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Home Energy Management System Based on Solar Power System

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Abstract—*In this paper a system is proposed which control the power from photovoltaic (PV) cell, energy storage battery and grid. The PV module is connected to battery and inverter by a DC-DC boost converter which is control by incremental cost conductance method for MPPT. When the load is less and we have surplus energy from PV module the battery is in charging mode and the power requirement of load is compensated by PV module. When load increases the power requirement compensated by grid and battery. The single phase VSI is connected to batter and PV side boost converter and is controlled by sinusoidal pulse width modulation (SPWM). Different performance index in MATLAB2016a is evaluated and shown. The experimental result shows that proposed system has expected performance.*

1. INTRODUCTION

Demand of electricity has been growing day by day but with the use of more and more fossil fuel environmental pollution is also increasing. So continuous efforts are being made to reduce pollution without affecting the supply of electricity. This lead to modernization of grid that transformed traditional power grid to smart grid. By the use of smart grid bidirectional interaction between power grid and user has been made possible. With the introduction of this technology of bidirectional interaction though efficiency and reliability of power system has increased but from the user point of view the main advantage is that they can adjust their energy consumption and participate into the Demand Response (DR) program to save their expenses by earning incentives.

With the introduction of smart grid continuous efforts are being made to improve power DR mechanism to build a two way interactive platform. Home energy management system (HEMS) is an extension of smart grid DR project on residential site. HEMS doesn't only improve the electricity efficiency by saving energy but also it provides support to the implementation of DR on consumer side that is the residential side. The main aim of HEMS system is to conserve energy, improve comfort level of consumer & also it aims to reduce cost.

As per the federal energy regulatory commission Domestic consumer side is the best place to reduce peak demand through the implementation of DR project so HEMS system is one of the best areas of research. Present researches are being made on intelligent meter, home area network, and automatic control technology and on HEMS scheduling.

2. MODELLING AND MATHEMATICAL FORMULATION OF DIFFERENT COMPONENT

There are four different system which combines make the whole system. These systems are PV array, DC-DC boost converter, bidirectional DC-DC converter, bidirectional voltage source inverter (VSI), battery storage system and load.

2.1 PV Array

A photovoltaic array is power generating unit which consist of many number of PV modules in series and parallel. The single diode model of PV cell is given in Fig. 1. In my experiment Tata Power Tata Power Solar System TP250MBZ module is taken. Its specification is given in Table 1.

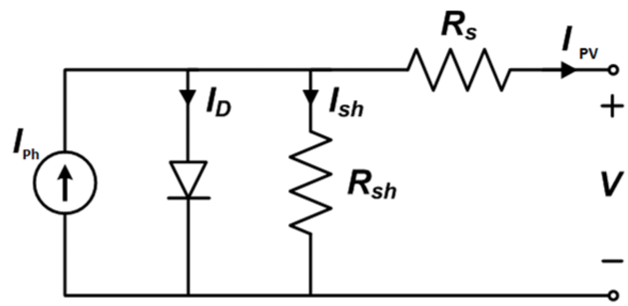

Fig. 1: Single Diode Model of photovoltaic cell

Table 1: PV Array Specification

Model	Tata Power Solar System TP250MBZ
P_{max}	249.86W
V_{oc}	37.6V
I_{sc}	8.55A
V_{mp}	31V
I_{mp}	8.06A
N_{Cell}	60

The irradiance distribution for this system is given as 600 w/m^2 at 25^0C.

$$I_d = I_0\left[\exp\left(\frac{V_d}{V_T}\right) - 1\right] \quad (1)$$

$$V_T = \frac{kT_{Cell}}{q} \times nI \times N_{cell} \quad (2)$$

$$V_{oc_T} = V_{oc}\left(1 + \beta\_V_{oc}\left(T - 25\right)\right) \quad (3)$$

$$I_{sc_T} = I_{sc}\left(1 + \alpha\_I_{sc}\left(T - 25\right)\right) \quad (4)$$

Where,

I_d = Diode current (A)

V_T = Thermal Voltage (V)

V_d = Diode voltage (V)

