

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 7, July 2017

Modelling and Simulation of Intelligent UPS for Grid

Asim Chaulagain¹, Narayan Mainali², Santosh Dhakal³, Subrat Aryal⁴, Dr. Nava Raj Karki⁵

Bachelor Students, Department of Electrical Engineering, IOE Central Campus Pulchowk, Lalitpur, Nepal^{1, 2, 3, 4}

Associate Professor, Department of Electrical Engineering, IOE Central Campus Pulchowk, Lalitpur, Nepal⁵

ABSTRACT: This project presents a multi-functional Intelligent UPS system for grid, which is composed of a three phase fully controlled rectifier, grid and PV as power source, Lead Acid Battery and an IGBT inverter. Along with the basic functions of a traditional UPS system, the proposed UPS system adds up with a new control strategy that incorporates renewable energy like PV in order to make the system more Greener. The system eliminates the use of buck converter and a new approach for battery charging has been proposed. The operating principle and system configuration of the proposed UPS system are analysed, and control strategies and algorithms are proposed. The proposed system is simulated in MATLAB/SIMULINK and the simulation results verify the credibility and productiveness of the proposed system and its control strategy. This research could assist in acquiring some valuable references in design sectors of next-generation electrical equipment in smart grid.

KEYWORDS: Control Strategy, dq Theorem, Multi-functional, Power Grid, Renewable, Uninterruptible Power Supply.

I. INTRODUCTION

The need for the continuous supply of electrical energy has been a most need in the present scenario. The recent technologies and equipment completely depend upon the continuous supply of power. Different sectors like industrial states, communication systems, hospitals and medical centres are classified as critical consumers where there should be continuous electrical energy. The one of the easiest solution for the continuous supply of electrical energy is UPS. Uninterruptible power supplies (UPSs) simply provides back up power to load in case of power failure and these systems are widely used to provide clean and continuous energy supply to critical loads. Due to the ability to supply power to the critical load, as well as the continuous shift from normal to backup mode and vice versa, and the decoupling capability of the utility and the load under power outage, the development of on-line UPS has flourished and thrived rapidly in recent years.

In the context of Nepal, our social development is being inhibited by inadequate energy supply. Although having capacity of generating 83,000 megawatts of electrical energy through its ample water resources, Nepal does not yet have strategy for sustainable and efficient energy use. This has resulted power supply being critical during the dry season and load shedding for several hours a day. Relying only upon water resources will not be sufficient and hence other renewable resources like Solar Energy should be integrated. Solar Energy, being the most promising field of Renewable Energy, is arguably the best solution for current energy crisis to an energy-wanting country like Nepal. If effectively connected to power grid with proper assimilation of energy storage equipment like battery, a continuous supply of electrical power can be achieved. This gives the idea of UPS using Solar Energy alongside grid which is the core study of this project.

Approaches were made to use Traditional UPS with the grid by Alternative Energy Promotion Centre (AEPC), Nepal but were not successful till now. Though Traditional UPS meet the continuous power supply demand, it doesn't involve correlation of power grid and renewable energies effectively. The Traditional UPS cannot limit the power supplied by

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Vol. 6, Issue 7, July 2017

the grid, which results in wastage of surplus power from the grid. Hence, instead of Traditional UPS system, new and improved version of UPS i.e. Intelligent Uninterruptible Power Supply (IUPS) is proposed. IUPS incorporate the use of renewable source of energy like Photo Voltaic system, Wind, etc. along with the grid. By doing so, the power from the grid can be limited and hence power can be utilized in an effective way. Power waste will minimize and there will be circulation of power between grid and load and also between renewable sources and load. If there is any failure in the power supplied in the grid, the backup UPS will provide the necessary power to the consumer/load. For this a storage battery is proposed and the battery is charged with the help of Photo Voltaic Arrays (PV) and also from the grid. The main advantages of using Intelligent UPS system over traditional UPS system is that it is simpler, effective and is less cheap. In the mean time we can easily interface the renewable energy sources as well as interface distributed generation easily.

II. LITERATURE SURVEY

The initiation of this project “Modelling and Simulation of Intelligent UPS for Grid” was done referring various thesis papers, journals, websites and books and the final concept was devised. At the initial phase, the different types of UPS used in present context were studied. According to the International Electrotechnical Commission (IEC) Standard 62040-3, a variety of design approaches are used to implement UPS systems, each with distinct performance characteristics and are categorized into three different types: offline, line interactive, and online [1], [2], [3], [4], [5] and [7]. The idea of IUPS was obtained from these researches and implementing those ideas, the proposed system was made. The topological configuration of IUPS is similar to Double Conversion On-line UPS.

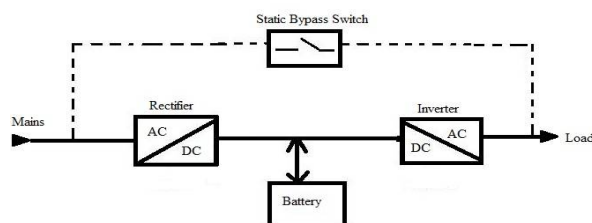


Fig.1 Double Conversion On-line UPS

III. PROPOSED SYSTEM

Intelligent UPS is designed in such way; it will operate in the different multifunctional modes according to the necessary conditions. Figure 2 shows the block diagram of the proposed IUPS.

