Designing and Simulation of Grid Connected Inverter with LCL Filter

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Abstract— In this paper a grid connected inverter is designed in Linear Technology simulator LTSpice. Keeping in mind that the grid connected inverter is very expensive a cheaper and simple inverter has been designed. We use highly efficient MOSFET switching along with efficient op-amps. We have used zero-crossing detector circuit to detect the grid frequency and make frequency synchronization. A 12 volt solar power is provided by the DC source and 12 volts pure sine wave AC generated which can be step-up to required level. We have used a real time analog pulse width modulator generating pulse width modulated signal at 7.75 kHz. This PWM output is applied to the H-Bridge switching circuit to generate sine wave output hence this switching signal SPWM. The output of the H-Bridge output is analogous to the SPWM. This signal has been filtered to reduce the harmonic distortion. We have used an efficient LCL filter to minimize the harmonic distortion in the output of inverter. The output of our inverter has the total harmonic distortion 0.3%. A MOSFET driver helps efficiently operate the MOSFET at high frequency. The efficiency of our design is more than 98%.

Key words: Grid Connected Solar Inverter, LTSpice, MOSFET Switching, Reverse Metering, Micro PV system

I. INTRODUCTION

In the time of increasing demand of energy day by day, solar energy is the one of the best option. According to International Energy Outlook 2009 by the U.S Energy Information Administration, estimated that the generation rate of global electricity will be increased to 23.2 trillion kWh in 2015, and for the next 5 years generation rate will increase up to 31.8 trillion kWh Renewable and clean type of energy makes it more attractive. So in the field of green and clean energy solar energy plays very important role. We can use solar energy anywhere in the universe where sunlight is present. Easiest way of the using solar energy is PV solar energy system. The main problem with the PV solar array is its initial cost which makes it's difficult to implement practically. Grid connected micro PV System can play very important role to minimize or compensates the initial setup cost of the grid connected PV system. Grid connected PV system also ensures maximum utilization of the solar power [1].

A. Grid Connected Micro PV System

Grid connected PV system has two parts: PV array, converts directly solar irradiance into the direct current electrical energy and a grid synchronized converter that convert direct current into the alternating current energy in synchronous with gird. Some of the grid connected system also has battery to store the direct current energy to feed the grid during sun outage or in night [2]. Usually micro grid connected system does not have battery since batteries increases system cost and also don't have long working period.

B. Grid Connected Solar Inverter

It is a power inverter having special characteristics of grid synchronization. Hence grid connected solar inverter converts direct current electricity from PV array into the alternating current, which is analogous to the grid. Grid connected inverters are generally current type inverters, its output voltage is variable according to the grid voltage and power generated by PV array. Technical term for the connected solar inverter is "grid-interactive inverter because of it has capability to synchronize its output to the utility grid. Basically grid interactive inverter works only when utility grid is present so it is not a stand-alone device.

The alternating electricity converted by inverter is same as grid electricity i.e. pure sine wave, 220 volts amplitude and 50 cycles per second. The main challenges in connection with the utility grid are it's synchronization in phase and voltage management to establish the optimized power flow. That the grid connected system monitors the grid and converted alternating power to ensure synchronization with the grid. Voltage of the inverter must be slightly high to ensure the power flow towards grid. Amplitude of the inverter depends upon the power generated by PV panel. The grid connected inverter must disconnect from grid line when grid is not present to avoid islanding [3].

When inverter produces more electricity than the load on utility grid net power flows towards grid and meter run backward. This is known as the reverse metering [5]. So that we can sell this excess energy to the utility grid depends upon the tariff policy of the utility grid provider. Usually these policies are decided by the government of the country. Using grid connected system user can earn money by selling the power to the company [4]. Grid connected system decreases the load on the utility grid so it decreases the dependency on the utility grid power which is usually fossil fuel energy. So that we can say that grid connected system promotes the green energy. To promote the use of grid connected PV system government of India provide different subsidies. Grid connected systems are usually more expensive than the normal power inverter due to its addition and complex circuitry. We are trying to design a simple, efficient and cheaper grid connected inverter with higher reliability.

