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Simulation and Analysis of Photo-Voltaic (PV) based Solar Inverter System

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***Abstract*—The energy demand in the world is steadily increasing and new types of energy sources must be found in order to cover the future demands, since the conventional sources are about to be emptied. One type of renewable energy source is the photovoltaic (PV) cell, which converts sunlight to electrical current, without any form for mechanical or thermal interlink.**

A photovoltaic (PV) based 500W solar inverter system is developed which consists of PV Array, battery bank and solar inverter cum charge controller. The system works on both Solar and AC mains power depending on the energy requirement.

The goal of this project is to Simulate, design, develope and analyzes the PV based inverter system. Simulation of solar cell is carried out in MATLAB/SimElectronics which can be used to analyze photovoltaic panel in varying atmospheric conditions. The inverter is MOSFET drive H Bridge PIC controlled single phase SPWM.

The system is tested on resistive and inductive load. Voltage/current waveform analysis, power quality and FFT analysis is carried out by using power quality analyzer as well as load sharing between photovoltaic array and battery, battery and mains supply is done.

***IndexTerms*— PWM-pulse width modulation, SPWM-Sinusoidal Pulse Width Modulation, PV- Photo Voltaic**

I. INTRODUCTION

Considered as one of the most luxuriant renewable energy, solar energy has its own unique superiority and tremendous potential in development and utilization. According to the various energy conversion ways, solar energy is mainly applied in the following three fields: solar-heat conversion domain (Solar water heaters, solar heat power generation etc.), solar-electricity conversion domain (Photovoltaic power generation etc.) and solar biology conversion domain (Photo biological hydrogen production etc.).Among them, PV power generation is the prime style of solar utilization.

Control methods and power management strategies of a Photo-Voltaic based inverter system are primarily discussed in this paper. System structure and working modes are analyzed in detail firstly, then control methods of the inverter in the system and power management tactics are made, at last, simulation based on Matlab/Simulink and experiment of the prototype are executed to verify the theoretical analysis.

II. SYSTEM STRUCTURE AND OPERATIONAL MODES

The topologic structure of the management PV system is shown in Fig.1, which consists of PV panels, batteries, load, and the inverter which connects the terminals.

There are two operational modes in the system according to the different working statuses of PV panels, battery and mains supply.

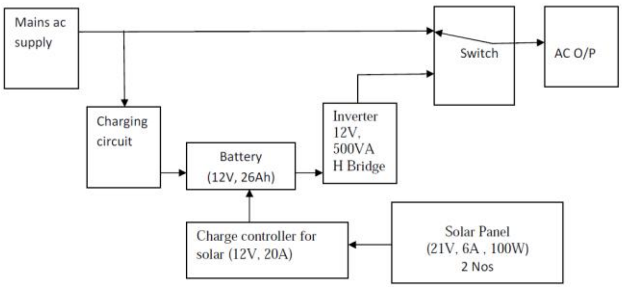

Fig. 1: Basic Block Diagram of Solar Inverter System

Inverter system can basically operate in two different modes as:-

A) Inverter Mode:

When AC mains supply fails then relay switches to battery and Inverter will operate in Inverter mode. When it is connected to mains voltage it is in charging mode and battery is in charging condition. We can change the charging C/N.

B) Charging Mode:

System Operates in Charging Mode when either the AC mains supply or the solar energy or both are available.

When mains is available:

The system detects that AC mains supply is available and it gives the signals to triac driver which controls the gate pulses given to triac. Due to the gate pulses the Output vtg of triac is controlled which in turn controls the charging current given to the battery. The o/p of triac is connected to the transformer which is operated as step-down transformer and it gives 12V and required charging current at the secondary which charges battery.

When the solar energy is available:

The panel o/p is given to the battery with a diode connected in between the positive terminals of the panel and the battery. Because of this the feedback from battery to the solar charging kit will not be there as the diode will be in reverse biased mode. Thus battery is totally charged by solar power and in this mode if mains is available then load is totally driven by it.

III. MATLAB SIMULATION

In the given paper simulation of solar cell and total inverter system is carried out.

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PV array simulation

Usually the solar cells are modelled using a specific type of equivalent circuit a photovoltaic model is based on diode behavior, which gives to photovoltaic cell its exponential characteristic. In Simulink® the solar cell can be modelled with three modeling systems [9]. The solar cell from MATLAB® 7.13 (2011b) is a solar current source, which includes solar induced current and temperature dependence [10].This block allows choosing one of two models: a model with 8 parameters in which describes the output current, and a model with 5 parameters if for this equation is applied the following simplifying assumptions: the impedance of the parallel resistor is infinite and the saturation current of the second diode is zero. The model with 5 parameters allows optimization of this block according to the equivalent circuit model parameters or by short circuit current and open circuit voltage [10].

