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Designing a Controller to Connect a Photovoltaic Generation System to Utility Grid

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***Abstract*— Generation Systems using renewable energy resources are flourishing as alternate sources to fuel the basic electricity needs and solve the problem of electricity crises to an extent. Grid-connected photovoltaic power systems having large capacity can feed the excess energy to the grid and gain revenue. This work deals with the design of an intelligent controller circuitry which allows transfer of excess energy from photovoltaic generation system to the grid. The power being generated could be fed to grid only if certain strict criteria are met. The waveform, amplitude, frequency and phase of the voltage generated from solar panels must exactly match with the grid voltage at any given instant. A miniature grid-tie system has been modeled and simulated in proteus. Different voltages were given as inputs to both generators and the controller performance has been analyzed under those different input conditions. The simulation results show that system switching operation is perfectly done by the proposed controller.**

***Index Terms*— Photovoltaic Generation Systems, Grid, Controller, Islanding.**

I. INTRODUCTION

Access to electricity is one of the most indispensable factors in promoting economic growth, standard and quality of living. A rough estimate indicates that about 1.7 billion people in the world lack access to electricity and of which one-third are Indians. Therefore to ensure proper access to electricity, now-a-days renewable energy sources are being exploited. Solar Power generation systems have been found to be an apt solution to cope up with the situation.

Renewable power generation systems can be wired in different configuration depending upon the demand and circumstances of an area. Three main configurations are:

- Off-grid solution
- Grid-tied solution
- Hybrid solution

A. Off-Grid Solution

The term off-grid refers to the generation systems not being connected to a national transmission grid. Off-grid electrification also known as Stand-Alone System is an approach in places with little possibility of electrification via utility grid.

B. Grid-Tied Solution

These are photovoltaic generation system connected to grid without any battery back-up. The power generated during day time is directly supplied to load requirements and the excess power being generated may be given to grid. During night time, since there is no generation by the photovoltaic system load is supplied electricity from grid.

C. Hybrid Solution

This type of system may termed as a grid-tied system with battery back-up ,implies it incorporates energy storage in the form of a battery to keep "critical load" circuits in the house operating during a utility outage. During night time, even if an outage occurs the unit disconnects from the utility and powers specific circuits in the home via the battery bank.

A review of existing literature reveals that electronic controllers based on various techniques are available today. A controller system which is configured to work both in off-grid and on grid mode is mentioned in [1]. A control technique to stabilize input to the inverter is studied in [2]. Due to widespread demand of solar electrification, many controllers are available to make grid feeding safer. Modern solar inverter are developed focusing on the advantage of grid connectivity and hence it comes with all the advanced features including power quality maintenance, maximum power generation and automatic and safe grid connectivity. In this work a controller for a photovoltaic generation system is being designed which is a separate unit so as to use in conjunction with an ordinary pure sine wave inverter. The goal of this work is to make the generation system more economical.

II .SYSTEM DESCRIPTION

When sunlight shines on solar panels, they convert the light energy into electricity in the form of Direct Current (DC). That DC is converted into AC power by the power inverter, and it is then available for day to day use by electronic appliances, most of which are designed to work on ac. When a grid-connected solar electric system generates more power than what is utilized, the excess electricity generated can be sent out into the utility grid. Taking into account a typical case, when a consumer moves out of the house on a vacation, the power produced by the solar panels will be much in excess of the demand. In such a situation, the excess power can be redirected to electric grid avoiding the wastage of energy. The consumer only needs to pay an amount which will the difference between power fed into grid and consumed from the grid.

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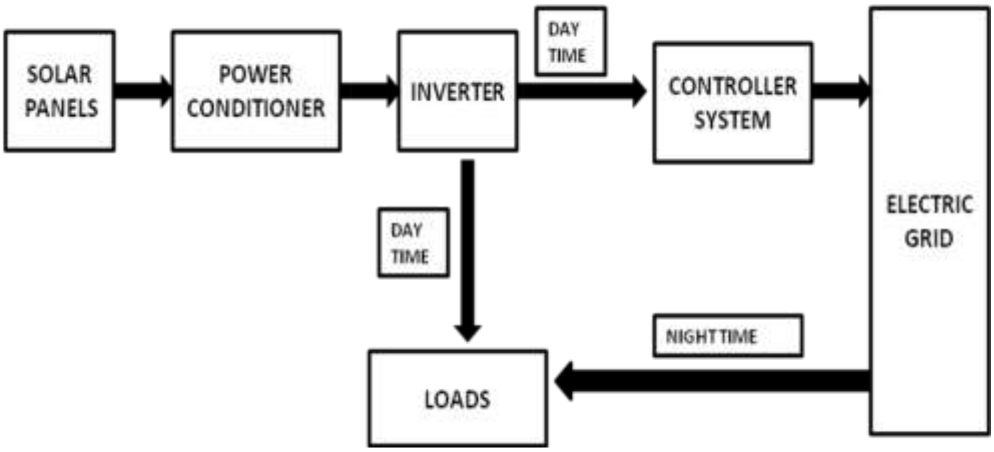


