery . Thus it leads to charging of battery .

Now if in a given switching period , if on time of upper switch is higher than on time of lower switch (d_lower<0.5) then battery gets charged .

Typical waveforms for charging of battery are shown below .

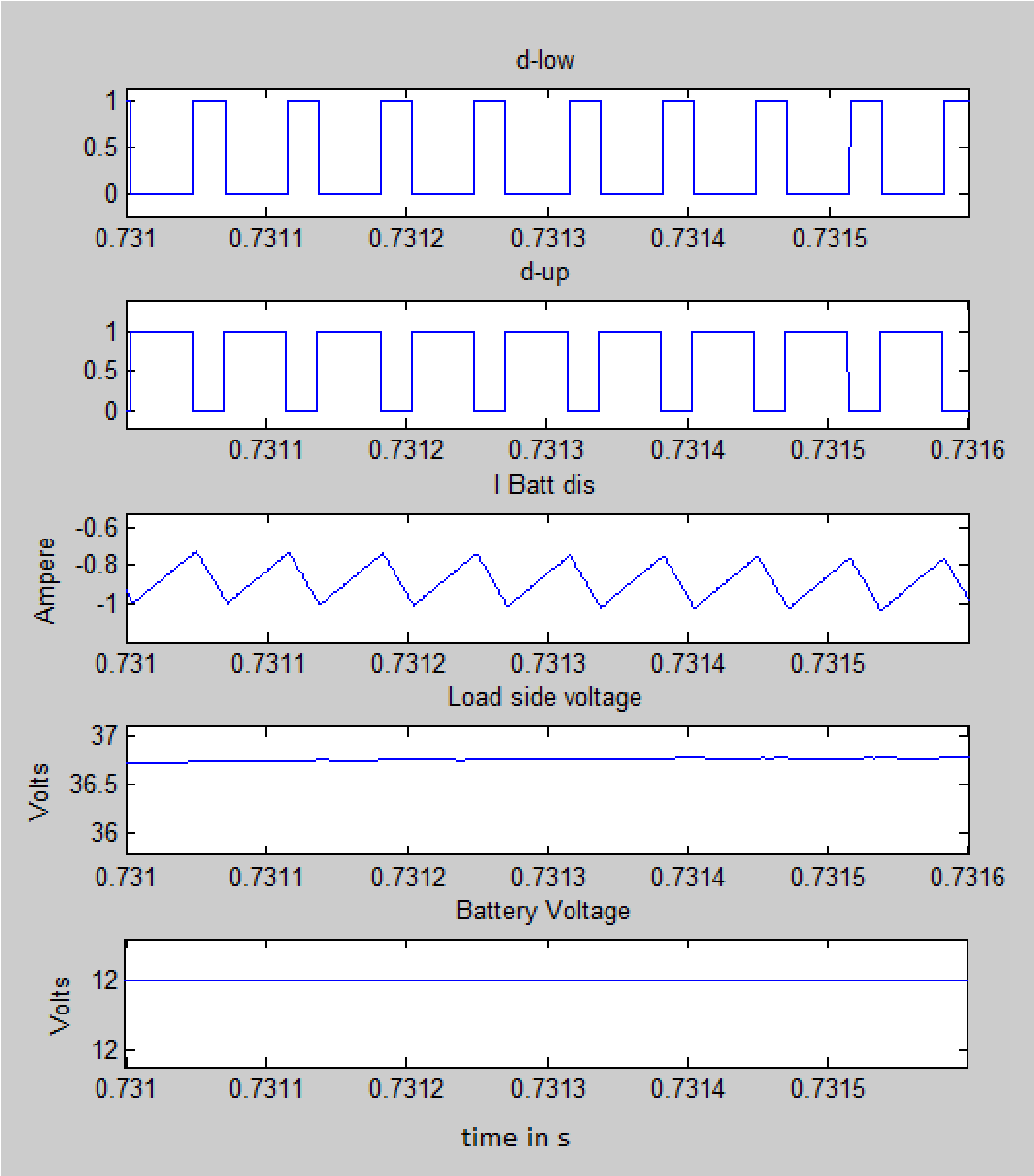


Fig 2.6 Typical Waveforms for Bidirectional DC-DC converter- I

And if in a given switching period , if on time of lower switch is higher than on time of upper switch (d_lower >0.5), then battery gets discharged . Typical waveforms for discharging of battery are shown below .

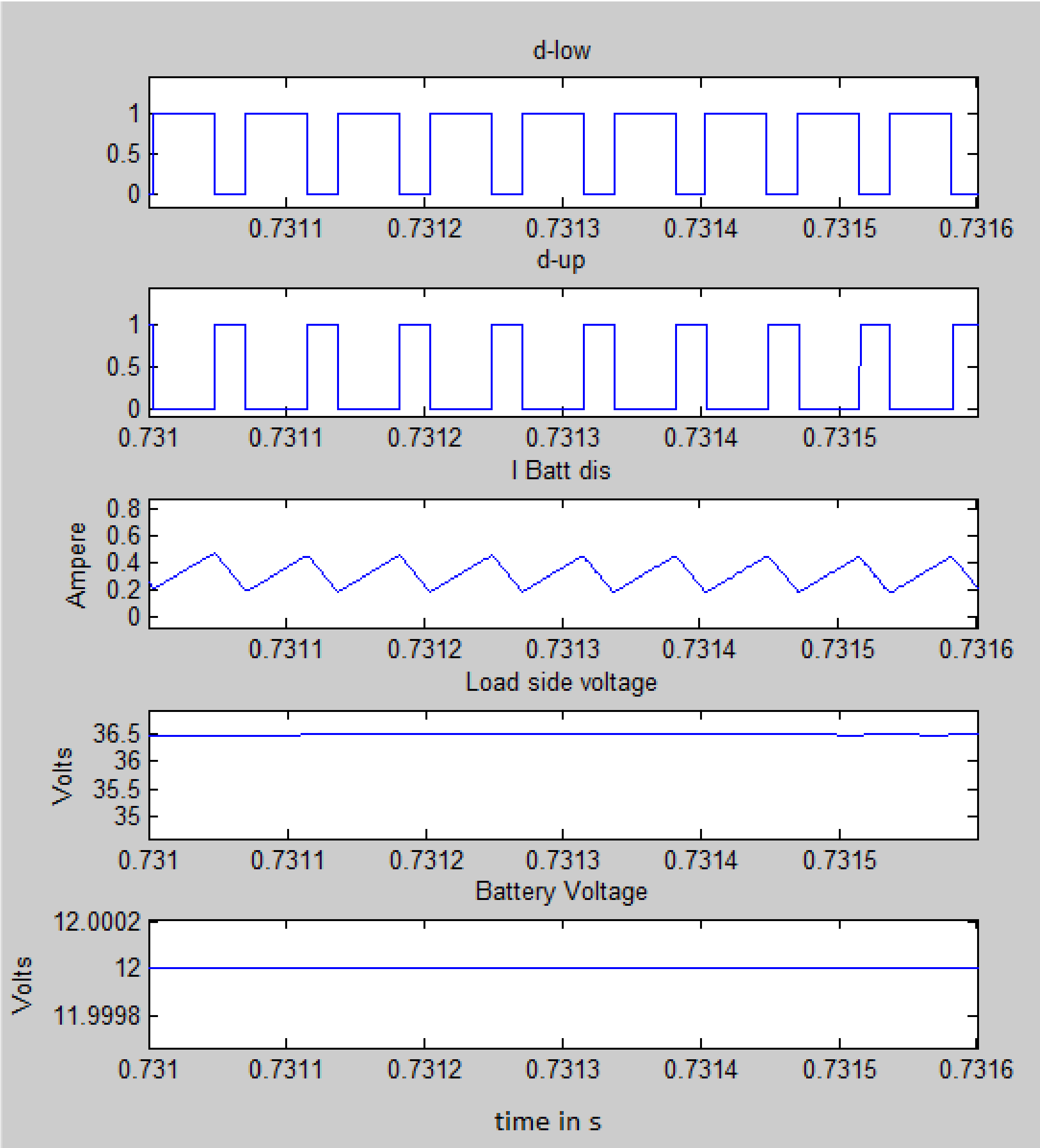


Fig 2.7 Typical Waveforms for Bidirectional DC-DC converter- II

Thus by controlling relative duty cycle of both the switches we can control the direction and amount of net power flow . For overcharging and over discharging control , inductor current is required to be within the desired limits .

c) Inverter

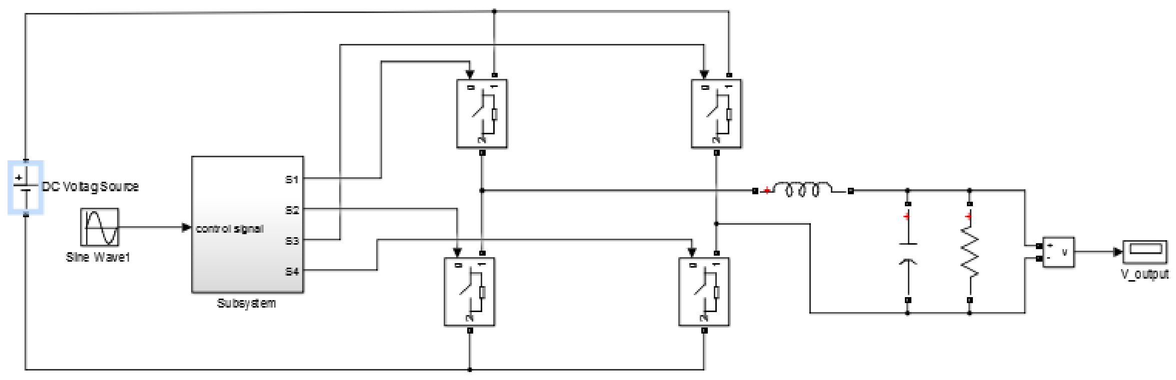


Fig.2.8 Schematic for SPWM unipolar inverter

A power inverter, or inverter, is an electronic device or circuitry that changes direct current (DC) to alternating current (AC). The inverter does not produce any power , the power is provided by the DC source.

As in our topology , power inverter is used to substitute for standard line power, a sine wave output is desirable because normal household loads are engineered to work best with a sine wave AC power source. The standard electric utility power is a sine wave .

So to get the desired DC-AC conversion ,a SPWM (Sine Pulse width modulation) unipolar full bridge inverter is used .

SPWM technique is a PWM technique in which angular pulse width is proportional to the amplitude of the modulating signal .

SPWM technique is chosen over other techniques (square , quasi etc) as it is observed that major harmonic after fundamental comes at carrier frequency whereas in other techniques it comes at third or fifth harmonic of desired signal frequency . So to filter out fundamental at output , the filter requirements are less stringent compared to filtering out the harmonics in a square or quasi square waveform . As the filter is supposed to filter out only the high-frequency carrier , the filter size will be small .

Reasons for choosing unipolar configuration over bipolar configuration :

a) In unipolar Harmonic content next to fundamental comes at twice of carrier frequency whereas in bipolar it comes at carrier frequency . Thus reducing the size of output LC filter .

b) In unipolar inverter output voltage either goes from 0 to Vdc or from 0 to -Vdc . Whereas in bipolar inverter output voltage either goes from -Vdc to +Vdc . Thus Unipolar configuration lays less voltage stress on output terminals .

c) Unipolar configuration has higher efficiency as compared to that of bipolar configuration .

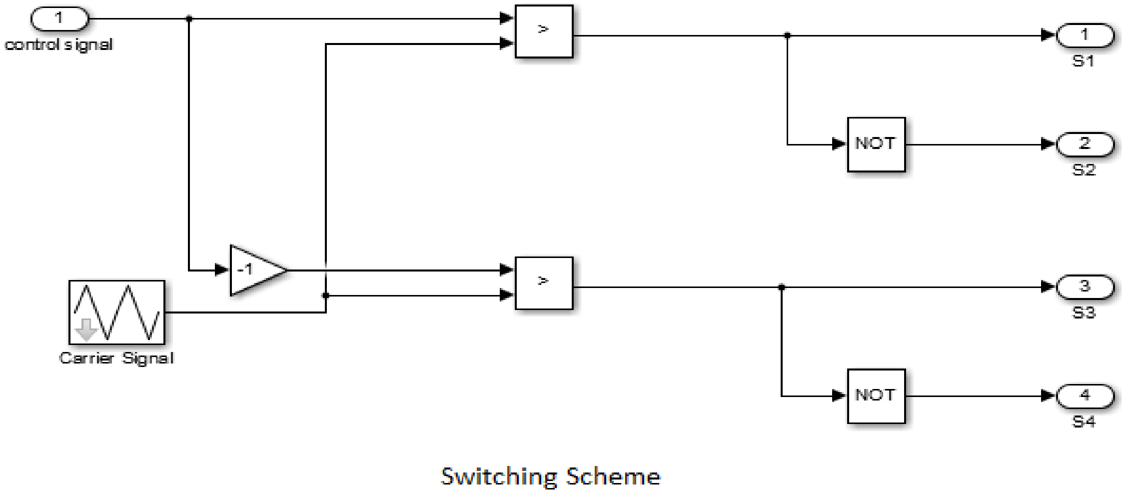


Fig.2.9 Switching scheme for SPWM unipolar inverter

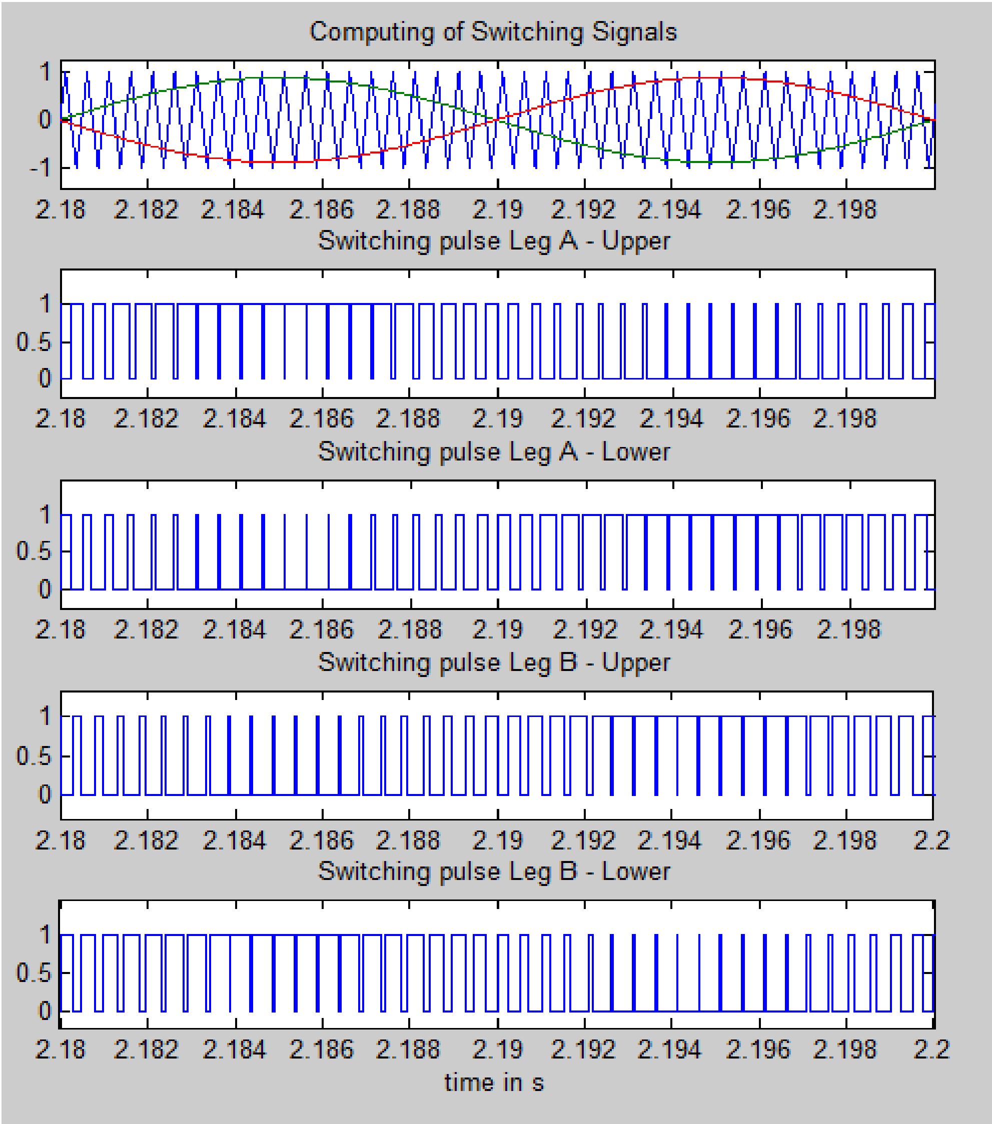


Fig 2.10 Typical waveform for SPWM unipolar inverter switching

Operation of Inverter

To generate sinusoidal AC output voltage , Inverter work as follows :

Modulating signal i.e. signal to be generated at output is generated by the control scheme . This modulating signal is then compared with carrier signal (high frequency ramp signal) to generate switching signals for full bridge converter switches .

Output Voltage generated by Full bridge is fed to LC filter to remove the unwanted harmonics and get a clean sinusoidal waveform .

d) LC filter

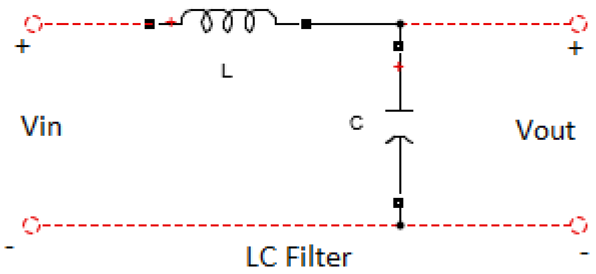


Fig.2.11

Under no loading condition : TF =Vout / Vin= 1 / | (1-LCw^2) |

Product LC is chosen by the gain which we want to provide to the fundmental component . Then L is chosen such that voltage drop across it at rated current is less than 10% of rated output voltage .C can then be calculated from the product LC .