International Journal of Innovative Research in Science, Engineering and Technology

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Vol. 6, Issue 7, July 2017

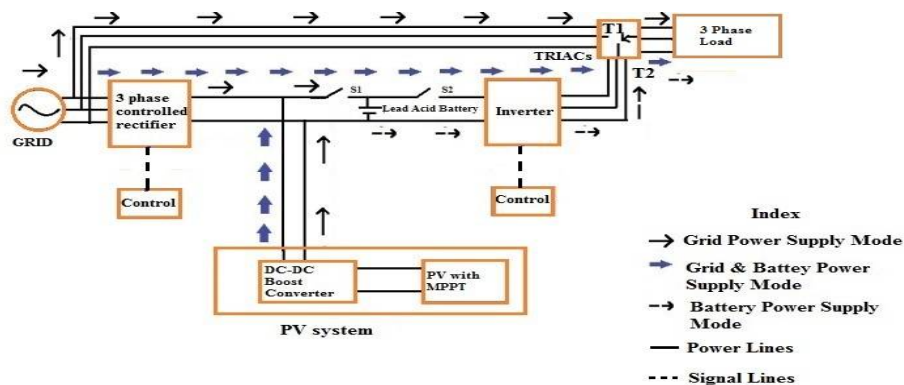


Fig.2 Schematic Diagram of Proposed System

The proposed system consists of two power sources; one is grid and another is Photo Voltaic (PV) system consisting of a 10KW PV array with Maximum Power Point Tracking (MPPT) system and a dc-dc boost converter, a three phase fully controlled rectifier for ac-dc conversion, an IGBT inverter for dc-ac conversion, TRIACs (T1 and T2) as bypass switch, IGBT switches (S1 and S2), a lead acid battery for energy storage and three phase load. The IGBT switches and TRIACs are used in order to demonstrate the three different modes of operation of IUPS.

Mode 1: Grid Power Supply Mode

In this mode of operation, switch S1 is closed and Switch S2 is open. The Grid supplies the power to the load via bypass switch i.e. T1. At the same time, ac-dc conversion takes place via rectifier and the battery charges from the dc link of grid and PV. Figure 3 shows the mode 1 operation of IUPS.

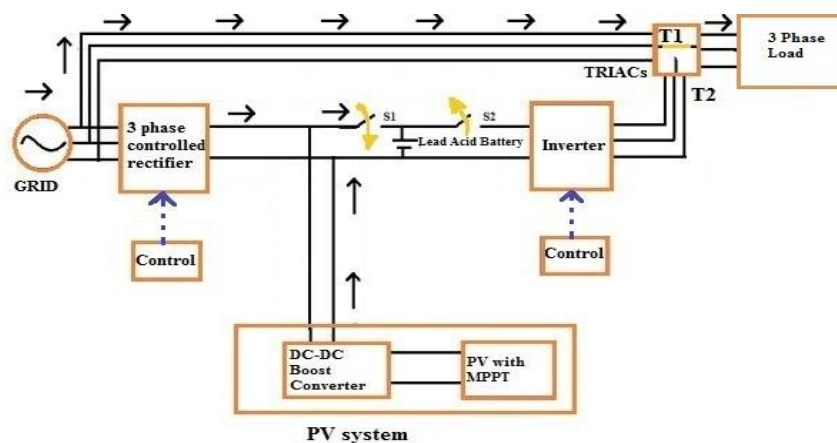


Fig. 3 Grid Power Supply Mode

Mode 2: Grid and Battery Power Supply Mode

In this mode of operation, both switches S1 and S2 are closed. The bypass switch between grid and load (T1) is switched off and bypass switch between load and inverter (T2) is switched on. Ac-dc-ac conversion takes place following the path grid-rectifier-dc link-inverter-load. Thus, the dc link supplies power to the load via inverter and also battery charges from the dc link. Figure 4 shows mode2 operation of IUPS.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 7, July 2017

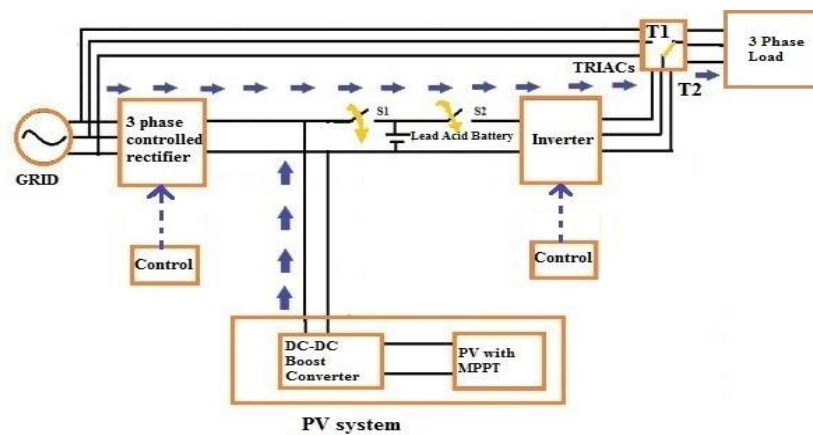


Fig. 4 Grid Power Supply Mode

Mode 3: Battery Power Supply Mode

In this mode switch S1 is opened and S2 is closed. The battery discharges and supply power to the load via dc-ac conversion through inverter. Figure 5 shows the mode 3 operation of IUPS.