The model shown in Figure 2 represents a PV cell array connected to a variable resistor. This resistor has an input ramp which just varies resistance linearly in closed circuit until it reaches the 30th steps. In the present project ELDORA 100 POLY CRYSTALLINE SOLAR PV MODULES are used. These modules consist of 36 cells with 18 in series and 18 in parallel. Thus the array subsystem consist of 6 rows of photovoltaic solar cells connected in series and parallel, formed by 6 solar cells of SimElectronics® library (Figure 3). This structure can be built in any configurations by connecting multiple strings of solar cells in series or in parallel [10].Control of solar radiation is realized by Signal Builder block.

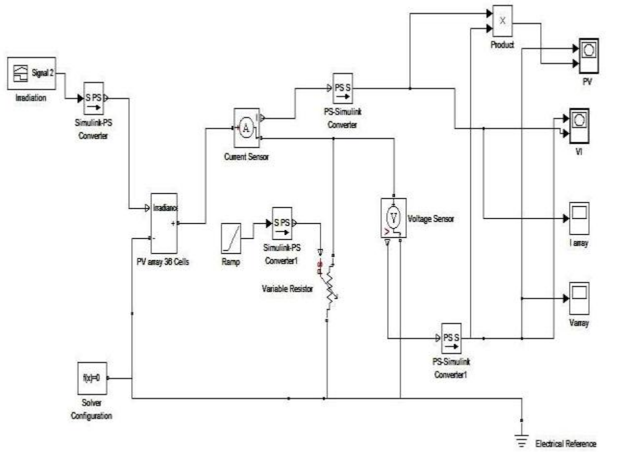

Fig. 2: Simulink model of PV array.

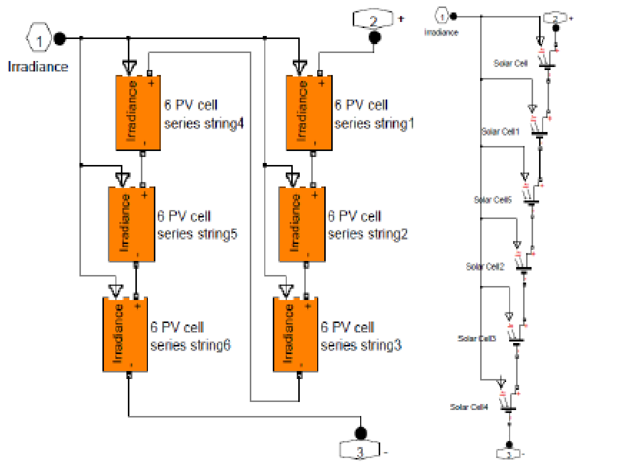

Fig. 3 Connection of solar cells in PV panel subsystem

The advantage of using of this high level of implementation is to create a simple equivalent circuit, which have much more complex parameters, including the effect of temperature in the device which is very important for behavior of this type of system. The photovoltaic panel model is validated by simulating at a value of irradiance of 1000 W/m^2 and a temperature of 25°*C*.

Parameter	Value
Short-circuit current [A]	Isc =3.12
Open -Circuit voltage [v]	Voc=1.2
Quality factor	N=1.5
Series resistance [Ω]	Rs=0
First order temperature coefficient for Iph	TIPH1=0
Temperature exponent for Rs,	TRS1 = 0
Parameter extraction temperature	25°C
Fixed circuit temperature	TFIXED=25°C

I-Parameters of Solar cell in MATLAB Simulink

The V-I and V-P characteristics of the photovoltaic array is given in Figure 4 and Figure 5. The V-I curve represent the standard behavior of the photovoltaic cell and photovoltaic array respectively.

