Renewable Energy Sources based Power Converter with Voltage and Load Angle Control

Abhishek Gandhar
Associate Proffesor,
Bharatividyapeeth
College of Engineering,
New Delhi, India
abhishek.gandhar@gmail.com

Ashutosh Jindal
Scholar,
Bharatividyapeeth
College of Engineering,
New Delhi, India
jindal.ashutosh21@gmail.com

Vishal Srivastava
Scholar,
Bharatividyapeeth
College of Engineering,
New Delhi, India
vishurockssrivastava@gmail.com

Utkarsh Agarwal
Scholar,
Bharatividyapeeth
College of engineering
New Delhi, India
parimal.pankaj64@gmail.com

Abstract— **This paper presents an integrated solution for the interconnection of photovoltaic cells with the main grid. Solar energy provides a promising solution for the energy crisis. PWM charge controller and 3-level SPWM inverter is designed with load angle control and synchronization. The system is simulated using Proteus and PIC18f4520 is used for control and switching signals. Simulation results verified the lower value of harmonic content in the SPWM and the switching frequency confirmed the applicability of microcontroller in the power system.**

Keywords—SPWM; Phase synchronization; PIC18F4520;

I. Introduction

Many developing countries like India can't meet increasing electricity demand by conventional sources alone, due to geographical and economic constraints in installing new power plants and erecting a robust transmission network. Being a developing country, India is not able to provide electricity supply to a large part of its population. Every night, thousands of villages across India plunge into darkness. There are still many, for whom grid electricity is a farfetched dream. Lifespan of Conventional Sources is limited and they are polluting in nature.

Distributed Energy Generation with provision of energy storage by Renewable Energy Sources is a sustainable, viable solution to address the problem. The topic above said boasts of rich literature with regards to methodology of generation and its interconnection to the grid. Distributed Energy Generation (DER) implies generating the power locally, instead of sharing it through a central pool, thus bypassing the issues like requirement of transmission network and its associated losses, which is a major techno-economical glitch in the electrification of rural India.

India receives an incident solar energy of 5,000 trillion kWh per year with most parts receiving 4-7kWh per sq. m. per day. [1] With government encouraging grid connected and islanded solar systems by means of subsidies and consumer-centric net metering policies, DER presents a strong case. However, interconnection of these renewable sources to the local grid or utility grid remains a challenge, as it requires synchronization between the many individual sources, in terms of voltage, frequency and relative phase difference.

Existing microgrids are generally 3 phase, however if such a grid is intended for residential consumption only, then 1 phase grid is superior to the 3 phase systems as, for power distribution within short distance, cost of terminal equipment like 3 phase transformers required for conversion dominates the cost of transmission lines.

Conventional synchronization techniques are based mainly on Field Programmable Gate Array (FPGA) used in conjunction with Digital Signal Processing (DSP), which is costly and power-inefficient for small applications. Replacement of FPGAs and DSPs with microcontrollers for small systems would help economics, in a positive way and it requires lot less logistics as they are available in easy to solder DIP, SOIC and QFP packages. Microcontrollers also take less development time with software and the peripherals are ready to use.

We have demonstrated Phase Synchronization using Microcontroller based PLL between two individual Single Phase Inverters having their own battery bank, which is charged using a PWM based charge controller to cater to off duty hours.

II. BACKGROUND LITERATURE

With only a very small fraction of available solar energy being utilized for electricity, there exists an urgent need to develop technology to increase efficiency and interconnecting the existing such that it can eradicate the energy crisis of the world.

Grid interconnection of PV modules is one of the superior ways to harness more solar energy from the existing PV modules to achieve higher reliability at relatively lower capital cost [2]. Although, the technical requirements for the safe operation of a PV cell along with interconnect have to be ensured.