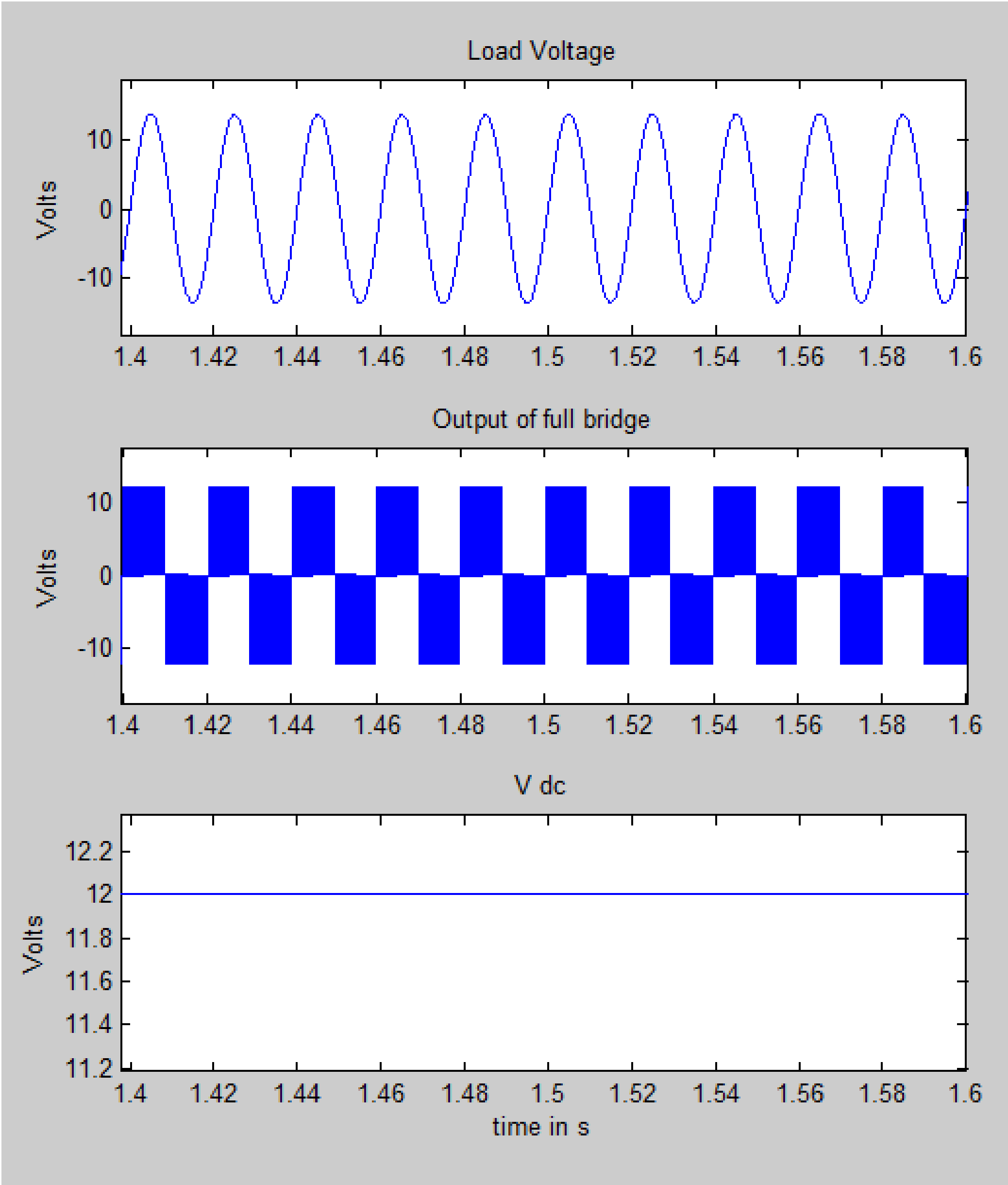


Fig 2.12 Typical waveform for SPWM unipolar inverter input output

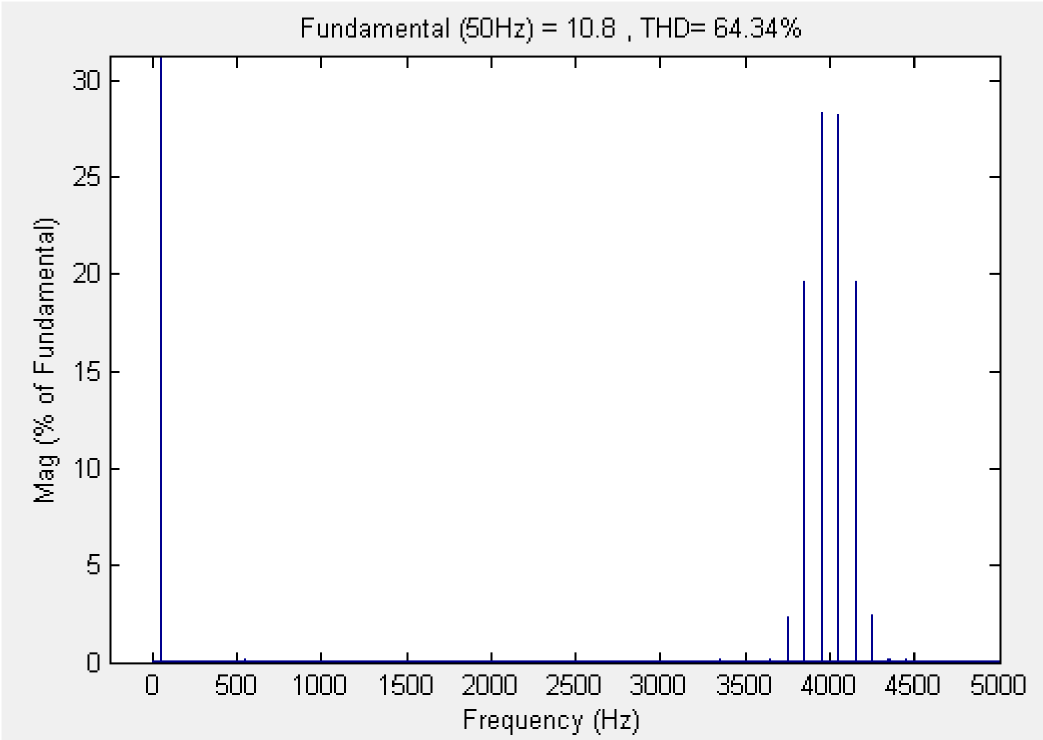


Fig.2.13 Frequency spectrum at output of Full bride SPWM inverter

It can be seen that the major harmonic after fundamental (50Hz) is at twice the carrier frequency (2*2000Hz) .

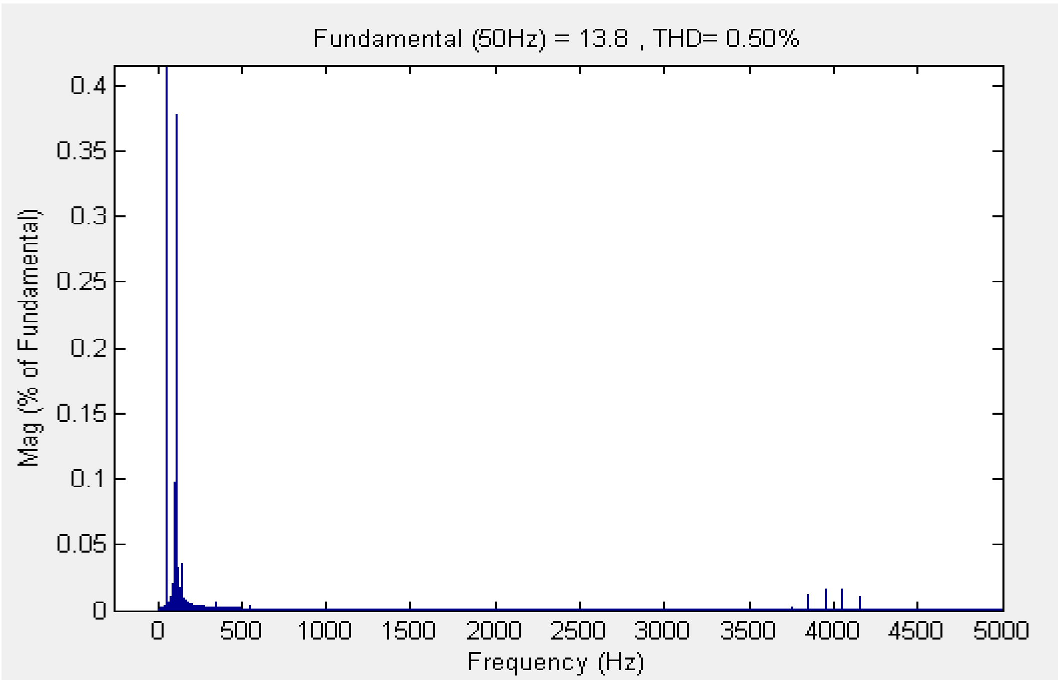


Fig.2.14 Frequency spectrum at output of LC filter

It can be seen Components at twice the carrier frequency are highly attenuated as desired and THD has reduced to 0.5% .

2.1.3Operation of the proposed configuration

The proposed configuration as shown in Fig. 2.2, has three converters (Boost converter , Bidirectional Converter and Inverter)and total 7(1+2+4) control switches .

Boost converter and bidirectional dc-dc converter are used to connect PV panel and Battery respectively to the DC link .This DC link voltage gets converted into AC voltage by the inverter which further gets stepped up by the low frequency transformer so as to get a output voltage similar to grid voltage .

Operation of system in various modes is controlled by the proposed control scheme described in later chapter .

2.2 Grid Connected Scheme

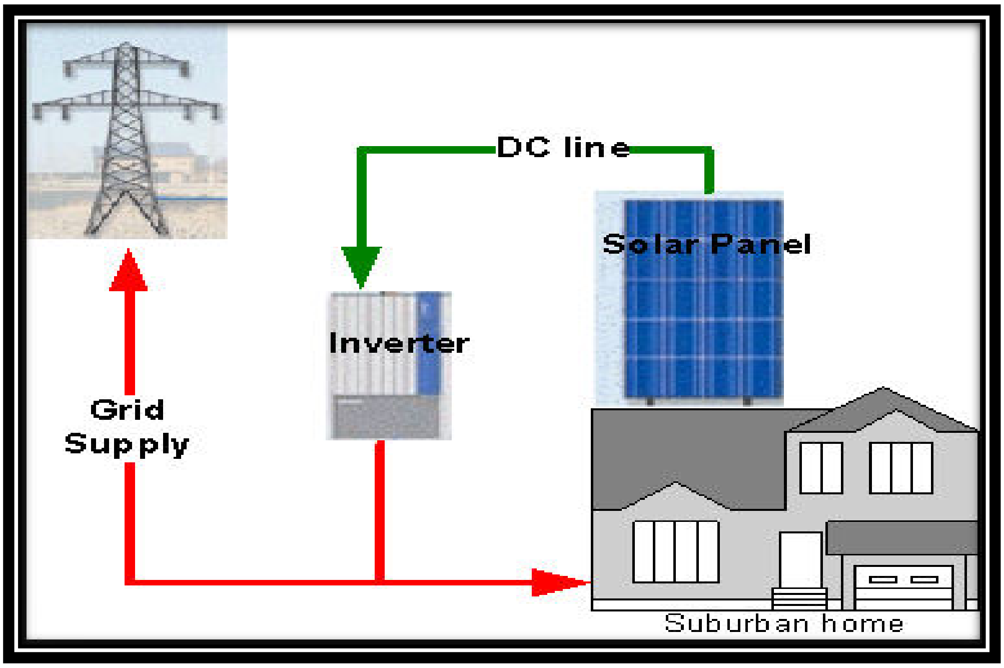


Fig 2.15 Block diagram for Grid connected Scheme

As clearly seen in picture , Grid connected scheme has solar panel and grid as energy source . It extracts maximum possible power from solar panels , feed the load . Now if power generated from PV is greater than required by load , then excess power is fed to grid and if power generated from PV is less than required by load , deficit power is drawn from grid .This reduces the grid power consumption and cuts down the electricity bill .Also it can generate revenue for the user if he supplies more than what he consumed from grid . Proposed scheme does not have any storage element . Thus it reduces the maintenance cost and space requirement significantly . It is an ideal product for user having access to uninterruptible grid power supply .Only drawback associated with this topology , is that it can’t handle the situation of Power cut .

Proposed Topology for this scheme is as shown below :

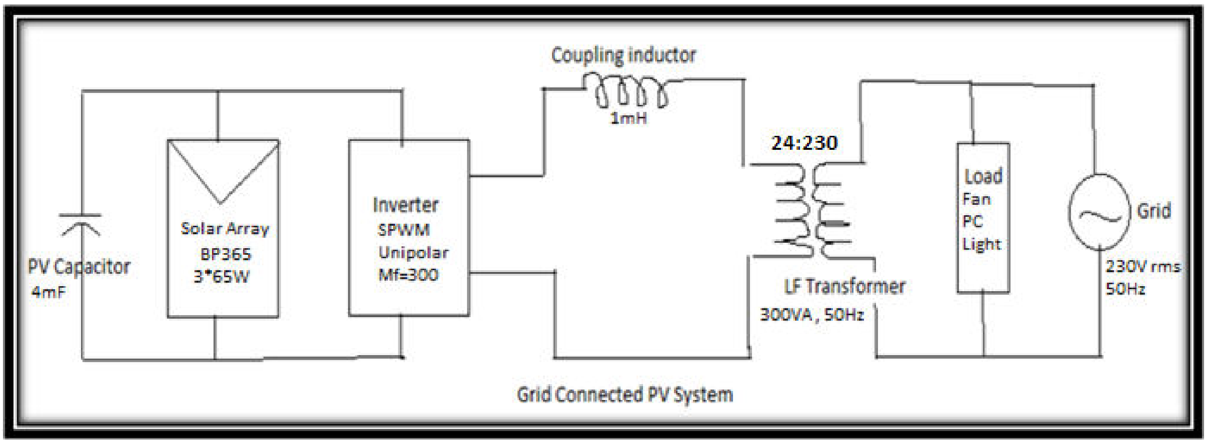


Fig 2.16 Proposed topology for grid connected scheme

In this topology Solar panel is operated to extract maximum possible power from it . DC output of PV gets converted into AC by inverter . This AC output is coupled to the grid by using a coupling inductor and a low frequency transformer .

Subunits	Specifications
Solar Panel	BP365(Vmp=17.6V , Pmp=65W)
PV Capacitor	4mF
Inverter	H-bridgeSPWM Unipolar
LF Transformer	20/230V, 100VA, 50Hz
Load	Step Load (LED , Fan , PC)

Table 2.2 System specifications for Grid connected scheme

2.2.1Major functions to be performed by the above topology are as follows :

- capable of integrating PV with grid power supply
- Maximum power extraction from Solar panel
- Feed the excess power to grid or absorb deficit power from grid at unity power factor thus reducing the grid power consumption .
- Adjusting in accordance with Atmospheric conditions and loading conditions.

The only major concept involved in this topology is of integration of PV with grid i.e. we have to ensure real power transfer to/from grid . For this we have to maintain unity power factor (grid current either in phase or out of phase with grid voltage) operation at grid terminals .

2.2.2 Coupling of AC sources

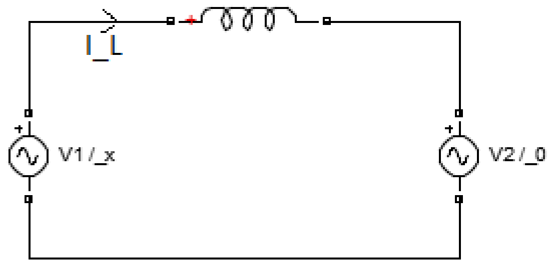


Fig 2.17 Coupling of two AC sources

Applying KVL

$$I\_L = \frac{(V1/\_x - V2/\_0)}{jwL}$$

$$I\_L = \frac{V1(\cos x + j\sin x) - V2}{jwL}$$

For unity power factor operation

$V1 \cos x = V2$

So $\quad I\_L = \frac{V2 \operatorname{Tan} x}{wL}$

In above topology , Solar panel along with inverter act as a AC source and grid power supply as other AC source . These two AC sources are to be coupled so that real power gets transferred to the grid .

By controlling coupling inductor current (magnitude and phase) we can perform MPPT and ensure unity power factor operation at grid . It is described in control scheme chapter .

Chapter 3

Modelling and Sizing of PV Array and Battery

In order to design a PV system it is necessary to design a model of Solar panel which is to be used for simulation purpose . This model should use data available in actual solar panel's datasheet so that it can be purchased at hardware stage . We have chosen BP365 Solar module as it is available in market and has high power capacity at MPP .

At STC (Insolation = 1kW/m^2 , 1.5AM ,Cell temp. = 25C)

Parameters	Values
Voltage at Pmax (Vmp)	17.6V
Current at Pmax (Imp)	3.69A
Short-circuit current (Isc)	3.99A
Open-circuit voltage (Voc)	22.1V

Table 3.1 BP365Datasheet Parameters

Using these data we can make a mathematical model of solar module for simulation purpose .

3.1Mathematical module of PV module :

Electrical circuit equivalent of PV cell is as follows :

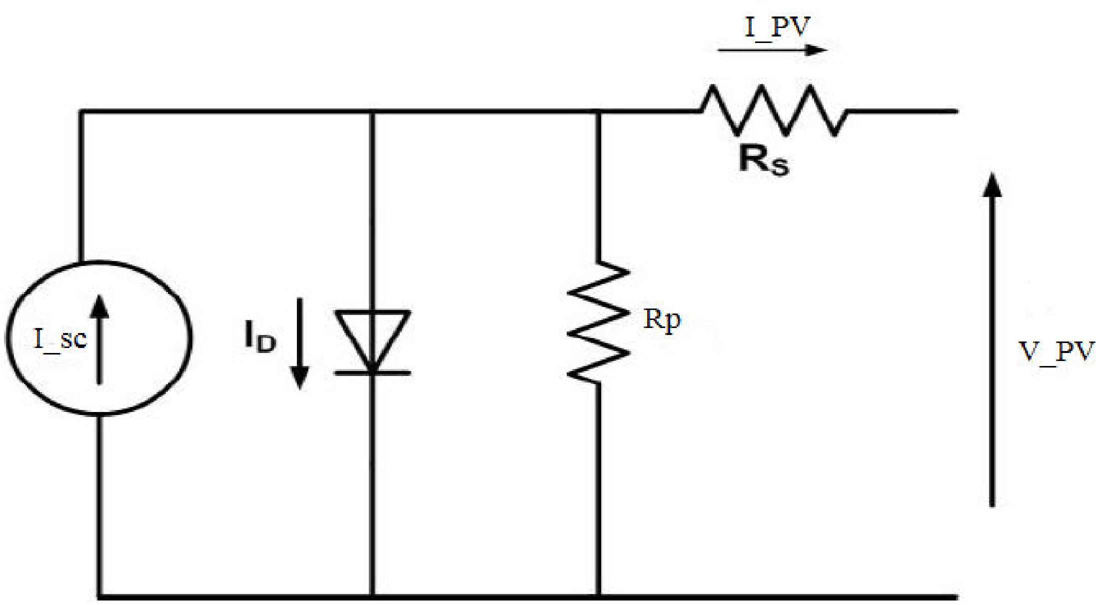


Fig. 3.1. Equivalent Circuit of a Solar Cell

V_PV and I_PV are the terminal voltage and current coming out of a solar module respectively .To calculate equivalent circuit parameters (Rs,Rp,Io(reverse saturation current of diode)) from datasheet parameters mathematical equations are used and solved using iterative methods .

Governing mathematical equations :

KCL:

$$I_{SC} - I_D - \frac{V_D}{R_p} - I_{PV} = 0$$

Diode characteristic:

$$I_D = I_o\left(e^{V_D/V_T} - 1\right)$$

KVL:

$$V_{PVcell} = V_D - R_s I_{PV}$$

Solving these equations for Rs ,Rp ,Io . Code implementation is as shown below

```
% calculation of PV module parameters
% limitation: constant temperature
Ns = round(Voc/0.61); % default number of cells in series
Vt = 26e-3; % thermal voltage
G = Isc/1000; % irradiation to short-circuit current gain
Vmpc = Vr/Ns; % cell voltage at rated Pmax
Vocc = Voc/Ns; % cell open-circuit voltage
Rmpp = Vmpc/Ir; % cell load resistance at Pmax
%
Rp = 100*Vocc/Isc; % initial value for Rp
Vdm = Vocc; % initial value for Vdm
%
% iterative solution for model parameters: Io, Rs, Rp
for i=1:10
%
 Idm = Isc - Ir - Vdm/Rp; % pn-junction (diode) current at MPP
 Io = (Isc-Vocc/Rp)/(exp(Vocc/Vt)-1); % pn-junction reverse saturation current
 Vdm = Vt*log(Idm/Io+1); % pn-junction (diode) voltage at MPP
 Rs = (Vdm-Vmpc)/Ir; % cell series resistance
 Rd = (Rmpp - Rs)*Rp/(Rp-Rmpp+Rs); % diode incremental resistance at MPP
 Idm = Vt/Rd; % diode current at MPP based on incremental resistance
 Rp = Vdm/(Isc-Ir-Idm); % cell parallel resistance
%
end
```

Fig. 3.2 Code implementation to solve PV parameters

Once the parameters are calculated , mathematical model can be formed as shown below :

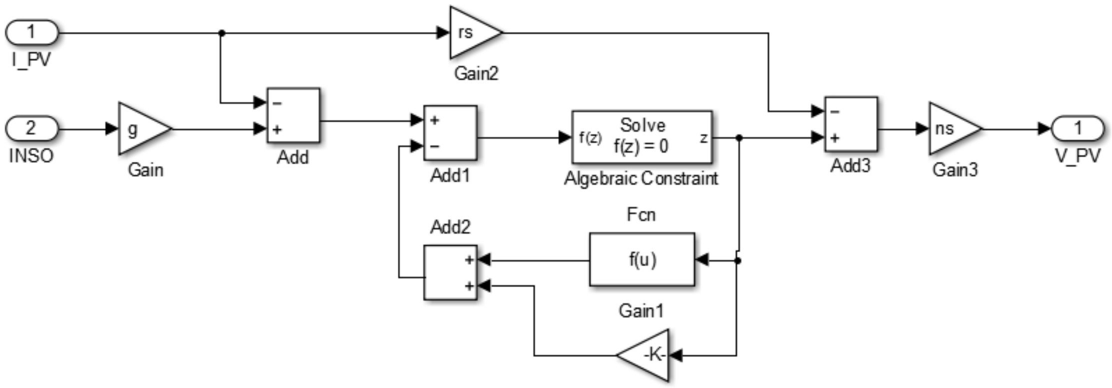


Fig. 3.3 Mathematical Model of PV module

Here k = 1/Rp ;

And f(u) = io*(exp(u/vt)-1) ;

3.2 Load Characteristics and PV Output Power Variation

The I-V and P-V characteristics of the modelled solar array at various values of solar insolation are shown below:

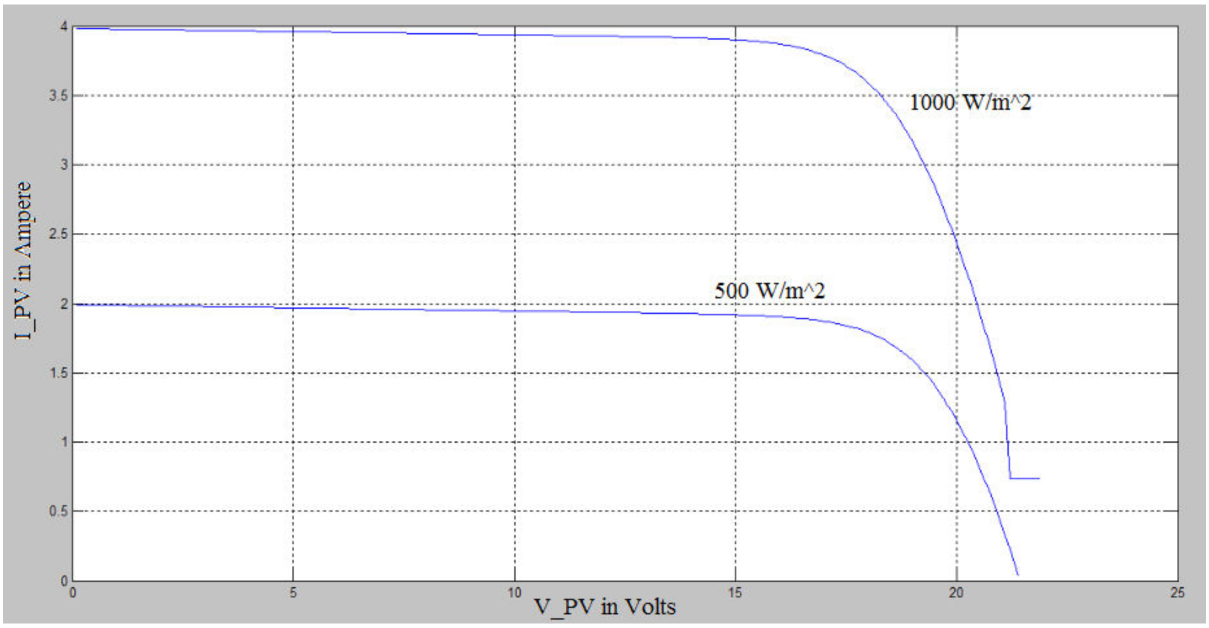


Fig 3.4 I-V Characteristic of the modelled Solar Module

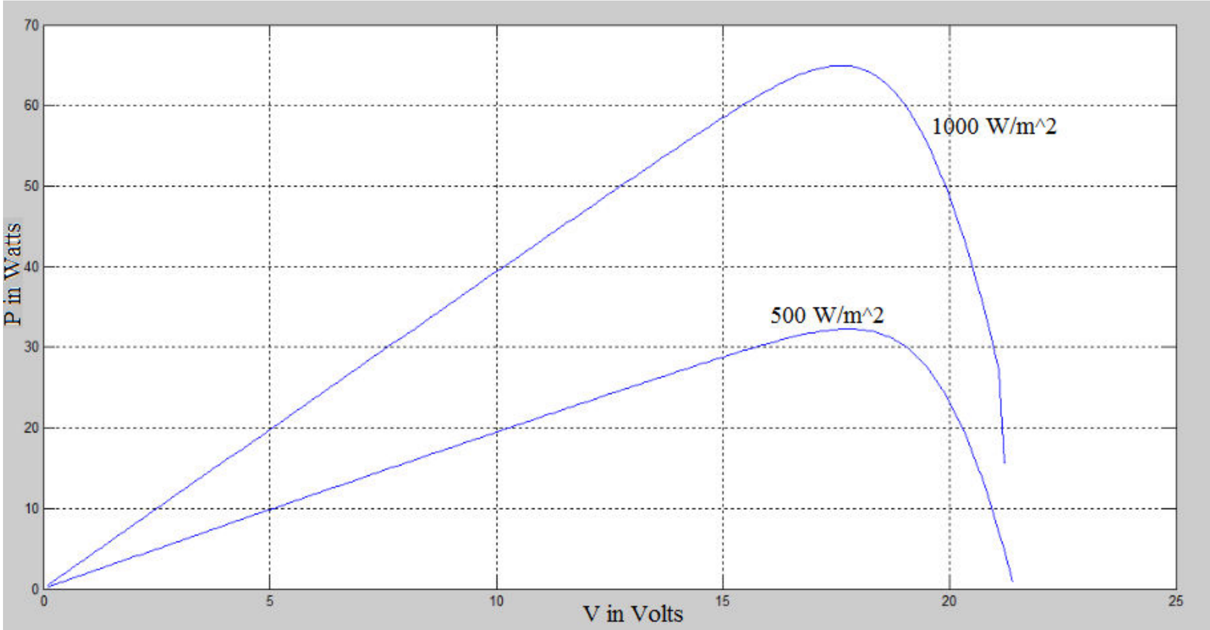


Fig. 3.5 P-V Characteristic of the Modelled Solar Module

3.3Sizing of Solar Panel ,Battery and Load

3.3.1 For the case of standalone scheme (i.e. for rural household)

In rural households, the load requirement is higher during night than during day time when the solar radiation is high. So optimum sizing necessitates the energy discharged by the battery over a whole day should be returned to the battery by the PV modules during the daytime.

For simplicity we have considered three loads of 60W , 20W , 50W with a battery backup of four hours . In a normal day eight hours of bright sunshine is expected . Thus one PV module (BP365) is sufficient to cater our need .

Determination of the Size of Battery

Stand alone PV based systems require the battery capacity to sustain for extra few hours without solar radiation. To select an optimum size of battery an additional 4 hours of back up for the battery has been considered. In the present case it is needed that the PV voltage and battery voltage be kept close to each other as they are connected to the same dc-link capacitor bank through DC-DC converters . Thus battery of 12V is chosen .

The Amp-Hr discharge requirement for battery is given as follows :

Amp-Hr discharge requirement =

discharge requirement in Whr / nominal voltage of battery = 12V

Discharge requirement = 130W*4hr = 520Whr

Amp-Hr discharge requirement = 520Whr/12V = 43.34Ahr

The regular Lead-Acid Batteries can be discharged till 50% of SOC. Hence using a regular battery, the Amp-hr requirement of the battery is (43.34/0.5) = 86.68 Amp-hr. The efficiency of the battery is considered to be 90%, which gives Amp-hr rating of 96.2 Amp-hr. For convenience, we can choose a battery of 100 Amp-hr rating.

3.3.2 For the case of grid connected scheme (i.e. for urban household)

Load to be applied in simulation is taken as real loads used in normal cabin/office i.e. PC , Fan ,Tubelight .

Electrical parameters of these loads are taken as :

Load	**Wattage**	**Power Factor**	**VAR**
Tube light	2*20W	0.9lag	19.372VAR
PC	1*150W	0.95lag	49.3VAR
Fan	1*40W	0.6 lag	53.34VAR

Table 3.2 Office/Cabin Load Modelling

Total VA : 260VA

As Grid is operated at unity power factor so VARs will be solely supplied by Solar panel . Real power may be supplied by both Solar panel and grid . As in worst case (i.e. when all loads are on)we require 122VA from solar panel , thus choosing 3 modules (65W*3 = 195W) to be on safe side as output power of Solar panel reduces with decreasing sunlight intensity .

Chapter 4

Control Schemes for Proposed Topologies

Control Schemes are required to make the system function as desired under all the variations (disturbances) applicable to the system .

Variations applicable to the system are as follows :

- Load connected at output - Power rating of loads
- State of charge of battery - Overcharge , Over discharge
- Atmospheric condition - Temperature , Sunlight intensity

4.1 For Standalone Scheme

In PV based power generation with battery as an energy storage element, it is required to supply the load demand by controlling the power sharing between PV and Battery. To extract maximum power from PV, PV must be operated at Maximum Power Point and the battery is to be controlled to supply extra load demand if needed, or get charged if the load requirement is less than supplied by PV. Battery charging/discharging requires the battery to be charged or discharged in a way that the battery current is within its permissible limit .The dc link voltage can be controlled either by the battery or by the PV . The PV and Battery should control the power sharing between them in such a way that the load demand is met by controlling the dc link voltage Vdc , and by controlling the battery current. Moreover, during charging, battery current should not exceed its maximum limits. The PV and Battery can be operated in two ways, MPPT mode of operation and Non-MPPT mode of operation. In MPPT mode of operation, PV is controlled to deliver maximum power while the battery charges/discharges to control the DC link voltage, while in Non-MPPT mode of operation, PV charges the battery with a constant load current and maintains the DC-link voltage.that

4.1.1MPPT Mode of Operation

In MPPT mode of operation, the load demand is met by the power delivered by the PV and battery, as expressed in the following equation

P_pv + P_bat = P_load

where P_pv = Power supplied by PV at MPP

P_bat = Power supplied(+ve) or taken (-ve) by battery

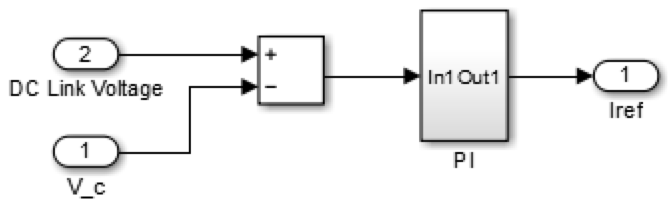
P_load = Power taken by load

In this mode, P_bat is –ve when power delivered by PV is higher than that required by the load. The battery takes a charging current in this mode, provided that the battery current doesn’t exceed its reference value . P_bat is +ve when battery is discharging to meet the load demand. During very low radiation or night time, battery supplies the entire load demand.

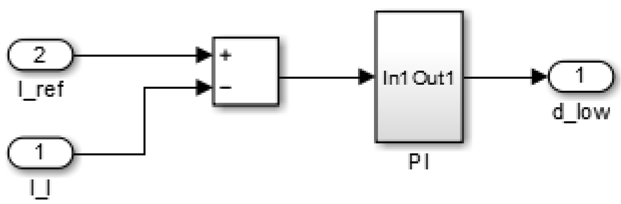
Roles assigned to converters in MPPT mode by control scheme are as follows :

Boost converter	:	Operate PV at MPP
Bidirectional converter	:	Control DC link Voltage

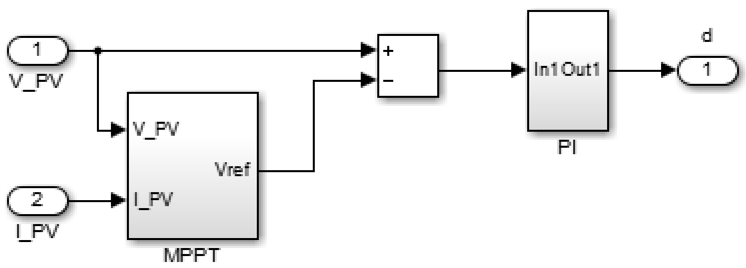
The control scheme for MPPT mode is as follows :



Caluclation of I_ref



Duty Cycle Generator for Bidirectional DC-DC converter



Duty Cycle Generator for Boost converter

Fig4.1 control scheme for MPPT mode

Here V_c	=	Actual DC link voltage
Iref	=	Battery discharging current
I_L	=	Inductor current coming from battery
d_low	=	Duty ratio for lower switch of bidirectional converter
V_PV	=	Actual PV terminal voltage
I_PV	=	Actual ouput current of PV

Vref = Reference PV terminal Voltage for MPPT

d = Duty ratio for Boost converter

4.1.2Non-MPPT Mode of Operation

In Non-MPPT mode also the relation P_pv + P_bat = P_load follows where P_bat is negative and the battery charging current is maintained at its reference value. PV is having excess power in this case if operated at Maximum Power Point, hence PV is operated at some other operating point(on the decreasing slope of P vs V characteristic) to supply the load demand and charge the battery with full charging current.

Roles assigned to converters in non-MPPT mode by control scheme are as follows :

Boost converter : Control DC link Voltage

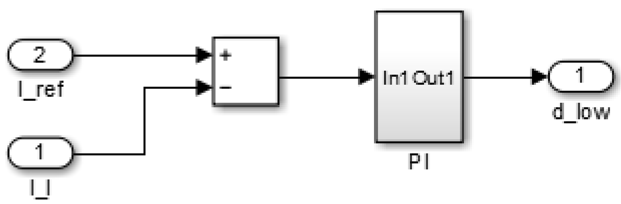
Bidirectional converter : Charge battery with maximum permissible current

Any small change in load demand is handled by PV in this mode. The system operates in the Non-MPPT mode, as long as the operating point doesn't cross the Maximum operating point or DC link voltage doesn't fall below some specific value(33V).The check in DC link voltage is provided to give the battery a faster control. Any drastic change in load will cause DC link voltage to fall below 33V , the controller will shift from Non-MPPT mode to MPPT mode giving the battery the responsibility to maintain DC link voltage

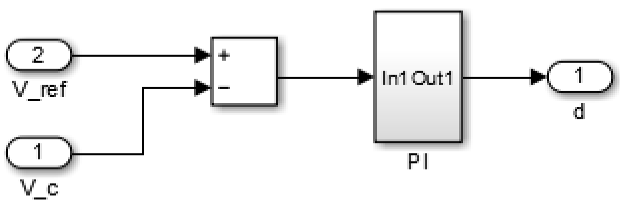
The control scheme for non-MPPT mode is as follows :

Battery is charged by maximum permissible current i.e. 1A .

So I_ref = -1A



Duty Cycle Generator for Bidirectional DC-DC converter



Duty Cycle Generator for Boost converter

Fig4.2 Control scheme for non-MPPT mode

Here V_c	=	Actual DC link voltage
Iref	=	Battery discharging current = -1A
I_L	=	Inductor current coming from battery
d_low	=	Duty ratio for lower switch of bidirectional converter
d	=	Duty ratio for Boost converter

4.1.3Transition between MPPT and Non-MPPT Mode of Operation

Efficient operation of the system requires the two conditions (DC link voltage and battery discharging current)for MPPT mode and Non-MPPT mode, to be checked consistently and shift the operating mode from one to the other and disabling the other mode.

Mode transition can be summarized as follows :

a). Power Produced by Solar Panel > Load Requirement

means excess power , now

IF battery charging current < Upper Limit

then PV in MPPT mode

i.e. Extract maximum power from PV and feed excess power to battery .

IF battery charging current > Upper Limit

then PV in Non-MPPT mode

i.e. extract as much as required by load and maximum charging limit of battery .

b). Power Produced by Solar Panel < Load Requirement

means shortage of power , now

IF battery discharging current < Upper Limit

then PV in MPPT mode

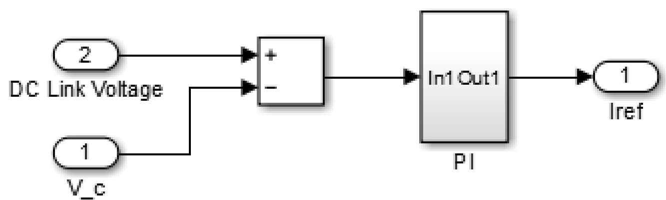
i.e. Extract maximum power from PV and feed deficit power from battery .

IF battery discharging current > Upper Limit

then Shutdown the system

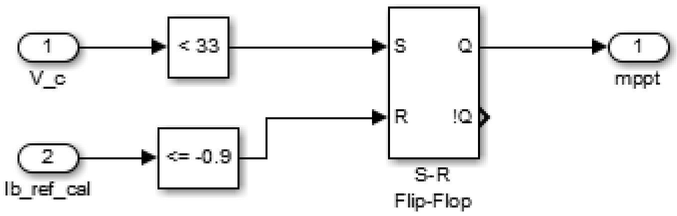
i.e. Available energy is not able to satisfy the load requirement .

Mathematically the mode transition is implemented as follows :



Calculation of Iref

Ib_ref_cal = Iref ;



MPPT decision block

Fig.4.3 Mode transition implementation

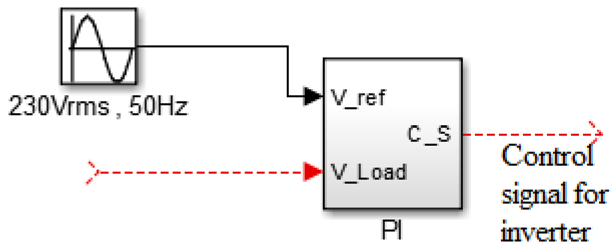
If MPPT = 0 then Iref = -1A

If DC link voltage falls below 33 V , means that generated power is not sufficient , it sets the flip flop and MPPT =1 i.e. the system will operate in MPPT mode to generate more power .

If Battery charging current exceeds the upper limit , i.e. more than required power is generated , it resets the flip flop and MPPT =0 i.e. the system will operate in non-MPPT mode to reduce the power production .

A small margin is left for both DC link voltage (2V) and battery discharging current (0.1A) otherwise there will be oscillations between the two modes .

4.1.4AC side control for Single Phase VSI



Block Diagram for AC side control

Fig. 4.4

To maintain output voltage as grid voltage , closed loop control is implemented . As shown in block diagram output load voltage is compared to reference sine wave of 230Vrms and 50 Hz . This is fed to PI controller to generate control signal for inverter which will further compare it to carrier wave and generate switching signal for full bridge switches .

4.2 For Grid connected Scheme

As infinite amount of power can be drawn / fed from / to grid power supply , thus there is no need of mode transition in this topology .Control scheme will simply make the system to extract maximum possible power from PV , feed the load , draw deficit power from grid or feed the excess power to grid at unity power factor .

Main objective of control scheme is to :

- extracting maximum power from PV
- Ensuring unity power factor operation for grid .
- handle variations in atmospheric conditions

Proposed control scheme

- Achieves Desired features by controlling current fed to grid.
- Its amplitude ensures MPPT for PV .
- Its phase ensures unity power factor operation for grid .

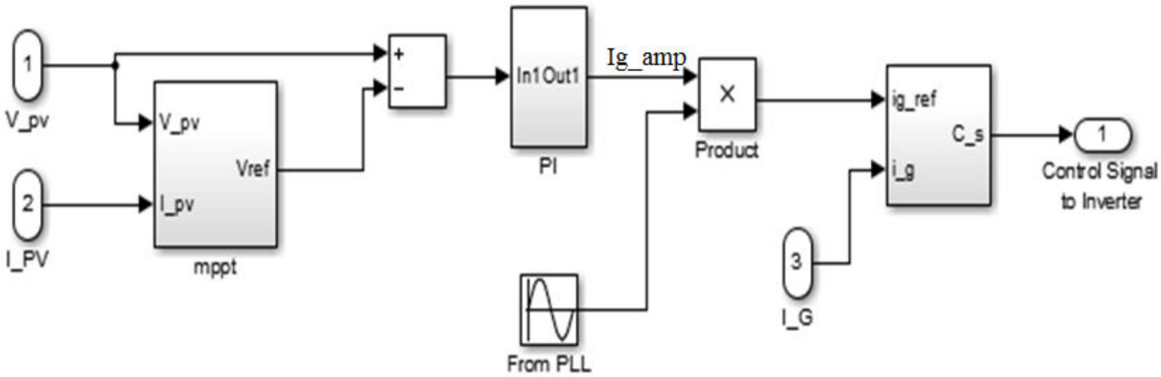


Fig. 4.5 Block Diagram of Proposed control scheme

Here	Ig_amp	=	reference amplitude for grid current
	V_PV	=	Actual PV terminal voltage
	I_PV	=	Actual ouput current of PV
	Vref	=	Reference PV terminal Voltage for MPPT
	Ig_ref	=	Instantaneous reference grid current
	Ig	=	Instantaneous actual grid current

4.2.1Working of control scheme

As shown in above block diagram , MPPT algorithm calculates Vref using VPV and IPV to operate PV at MPPT . Now by using dual loop control technique , this calculated reference voltage value is used to calculate amplitude of grid current using VPV . Amplitude of grid current ensures MPPT for PV .

To ensure unity power factor operation at grid we have to generate a reference unity , clean sine wave in phase with grid voltage . this waveform is multiplied by amplitude to get instantaneous reference value for grid current .

Based on this reference value for instantaneous grid current and actual instantaneous grid current , control signal for inverter is generated which is further compared with carrier signal to generate gate pulses for switches .

4.3. MPPT Algorithm- Perturb and observe

Maximum power point tracking (MPPT or sometimes just PPT) is a technique used commonly with photovoltaic (PV) solar systems to maximize power extraction under all conditions .

When a load is directly connected to the solar panel, the operating point of the panel will be governed by load and will be rarely at peak power point. The impedance seen by the panel derives the operating point of the solar panel. Thus by varying the impedance seen by the panel, the operating point can be moved towards peak power point. Since panels are DC devices, DC-DC converters must be utilized to transform the impedance of one circuit (source) to the other circuit (load). Changing the duty ratio of the DC-DC converter results in an impedance change as seen by the panel. For given conditions , at a particular impedance (or duty ratio) the operating point will be at the peak power transfer point. The I-V curve of the panel can vary considerably with variation in atmospheric conditions such as radiance and temperature. Therefore it is not feasible to fix the duty ratio with such dynamically changing operating conditions.

MPPT implementations utilize algorithms that frequently sample panel voltages and currents, then adjust the duty ratio as needed. Microcontrollers are employed to implement the algorithms.

There are number of ways for MPPT (Maximum Power Point Tracking) .

The MPPT algorithm that is being used is P&O (Perturb and Observe) as it is less complex as compared to other algorithms and is easy to implement in DSP .

In this method the controller adjusts the voltage by a small amount from the array and measures power; if the power increases, further adjustments in that direction are tried until power no longer increases. It is most common, although this method can result in oscillations of power output.