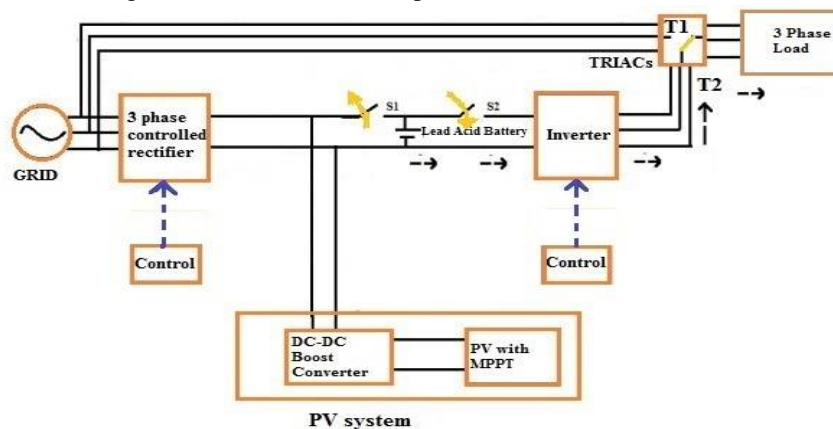


Fig. 5 Battery Power Supply Mode

IV. PROPOSED CONTROL STRATEGY

1. CONTROL OF PHOTO VOLTAIC SYSTEM

For the operation of the proposed IUPS system, the power from PV Array has to be kept maximum i.e. maximum power from the PV array is to be tracked and for that Incremental Conductance Method [9] is used. In Incremental Conductance Method, the array terminal voltage is always adjusted according to the MPP voltage; it is based on the incremental and instantaneous conductance of the PV module.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

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Vol. 6, Issue 7, July 2017

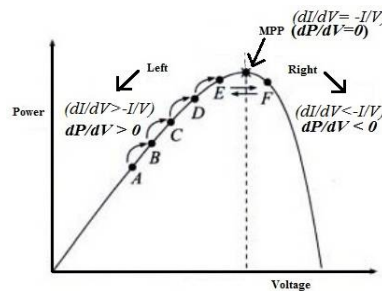


Fig. 6 Idea of incremental conductance method on a P-V curve of solar module

Figure 6 shows that the slope of the P-V array power curve is zero at the MPP, increasing on the left of the MPP and decreasing on the Right hand side of the MPP. The basic equations of this method are as follows:

$$\frac{dI}{dV} > -\frac{I}{V} \text{ then left of MPP} \dots\dots\dots (i)$$

$$\frac{dI}{dV} = -\frac{I}{V} \text{ then it is at MPP} \dots\dots\dots (ii)$$

$$\frac{dI}{dV} < -\frac{I}{V} \text{ then right of MPP} \dots\dots\dots (iii)$$

I and V are P-V array output current and voltage respectively. The left hand side of equations represents incremental conductance of P-V module and the right hand side represents the instantaneous conductance. When the ratio of change in output conductance is equal to the negative output conductance, the solar array will operate at the maximum power point. Depending on the result, the panel operating voltage is either increased, or decreased until the MPP is reached. The MPPT regulates the PWM control signal of the DC-DC boost converter [6], [10] until the condition: $\frac{dI}{dV} + \frac{I}{V} = 1$ is satisfied.

2. CONTROL OF THREE PHASE FULLY CONTROLLED RECTIFIER

The main principle of this control strategy is that if the irradiance of sun is high and SOC of the battery is also high i.e. PV power is high, the firing angle (α) for the rectifier is increased such that output current from the rectifier is low and if PV power is low, the firing angle is decreased such that output current from the rectifier is high. Table 1 shows the control of 3 phase fully controlled rectifier.

Table 1 Control Strategy of Rectifier

SOC (%)	Irradiance (W/m ²)	Firing angle (degree)
Greater than 70 (high)	Greater than 500 (high)	20
Less than 70 (low)	Less than 500 (low)	0
Greater than 70 (high)	Less than 500 (low)	5
Less than 70 (low)	Greater than 500 (high)	5

The value of firing angle thus set is given to PWM generator where it generates the gate pulses which are given to gates of thyristor used in 3 phase fully controlled rectifier. Figure 7 shows the basic block diagram of strategy for rectifier control.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 7, July 2017

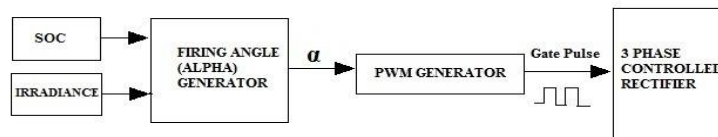


Fig. 7Block diagram of rectifier control

By such control, the current of the dc link is maintained almost constant and this constant current is used as a charging current for the Lead Acid battery.