Solar energy is so abundant in this world that it has the potential of satisfying all the energy needs on its own. It has the potential of thousands of terawatts. Thar Desert has the potential to serve the energy requirements of the world if all its available solar energy is harnessed. Government policies are favoring the development of Grid connected systems. MNRE plans to set up 25 solar parks, each with a capacity of 500 to 1000 MW; thereby adding around 20000 MW of solar

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power installed capacity [3]. This policy is aimed at reducing cost of energy generation through Solar PV Systems at the same time pioneering long term policy and Research & Development in domestic arena. Most states are competing in the race to provide exorbitant unit rates to boost state solar provision.Recently a 500 MW plant was inaugurated in Gujarat to corroborate efforts to meet the target. When fully built out; the Charanka Solar Park will supply 500 MW of solar power systems using state-of-the-art thin film and crystalline technology [4].

III. MODEL DESCRIPTION AND BLOCK DIAGRAM

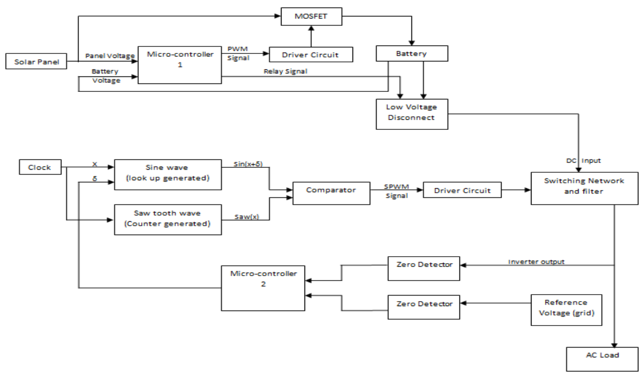


Figure 1. Project Block Digram

The current system includes Solar panel of 50W with square packing as the primary source. The solar panel feeds a DC battery bank to provide back-up during off duty hours. The charging of battery is controlled by a PWM based charger which modulates the charging current of the battery depending upon the instantaneous panel voltage and battery voltage. The battery supplies a single phase full bridge inverter. The inverter uses three-level SPWM modulation and uses PIC18F4520 microcontroller. PIC18F4520 provides an inexpensive solution over DSPs and FPGAs. The inverter operates at a switching frequency of 2 kHz. The inverter's output is connected to a LC filter for providing a near sinusoidal wave with minimum THD. The inverter is also equipped with phase control methodology which helps it in phase synchronization and maintaining active power flow. The reactive power control is achieved by adjusting the DC voltage fed to the inverter. For phase synchronization a circuit is designed for the measurement of the phase difference between the main grid voltage and the supply voltage of the inverter and feed the phase value to the inverter circuit. The circuit uses a zero comparator and PIC18F4520 as the microcontroller for phase measurement.

IV. SYSTEM WORKING

The active and reactive power flow into a two bus power system connected by a short transmission line is given by [5]:

$$P = \frac{EV \sin\delta}{Xs} \quad (1)$$

$$Q = \frac{E(E - V\cos\delta)}{Xs} \quad (2)$$

Where P & Q are active and reactive power received at the load end, E is the RMS voltage of the sending end and V is the receiving end voltage, while Xs is the transfer reactance and δ is the relative phase difference between E & V.

The active power flow is controlled by the relative phase difference and the reactive power is dependent on the voltage difference. The phase difference is controlled by the phase measurement circuit and the inverter control circuitry. While the voltage difference is controlled by the charge controller circuit

A. Charge controller

The charge controller regulates the current coming from the solar panel depending upon the panel and battery voltage to keep the battery at the highest state of charge [6]. It is a single switch PWM based circuit. By varying the duty cycle of the MOSFET, it is possible to control the charging current of the battery in turn controlling the charging rate. The charge controller has several advantages including prevention of battery from overcharging and deep discharge.

The charging current of the battery is given as

$$I = \frac{Vs - Vb}{Rint} \quad (SW1\ on) \quad (3)$$

$$= \quad 0 \quad (SW1\ off)$$

$$Iavg = \frac{Vs - Vb}{Rint}\theta \quad (4)$$

Where I denote the charging current of the battery Vs denote panel voltage and Vb denote battery voltage, Rint refers to the net system resistance between panel and the battery including battery's internal resistance as well, α denotes the duty cycle of the controller.