C. Advantages of Grid Connected Inverter System

Grid connected inverter has the capability of the connecting power source to the grid so that it is used in solar, wind hydro power generation etc. So that we can connect different generation unit to create a power full source so that it can run many house hold appliances, industries etc. Using grid connected inverter number of PV arrays of a solar power generation unit is connected to the grid. In grid connected micro PV system user can also extend the capacity of the system by adding a new grid connected inverter and PV array. User does not need to replace the bigger inverter with old one. With grid connected inverter user can sell electricity and make money. Grid connected

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inverter ensures that the converted alternating power is perfectly synchronized with the grid power and on the direct current side a maximum power point tracking (MPPT) ensures the maximum solar power flow into the system [6]. This will increase the overall efficiency of the inverter. Solar power is very costly so that the efficiency is the one of the main concern in the designing of grid connected inverter. With grid connected micro inverter user can expand the capacity of generation unit whenever it is required.

II. DESIGN AND SIMULATION

A. Pulse Width Modulator

In order to generate the sine wave output from the inverter we will need a pulse width modulated signal according to the amplitude of the sine wave. This pulse width modulated signal is known as the sinusoidal pulse width modulated signal (SPWM). We have used a saw tooth and sine wave modulation to generate the pulse width modulated signal. Pulse width modulator consist a saw tooth wave generator along with voltage comparator with sine wave as a reference signal. After that this signal is modulated with the output of the zero crossing detectors. This modulated signal is applied to the switching unit to generate the pure sine wave output.

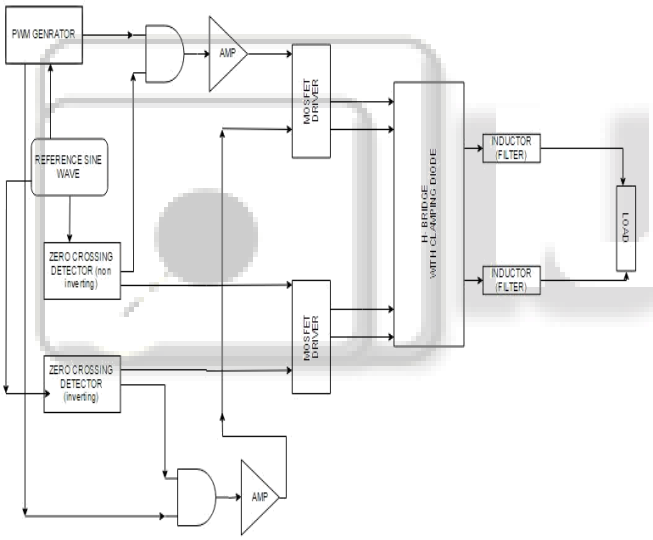

Fig. 1: Block Diagram of the Grid Connected Inverter

B. MOSFET Driver

The output of the pulse width modulator is of low power and high frequency signal. Due to gate capacitance a high current flows to charge up this capacitor pulse modulator is not able to feed this much current. So we need a MOSFET driver which charges gate capacitor at such high frequencies. We use here LTC1693-1 MOSFET driver IC. This IC consist basically two non-inverting power op-amps [11].