I_0 = Diode saturation current (A)

nI = Diode ideality factor a number close to 1.0

K = Boltzmann constant = 1.3806e-23 J/K

Q = Electron charge = 1.6022×10^{-19} C

T_{Cell} = Cell temperature (K)

N_{Cell} = Number of cells connected in series in a module

V_{oc} = Open-circuit voltage at 25^0C

V_{oc_T} = Open-circuit voltage at temperature T^0C

β_V_{oc}= Temperature coefficient (in $\%/^0C$)

T = Temperature in ^0C

I_{sc} = Short-Circuit current at 25^0C

I_{sc_T} = Short-Circuit current at temperature T^0C

α_I_{SC} = Temperature coefficient (in $\%/^0C$)

2.2 DC-DC Boost Converter

As we know the terminal voltage of photovoltaic cell is very low so for required level of voltage at VSI terminal and at bidirectional DC-DC converter terminal boost converter is used. The control signal for this boost converter is generated by maximum power point tracking (MPPT) algorithm. There are lots of MPPT algorithm is available in text [] such as perturb and observed method (P&O Method), incremental conductance method (INC), Fractional Short Circuit Current (I_{SC}), Fractional Open Circuit Voltage (V_{OC}) etc. The most commonly used method is P&O and INC algorithm. In my application P&O method is used.

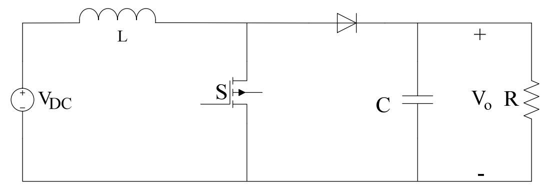

Fig. 2: Boost Converter Circuit Diagram

The output voltage of DC-DC boost converter is given as

$$V_0 = \frac{V_{DC}}{1 - D} \quad \text{In Ideal Condition} \quad (5)$$

$$V_0 = V_{DC}\left[\frac{1 - D}{\frac{r}{R} + (1 - D)^2}\right] \quad \text{In Practical Condition} \quad (6)$$

Where,

V_0 = Output Voltage

V_{DC} = Input Voltage

D = Duty Ratio

r = Inductor Resistance

R = Load Resistance

In P&O MPPT algorithm the present power output is compared with previous value and pulse is generated.

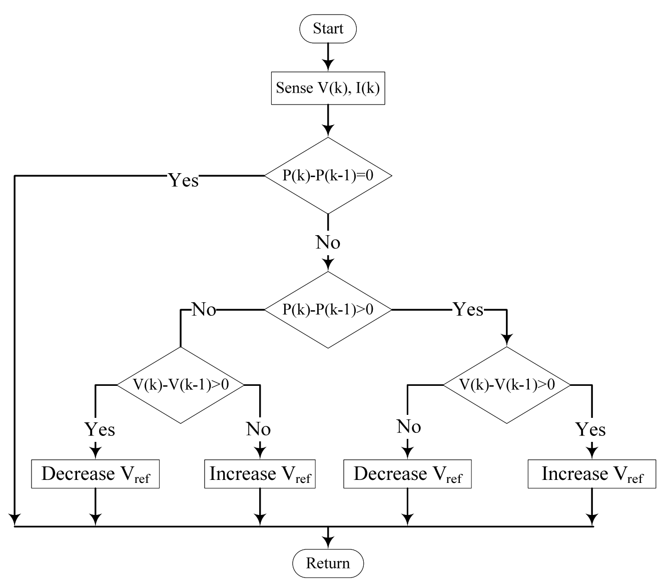

Fig. 3: P&O MPPT Algorithm Flow Chart

2.3 Bidirectional DC-DC Converter

Bidirectional DC-DC converter is used where bidirectional power flow is required. It is possible to control DC-DC converter in different modes such as voltage mode control (VMC), average current mode control (ACMC), or peak current mode control (PCMC). Here we use a DC-DC converter which acts a buck converter during charging of battery and it acts a boost converter during discharging operation. This feature of DC-DC converter is achieved by combining buck & boost converter model by replacing diode to a high frequency controlled semiconductor switch such as MOSFET or IGBT with anti-parallel diode.