3. CONTROL OF IGBT INVERTER

Figure 8 shows the block diagram for the control of IGBT Inverter. For the control of Inverter, dq theory [12] is used. In this method, the three phase ac voltages (V_a , V_b , V_c) are converted into two stationary dc voltages (V_d , V_q). The value of ωt (θ) for the conversion is given by Phase Locked Loop (PLL). A PLL is a control system that generates the output signal whose phase is identical to that of the input signal. The PLL that has been used in our proposed system is discrete PLL. The input frequency to PLL is given 50 Hz such that frequency can be controlled to 50 Hz. V_d and V_q are compared to respective reference values. The reference value V_{dref} is the input dc voltage to inverter while the value of V_{qref} is set to zero. As we are using voltage-frequency control method, the dc quantity V_d alone can represent the 3 phase ac rotating quantity and hence both active and reactive power can be controlled. The errors thus obtained are then fed to PI controller. PI generates V_d^* and V_q^* and dq-abc conversion gives new 3 phase ac quantities (V_a^* , V_b^* and V_c^*).

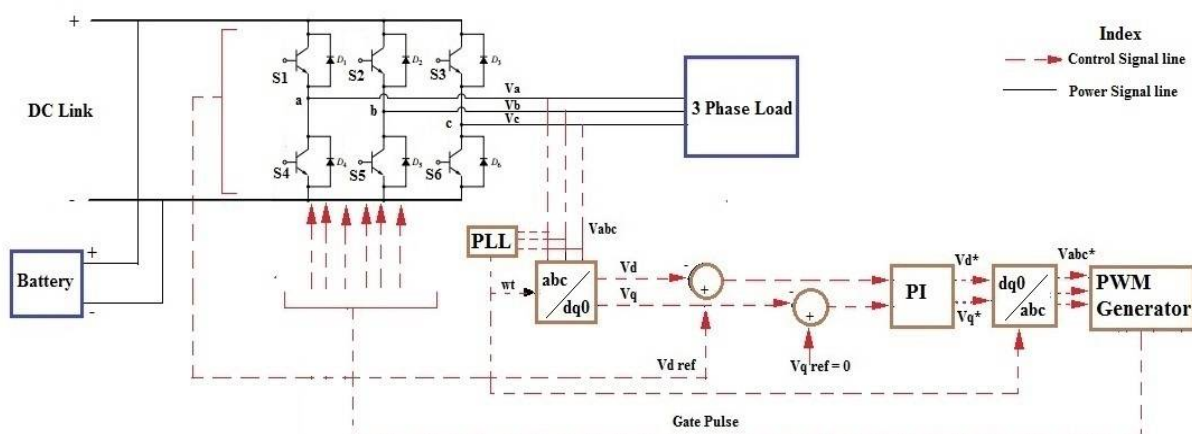


Fig. 8Block diagram of inverter control

Thus obtained sinusoidal voltage acts as a modulating signal for Sinusoidal Pulse Width Modulation (SPWM) where it is compared with Triangular carrier signal and gate pulse for each of the transistors are generated. The SPWM technique used is of 2-level SPWM. It is called 2-level SPWM because the gate pulses are to each of the transistor switches used in the inverter are generated by comparing two signals i.e. one sinusoidal signal and another triangular signal. Rather than 2-level SPWM, we can also use 3-level SPWM where three signals are compared to generate gate pulses but due to the simplicity of the technique, 2-level SPWM has been preferred in our proposed system.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 7, July 2017

4. CONTROL OF IGBT SWITCHES AND TRIACS

IGBT switches and TRIACs provides major role for the operation of mode selection of the system. With simultaneous opening and closing of these switches, the IUPS operates in 3 different modes. The IGBT switch S1 as show in Figure 2 deals with the battery charging operation. When S1 is closed, battery gets charged from the DC link and when S1 is opened, battery remains in standstill condition. Though Lead Acid Battery can be charged fully i.e. 100% SOC, for our simulation we have considered the maximum SOC of battery up to which it could be charged is 80.63% as simulation time is fixed just to 6 seconds. Until SOC of battery reaches 80.63%, the battery gets charged from the DC link. When SOC reaches greater than 80.63%, the switch S1 is opened, disconnecting the battery from DC link i.e. no further charging of battery takes place. The control mechanism of switch S1 can be easily understood from flowchart as shown in Figure 9.

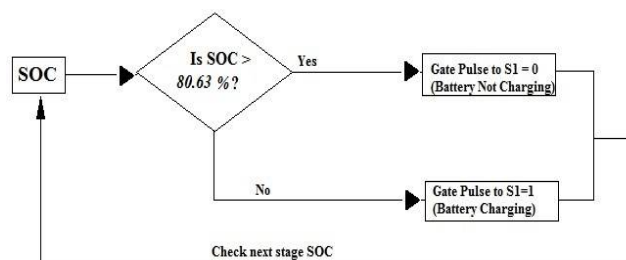


Fig. 9Flowchart showing the control mechanism of IGBT switch S1

The IGBT switch S2 is used in the discharging operation of the battery and connecting the circuit between the inverter and the battery. The minimum SOC of the battery is considered to be 80.2%. Below this value, we have assumed that battery do not have sufficient power to supply the load and hence cannot be discharged. The control strategy of the IGBT switch S2 can be clearly observed from the flowchart as shown in Figure 10.