θ is calculated as:

$$\theta = \frac{Ton}{Ton + Toff} \quad (5)$$

The battery was modeled by Thevenin equivalent circuit. The Thevenin model consists of a parallel RC network in series based on internal resistance model describing the dynamic characteristics of the battery [7].

B. Inverter

The inverter uses SPWM based switching technique. The microcontroller compares the value of a reference sinusoidal signal with a counter generated saw-tooth wave. This technique digitizes the power in an inverter so that a sequence of voltage can be used to turn on and off power switches [8]. The output signal is used to drive a power modulator circuit. Using the LC filter the higher order harmonics can be removed giving the fundamental component of sinusoidal wave. The inverter also uses a feedback circuit to facilitate phase synchronization.

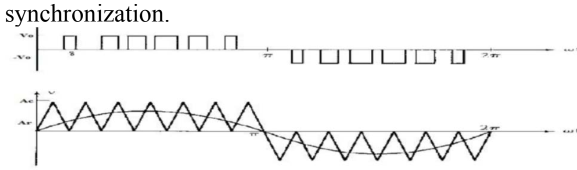


Figure 2. Three level SPWM Wave

The RMS output of the inverter is given as [9]

$$Vo = Vs\sqrt{\frac{pϪ}{\pi}} \rightarrow Vs\sqrt{\sum_{1}^{2p}\frac{Ϫn}{\pi}} \qquad (6)$$

Where Vs denotes the input dc voltage, p denotes number of pulses and Ϫ denotes pulse width.

Sin(x) being odd function have only sine terms as Fourier coefficients wave also possessing half wave symmetry makes the even order coefficients equal to zero.

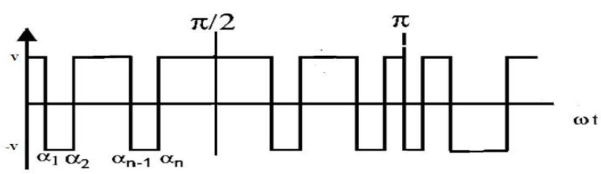


Figure 3. Two Level SPWM Wave

Generalized coefficients for n^{th} order coefficients are given by [10]

$$hn = \left(4\frac{Vs}{n\pi}\right)[1 - 2n\cos\alpha 1 + 2n\cos\alpha 2 - 2n\cos\alpha 3 \ldots\ldots + 2n\cos\alpha n] \qquad (7)$$

C. Phase measurement circuit

The phase measurement circuit uses zero crossing detection method for phase measurement. The signals are passed through a sine to square convertor circuit. The square waves thus obtained are fed to a microcontroller. A counter is used to count the phase difference and the binary equivalent of the phase difference is fed to the inverter for phase synchronization. The phase difference is measured on a calibrated time scale and by assuming a linear relationship approximate phase difference can be calculated as

$$\frac{counter\ value}{counter\ value\ at\ set\ phase\ difference(90°)} * setphase\ differnce(90°) \qquad (8)$$

The phase synchronization is achieved by the inverter by using phase difference as a negative feedback. The synchronization is necessary for coupling an AC source to the grid. The source is transferred on the grid usually at no load condition. It is necessary to have a zero phase difference for achieving the same. Also the load angle can be explicitly controlled by the same logic used for synchronizing by changing the reference value of set phase difference.

V. SIMULATION SOFTWARE

The foresaid modules were simulated on the simulation software Proteus8.0. Proteus is a product of Labcenter Electronics and is a Virtual System Modeling (VSM) software designed for circuit simulation, circuit printing and embedded programming. Compared to MATLAB, it is lighter in terms of system requirements and is much easier to use. Whereas, MATLAB is more control and system oriented, Proteus8.0 is mainly used for embedded systems and electronics. It also supports frequency response study of systems and provides data logging and graphs for dc and ac sweeps as well including Fourier and noise analysis.