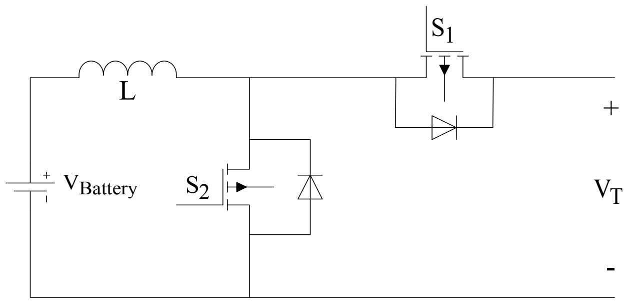

Fig. 4: Bidirectional DC-DC Converter

This converter can acts as both boost and buck in discharging and charging period respectively. When S_1 is operated converter acts as buck converter and battery is in charging mode. When switch S_2 is operated converter acts as boost converter. The output is given as follows

$$Vo = \frac{V_{Battery}}{1-D} \quad \text{Boost Converter} \tag{7}$$

$$Vo = V_{Battery} \times D \quad \text{Buck Converter} \tag{8}$$

2.4 Bidirectional VSI

Bidirectional Inverter is basic 1-Ph VSI combined with diode bridge rectifier (DBR). For charging of battery, supply is given from PV and from grid. For charging from grid the diode bridge rectifier is used. When there is no power supply from PV, the power supply form battery and grid. When the PV system power is not used in load then it is used in charging of battery and fed to grid via VSI. The VSI is controlled by sinusoidal pulse width modulation (SPWM). The SPWM controller module is composed of phase locked loop (PLL), voltage regulator, and current regulator. By changing modulation index we can change total harmonic distortion (THD).

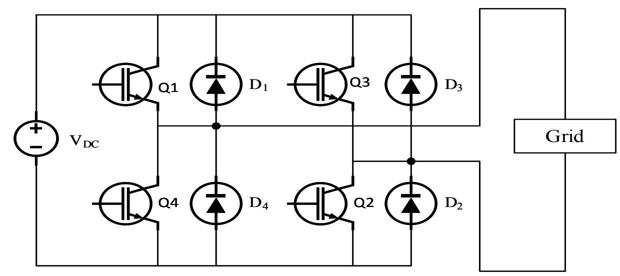

Fig. 5: Bidirectional VSI

$$V_{rms} = V_{DC} \text{ RMS voltage output of VSI} \tag{10}$$

$$V_{rms} = \frac{V_m}{\sqrt{2}} \text{ RMS voltage output of DBR} \tag{11}$$

$$V_o = \frac{2 \times V_m}{\pi} \text{ Average voltage output of DBR} \tag{12}$$

$$\text{Modulation Index (m)} = \frac{\text{Magnitude of Reference Wave}}{\text{Magnitude of Careere Wave}} \tag{9}$$

3. SIMULINK MODEL

The block diagram of proposed system is given in Fig. 6. This proposed system has two load each of 3 KW and is scheduled to connect with system at different time.

The Simulink model of PV array system, DC-DC boost converter, bidirectional DC-DC converter, bidirectional VSI is given in Fig. 7, Fig. 8, Fig. 9 and Fig. 10 respectively.