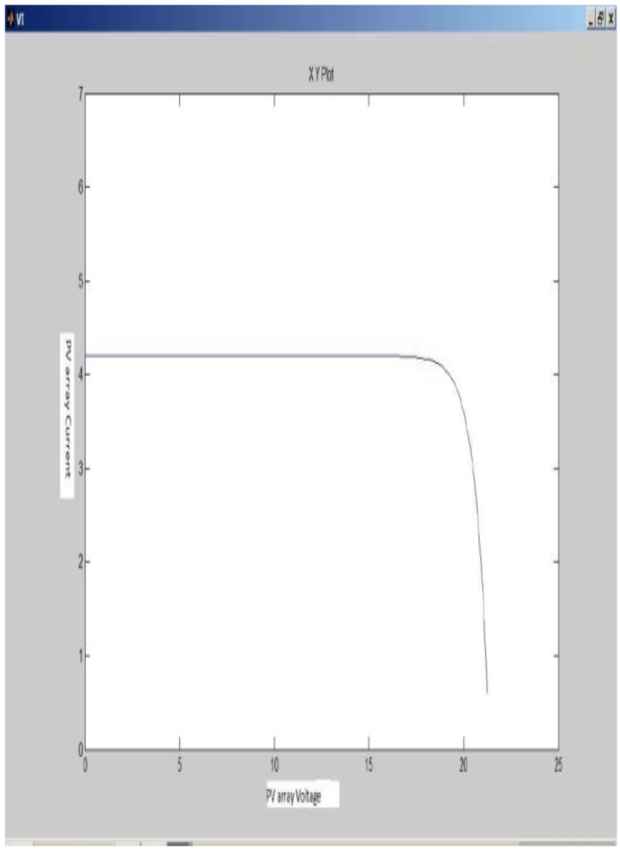

Fig. 4: V-I characteristics of photovoltaic array

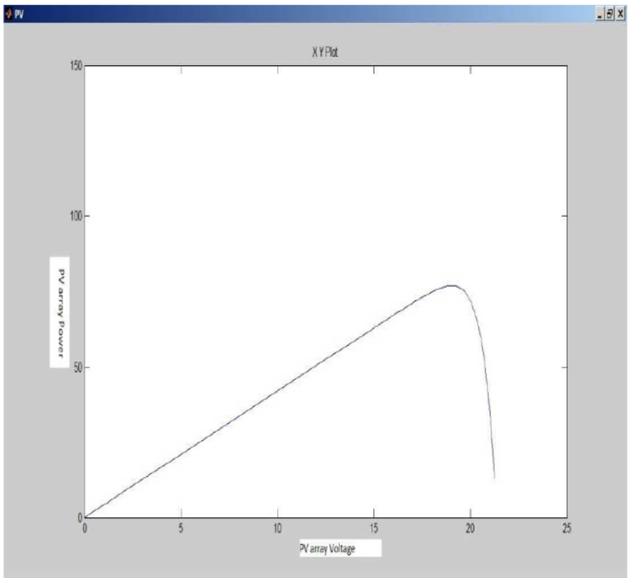

Fig. 5: V-P characteristics of the photovoltaic array

Simulation of total solar inverter system

The simulation of total solar inverter system is shown in Figure 6. The solar cell array and battery is connected with two MOSFET based inverter which further connected to the load through single phase transformer. The two MOSFET based bridges are used as the inverter operating voltage is low and are connected in parallel with each other. The battery is lead acid 12V 26Ah. The PWM Generator block is used to fire single-phase bridge. The pulses are generated by comparing a triangular carrier waveform to a reference modulating signal. The pulses are produced at 20KHz switching frequency with carrier frequency of 36KHz.The universal bridge is implemented as MOSFET based inverter with parameters as Snubber resistance -1ohm,Snubber capacitance -47microfarad and on state resistance – 8 milliohm.

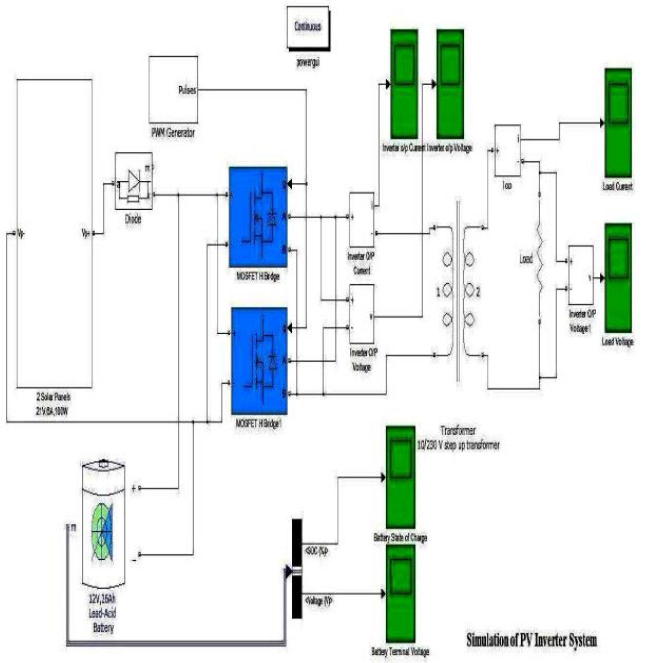

Fig. 6: Simulation of Solar inverter system

IV. SIMULATION RESULTS

MATLAB Simulation at different rating load is carried out.

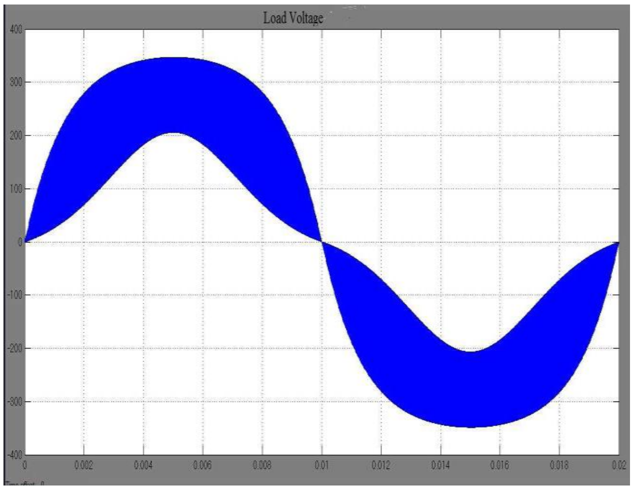

Fig. 7: System output voltage in Volts at 500 W resistive load with parallel combination of battery and PV panel