The block diagram implementing the method is as shown below :

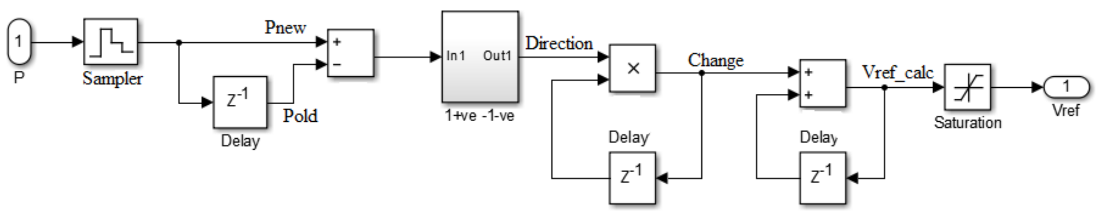


Fig. 4.6 Block diagram for MPPT algorithm implementation

As shown in block diagram , Samples of PV power are calculated at regular intervals using samples of VPV and IPV and multiplying them . If new sample of power is greater than previous sample , it proceeds in same direction else it reverses its direction . Calculated step change is made to the voltage reference and fed to a saturation block so that it remains within its permissible limits (i.e. 0 and Voc). Now the converter tries to make VPV as vref .

Chapter 5

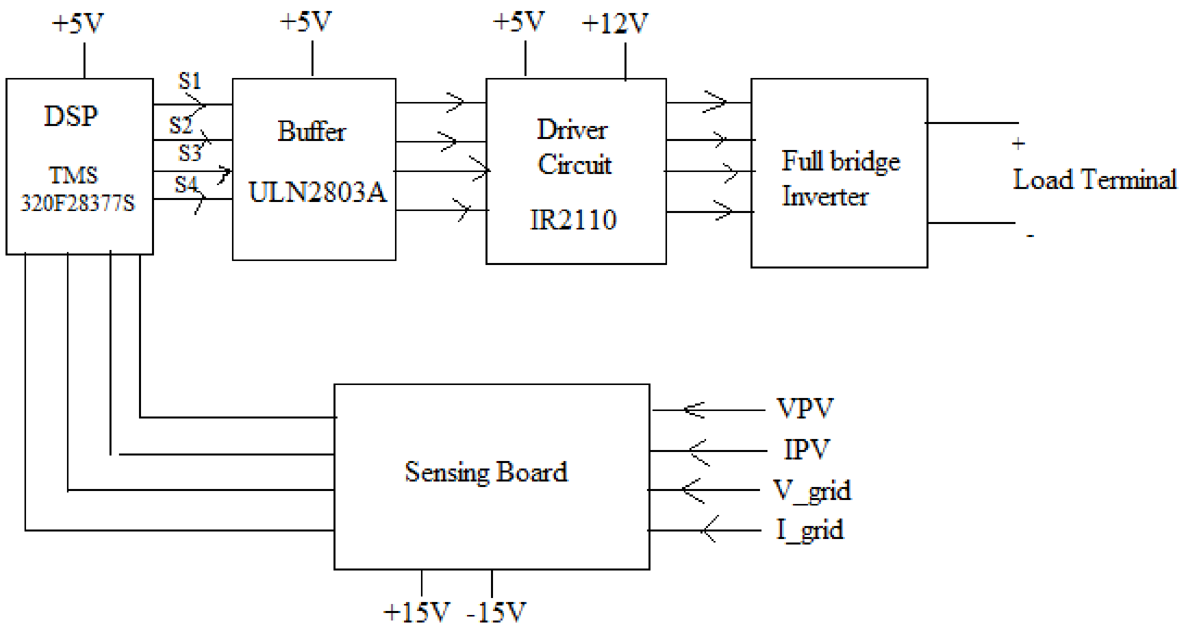
Hardware Implementation

A laboratory prototype of the proposed system has been developed to validate the viability of the scheme. Implementation of hardware prototype requires selection of proper hardware components. Sizing and design issues pertaining to major components of the prototype are presented below.

5.1. DSP Controller

The hardware prototype to be built needs to perform various computing, sensing of input signals and generation of output signals. For the scheme presented , requires sensing of voltages and currents in the power circuit, performing MPPT check through an algorithm, computation of different PI loop outputs, generation of PWM signals etc. Implementation of all these functions necessitates the use of a DSP controller. For convenience, TI DSP TMS320F28377S is chosen which has 16 ADC input pins and 24 PWM channels, 200 MHz clock frequency. Higher clock frequency of 200 MHz range can be easily used to perform control actions for 15 kHz switching frequency signals, MPPT checking which is generally performed at an interval of 0.1-0.2 seconds and control of output voltage of frequency 50 Hz.

The overall schematic diagram for grid connected scheme which is controlled by DSP is presented below.



Hardware Block diagram for grid connected scheme

Fig 5.1

Overall working of DSP

Sensed signals (VPV , IPV , V_grid , I_grid) are fed into DSP through ADC . Shifting and scaling is removed inside DSP mathematically . Implemented control scheme in discrete form calculates new compare value for PWM registers . Accordingly , switching signals are generated by PWM (by applying dead band) .These switching signals get amplified by buffer circuit and driver circuit and fed to gates of full bridge inverter switches .

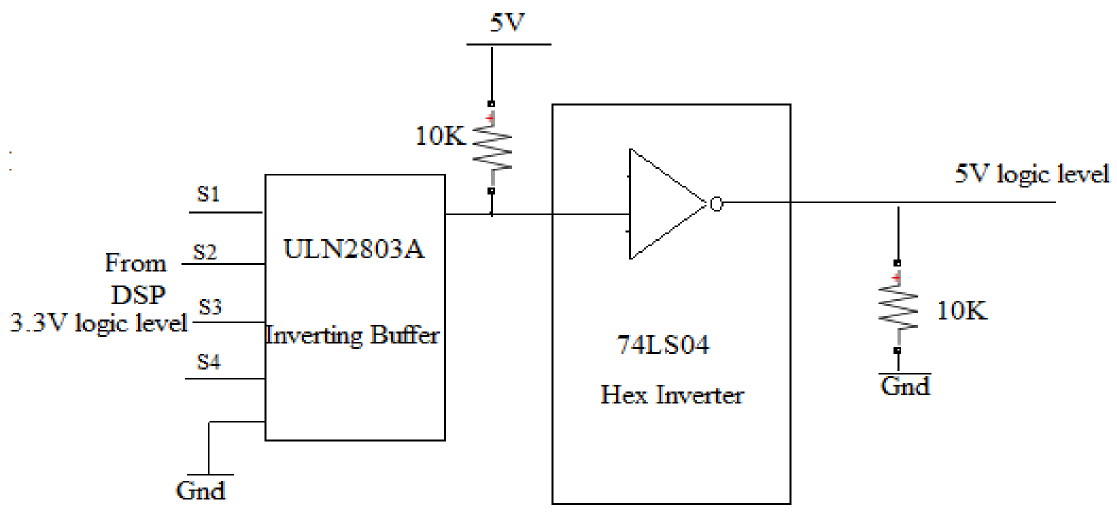
5.2Various subunits required to build complete system are as follows :

5.2.1 Buffer circuit

As PWM signals generated from DSP are of 3.3V level but driver circuit is based on 5V logic level . So Buffer circuit is designed to act as bridge between DSP and driver circuit i.e. convert 3.3V logic signals to 5V logic signals .

Components used are ULN2803A (inverting Buffer) , Hex inverter 74LS04 , Pull up and Pull down resistors (10K ohm) . ULN2803A consists of switches (darlington pairs) which gets turn on on receiving gate signal . We require four switches and four inverters . Both are available within single ULN2803A and 74LS04 .

To make the schematic look simpler only one buffer is shown . Rest three can be replicated to get total 4 buffers .



Schematic diagram for buffer circuit

Fig 5.2

5.2.2Driver Circuit

Switching signal provided by buffer circuit are not able to drive the gate capacitance of full bridge switches directly because of less current sourcing capability and less voltage level . High speed switching requires high current sourcing capability .

Thus a intermediate circuit is designed to provide gate pulses of +12V with high current sourcing capability to switches of full bridge by taking input as low power signals provided by buffer circuit .

Commonly used driver for Full bridge switching is IR2110 .

The IR2110/IR2113 are high voltage, high speed power MOSFET and IGBT drivers with independent high and low side referenced output channels. The output drivers feature a high pulse current buffer stage . The floating channel can be used to drive an N-channel power MOSFET or IGBT in the high side configuration which operates up to 500 or 600 volts.

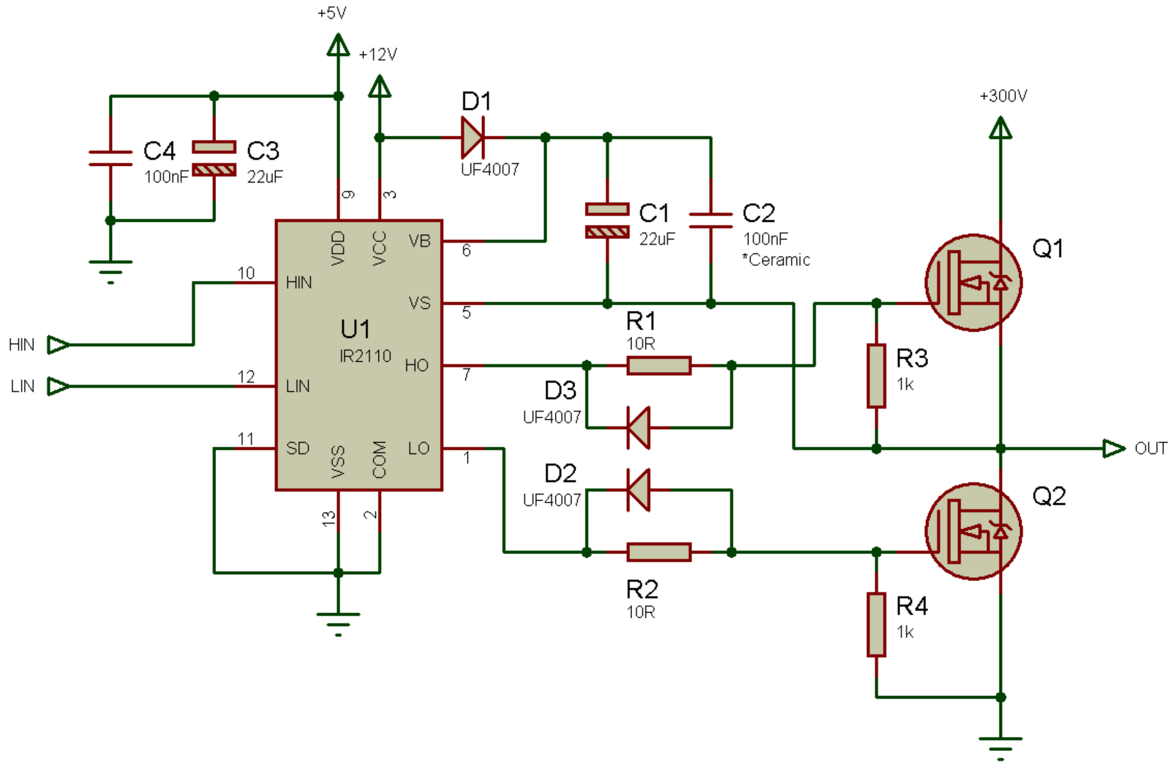


Fig 5.3Schematic for using driver for single leg .

Same can be done for another leg .

5.2.3Full bridge inverter

To implement SPWM inverter , full bridge configuration is used . To make full bridge ,MOSFETs are used because drive circuitry of MOSFET is much less complex as compared to that of IGBT .Maximum voltage across a MOSFET in a full bridge configuration is Vdc . Here in our case maximum voltage that can come across MOSFET is 3*Voc (3*22.1=66.3V) as PV panels connected in series act as DC terminal of inverter . Maximum current across switch is Isc = 3.91A . With a safety factor of 2 minimum voltage rating and current rating are required to be 132.6V and 8A .

Available MOSFET satisfying required conditions with low on state resistance is IRFP260N .

Its forward blocking voltage capability = 200V

Current rating = 50A

Rds on = 40m ohm

Schematic for full bridge inverter is shown in previous chapter .

5.2.4Sensing Circuit

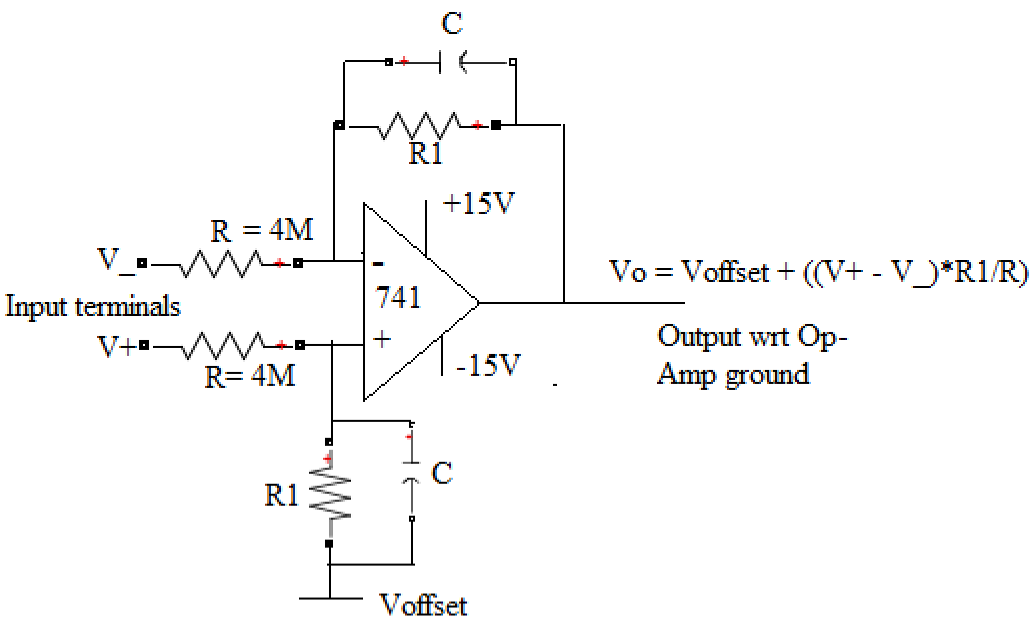
For performing, closed loop control of the system, sensing the voltages and currents are necessary. VPV and IPV are required to perform MPPT . V_grid and I_grid are required to ensure unity power factor operation of grid .

Every signal to be sensed has to be brought within the sensing range of DSP i.e. 0 to 3V . For DC signals , only scaling will serve the purpose . But for AC signals , they need to be scaled as well as shifted . Op-Amp circuits are used to scale and shift .

Basic schematic diagram to scale and shift Voltage signal using a Op-Amp is as follows :

For VPV R1=18K ohm

For V_grid R1=180K ohm

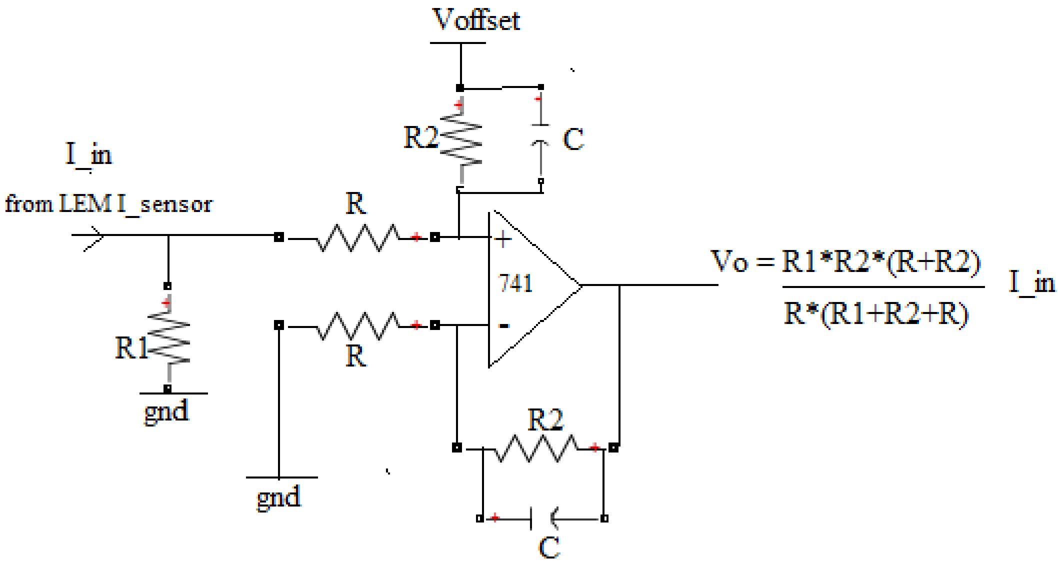


Cicuit Diagram for Voltage scaling and shifting

Fig 5.4

Basic schematic diagram to scale and shift current signal using a Op-Amp is as follows :

For current sensing, LEM current transducers LA-25P is used .



Circuit diagram for current scaling and shifting

Fig 5.5

Hardware Subunit	Components
Buffer Circuit	ULN2803A , 74LS04
Driver Circuit	IR2110
Full Bridge Inverter	IRFP260N
Sensing Board	LM741
Current Sensor	LA25-P

Table 5.1 Hardware subunits and required components

5.2.5Enhanced PLL

For unity power factor operation of grid we have to produce a unity , clean (removal of clipping effect at peaks and other distortions) sine wave in phase with the grid voltage .

As Grid voltage is a non-stationary signal thus Fourier techniques fail here. So Enhanced Phase Locked Loop technique is used .Technique is simulated and implemented on DSP and tested for real grid voltage .

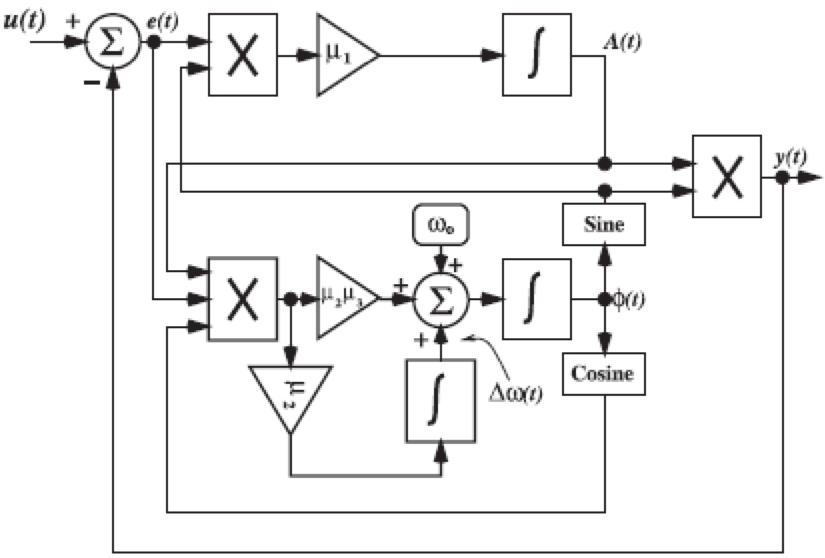


Fig 5.6 Block Diagram for ePLL

y(t)/A(t) is the desired waveform . For implementation of ePLL in DSP discrete form of integration and differentiation is used .

Parameters	**Values**
U1	50
U2	500
U3	0.08
Wo	50

Table 5.2 Parameters for ePLL implementation

5.3 Hardware Prototype Pictures :

Above mentioned circuits are implemented and tested individually . Due to chances of error at initial stage of design , hardware was implemented on vero boards and later it was implemented on PCB .