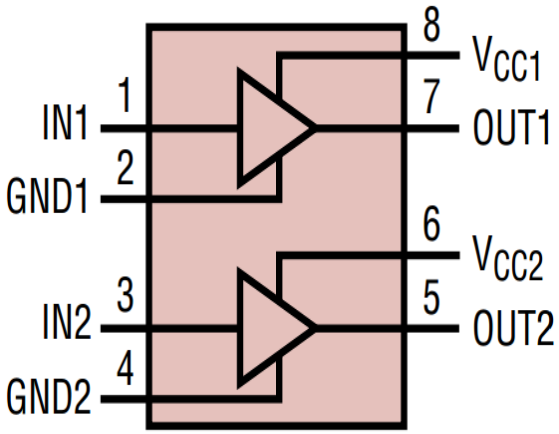

Fig. 2: Internal Block Diagram of LTC1693-1

C. Switching Circuit

We have uses four MOFETs in H-Bridge configuration for the switching of the direct current solar power. We have used International Rectifier's IRFZ44N enhancement type N-channel MOSFET [12]. This is very efficient and cheaper MOSFET to ensure higher efficiency. This H-Bridge is used to switch 12 volts DC supply.

III. COMPLETE CIRCUIT OF DESIGNED INVETER

The inverter is designed in the LTSpice software. The output of this inverter is simulated in this software. We have also calculated the total harmonic distortion (THD) of the inverter output. Switching circuit is switched by the PWM signal generated by the PWM generator.

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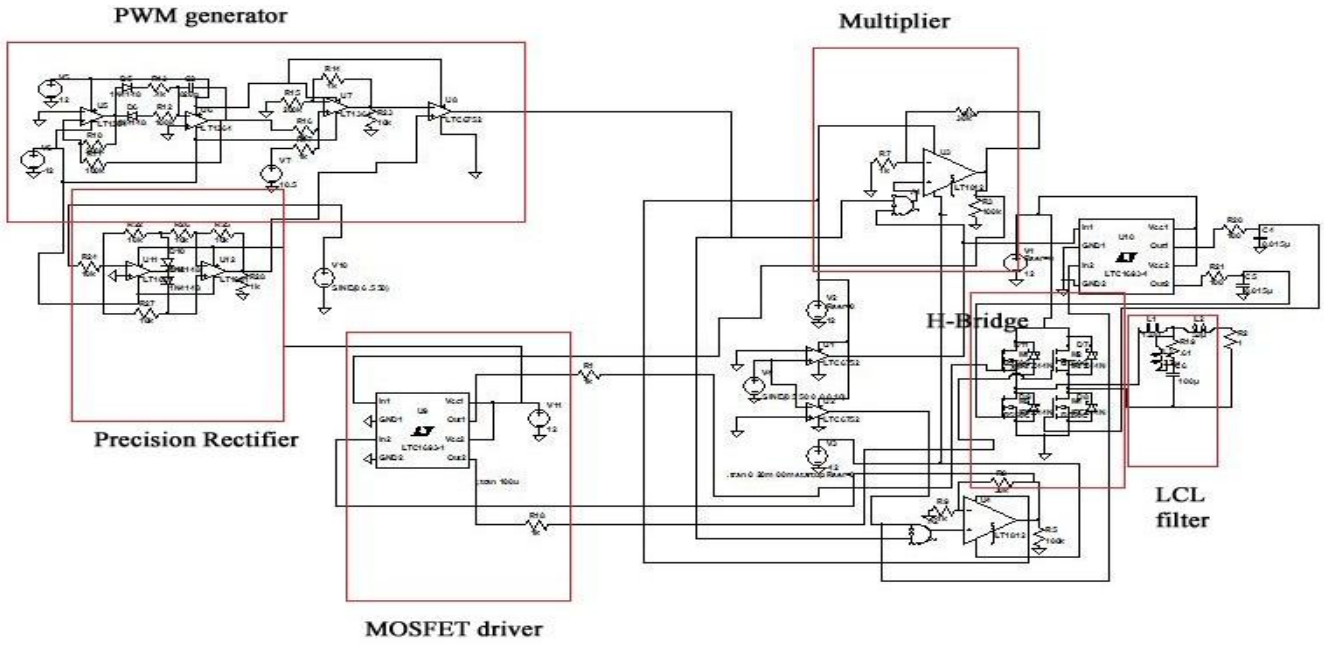

Fig. 3: Complete Diagram of the Designed Inverter

IV. SWITCHING CIRCUIT

Switching is the process here by which we generate the alternating current using direct current. An efficient switching can improve the efficiency of the overall system so we used MOSFETs as switch here. MOSFET is powered by solar energy of 12 volts (we have use a dc source of 12 volts). The output of circuit is analogous to the output of PWM generator. PWM signal is applied to the upper side MOSFETs and lower side MOSFETs are switched with zero crossing detectors. An antiparallel diode is also used across all MOSFETs to provide the path of inductor current while MOFET is in off state. This is very important to avoid access charge accumulation on inductor and due to this accumulated charge a very high current can flow [7].