Fig. 1 Block Diagram for a Grid-Connected Photovoltaic Generation System

Another situation is if a consumer's power usage is more than what his photovoltaic generation system produces, then there must be a provision to automatically pull the power from the utility grid. Under this scenario, an intelligent controller which monitors the two way transfer of electricity becomes vital. Here a two way metering system is required to monitor this back and forth transfer. When energy is transferred to grid, the meter spins in one direction and retrieval of energy from the grid spins the meter in opposite direction. The process is called net metering where the consumer is only billed for the "net" electricity purchased over the billing period. If the production is more than usage during a billing period, the utility company can pay back on a net tariff basis.

Despite these benefits, such an energy production method is rarely supported by the utility providers. The major reason is that there are certain criteria which have to be strictly met to allow such to and fro transfer in a grid-connected system [3]. The parameters such as voltage, amplitude, phase, and frequency of photovoltaic system must be exactly matched to enable such a transfer into grid, implies generated electricity must have the same voltage parameters as that of the grid at the instant of transfer into grid. Otherwise there is a possibility of damage to other systems connected to the grid caused due to instant load variation.

Performance of a controller system to connect/disconnect a photovoltaic power generation system from the grid is presented here. The proposed controller is meant to sense the photovoltaic and grid voltage waveforms, frequencies, and phase between the two systems and perform accordingly. A low cost simple circuitry has been developed to measure the PV generator and the grid parameters. Based on the measurement, a control decision is taken to connect the two systems only when the two system parameters are same or at least within a tolerance limit.

III FUNCTIONAL DESCRIPTION OF A GRID INTERACTIVE SYSTEM

The block representation of a grid-tied system is given in Fig1.The grid interactive roof top solar PV system generally comprises the following equipments.

i. SPV Power Source
ii. Inverter
iii. Controller System

A. SPV Power Source

Photovoltaic solar system use the light available from the sun, convert it electricity and feed this into the main electricity grid or load as per the need. The power produced by the PV panels varies depending on the intensity and the angle of light falling on them.

Maximum power is delivered by the system when the panels are able to 'track' the sun's movements according to the changing time and seasons. But, these tracking mechanisms add to the system cost. Hence most of installations either have fixed panels or compromise by making some limited manual adjustments. The best elevations vary with the latitude of the location. No. of cells and modules may vary depending upon the manufacturer, load requirement and practices.

B. Power Conditioning

To import maximum power from the solar panels it is effective to employ a technique called Maximum Power Point Tracking (MPPT) [4].Solar modules have a non-linear relationship between irradiation and total resistance which can be analyzed based on the I-V curve obtained by plotting panel voltage against current. The MPPT system samples the panel output and apply proper load accordingly so as to harvest maximum power at any given time as long as the sun is available. Also to improve the voltage quality a dc-dc converter can be used to change one dc voltage to another dc voltage so as to be fed into the inverter.

C. Inverters

The DC power being produced is converted to AC by the power inverter. The voltage may be at any required voltage and frequency. But it is specifically taken to be 230V and 50 cycles per second to make grid compatible. The standards that inverters for PV and grid applications must fulfill is discussed in [5].It focus which on power quality, injection of dc currents into the grid, detection of islanding operation, and system grounding Now-a-days micro-inverters convert direct current from individual solar panels into alternating current for the electric grid. The desirable features of the solar power inverter are:

The output of the inverter must be clean and synchronize automatically its AC output.

D. Controller System

The controller shall have the software and controls capable of operating the complete system for safe and efficient operation and includes the islanding protection, monitoring of all the phases and fluctuations in the grid and protection against internal faults in the power conditioner, operational errors and switching transients etc.

In case of utility outage, or low or high voltage, the solar PV system will not be synchronous with the grid and the controller will disconnect the system from grid. Once the utility comes into service PV system will check for synchronization with grid if the two systems are within confirmable tolerance only then reconnection is achieved.

Islanding refers to the condition in which a system continues to power a location even when there is a utility outage [3]. Even though there's no power from the electrical grid, Islanding can be dangerous to utility workers, who may not be aware of this situation .So, the controller must detect islanding and at once stop power injection into grid; this is referred to as anti-islanding.