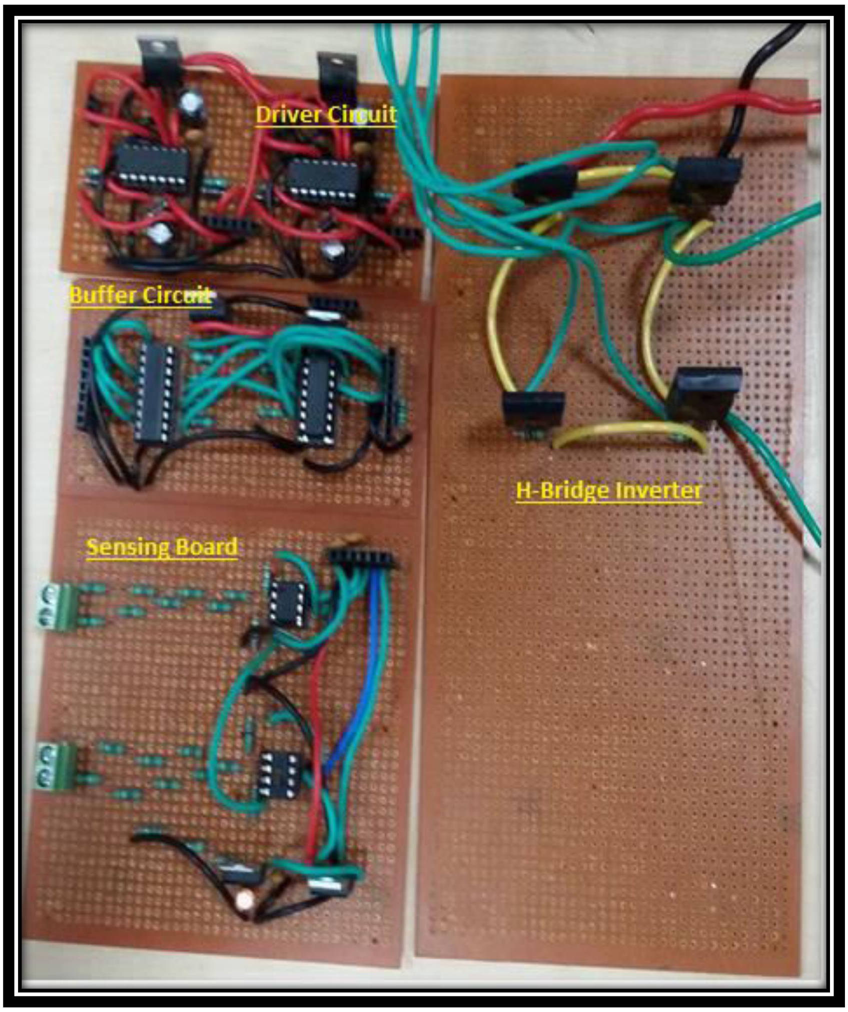


Fig 5.7 Vero board implementation

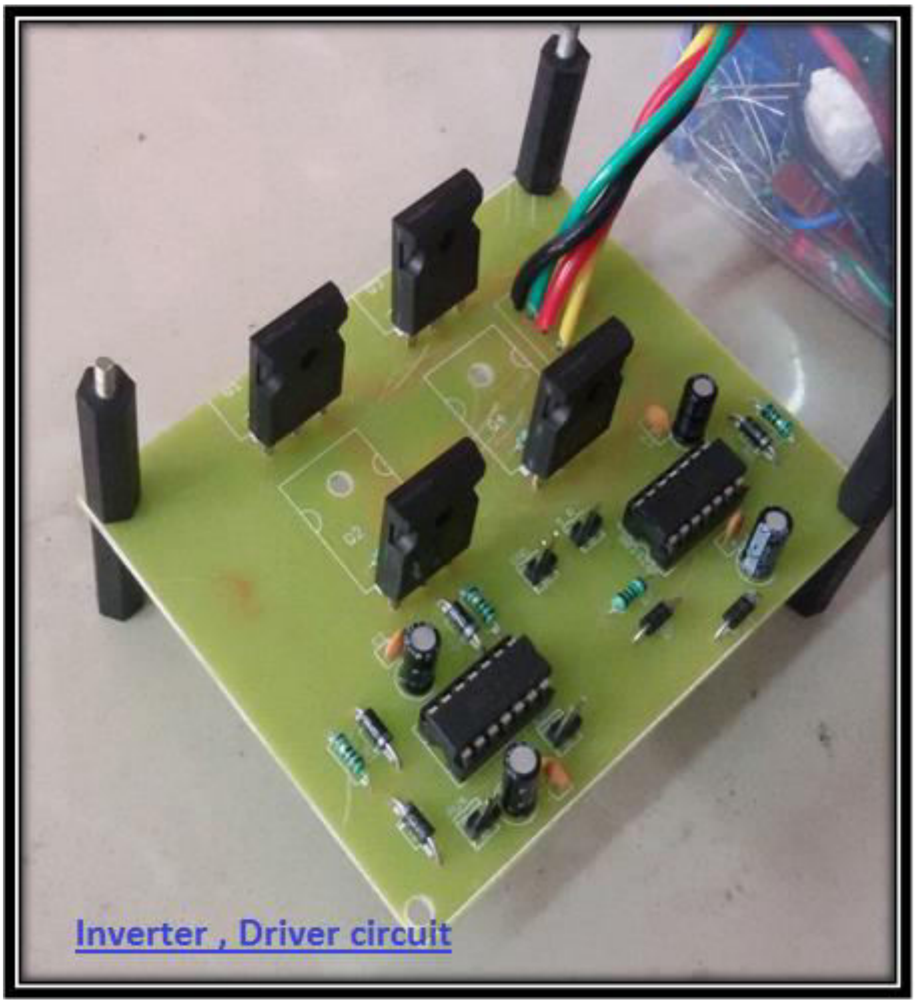


Fig 5.8 PCB implementation

Combined operation of subunits :

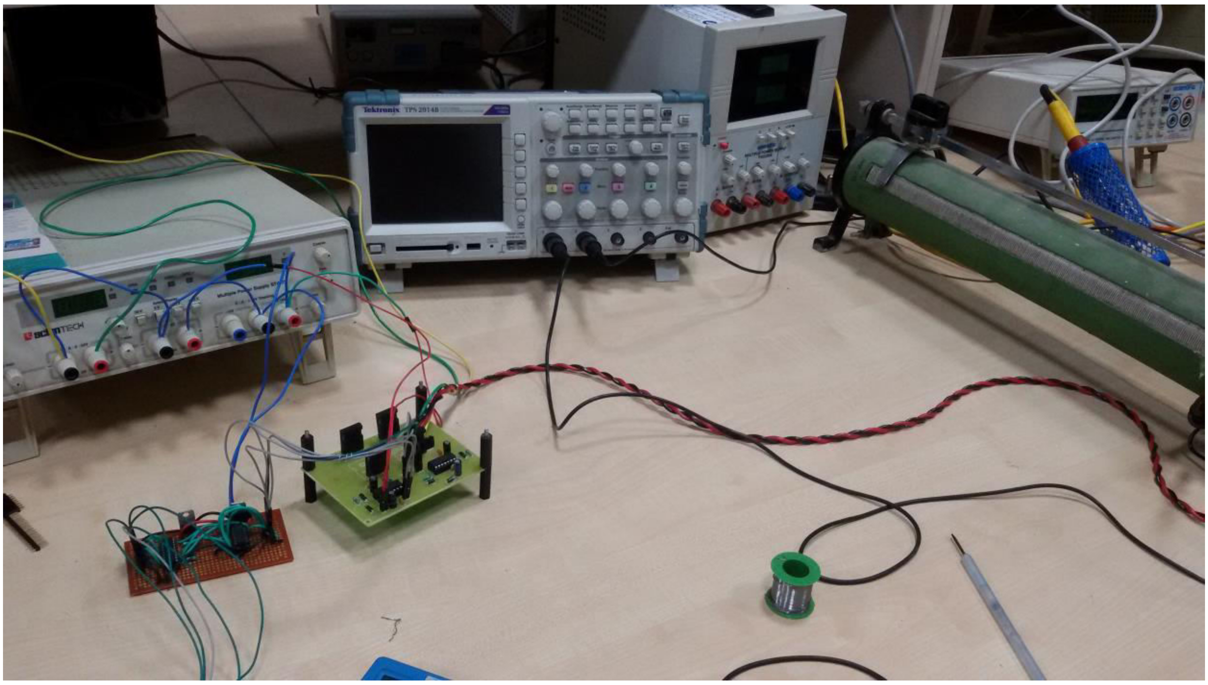


Fig 5.9SPWM Unipolar inverter implementation

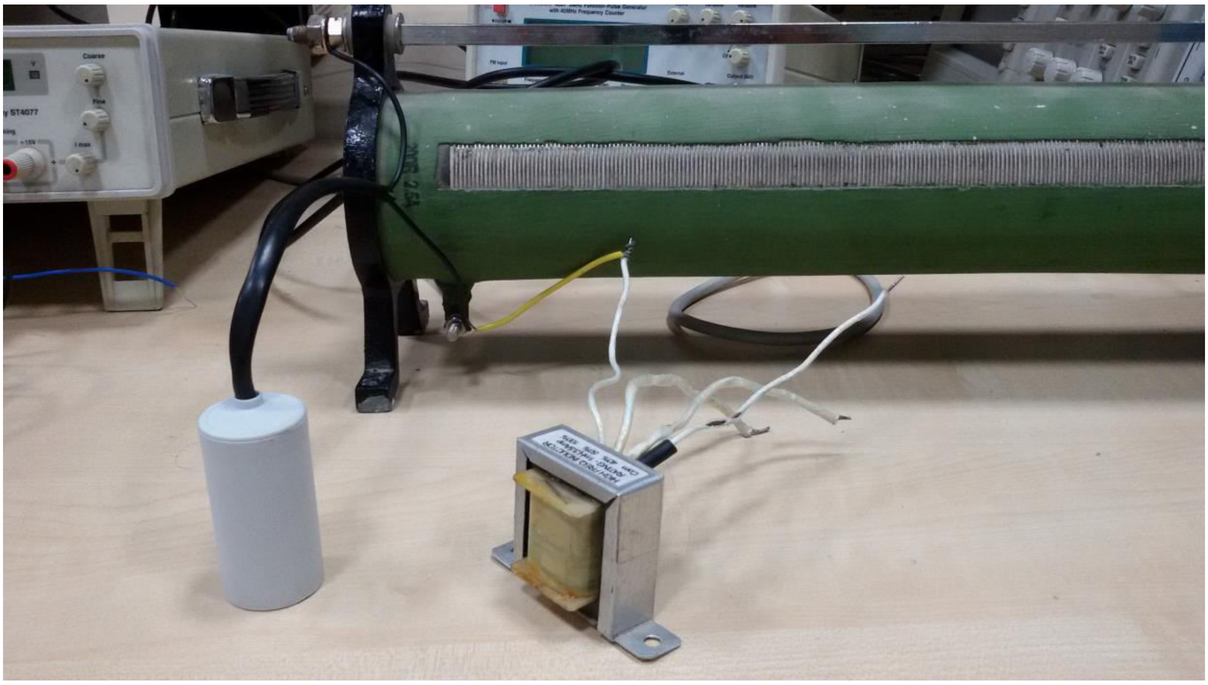


Fig. 5.10 Rheostat as load with LC filter

Chapter 6

Results and Discussions

Detailed simulation studies are carried out to confirm the validity of the proposed scheme. Subsequently the viability of the scheme is verified by performing detailed experimental studies on the laboratory prototype developed for the purpose (ongoing). Simulation for the above system is carried out in MATLAB/SIMULINK to emulate different operating conditions. Sudden changes are applied to system in form of step load .

6.1Simulation results for Standalone scheme :

6.1.1. MPPT Mode of Operation

In this mode, PV operates at MPP, delivering maximum power and DC link is maintained by battery by taking a charging current less than the maximum permissible charging current . PV operates at 1 kW/m2 with current at MPP Impp = 3.69A. Load connected is 60W. The maximum battery charging current is taken as 1 Ampere.

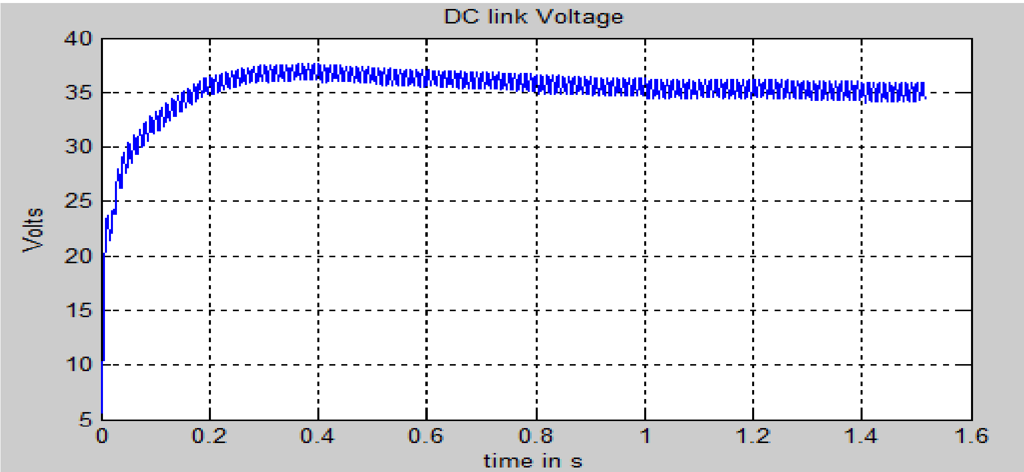


Fig. 6.1. DC link voltage at MPPT

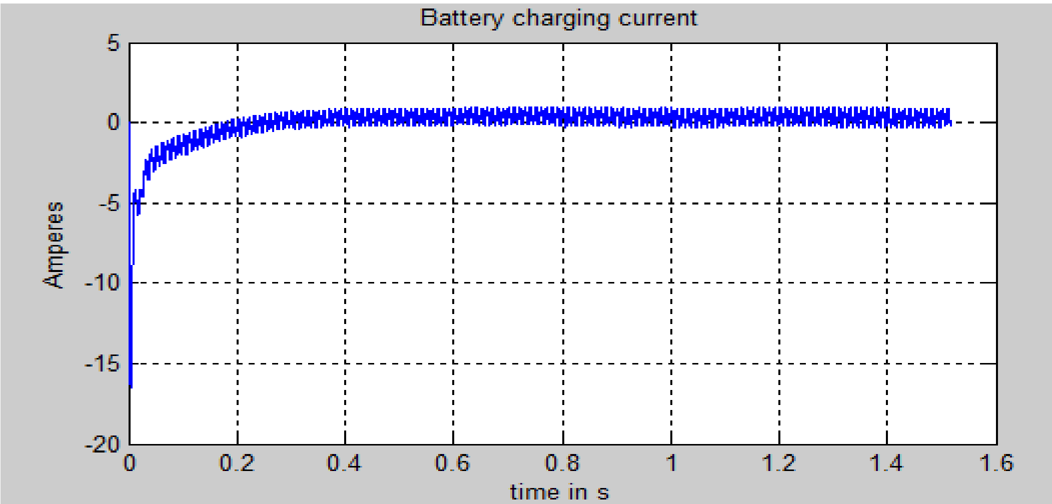


Fig. 6.2. Battery Charging Current at MPPT

In mppt mode of operation, the dc link voltage Vdc stabilizes at 35V(Fig. 6.1) due to the control action performed by the battery converter. As total power developed by PV is higher than that required for load, the battery takes a charging current(Fig. 6.2) , which is less than maximum permissible limit (1A). This validates the controller scheme proposed for MPPT mode of operation.

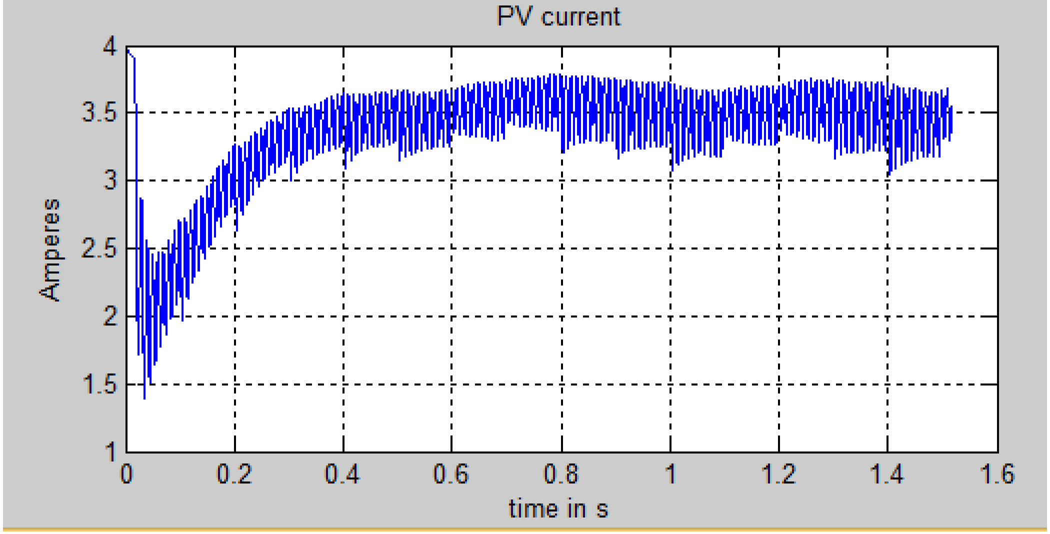


Fig. 6.3. PV Current at MPPT

From Fig 6.3, it can be inferred that PV operates to deliver maximum power at solar insolation of 1 kW/m2 with Impp = 3.69A, while Fig. 6.1 and 6.2 show that the dc link voltage is maintained at 35V, by control action performed by the battery converter.

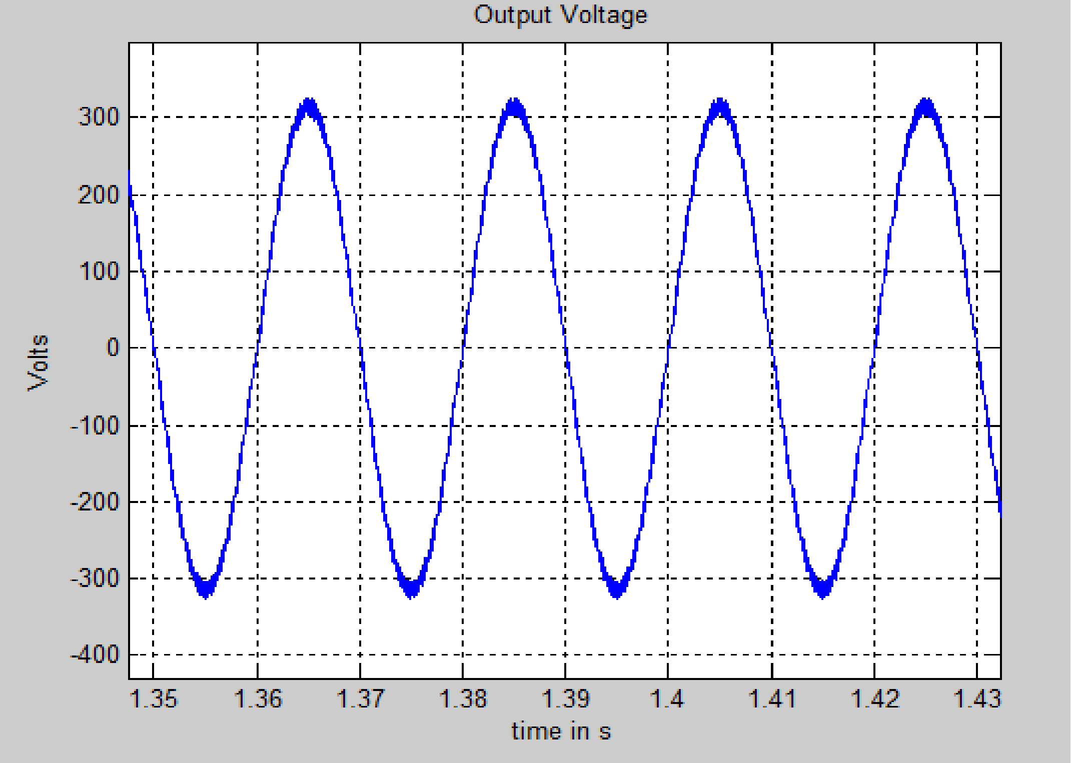


Fig. 6.4. Output Voltage Shape at MPPT

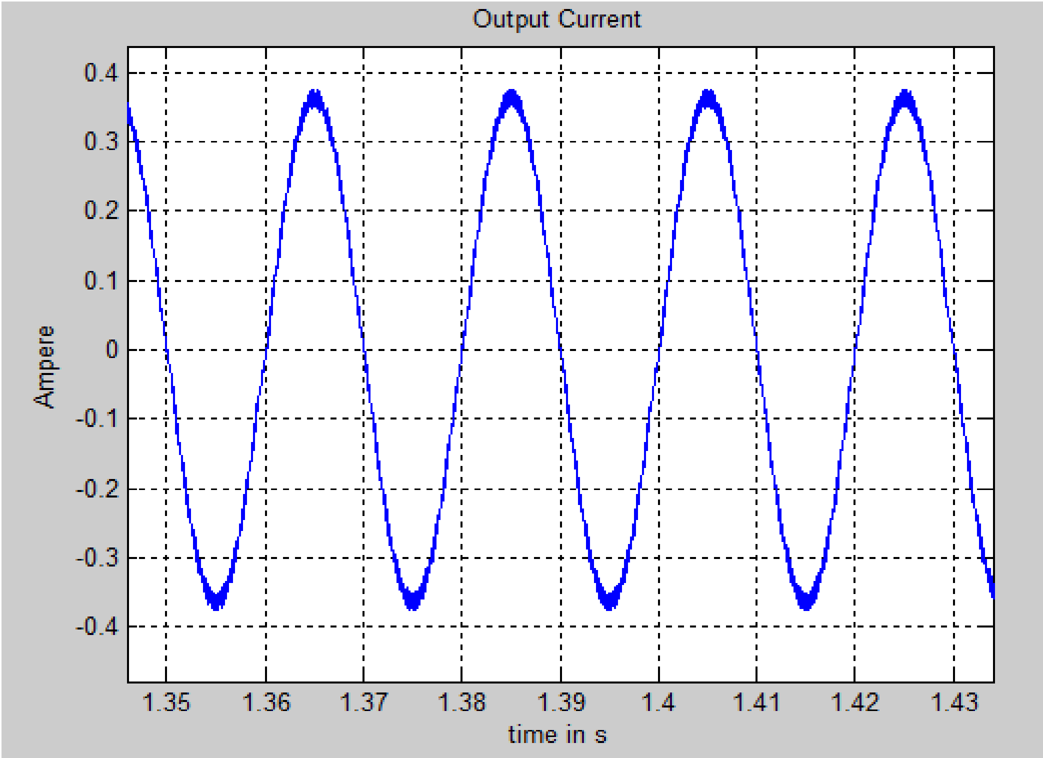


Fig. 6.5. Output Current Shape at MPPT

Fig. 6.4 and Fig. 6.5 gives the steady state output voltage and current waveforms. This justifies the fact that the output voltage and current are maintained sinusoidal by the control action performed of the single phase inverter.