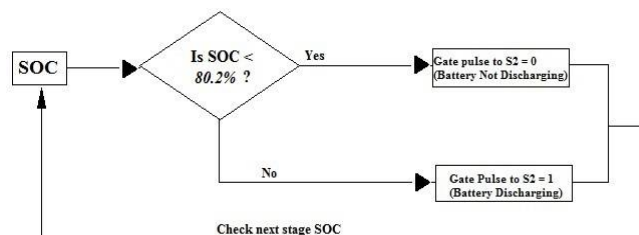


Fig. 10Flowchart showing the control mechanism of IGBT switch S2

The TRIACs T1 and T2 as shown in Figure 2 act as AC bypass switches. The control of these TRIACs are done in such a way that, wherever the grid voltage is minimum (less than 220V) or the grid failure occurs or SOC of battery is high, the firing angle (α) for T1 is set to 1800 i.e. T1 is not conducting or gate pulse to T1 is set to 0. In this same situation the reverse gate pulse to T2 is given. In other words, the firing angle (α) for T2 is set to 00 signifying that the T2 is fully conducting and hence power flows following the path Inverter-T2-load. When the grid voltage is sufficient (greater than 220V) or SOC of battery is low, the firing angle (α) for T1 is set to 00. Hence T1 is on and power flows following the path grid-T1-load. At the same time, T2 is closed i.e. firing angle for T2 is set to 1800. Figure 11 shows the control strategy of TRIACs T1 and T2.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 7, July 2017

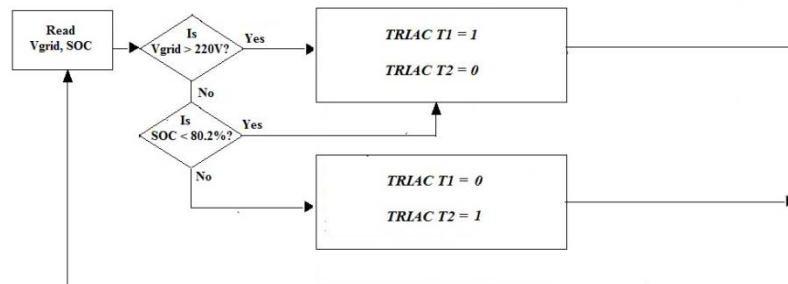


Fig. 11 Flowchart showing the control mechanism of TRIACs T1 and T2

V. SIMULATION AND RESULTS

The overall simulation was done in MATLAB/SIMULINK. Simulink is a block diagram environment for multi domain simulation and Model-Based Design. It supports simulation, automatic code generation, and continuous test and verification of embedded systems. The simulation time was set to 6 seconds. The solver used in our simulation is Ode45 and type is Variable-Step. The overall simulation model of the proposed system is shown in Figure 12. For simulation of the proposed system, following assumptions were made:

- A 3 phase source and step down transformer is assumed to be a power grid.
- Line capacitance is neglected.
- Initial SOC of battery is assumed to be 80%.
- The maximum SOC of battery is assumed to be 80.63% due to the time limitation of the simulation.
- The 3 phase CB is closed at time $t=1.5$ seconds such that load 2 is connected at that instant of time

Table 2 Components Rating

Power Grid Rating	Phase to Phase rms voltage	25kV
	Frequency	50 Hz
	3 phase Short Circuit level	10 MVA
	X/R Ratio	5
Step down Transformer Rating	Primary Side Voltage (rms)	25kV
	Secondary Side Voltage (rms)	220 V
	Connection Type	Delta-Star
PV Array Rating	No series connected modules per string (Nser)	6
	No of parallel strings (Npar)	5
	No of cells per module	66
	Module type	SunPower SPR-305-WHT
Battery Rating	Battery Type	Lead Acid
	Nominal Voltage	250 V
	No of cells in series	125
	Voltage per cell	2V
	Rated Capacity	1 Ah
	Maximum Capacity	5.38 Ah
	Maximum Battery Voltage	280V
	Initial SOC	80 %

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 7, July 2017

LC Filter Rating	Inductance	2mH
	Nominal voltage of Capacitance load	220V
	Frequency	50Hz
	Capacitive reactive power	3 kVAR
Load 1 and Load 2 Rating	Type	R, RL
	Nominal Voltage	220 V
	Frequency	50Hz
	Active Power and Reactive Power	10kW, 5 kW/5kVAR