Compared to its previous version which used separate programs to design and simulate circuits, the current version provides a single window side by side view for different features. Proteus works on SPICE3f5 analogue simulator kernel combined with an event-driven digital simulator that allows users to utilize any SPICE model by any manufacturer [11].The circuits for charge controller, inverter and phase synchronization were drawn in the Proteus.Charge controller was simulated for the charging current. The inverter was simulated and Fourier analysis of the output was recorded. The phase synchronization was also simulated and the response was recorded.

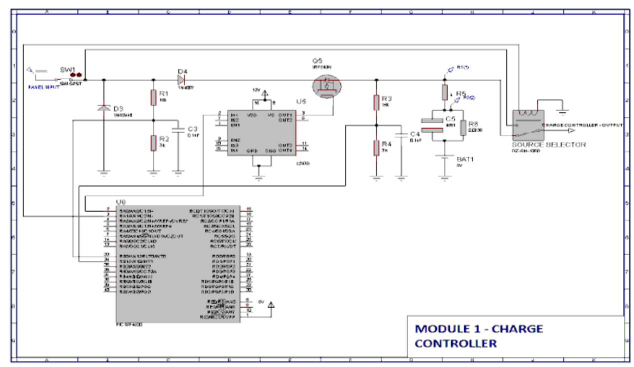


Figure 4. Simulation Diagram of charge controller

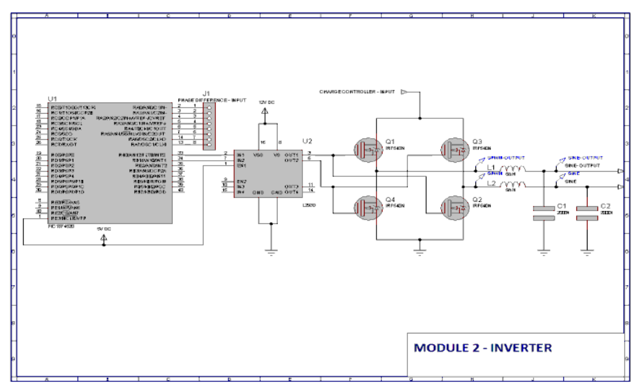


Figure 5. Simulation Diagram of Inverter

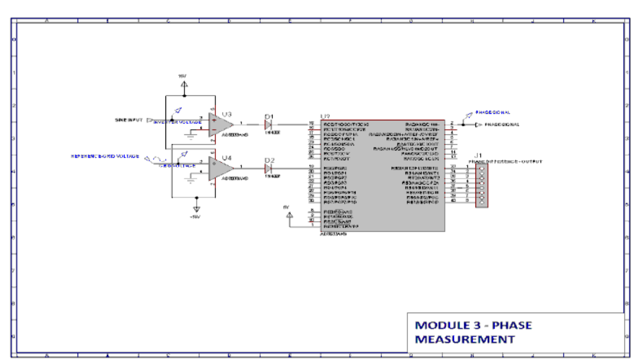


Figure 6. Simulation Diagram of Phase Measurement

VI. RESULTS AND WAVEFORM

The system described above is simulated using Proteus 8.0 blocks and the circuit diagram is presented in Fig 5. An ideal DC battery is used to simulate 50W solar panel. Voltage of the battery is explicitly changed to simulate the test conditions. In this paper, three cases have been considered.

Voltage of the panel is set lower than the battery voltage to simulate no sunlight condition. Panel was disconnected from the load and it was switched over to the battery by relay action. Duty cycle of the charge controller was set to zero by microcontroller and charging circuit was cut-off.

Voltage of the panel was set greater than the threshold and battery not fully charged. In this case, panel feeds the load and charging of the battery takes place simultaneously through a parallel circuit. Duty cycle was and charging current was

Panel voltage was greater than the threshold and battery fully charged. Charging circuit was cut off with zero duty cycle, and panel supplied the load and the load current was 2.1A. The load current was large enough for sufficient charging of the battery backup attached with the system. The battery charging curves were plotted giving the estimate time for the charging of the battery before it is capable for providing backup in off duty hours.