6.1.2. Step Change in Load in MPPT Mode of Operation

Sudden load variation is applied at t=1.5s . It is taken into care that system remains in MPPT mode .As load requirement is higher than maximum power produced by PV thus it operates at MPP, delivering maximum power and DC link is maintained by battery by providing a discharging current. PV operates at 1 kW/m2 with current at MPP Impp = 3.69A. Load connected is 75W.

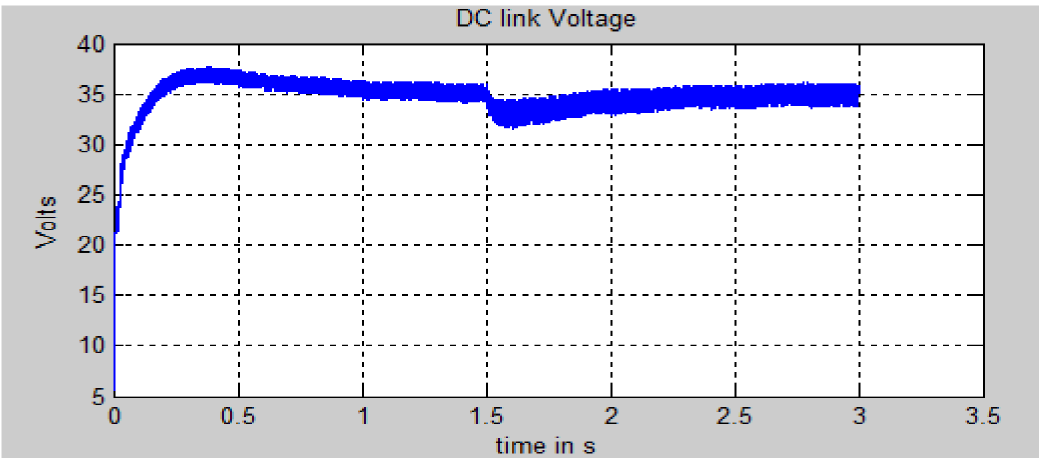


Fig. 6.6. DC Link Voltage Variation under Load Changes

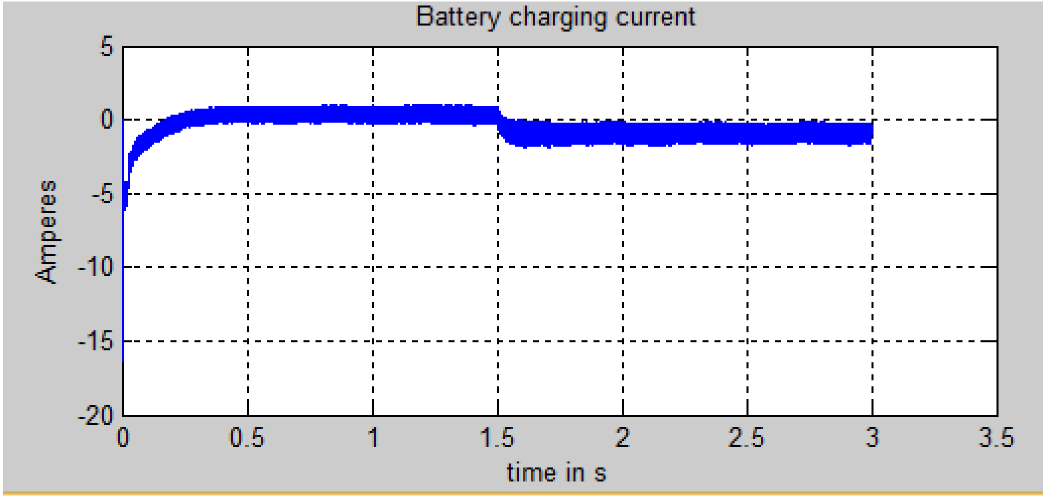


Fig. 6.7. Battery Current at MPPT Operation under Load Changes

Initially, the dc link voltage stabilizes at 35V by the control action performed by the battery converter which takes in a charging current while PV continues to operate at MPP with Impp of 3.69A. At 1.5 second, an increment in load takes place, which causes a fall in dc link voltage(Fig. 6.6). As battery converter is controlling the dc link voltage, a fall in dc link voltage triggers the battery current to increase(Fig. 6.7) for supplying the extra load demand by restoring the dc link voltage at 35V. This supports the control scheme proposed for MPPT mode of operation that dc link voltage changes can be handled by the control action of battery converter.

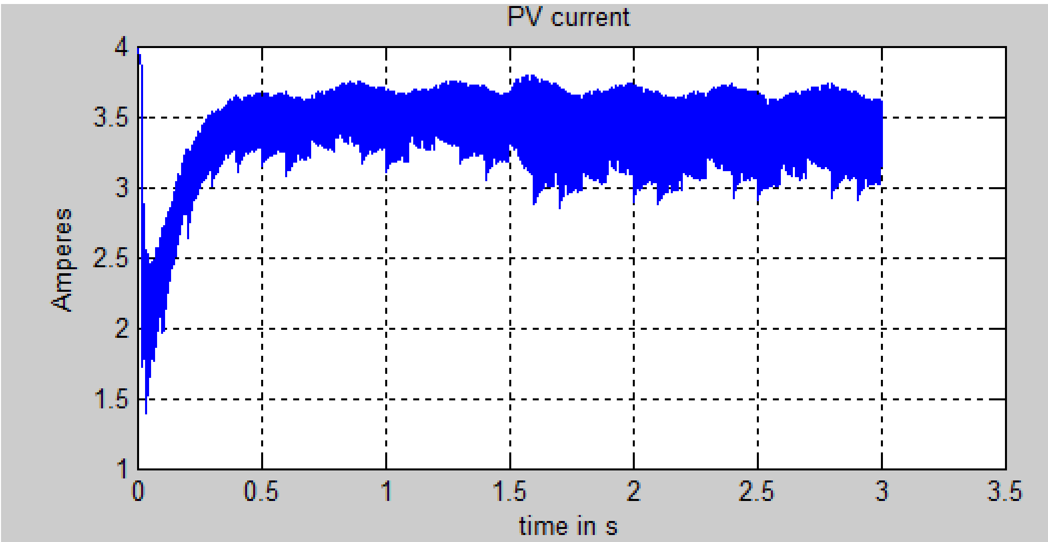


Fig. 6.8. PV Operating at MPPT and Delivering Constant Current

From Fig. 6.8, it can be inferred that the PV converter continues to operate at MPPT, regardless of load changes taking place.

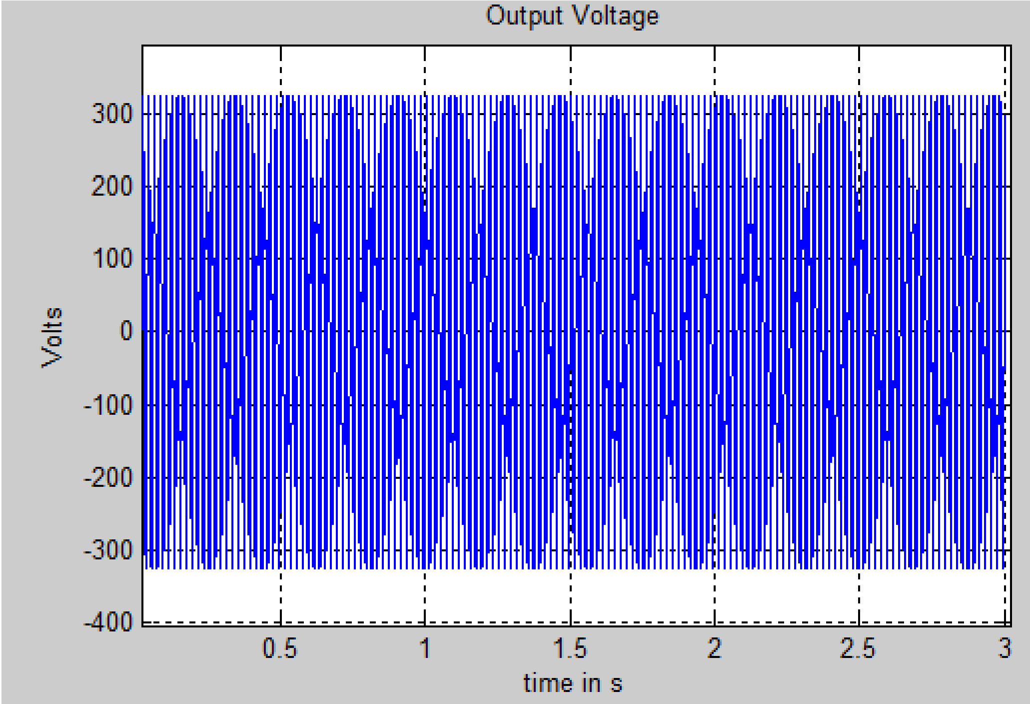


Fig. 6.9. Output Voltage under Load Changes

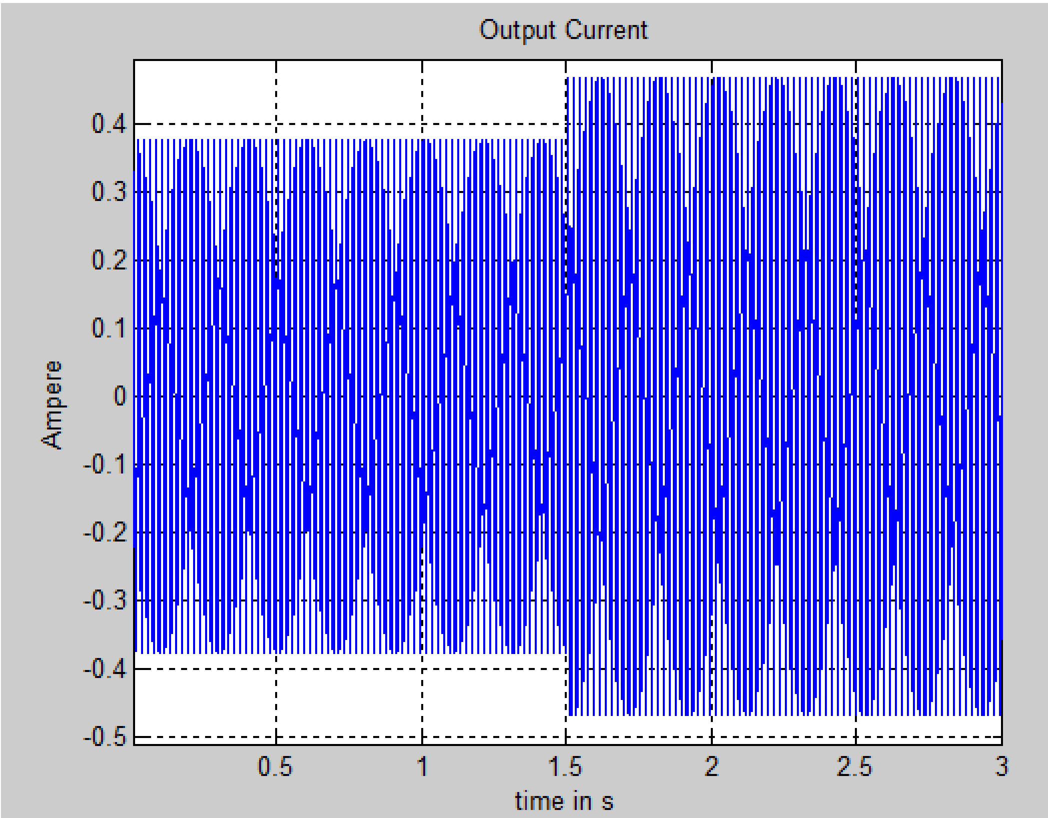


Fig. 6.10. Changes in Load Current

Fig 6.9 and Fig. 6.10 show the output voltage and current changes respectively. The load voltage falls at an increment of load at 1.5 second, but is quickly restored due to the fast control action of inverter and battery controller(Fig. 6.9).The load current increases at 1.5 second due to addition of load .

6.1.3. Non-MPPT Mode of Operation

In this mode, PV operates at a operating point other than MPP, delivering the power required by load and charges the battery with a constant current specified by maximum permissible charging current. PV operates at 1 kW/m2 and the load connected is 20W. PV maximum power point current Impp is 3.69A. The maximum battery charging current is taken as 1 Ampere.

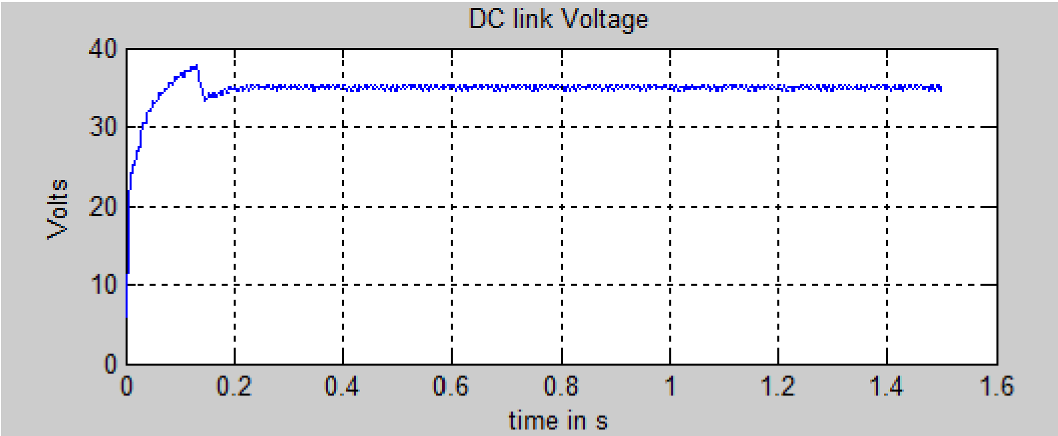


Fig. 6.11. DC Link Voltage at Non-MPPT Mode

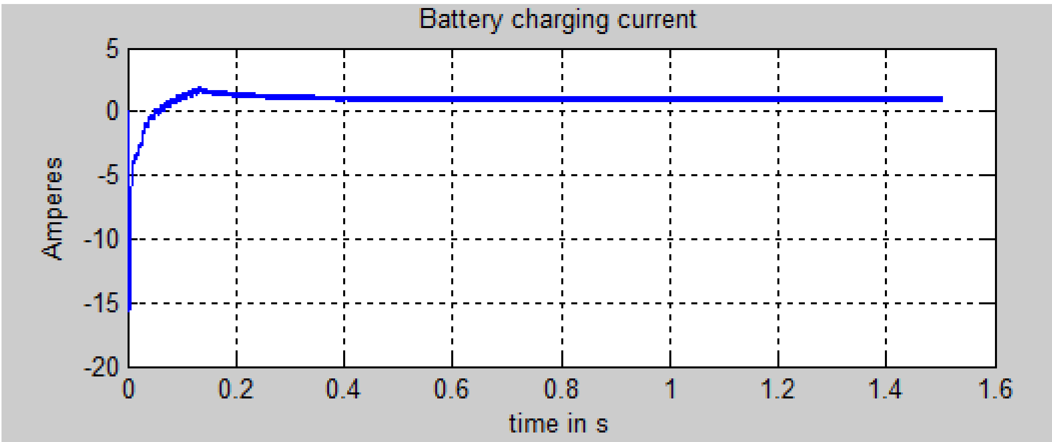


Fig. 6.12. Battery Charging Current at Non-MPPT Mode

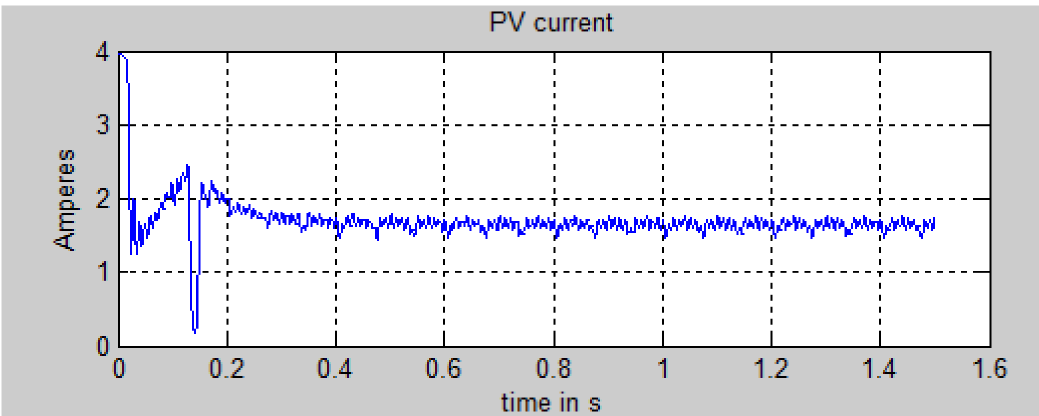


Fig. 6.13. PV Current at Non-MPPT Mode

From Fig. 6.11, 6.12 and 6.13, it can be seen that PV converter maintains the dc link voltage at 35V, while the battery converter maintains the charging current at 1A, as specified by the controller. PV operates at a current which is lower than the current Impp = 3.69A. These figures justify the control scheme of charging the battery with a constant current and maintaining the dc link voltage by the PV converter.

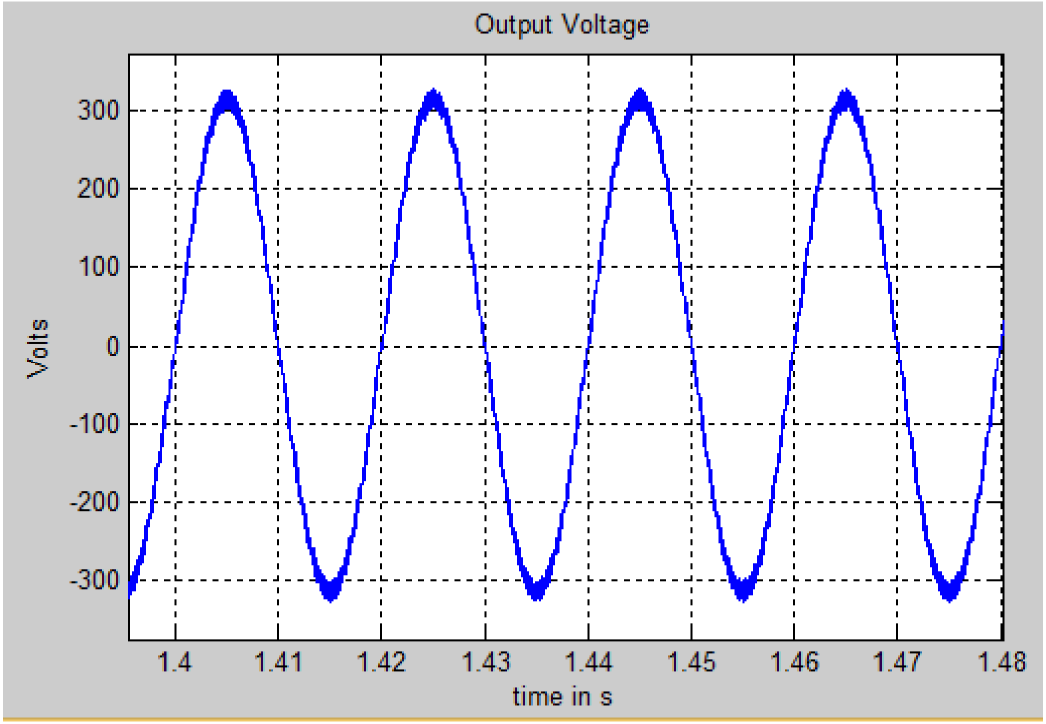


Fig. 6.14. Output Voltage Shape at Non-MPPT Mode

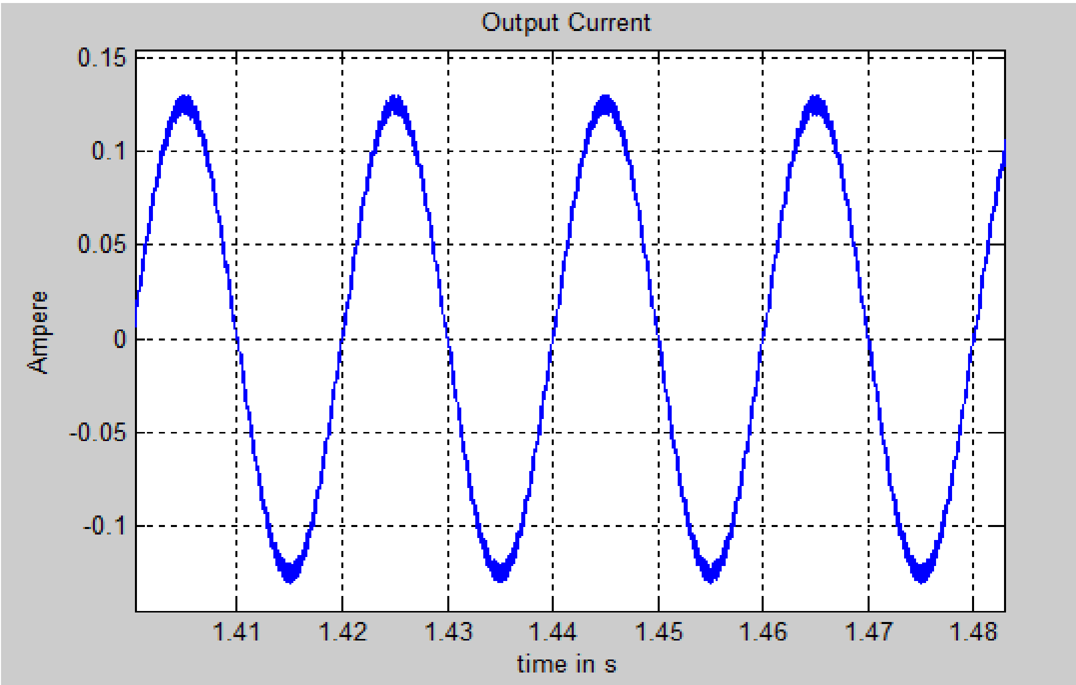


Fig. 6.15. Output Current Shape at Non-MPPT Mode

The output voltage and current shapes at Non-MPPT mode of operation can be seen from Fig. 6.14 and Fig. 6.15.