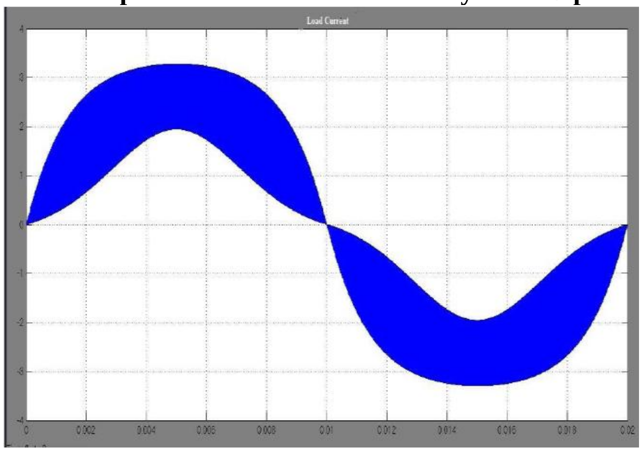

Fig. 8: System output current in amperes at 500 W resistive load with parallel combination of battery and PV panels

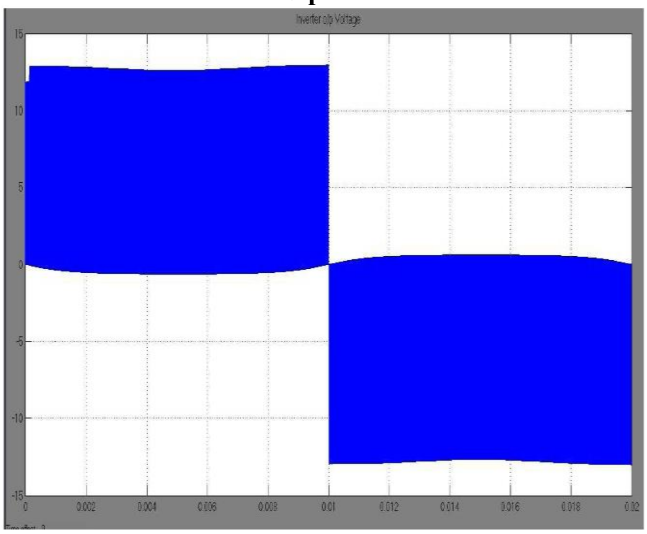

Fig. 9: Inverter output voltage in volts with PV and Battery connected at 500W resistive load

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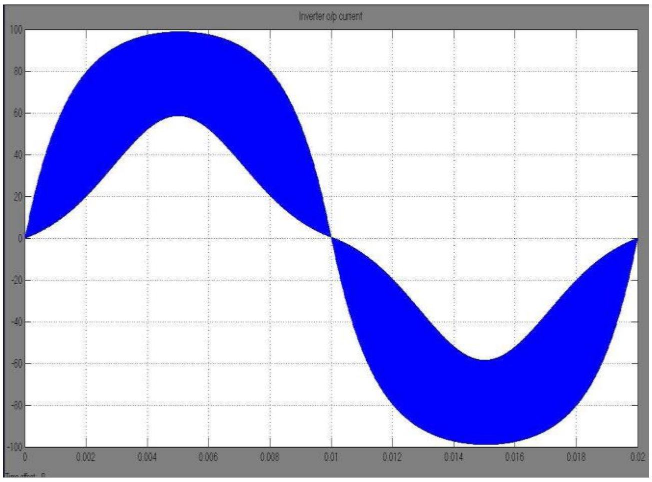


Fig. 10: Inverter output current in amperes with PV and Battery connected at 500W resistive load

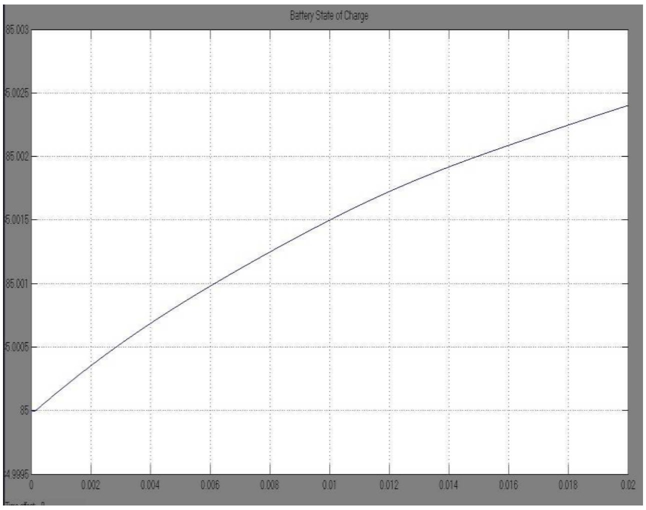


Fig. 11: Battery state of charge in percentage when connected to PV panel at 500W resistive load