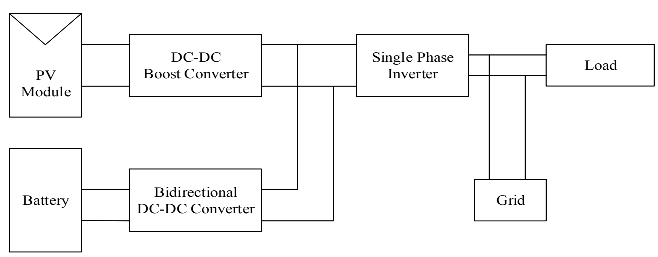

Fig. 6: Block Diagram of Proposed System

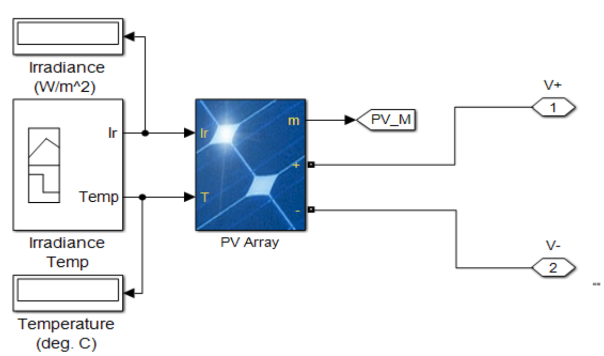

Fig. 7: PV Array Model

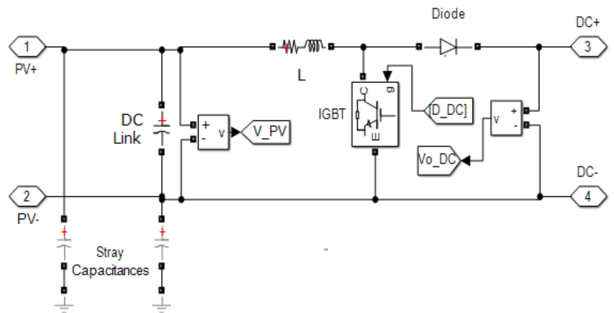

Fig. 8: DC-DC Boost Converter Model

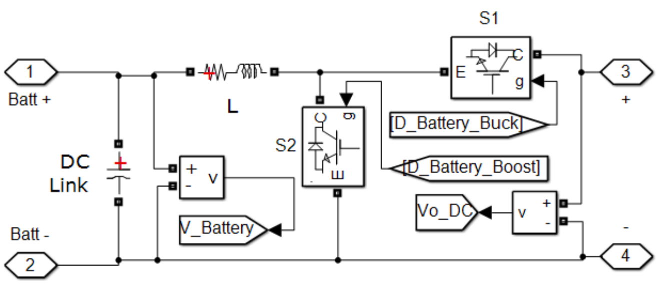

Fig. 9: Bidirectional DC-DC Converter Model

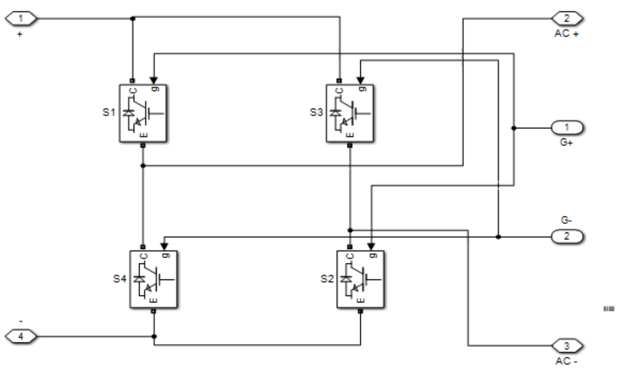

Fig. 10: Bidirectional VSI Model

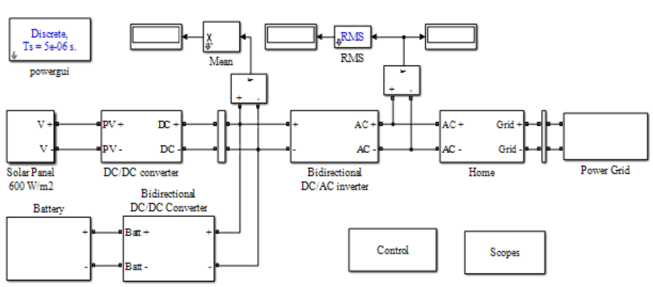

Fig. 11: Complete Simulink Model of HEMS Based on Solar SystemBy combining all the above model the full Simulink model of proposed system is given in Fig. 11.

4. SIMULATION RESULTS

The simulation is done on MATLAB2016a Simulink program and the output waveform of proposed system is as follows