6.1.4. Step Change in Load in Non-MPPT Mode of Operation

A 20 watt load is added at 1.5 second .

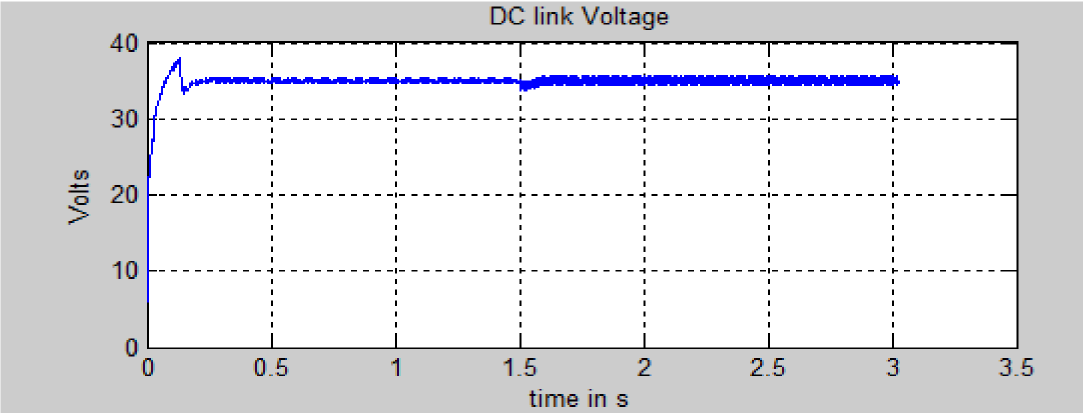


Fig. 6.16. DC Link Voltage Variation under Non-MPPT Mode

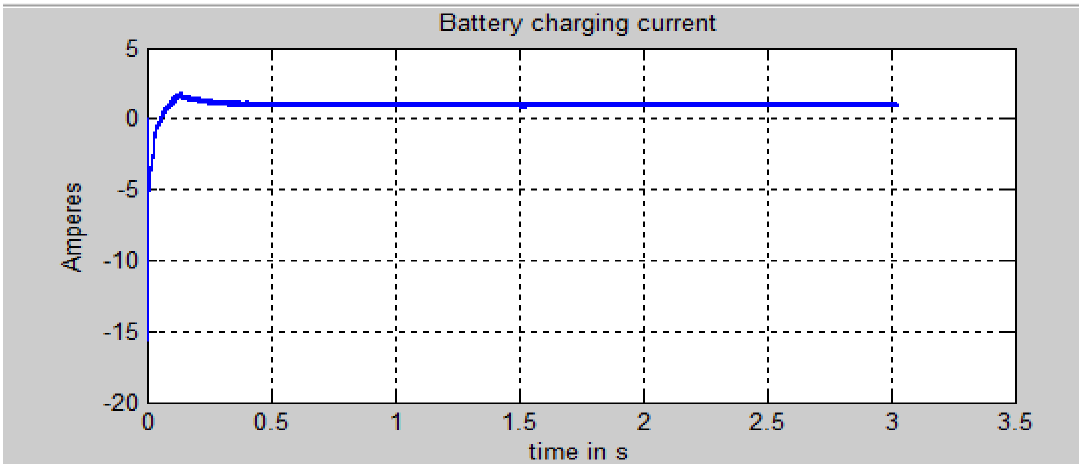


Fig. 6.17. Constant Battery Charging current

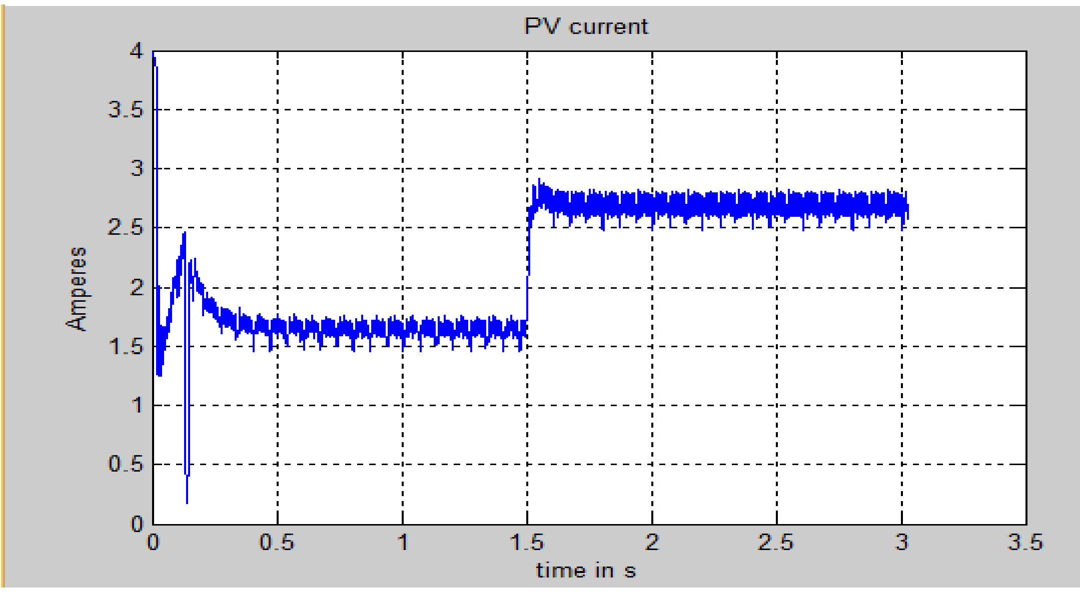


Fig. 6.18. PV Current Variation with Load Changes in Non-MPPT Mode

In this case, initially PV operates at current (Fig. 6.18), and the battery charging current is maintained at 1A(maximum charging current limit). At 1.5 seconds, a load addition of 20W takes place, which causes the dc link voltage to fall(Fig. 6.16). As PV is maintaining the dc link voltage, with fall of dc link voltage PV current increases(Fig. 6.17) to a new value to restore the dc link voltage. These changes in load and subsequent changes in dc link voltage and its restoration justifies the control scheme for Non-MPPT mode of operation, where PV supplies the power required to charge the battery and to supply the load demand.

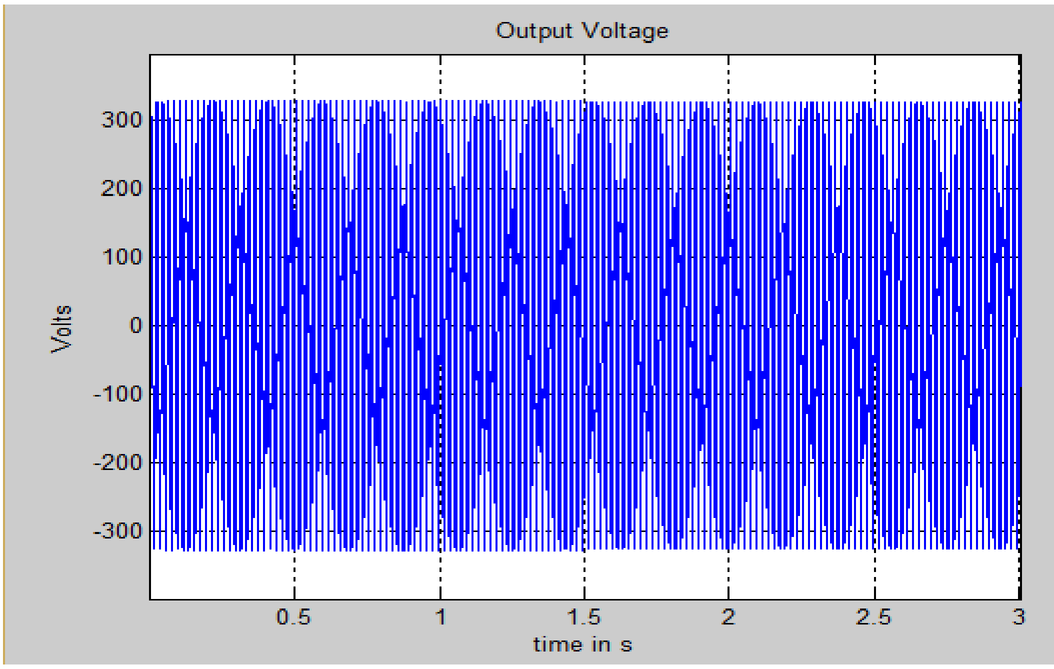


Fig. 6.19. Output Voltage under Load Variation

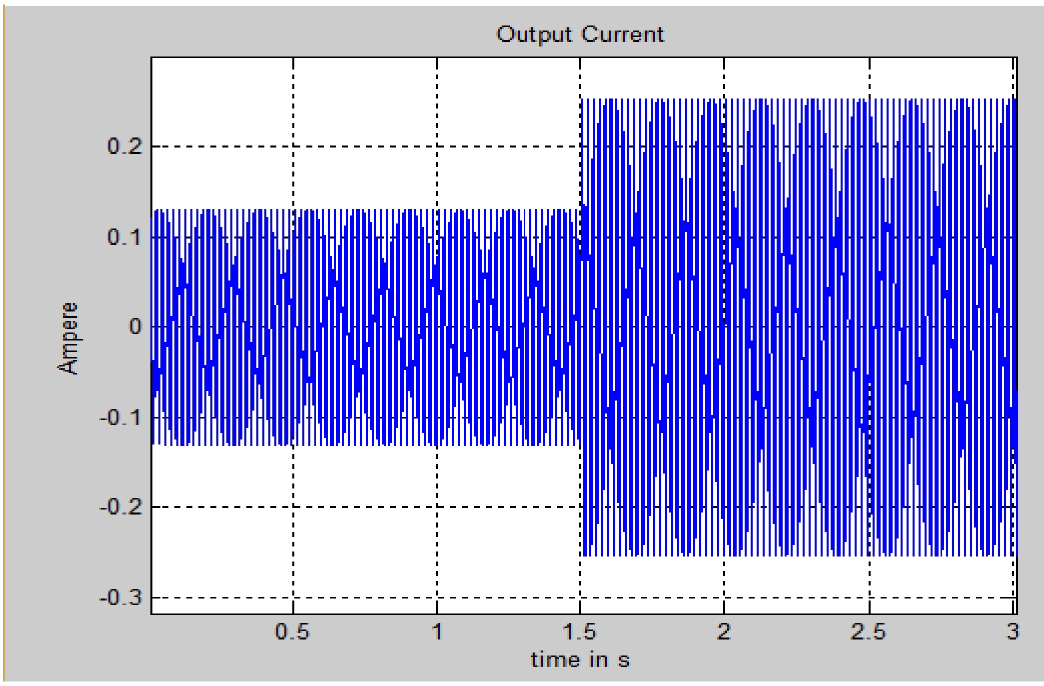


Fig. 6.20. Output Load Current Variation under Load Changes

The changes in output voltage and output current can be seen from Fig. 6.19 and Fig. 6.20, where the output voltage momentarily falls due to increment in load, and again gets restored by the controller, while the load current increases.

6.1.5. Change in Mode of Operation from MPPT to Non-MPPT and vice-versa caused by Step Change in Load

To check the validity of control scheme over mode transition (i.e MPPT to non-MPPT to MPPT) three different loads are connected which require the mode to be transitioned .
Sudden load variation is applied at t=1s and at t=2s .

t < 1s	load = 60 W	MPPT mode
1s<t<2s	load = 20 W	non-MPPT mode
t>2s	load = 75 W	MPPT mode

Mode transition is required at t=1s and at t=2s .Control scheme is responsible for this transition .

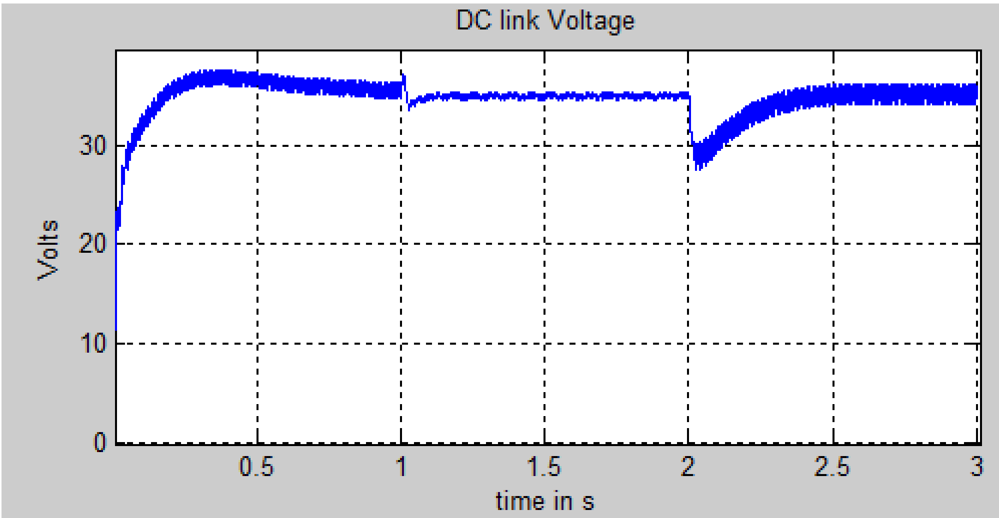


Fig. 6.21. DC Link Voltage Variation under Mode transition

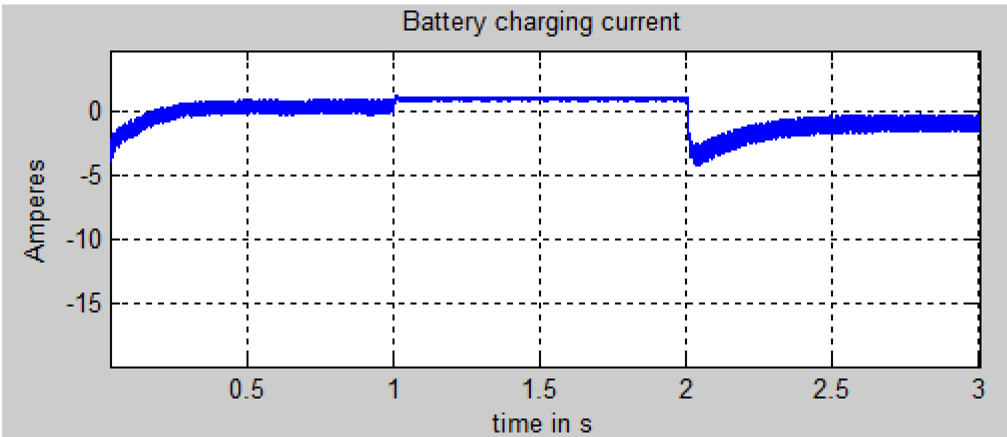


Fig. 6.22. Battery Current Variation under Load Changes

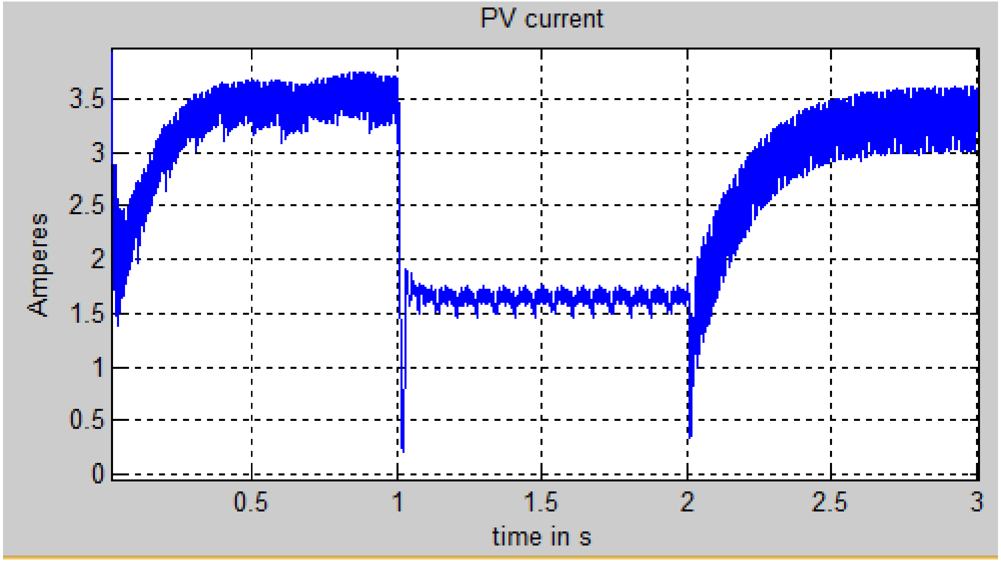


Fig. 6.23. PV Current Variation under Load Changes

It can be seen that at t=1s , due to reduction of load , DC link Voltage rises momentarily due to excess power . Control scheme reduces the power production by bringing the system into non-MPPT mode .Soon DC link voltage restores the desired value . And battery gets maximum permissible charging current (1A) .

At t=2s it can be seen that , due to rise of load , DC link Voltage falls momentarily due to less power . Control scheme increases the power production by bringing the system into MPPT mode .Soon DC link voltage restores the desired value by drawing current from battery .

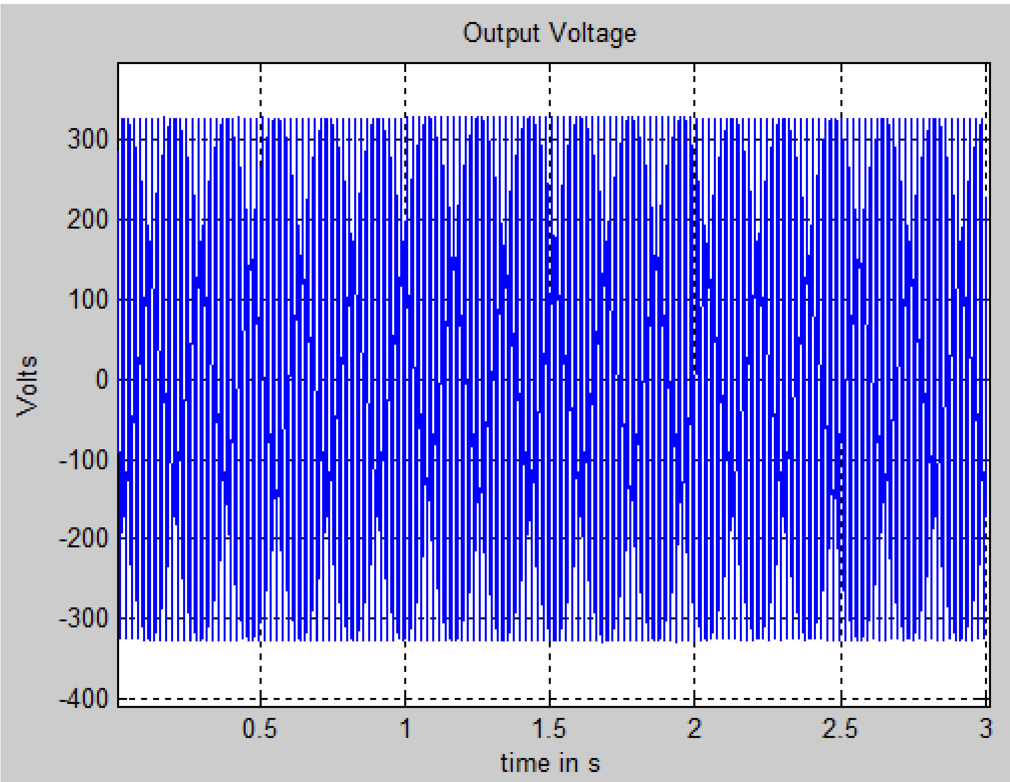


Fig. 6.24. Load Voltage Variation under Load Changes

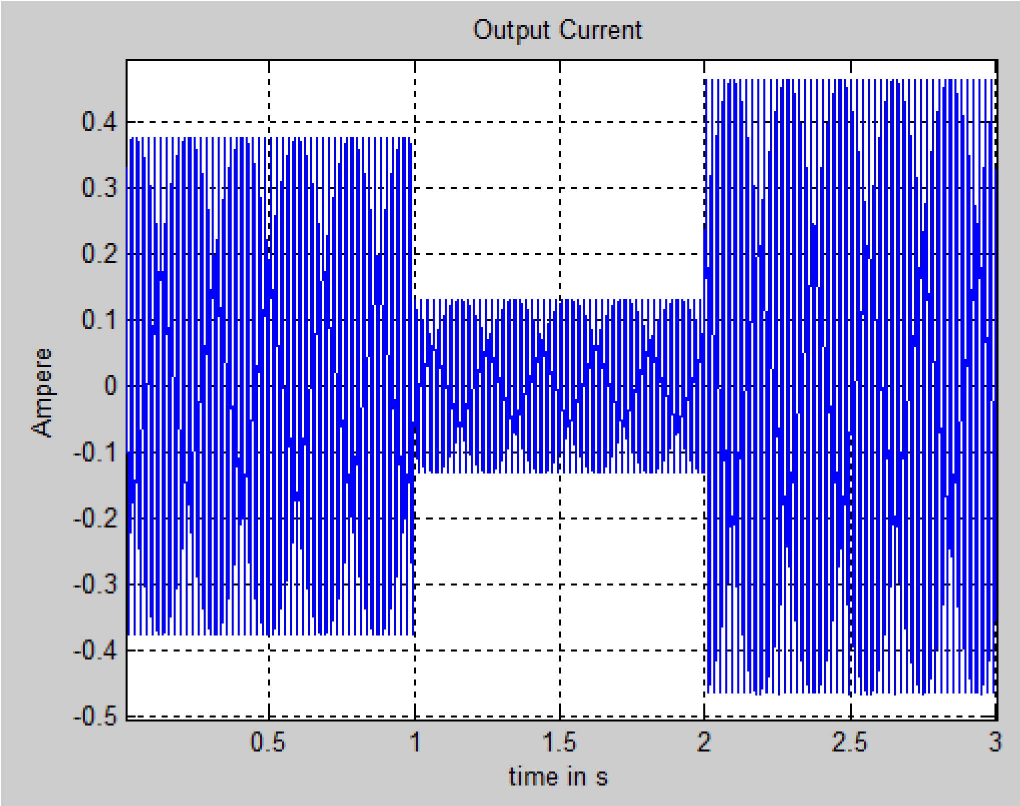


Fig. 6.25. Load Current Variation under Load Changes

The changes in output voltage and output current can be seen from Fig. 6.19 and Fig. 6.20, where the output voltage momentarily swells due to decrement in load at t=1s , then it momentarily falls due to increment in load at t=2s, and again gets restored by the controller, while the load current decreases at t=1s and increases at t=2s .