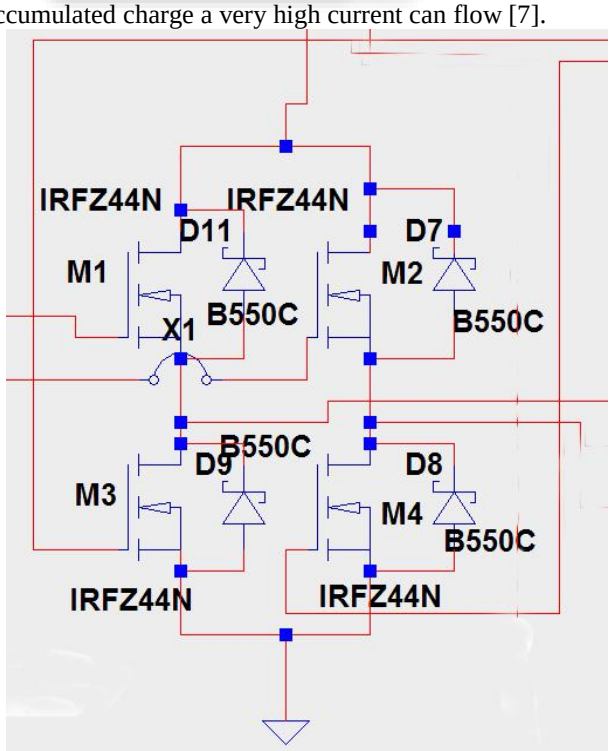

Fig. 4: H-Bridge with Anti Parallel Diode

V. FILTER

We have used an efficient LCL filter to minimize the total harmonic distortion to the minimum level. The design and parameter for the LCL filter finds out using equations given below [8].

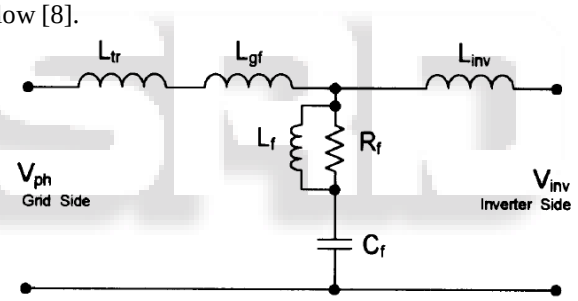

Fig. 5: Designed LCL filter

The equation for these designing parameters are given as

$$L_{inv} = \frac{V_{dc}}{16 f_{sw} \Delta L_{max}} \quad (1)$$

$$C_f = 0.05 C_b \quad (2)$$

$$L_g = r L_{inv} \quad (3)$$

$$L_f = \frac{R_f}{2\pi f_{res}} \quad (4)$$

$$w_{res} = \sqrt{\frac{L_{inv}+L_g}{L_{inv} L_g C_f}} \quad (5)$$

Where w_{res} is the resonance angular frequency f_{sw} is the switching frequency L_g is grid side inductance L_{inv} is inverter side inductance.

VI. PULSE WIDTH MODULATION

A. Pulse Width Modulator Circuit

This circuit is used to generate the pulse width modulated signal which is used to switch the H-Bridge. We have use a saw tooth wave generator and its output is compared with the sine wave using voltage comparator [10]. We have generated signal of different duty cycle depending upon the

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amplitude of the sine wave. Duty cycle is the ratio of the on time of a pulse to its time period.