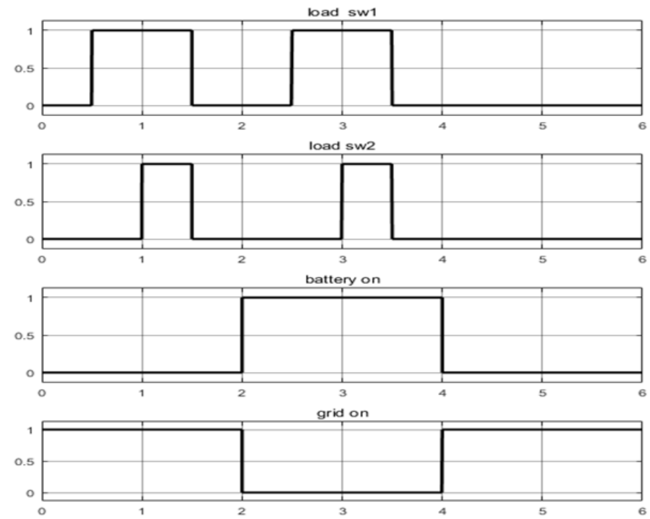

Fig. 12. Load, Battery and Grid Switching Sequence

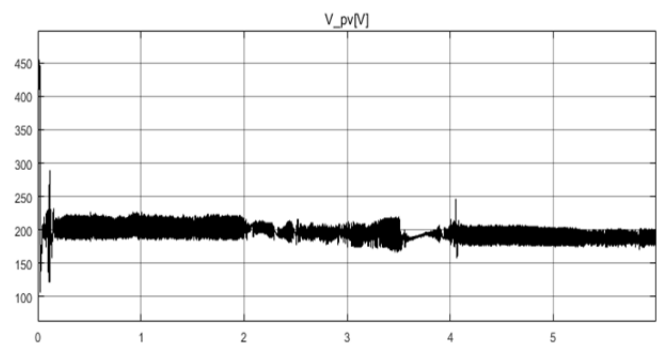

Fig. 13. PV Cell Terminal Voltage

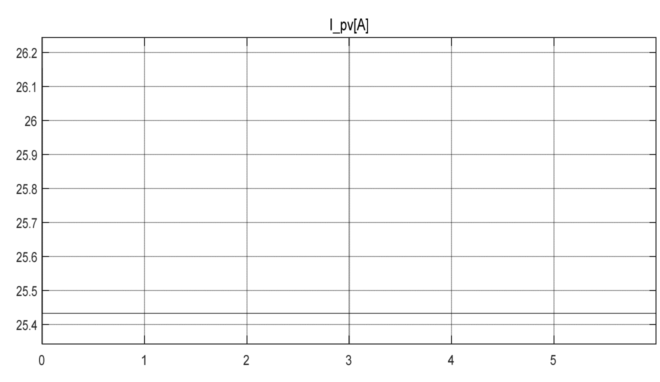

Fig. 14. PV Cell Output Current

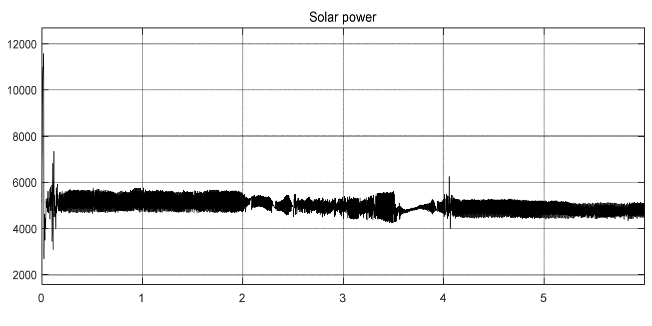

Fig. 15. Power Generated By Solar Cell

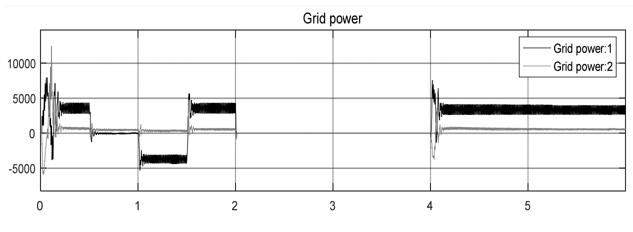

Fig. 16. Power or Supply to Grid

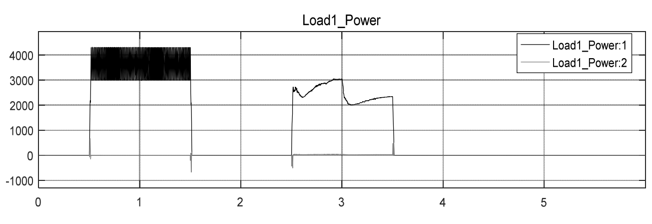

Fig. 17. Load-1 Power Consumption

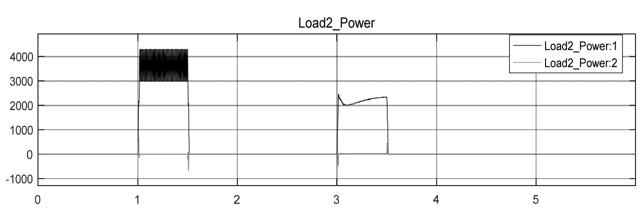

Fig. 18. Load-2 Power Consumption

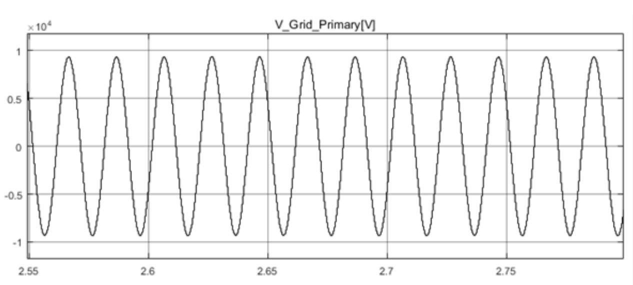

Fig. 19. Grid Voltage

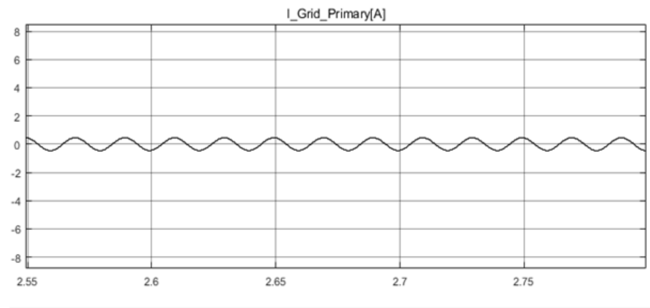

Fig. 20. Grid Current

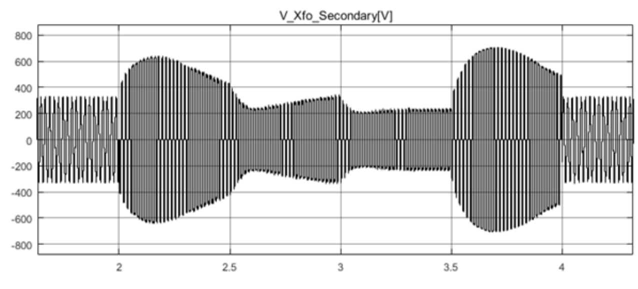

Fig. 21. Transformer Secondary at VSI Terminal

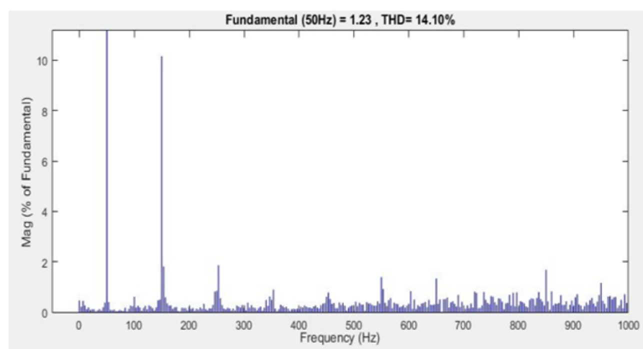

Fig. 22. THD in Load Current

The output of VSI is passed through a low pass LC filter with cutoff frequency of 200Hz. So that the distortion to supply system is less and THD of system is limited to lower value. The output waveform of system is at 230V, 50Hz is given above.

5. CONCLUSION

The HEMS based on solar system has been designed and its performance is simulated under condition of varying irradiance and load disturbance condition. It is observed that this system gives the expected performance at rated condition. It is observed that the grid voltage harmonic have THD = 0.49% and this is in permissible limit as per IEEE-519 standards. This system effectively utilize solar power, battery power and grid power as per requirement and gives an alternative solution to utilize more power from solar power and if required then depends on grid power supply.

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