6.2 Simulation results for Grid connected scheme :

There is no need of mode transition in this scheme . PV is always operated in MPPT mode .Accordingly the grid current gets adjusted to maintain the power balance .

6.2.1 Single load operation

PV operates at MPP, delivering maximum power. PV operates at 1 kW/m2 with current at MPP Impp = 3.69A. load connected is 40W, 19.4VAr.

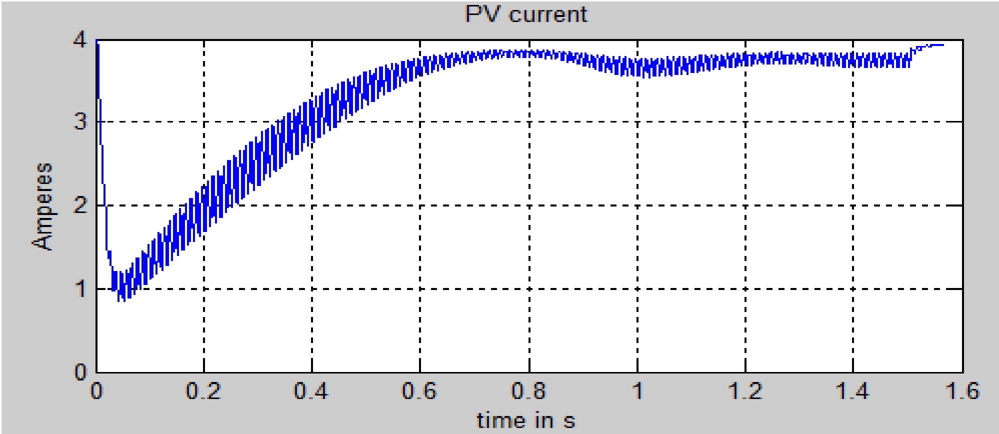


Fig. 6.26 PV current for grid connected scheme

From graph it can be seen that PV is operating at MPP thus delivering maximum power . As power produced by PV is more than required by load thus excess power is fed into grid .

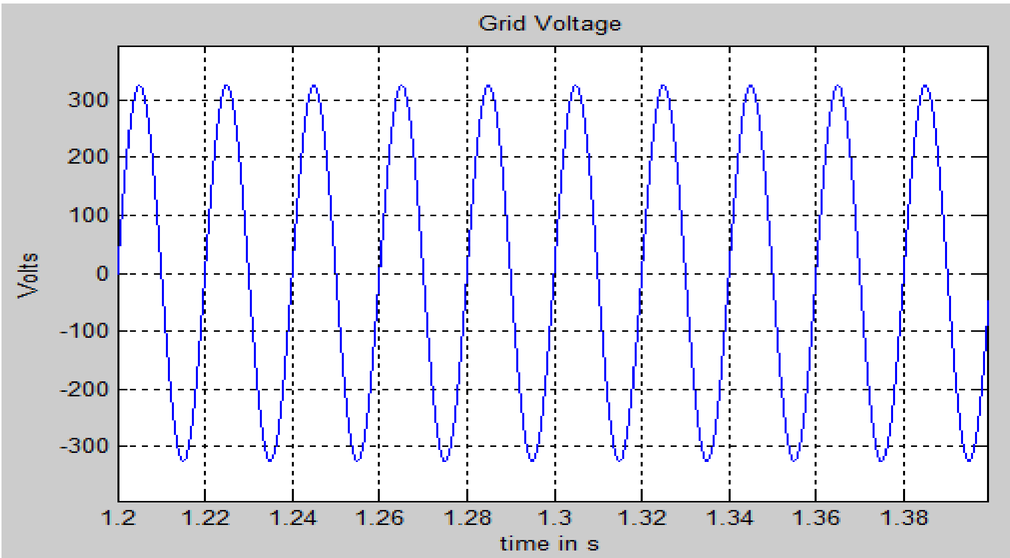


Fig. 6.27 Grid voltage for grid connected scheme

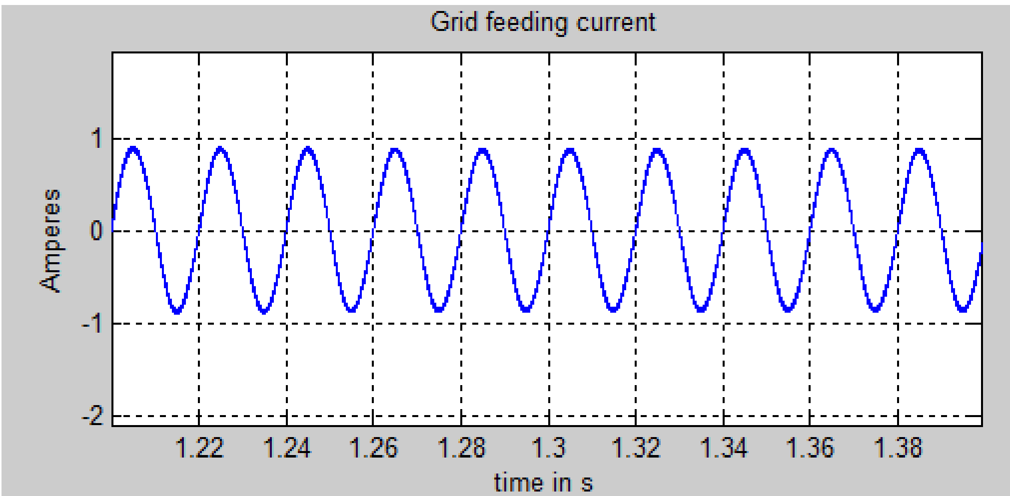


Fig. 6.28 Current fed to grid

From graph it can be seen that current fed to grid is in phase with grid voltage which means real power transfer to grid .

6.2.2. Step Change in Load

Actual cabin/office loads as modelled earlier are used .

To have variation in load , these are applied to system in step form .

t < 1.5s	-	Tube light
1.5s < t < 3s	-	Tube light + Fan
t > 3s	-	Tube light + Fan + PC

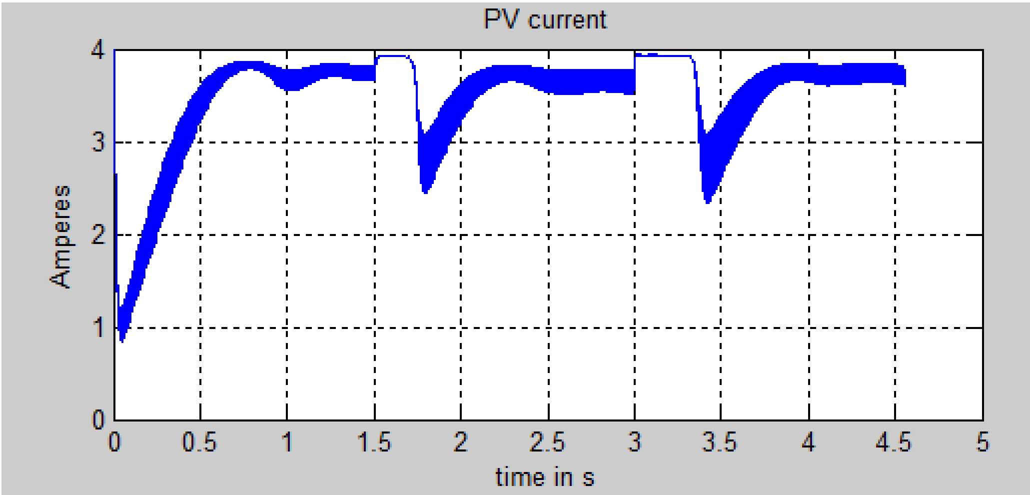


Fig. 6.29 PV current under load variation for grid connected scheme

as can be seen in graph , that due to controller action PV is operating at MPP irrespective of load variation .

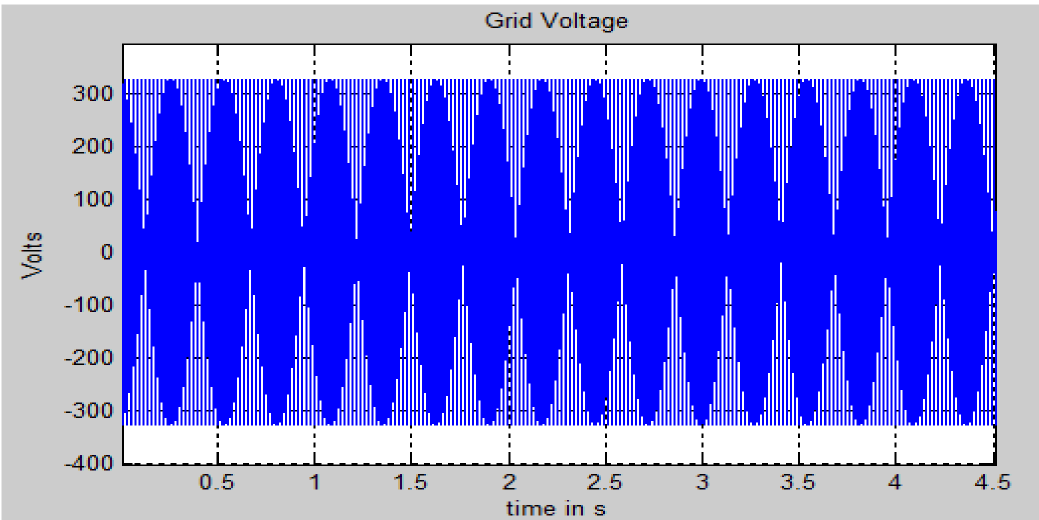


Fig 6.30 Grid voltage under load variation for grid connected scheme

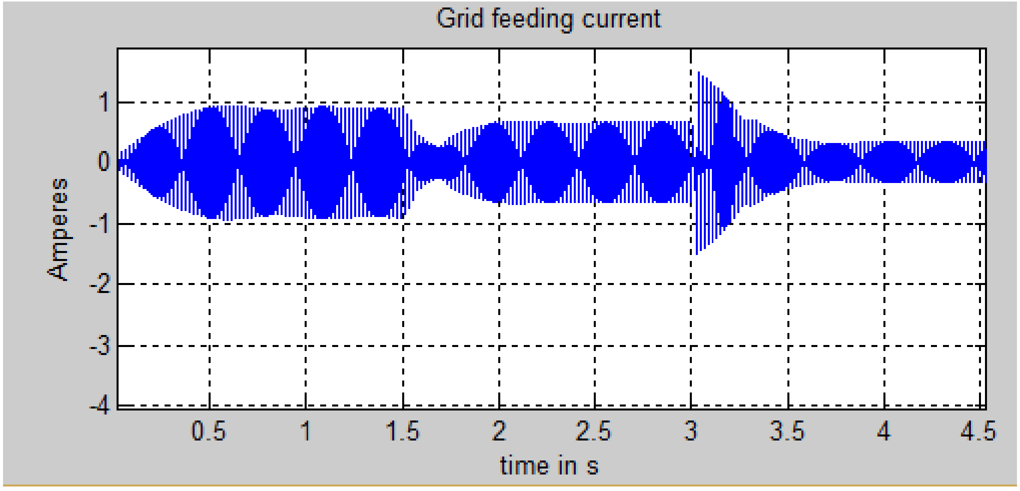


Fig. 6.31 Current fed to grid under load variation for grid connected scheme

As can be seen in graph , that as load increases current fed to grid decreases . And when all three loads are connected PV power is not sufficient so current is drawn from grid to satisfy the load requirement .

6.3 Experimental Validation

Hardware implementation is ongoing and the results obtained are presented here :

6.3.1SPWM unipolar inverter

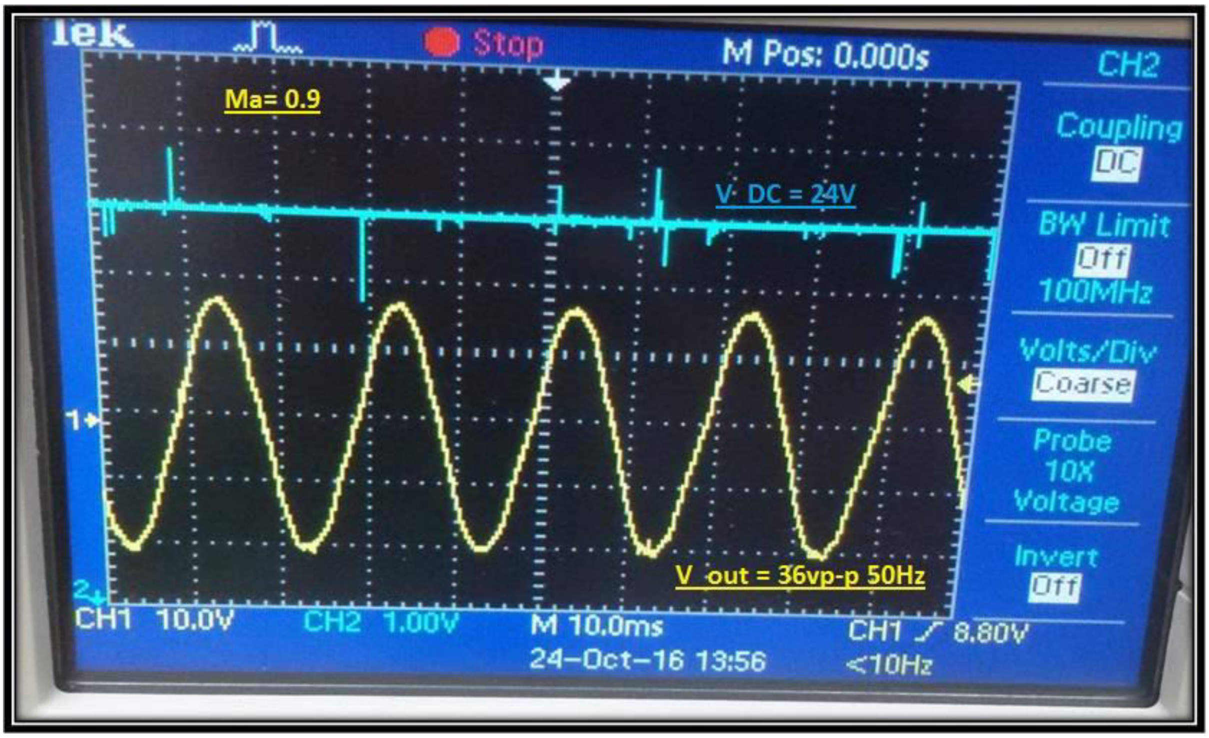


Fig 6.32 SPWM Inverter implementation

As seen in the above image , that DC voltage from DC power supply gets converted into AC sinusoidal voltage . Output is verified for various input DC voltages and various modulation indices .

6.3.2Enhanced Phase Locked Loop (ePLL)

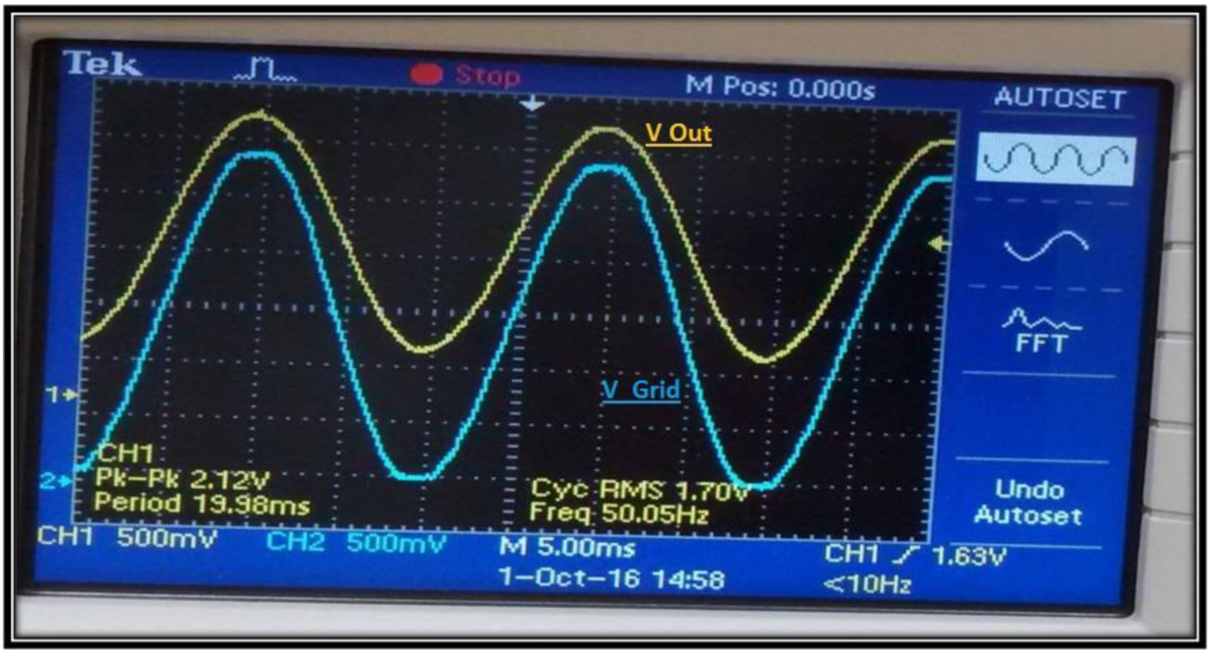


Fig 6.33 ePLL implementation

Actual grid voltage is sensed by DSP , then ePLL algorithm is applied on it to obtain unity , clean sinusoidal waveform in phase with grid voltage .

As can be seen in graph , result obtained is as desired .

Chapter 7

Conclusion and Future Work

7.1 Conclusions

The task of this project is to develop a reliable, efficient configuration for Grid integrated PV Based Single Phase Power Generating Unit for Urban Household Application with a battery as an energy storage element and with a control method for the proposed configuration. From the above chapters and from the results of the simulation and experimental studies, it can be observed that the proposed configuration, with the control method, has the ability to operate successfully under different operating conditions.

For standalone scheme in MPPT mode of operation, the PV boost converter has the ability to operate the PV at MPPT successfully while the battery converter is capable of responding quickly to maintain the dc link voltage. In non-MPPT mode of operation, the battery converter charges the battery with a constant current while PV maintains the load demand by maintaining the dc link voltage and by supplying the power necessary to charge the battery with a constant current. The control method proposed has successfully performed under various sudden load variation . Observation of these results depict that the control method is robust enough to maintain the dc link voltage for the inverter while controlling the battery charging/discharging in a reliable manner.

For grid integrated scheme ,results depict that the proposed topology along with control scheme is robust enough to extract maximum power from PV and ensure unity power factor operation at grid under various sudden load variation.

7.2 Future Work

Hardware implementation of above schemes is still ongoing .Main things to complete hardware are as follows :

a) Using Solar emulator in place of constant voltage power supply.
b) Integrating with grid power supply.
c) Testing actual loads like fan , PC , LED tube light .

Once the basic hardware is completed then focus can be shifted to increase efficiency of system . Firstly by efficient designing of the high frequency transformer and inductors using soft magnetic material and low resistive conductors .Secondly by reduction of switching frequency(down to 5 kHz), and using soft switching techniques .

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