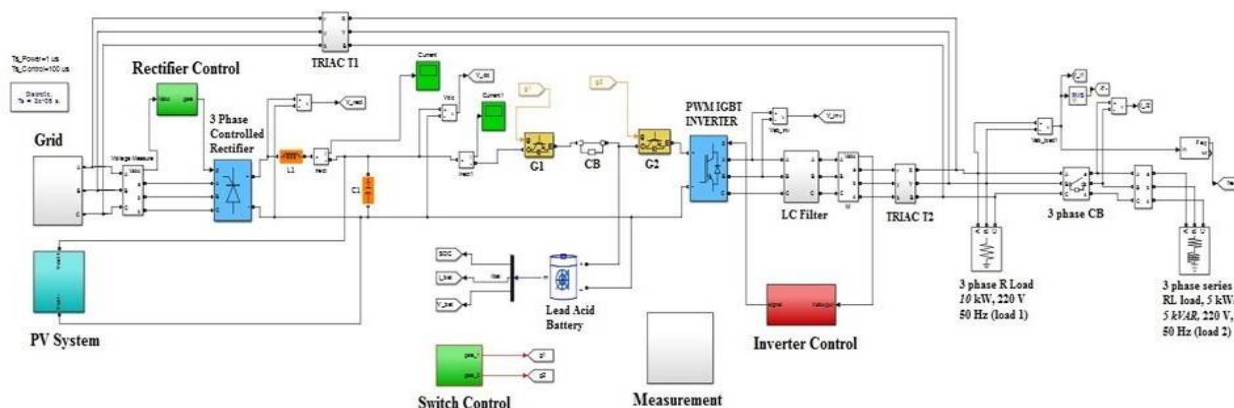


Fig. 12 Overall Simulation Block in MATLAB/SIMULINK

1. RESPONSE OF PV POWER, CURRENT AND VOLTAGE WITH SOLAR IRRADIANCE

The MPPT took certain time (0.6 sec) to track the maximum power. After that as irradiance changes, Power changes i.e. as solar irradiance is 1000 W/m², PV power is maximum (10 kW) and as solar irradiance decreases, power decreases and vice versa. The response of PV current is similar to that of solar irradiance. The PV voltage is maintained constant and at maximum value. At 5.3 seconds, mode 3 operation of IUPS takes place. Hence, switch S1 opens in this case and as a result of open circuit condition, PV voltage increases while PV current becomes zero and thus PV power becomes zero as show in Figure 13.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 7, July 2017

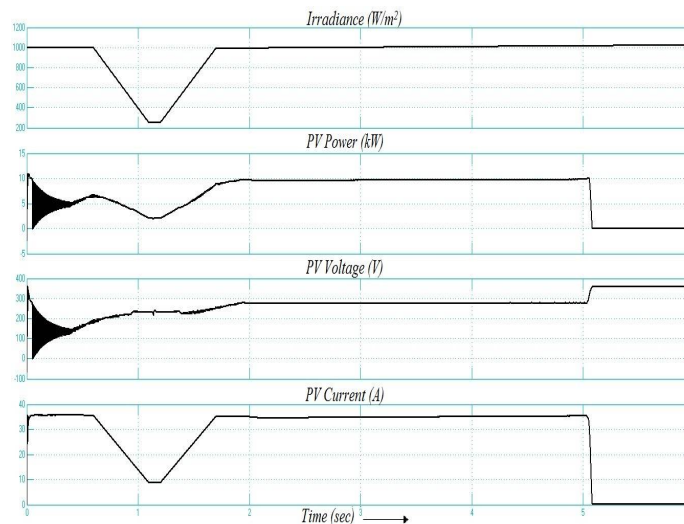


Fig. 13 Response of PV power, voltage and current with Solar Irradiance

2. RECTIFIER OUTPUT AS PER CHANGE IN FIRING ANGLE (α)

Figure 14 shows the waveform of rectifier current with the change in firing angle (α). For 0-1 seconds, SOC is less than 70% and Irradiance varies from 400-1000 W/m^2 . At that instant of time, firing angle (α) is set to 5 degree (medium value). The rectifier current is almost 12 A. For 1-1.3 seconds, both Irradiance and SOC are low. Thus at that instant of time firing angle is set to 0 degree (low value) and rectifier current increases to 16 A. For 1.3-4.2 seconds, firing angle is again 5 degree as $\text{SOC} < 70\%$ and Irradiance lies between 400-1000 W/m^2 . For 4.2-6 seconds, both Irradiance and SOC are high. At these instants of time, firing angle is set to maximum value i.e. 20 degree and rectifier current decreases to almost 11 A.