The inverter was simulated using the same software. The DC Source was taken as a fixed DC voltage of 12V. The inverter was tested for the SPWM and sinusoidal output, Fourier analysis for the waves were performed. On analyzing it was found that the SPWM wave had the first harmonic content after the fundamental at a frequency of 2 kHz with relatively low amplitude. The Fourier analysis of the sinusoidal output confirms the successful elimination of the harmonic content of the SPWM. The low value of high frequency harmonics implies lower value of filter inductance and reducing the size of the entire system enhancing modularity. Lower high frequency losses also imply smaller heat sinks required and thus increasing modularity and efficiency of the system.

The inverter is coupled with the phase synchronizing circuit, the output of the inverter was synchronized to the grid voltage as reference, and the grid voltage is represented by an AC source. The phase difference between the grid and inverter output was monitored. The output voltage of the inverter was in phase with the grid voltage after synchronization. The output was synchronized to the grid voltage with zero phase difference, however this reference phase difference can be changed to any arbitrary value by just varying the register value kin the controller (can be done in closed loop fashion) with this the inverter can be designed to supply fixed active power to the grid. This leads to full control over active power supplied by the source. Hence the inistial objectives were achieved.

TABLE I. CHARGE CONTROLLER SIMULATION RESULTS

Panel Voltage (V)	*Battery Voltage(V)*	*Duty Cycle (%)*	*Panel Current(A)*
10.3	12	0	0
19.0	7.4	95	1.70
18.5	9.2	50	0.57
17.4	11.5	10	0.03

TABLE II. PHASE MEASURMENT SIMULATION RESULTS

Phase Difference(°s)	*Counter Value*
10	9
45	41
90	82
130	119

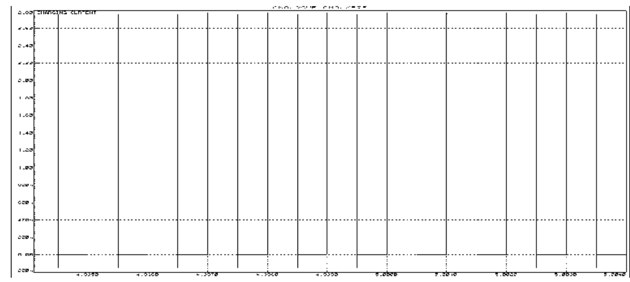


Figure 7. Charging current waveform at a duty cycle of 50% and battery voltage at