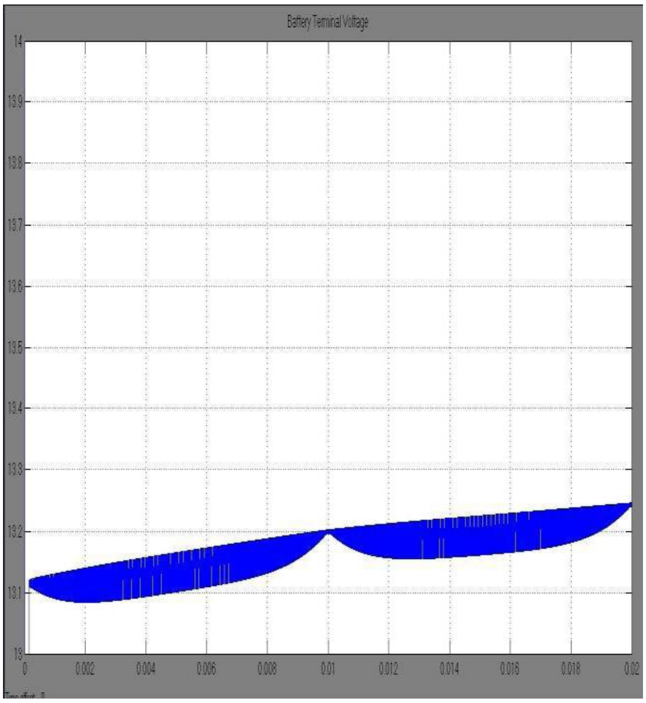


Fig. 12: Battery terminal voltage in volts when connected to PV panel at 500W resistive load

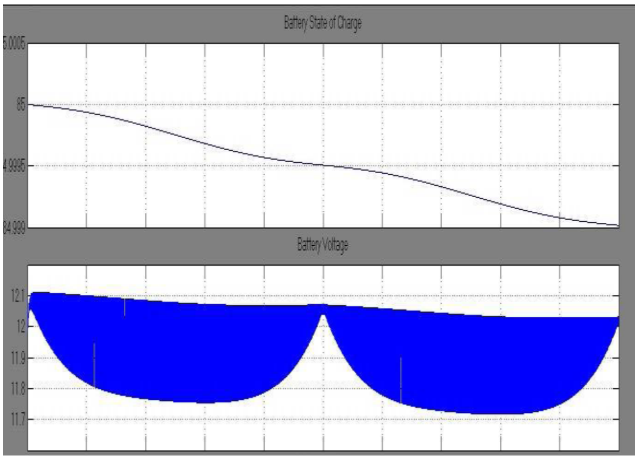


Fig. 13: Battery terminal voltage in volts and state of charge without PV panel at 500W resistive load

Sr. No	Load Condition	Simulated Values		Measured Values	
		O/P Voltage(V)	O/P Current(A)	O/P Voltage	O/P Current
1	500 W	235	2.32	220	2.25
2	200W	255	1.1	219	0.95
3	40W	270	0.25	222	0.2

II- Simulated and measured values at different rating load

From figure 12 it can be concluded that when battery and PV panel drive load battery goes in charging mode battery terminal voltage as well as state of charge increases, Figure 13 shows that when the battery alone connected to load its voltage as well as state of charge decreases.

V. TESTS AND MEASUREMENTS

The results of the different tests at different loads carried on the inverter system.

The whole system is tested in lab thus a 0-30V, 25A regulated DC supply is used as a PV array. The hardware set up with different components is shown Fig 14. The test results are used for detail analysis of load sharing between the different sources like battery, PV array and Mains AC supply.