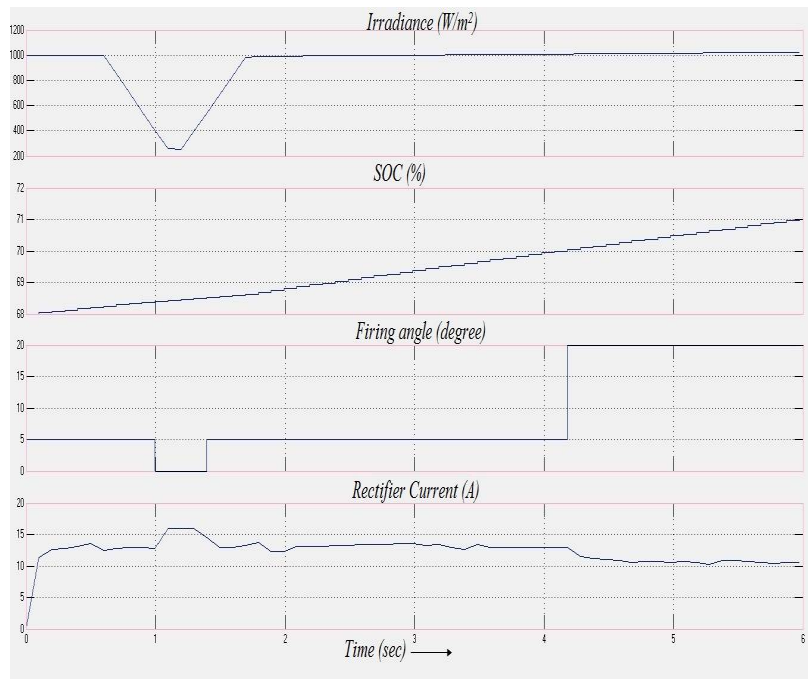


Fig. 14 Waveform of rectifier current in response to change in Irradiance, SOC and firing angle

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 7, July 2017

3. STATES OF IGBT SWITCHES AND TRIACS

Figure 15 shows the mode of operation of IUPS as per states of IGBT switches G1, G2 and TRIACs T1 and T2. During time interval of 0 - 1.2 seconds, $SOC < 80.2\%$. Hence, G1 is closed, G2 is opened, T1 is closed and T2 is opened. Hence, mode 1 operation takes place and power is supplied from grid and at same time battery charges. From 1.2 - 5.1 seconds, $80.2\% < SOC < 80.63\%$. Hence mode 2 operation takes place and power is supplied from grid via T2 and PV and battery also charges during this period. From 5.1 - 6 seconds, $SOC > 80.63\%$ and hence G1 closes and battery discharges and SOC decreases.

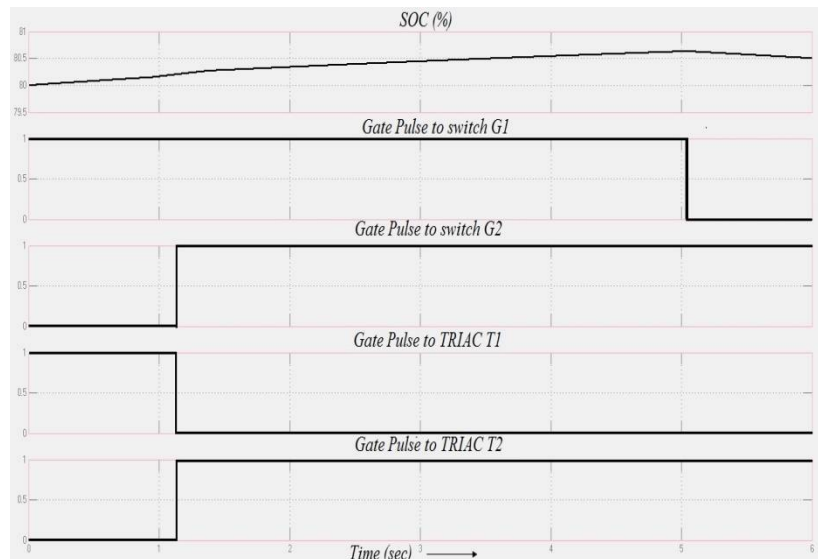


Fig. 15 States of IGBT Switches and TRIACs

4. BATTERY PARAMETERS

Figure 16 shows the waveform of battery current, battery voltage and change in SOC of battery. From 0 to 5.1 sec, the battery is in charging mode. During this period, the battery is being charged by almost 20 A constant current. The battery voltage rises and settles to 280 V (maximum battery voltage). The SOC of battery rises from 80% to 80.63%. After 5.1 seconds, mode 3 operation starts i.e. Battery is discharging. SOC and battery voltage slowly decreases and battery supplies a constant current of almost 20 A same as that of charging current.