The algorithm corresponding to the working of the controller has been represented as a flow chart in Fig 2.The inverter and grid parameters are to extracted and checked for a match .If the stringent conditions have been met then grid connection is performed. Again the systems are crosschecked for a proper and safe transfer of electricity. When the generation system is no more in generating mode, the controller initiates a disconnection.

The block diagram of the proposed controller is given in Fig 3. For a proper connection to take place; the ac output from the inverter must be synchronous with the grid. To ensure this condition, both the voltages must be crosschecked for a match in amplitude, frequency and phase .This is done with the help of

a microcontroller PIC16F877A. Peripheral Interface Controller (PIC) is a family of modified Harvard architecture microcontrollers made by Microchip Technologies. It is a CMOS FLASH-based 8-bit microcontroller with 40 pin package featuring EEPROM data memory (256 bytes), single ICD, 2 Comparators, 8 channels of 10-bit Analog-to-Digital (A/D) converter, 2 capture/compare/PWM modules and a Universal Asynchronous Receiver Transmitter (USART). The synchronous serial port can be configured as either 3-wire Serial Peripheral Interface (SPI) or 2-wire Inter-Integrated Circuit (I²C) bus. PICs have a set of registers that function as general purpose RAM. Special purpose control registers for on-chip hardware resources are also available. The addressability of memory varies depending on device series. PIC devices have some banking mechanism to extend addressing to additional memory. All of these features make it ideal for more advanced level A/D applications.

Whenever there is enough power to enable a transfer into grid, the control circuitry comes into action. The voltage from the inverter has to be stepped down from high value to a lower value since the maximum input a PIC can handle is 5 volts. It is then given to a rectifier and an analog to digital so that amplitude, amplitude of voltage generated by solar panels. The analog voltage given to the ADC is converted to digital pulse which is simultaneously fed to a frequency counter and a phase detection circuitry. The counter is configured to count the number of rising edges in the pulse train for a given short period of time which is in terms of microseconds and stores in the TRIS Registers of the PIC, which is the frequency, f_{inv} from the inverter. The phase detection circuitry compares the phase of the incoming signal as $\O_{inv}$ against the reference voltage from grid with the help of a comparison circuitry.

At the very same instant on the grid side the same process takes place. Here the voltage from utility line or grid is first stepped down to a lower value and is rectified to dc voltage, V_{grid} and input to PIC. The ADC convert the same voltage into digital pulses from which the frequency and phase of the voltage from the grid side is obtained. The frequency is counted, f_{grid} and fed in another TRIS Register of microcontroller. Phase, $\O_{grid}$ is given to the comparison circuitry.

The microcontroller has a provision to compare the two incoming dc voltages, where grid side voltage is set as reference against which voltage from inverter is compared. Also internal registers are initialized to increment every time a pulse is recognized, in a given time interval say 1second, from either side or these two values are compared. An ex-or gate is configured as phase comparator. When two incoming signals