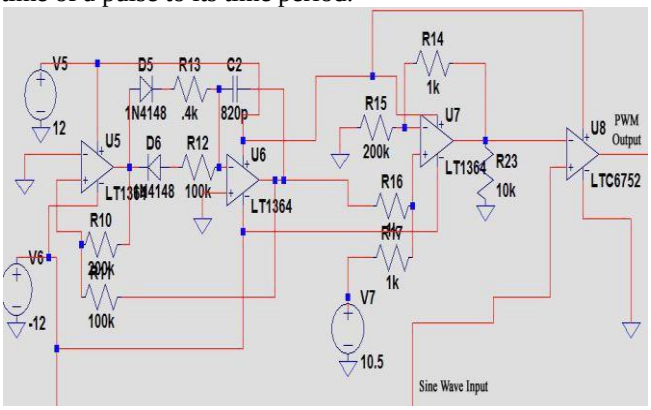

Fig. 6: Pulse Width Modulator

The output of the PWM generator along with the sine wave is shown in the figure 7. In figure 7 we can see that the width of pulse increases as the amplitude of the sine wave increases or we can say duty cycle of the signal increases with amplitude of sine wave.

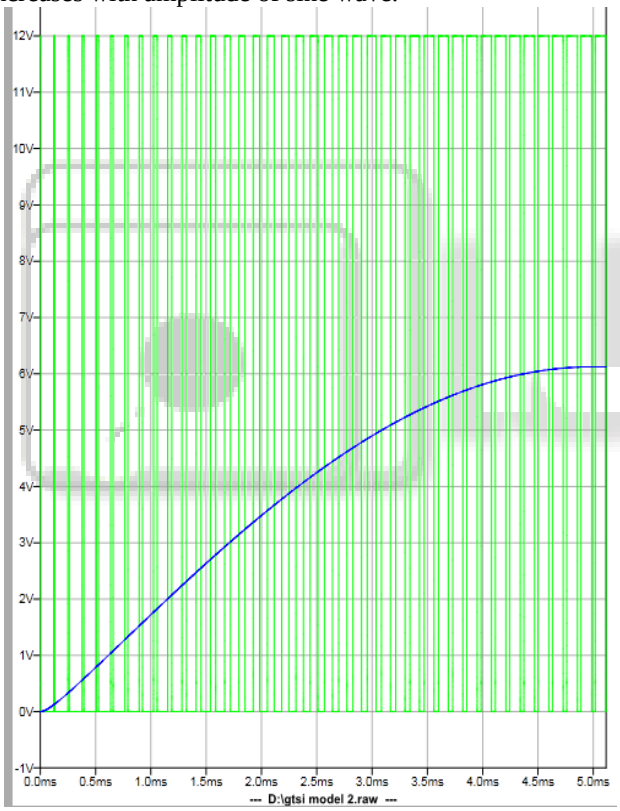

Fig. 7: PWM Output along with Sine Wave

B. Multiplier Circuit

This PWM signal is multiplied with the Output of zero crossing detector and we get the PWM modulated signal synchronized with grid frequency [10]. The circuit diagram for this circuit is shown in the figure 8.

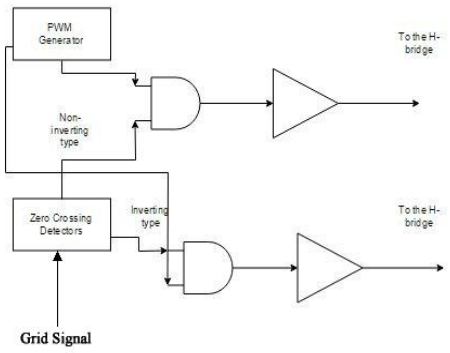

Fig. 8: Multiplier Circuit

The output of this circuit is applied to the MOSFET M1 and M2 respectively. The SPWM signal has been generated using the multiplier circuit. Zero crossing detector detects the voltage is crossing the zero value. It is basically a sine wave to square wave generator.