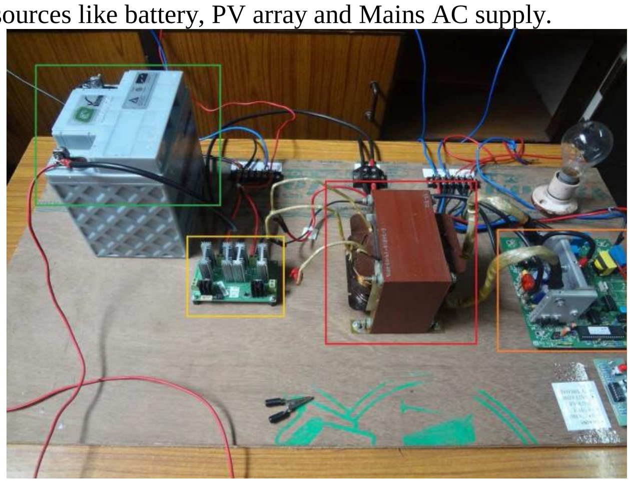


Fig. 14: Practical hardware setup of system

Load sharing between PV array and Battery

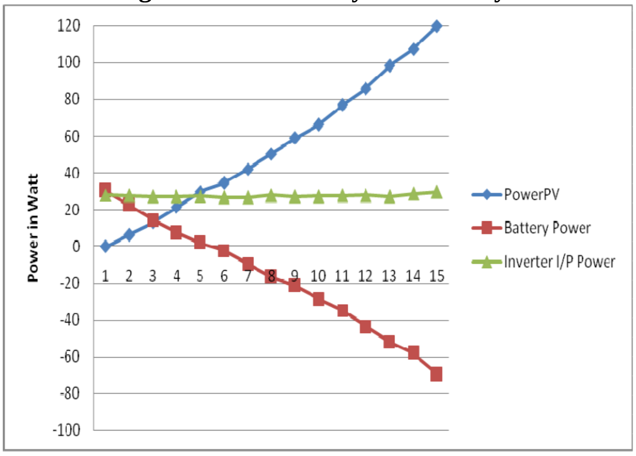


Fig. 15: No Load sharing between PV and battery

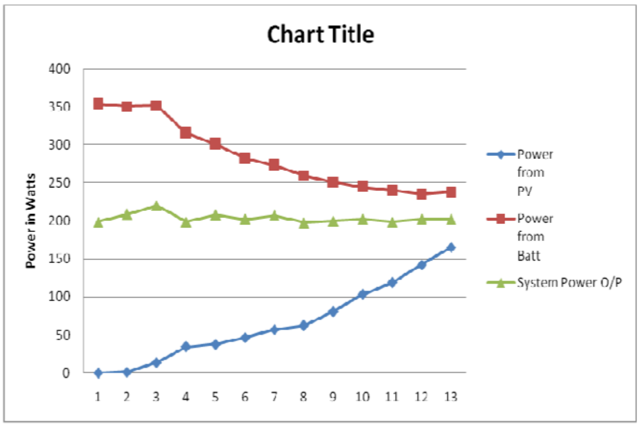


Fig. 16: 200W load sharing between PV and battery

Load sharing between PV array, battery and mains AC

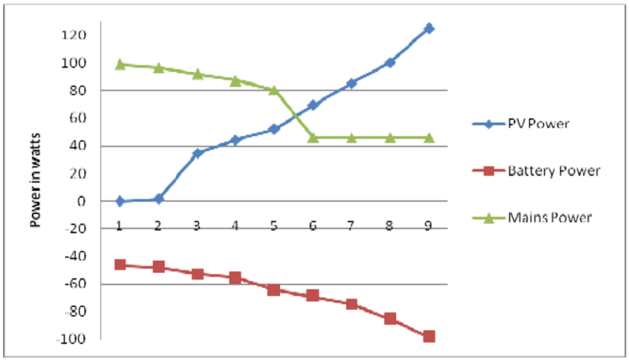


Fig. 17: No Load sharing between PV array, battery and mains

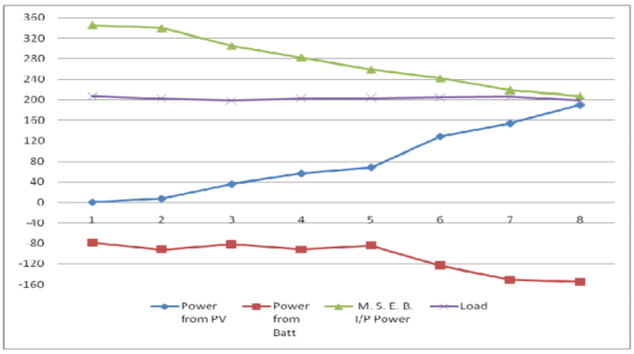
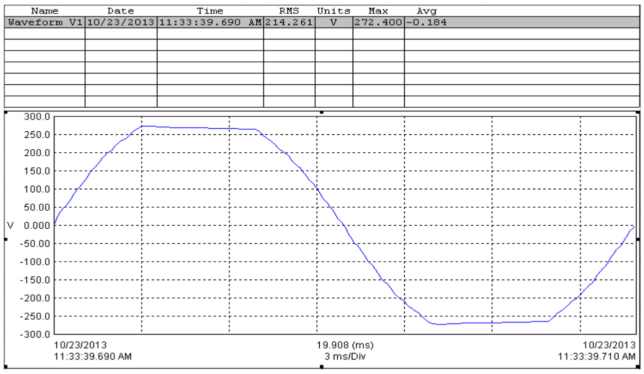


Fig. 18: 200W load sharing between PV array, Battery and Mains

From Fig.15 to Fig.18 it can be seen when system is running with battery and PV array as input the load is shared by both of them. When solar power exceeds it charges battery and supply power to load also. When system is running on mains it battery is in charging mode where as in this condition is solar power is available then battery is charged by solar power rather than from mains.