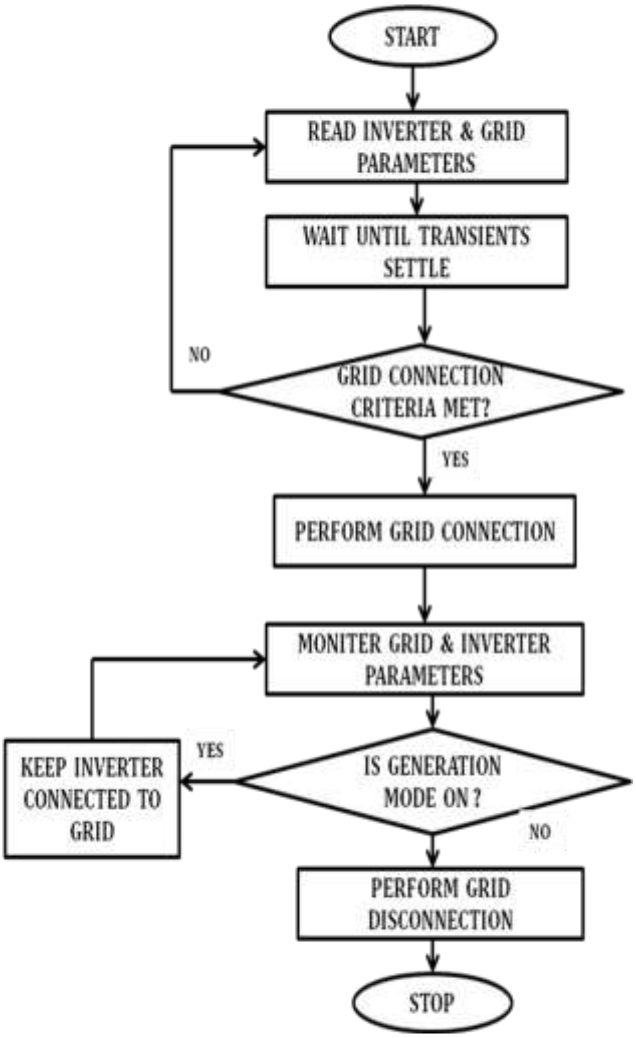


Fig. 2 Flow Chart showing control flow

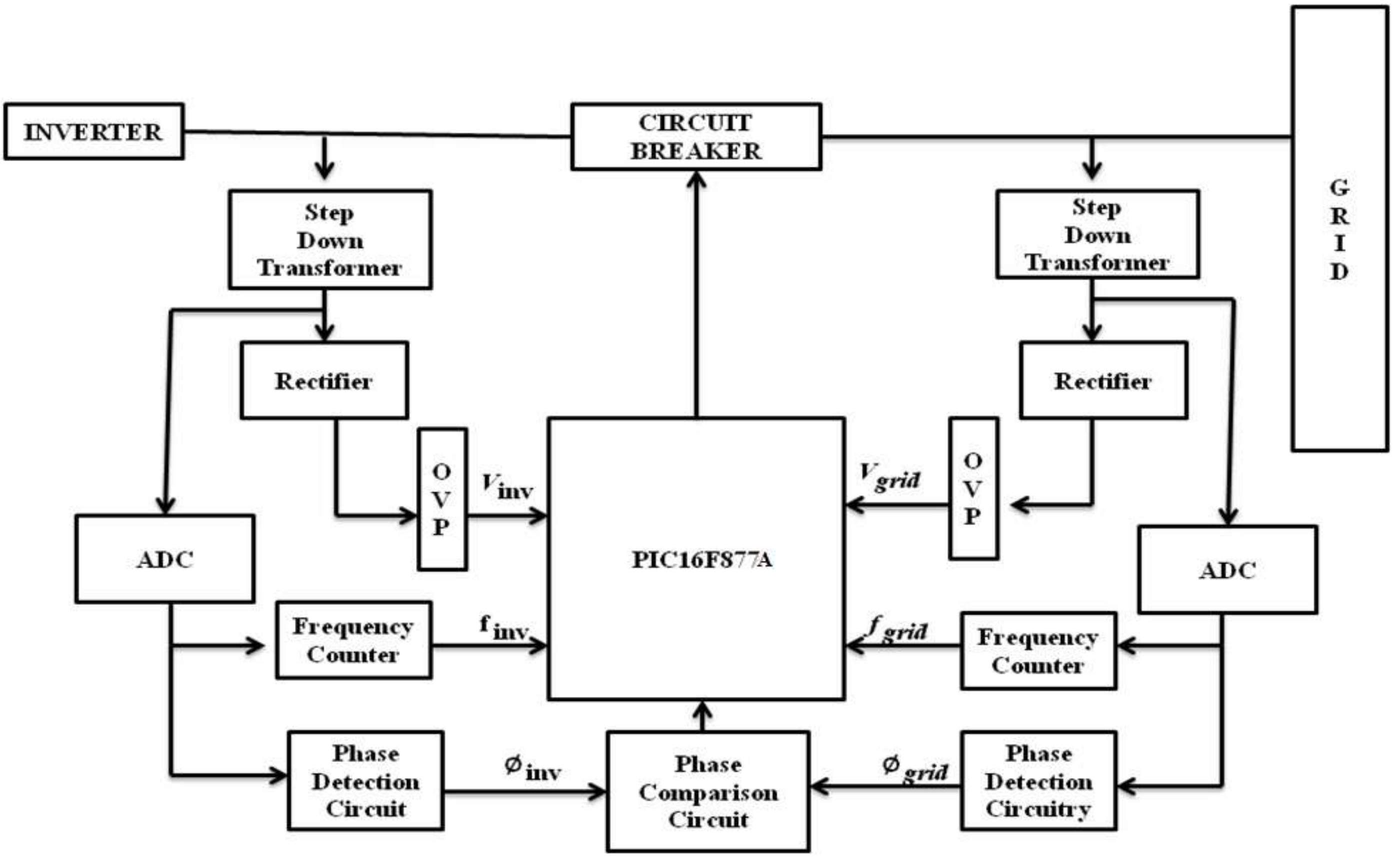


Fig. 3. Block representation of proposed controller system.