VII. SIMULATED RESULT AND THD

The output of our design is almost pure sine wave with minimum harmonic distortion. The simulated output of the inverter has been given in figure 9.

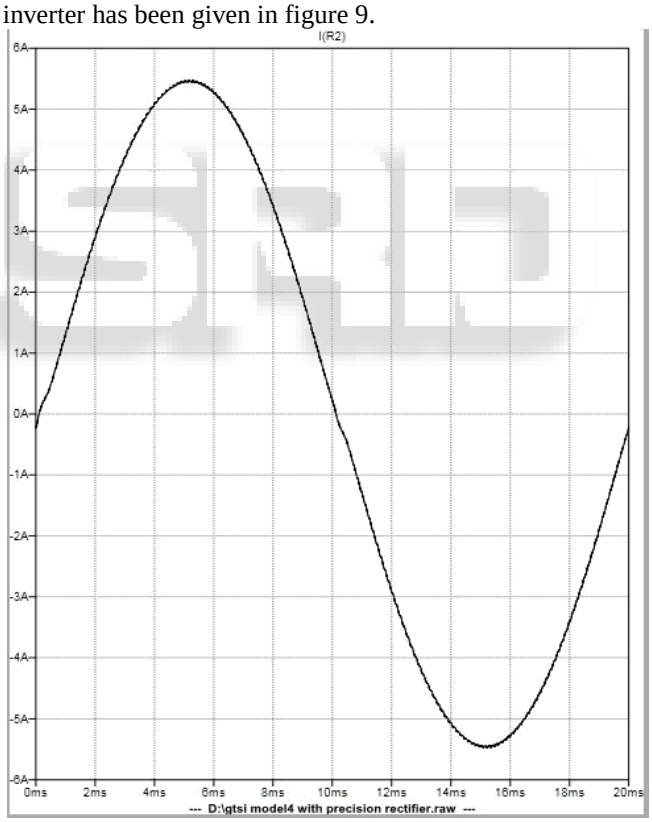

Fig. 9: Output of Grid Connected Inverter

As we can see the output is very smooth and almost pure sine wave in nature. To find out the total harmonic distortion (THD) we have to find its Fast Fourier Transformation (FFT). There is option in the LTSpice to calculate the FFT of the output signal. The total harmonic distortion can be finds using the relationship given as [10].

$$THD = \frac{\sqrt{I_2^2 + I_3^2 + I_4^2 \ldots}}{I_1} \times 100\ \% \qquad (6)$$

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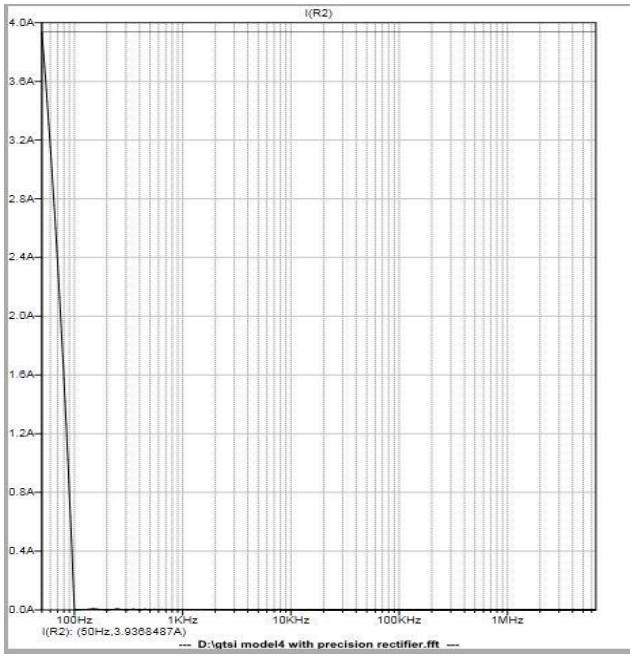