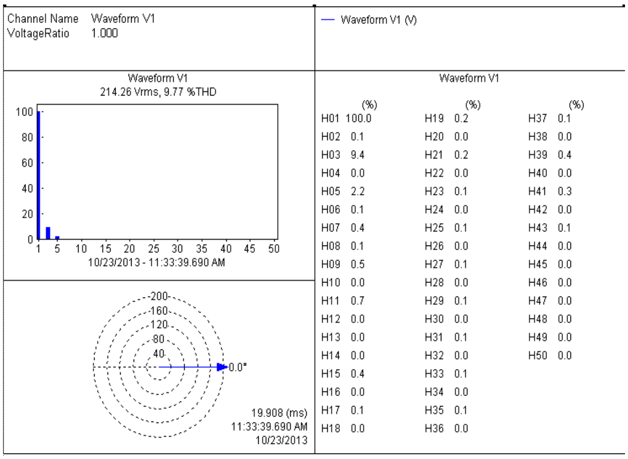
Test results by Qualistar Three Phase Power Quality Analyzer

At 500W resistive load



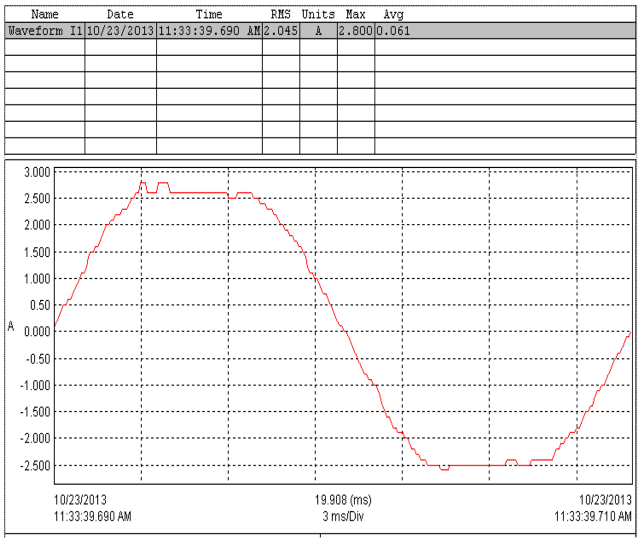
Name	Date	Time	RMS	Units	Max	Avg
Waveform V1	10/23/2013	11:33:39.690 AM	214.261	V	272.400	-0.184

Fig. 19: Inverter system output voltage waveform with R.M.S value of 214V



	(%)		(%)		(%)
H01	100.0	H19	0.2	H37	0.1
H02	0.1	H20	0.0	H38	0.0
H03	9.4	H21	0.2	H39	0.4
H04	0.0	H22	0.0	H40	0.0
H05	2.2	H23	0.1	H41	0.3
H06	0.1	H24	0.0	H42	0.0
H07	0.4	H25	0.1	H43	0.1
H08	0.1	H26	0.0	H44	0.0
H09	0.5	H27	0.1	H45	0.0
H10	0.0	H28	0.0	H46	0.0
H11	0.7	H29	0.1	H47	0.0
H12	0.0	H30	0.0	H48	0.0
H13	0.0	H31	0.1	H49	0.0
H14	0.0	H32	0.0	H50	0.0
H15	0.4	H33	0.1		
H16	0.0	H34	0.0		
H17	0.1	H35	0.1		
H18	0.0	H36	0.0		

Fig. 20: THD in output voltage waveform 9.77% with less harmonic contents



Name	Date	Time	RMS	Units	Max	Avg
Waveform I1	10/23/2013	11:33:39.690 AM	2.045	A	2.800	0.061

Fig. 21: Inverter system output current waveform with R.M.S value of 2.04A.