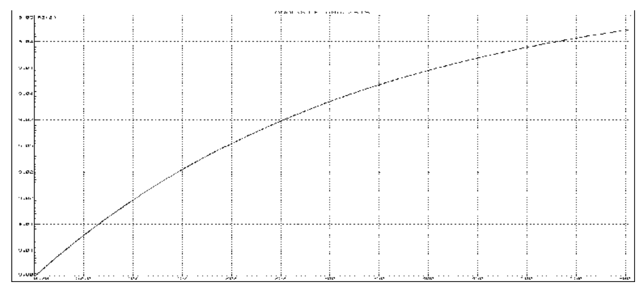


Figure 8. Charging characterstics of battery model

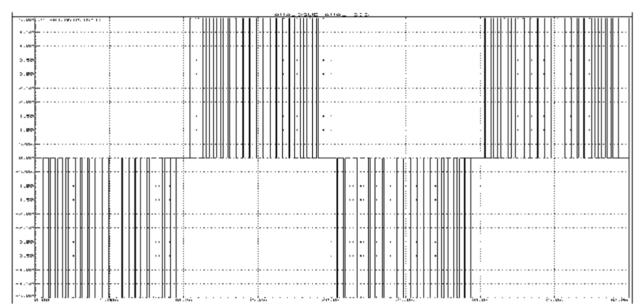


Figure 9. SPWM Output of the Inverter

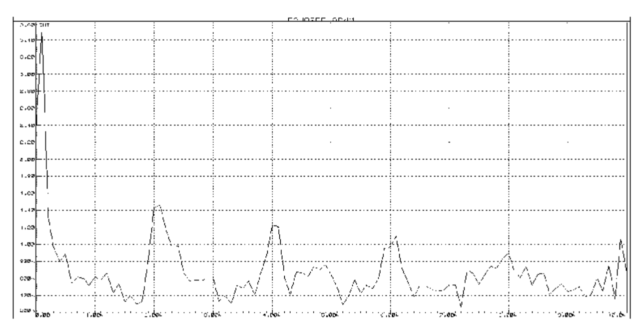


Figure 10. Fourier Analysis of the SPWM Output

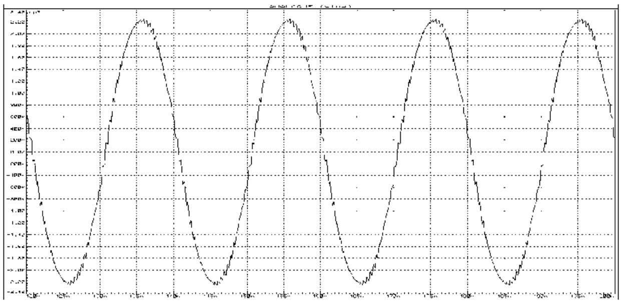


Figure 11. Sinusoisal output after passing through LC Filter

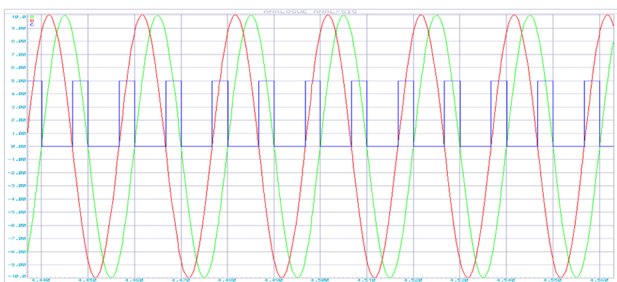
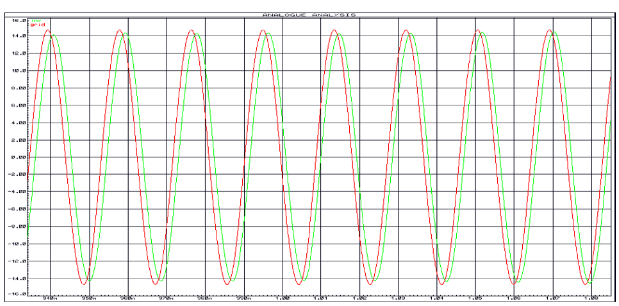
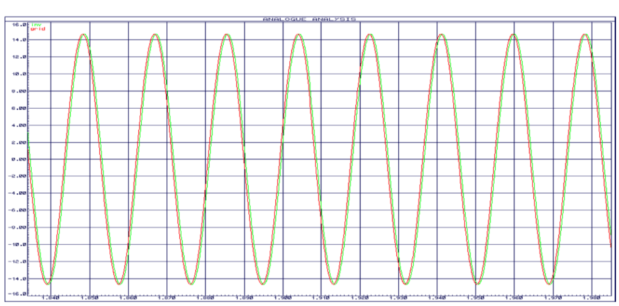


Figure 12. Phase measurement – Signal comparison.



a. Pre synchronized output



b. Post synchronized Output

Figure 13. (a & b) Output of the phase synchronization circuit

VII. CONCLUSION

In this paper interconnection of the independent solar converters were studied. It was deduced that such networks can serve as a viable solution to power crisis in the rural and urban India where sunlight is abundant in nature. The synchronization circuit made it possible to design independent VSC converters which are not dependent on grid voltage like Line or current commutated inverters. The microcontrollers used reduce the overall cost. For the test circuit independent controllers were used but for mass production and practical realization multiprocessor controllers can be utilized with shared peripherals reducing cost further. With using dc voltage control and parameter optimizing efficiency of the system can be further increased and made viable for the control of active and reactive power control in three and poly-phase systems as well.

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