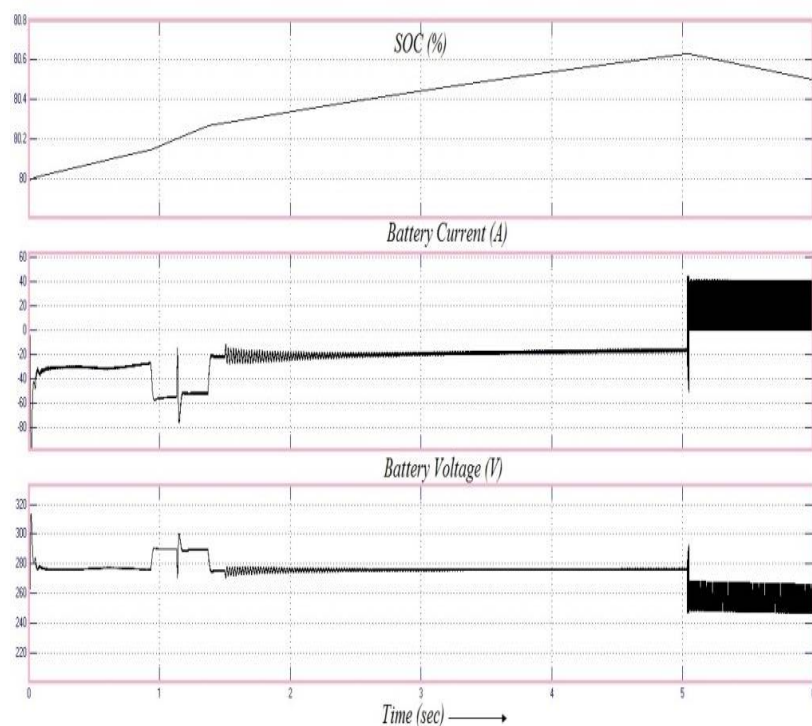


Fig. 16 Waveforms of battery voltage, battery current and SOC of battery

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 7, July 2017

5. VOLTAGE FREQUENCY WAVEFORM

Figure 17 shows waveform of rectifier voltage, dc link voltage, phase to phase voltage across loads, RMS value of load voltage and frequency of load voltage. From the waveform, it is clearly seen that the phase to phase voltage across loads is almost purely sine wave. The RMS value of load voltage is almost constant to 220 V as per the rating of our loads. The frequency is also almost constant to 50 Hz. This clearly signifies the Voltage-frequency control.

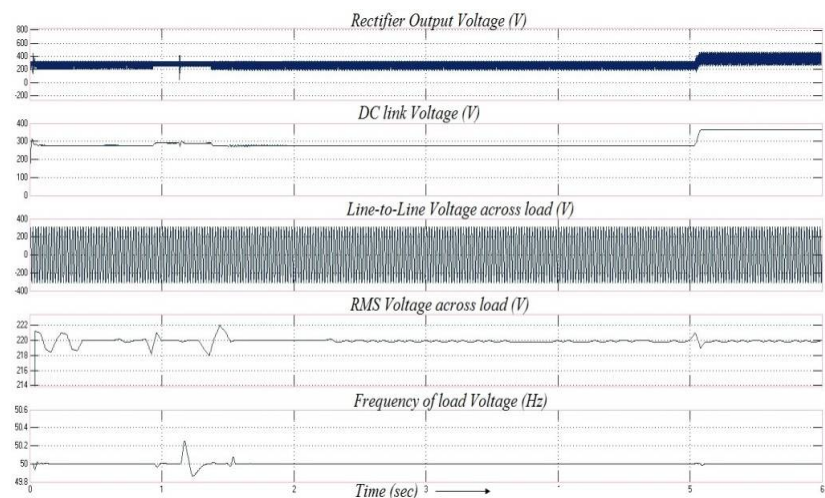


Fig. 17 Waveforms of Voltage and Frequency

6. ACTIVE AND REACTIVE POWER ACROSS LOAD 2

The Active and Reactive power consumed by the series RL load (load 2) are shown in figure 18. As the 3 phase circuit breaker is closed at time $t=1.5$ seconds, before this instant of time, there will be no active and reactive power consumed by the RL load. After 1.5 seconds, the active power consumed is found to be 5 kW and reactive power consumed is found to be 5 kVAR. The result obtained was accurate to the rating of the load.

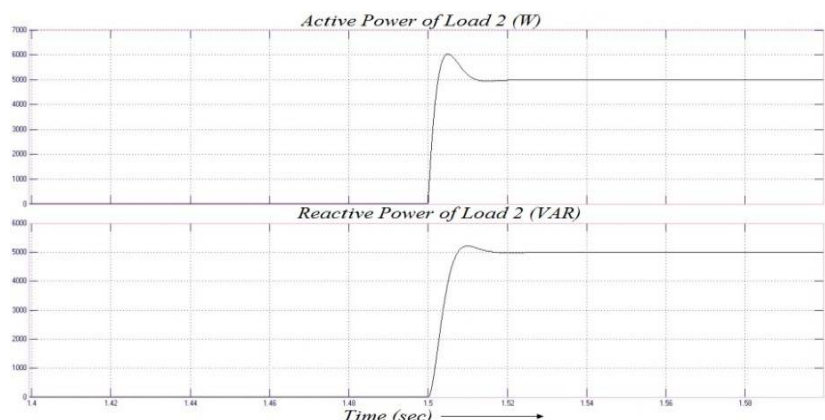


Fig. 18 Waveforms of active and reactive power of load 2

VI. CONCLUSION

With the advancement in modern smart grid, the traditional UPS system will become obsolete and can no longer satisfy the need of smart grids. Thus, the demand of more “Greener”, energy efficient, multifunctional and intelligent UPS system is increasing day by day. This project presented a new multifunctional intelligent UPS system for grid, scrutinized its configuration, operating principle and devised its control algorithms and strategies. From the simulation results, it can be inferred that the proposed next-generation UPS system can effectively operate in both normal state and backup mode and the proposed control possess good control performance. This research could assist in acquiring some valuable references in design sectors of next-generation electrical equipment in smart grid. With further addition of new

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 7, July 2017

control strategy that can result in the cyclic power transfer between battery, PV system and the grid, the proposed system can be made more efficient and energy deficiency can be resolved.

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