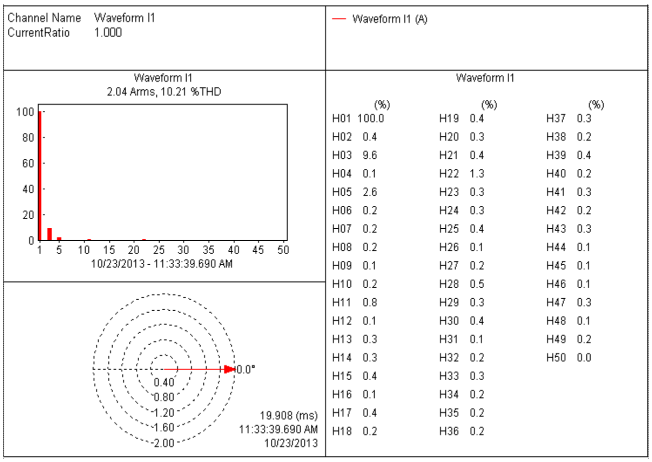


Fig. 22: THD in output current waveform 10.21% with odd harmonic contents

At 50W universal motor

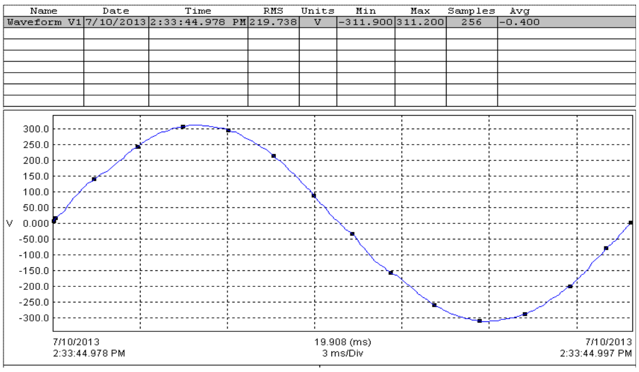


Fig. 23: Inverter system output voltage waveform with R.M.S value of 219V

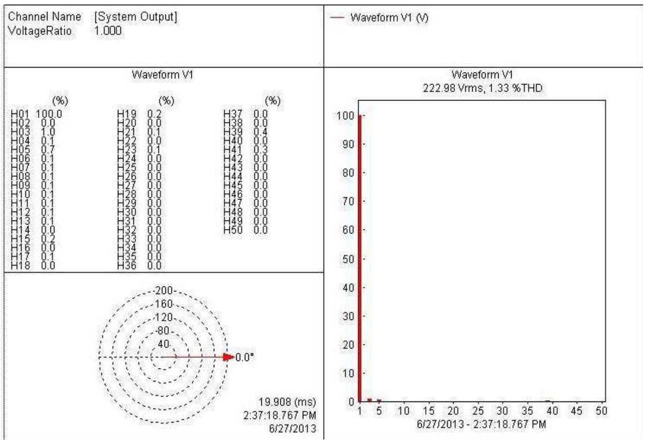


Fig. 24: THD in output voltage waveform 1.33% with less harmonic contents

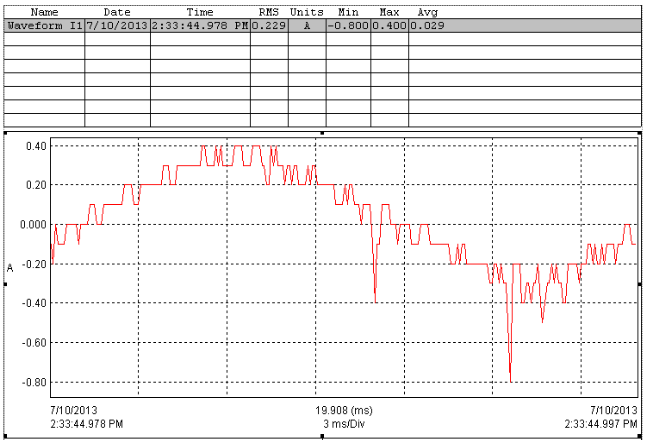


Fig. 25: Inverter system output current waveform with R.M.S value of 0.229A

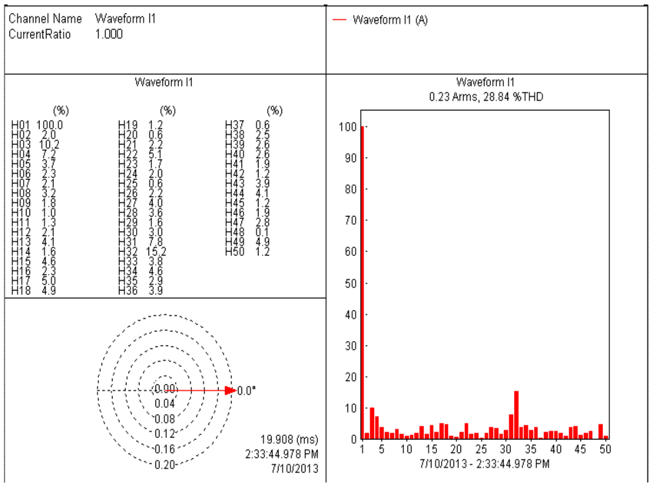


Fig. 26: THD in output current 28.84% with harmonic contents

VI. CONCLUSION

The Simulations were carried out as well for validating the design of the board as to compare the built system with its simulation model. Several readings have been taken and analyzed to validate the load sharing between the different energy sources at constant load. The final system works satisfactorily and tested with power analyzer for determining THD and it is found within range 1.25%.With 50W universal motor load the distortion of the current waveform with THD of 28.84% is found.

In the future, a more detailed model of the photovoltaic module can be developed from the one presented in this work. The more detailed model may take into account the effect of shading or partial shadows on the operation of the module. Also the effects of scaling up the photovoltaic sources may be investigated to determine the suitability for large scale deployment. Also control strategies in load sharing between mains and solar can be added which will includes the minimum power consumption from mains when ample solar energy is available.

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