Figure 10 Frequency spectrum of the output of Inverter

Table 1: Current Harmonic Values and their Frequency

Current Harmonics	Frequency (Hz)	Magnitude
I_1	50	3.93 A
I_2	100	623.05 µA
I_3	150	6.32mA
I_4	200	727.23µA
I_5	250	6.06mA
I_6	300	490.17µA
I_7	350	5.48mA
I_8	400	536.79µA
I_9	450	5.07mA
I_{10}	500	669.97µA

Here we have taken 10 harmonics for the calculation of THD. These values are given in the table 1. The calculated value of THD is 0.3% and rms current is equal to 3.93 amps. The value of THD is quite low so that it will produces minimum distortion in the output.

VIII. CONCLUSION

Grid frequency has been successfully sensed and generated pure sine wave output with perfectly synchronized in frequency. The output of the sine wave has very low total harmonic distortion which is 0.3% approx. Circuit of the inverter needed very small and simple circuitry. But we still need phase synchronization and output voltage management unit to connect this inverter to the grid. We are working to develop an efficient phase control method to synchronize the phase of generated current with grid. As we can see in figure 9 output of the inverter is slightly shifted in phase with grid signal. We are also working the use of high frequency transformer to reduce the size of inverter and improve its efficiency. Grid outage problem is very common in developing country so that an inverter must have stand-alone feature to run some small load as backup inverter. We are also trying to modify our design to work stand-alone.

REFRENCES

[1] Md. Nahid Hossain, Tushar Kanti Routh, Abdul Hamid,Bin Yousuf, Miah , Md. Asasduzzaman, Md. Iqbal Hossain and Ummul Husnaeen , "Design and Development of a Grid Tied Solar Inverter", IEEE/OSA/ IAPR International Conference on Informatics, Electronics & Vision, pp.1054-1058, Oct. 2012.

[2] Ducey, R.; Chapman, R.; Edwards, S., "The US Army Yuma Proving Ground 900-kVA photovoltaic power station in "Photovoltaic Specialists Conference, 1997., Conference Record of the Twenty-Sixth IEEE , pp.1261-1264, Sep-3 Oct 1997.

[3] "Power blackout risks, risk management options, emerging risk initiative - position paper", CRO Forum, Nov 2011.

[4] http://en.wikipedia.orglwiki/Grid-tie_inverter accessed in Sept. 2015.

[5] U.S. Department of Energy , "Solar Energy Grid Integration System "SEGIS"" program concept paper, p. 17 October 2007.

[6] H. Rezk and A. M. Eltamaly, "A comprehensive comparison of different MPPT techniques for photovoltaic systems," Solar Energy, vol. 112, pp. 1–11, 2015.

[7] Williams, B.W., "Unified Synthesis of Tapped-Inductor DC-to-DC Converters," in Power Electronics, IEEE Transactions on , vol.29, no.10, pp.5370-5383, Oct. 2014.

[8] Araujo, S.V.; Engler, A.; Sahan, B.; Antunes, F., "LCL filter design for grid-connected NPC inverters in offshore wind turbines," in Power Electronics, 2007, ICPE '07. 7th Internatonal Conference, pp.1133-1138, 22-26 Oct. 2007.

[9] Op-amp and liner integrated circuit by "Ramakant Gayakward" fourth edition, PHI learning private limited publications, page no. 46, 294, for op-amp application.

[10] Tusitha Abeyasekera, C. Mark Johnson, David J. Atkinson, and Matthew Armstrong, "Elimination of Subharmonics in Direct Look-Up Table (DLT) Sine Wave Reference Generators for Low-Cost Microprocessor-Controlled Inverters" IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 18, NO. 6, pp. 1315-1321, NOVEMBER 2003.

[11] Linear technology website "www.linear.com" for the data sheets of the different components used.

[12] International rectifier website, "www.irf.com" for the data sheet of IRFZ44N.

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