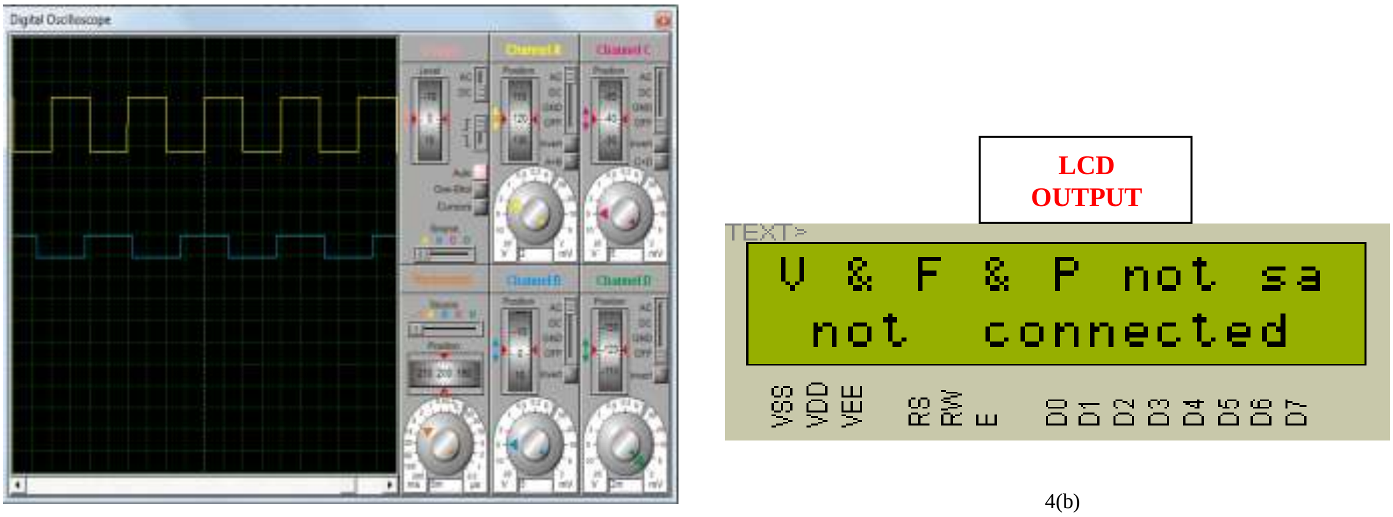
are in phase, an enable signal is fired into the PIC, which implies both signals are in phase and grid connection can be enabled. The PIC checks for the amplitude, frequency and phase on either side. The grid connection is enabled by the PIC only when the amplitude, frequency and phase of the inverter voltage are exactly same or are within tolerable limits as that of grid voltage. The controller will continuously check for this condition as long as there is power available for a grid transfer. Appropriate over voltage protection circuit (OVP) has been used to limit the peak maximum voltage applied to the PIC in worse situations.

IV TEST RESULTS

The system controller design has been simulated in proteus and the results are shown in Fig 4-8. The digital oscilloscope shows the two digital inputs corresponding to solar inverter and grid, being fed to the microcontroller for comparison. The oscilloscope has four channels. Only two have been utilized here. First voltage corresponds to the voltage produced by the pv system (channel A) and second voltage corresponds to grid side (channel B). Grid connection status is displayed on LCD.

Different scenarios have been illustrated here. Considering Fig.4(a) ,two different voltages are fed to the system. Fig 4(b) gives the output condition showing a mismatch in voltage, frequency and phase with a “not connected” status on LCD and hence pv system will not be connected to grid. The scenario when input voltage amplitudes differ is given in Fig 5.Fig 5 (a) gives the inputs with different amplitude but having same frequency and phase. The LCD status in Fig 5(b) is again “not connected” due to mismatching voltages, so grid connection cannot be initiated. Evenif voltage amplitudes are same , frequency and phase variations cannot be ignored as it affects the entire system and also grid connected systems. So frequency and phase mismatch should also be checked for. Fig 6(a) gives digital inputs having different frequency and the status “not connected” is seen on LCD which implies grid connection condition is not met (Fig 6(b)). Again Fig 7(a) gives digital inputs which are out of phase, LCD indicates no grid connection is enabled. When all the parameters on the inverter side match to the parameters on the grid side, Fig 8(a), a safer grid connection is established. The LCD indicates voltage ,frequency and phase on both sides are same and hence the status is “Connect to grid”. This is the point when a safer and transfer into grid is possible. The controller checks for this condition frequently and enables the transfer.

A high capacity relay has been connected between grid and the generation system (10 Amperes) .After a very short delay the solar inverter is connected to grid and eventually current decays and attains a steady state value. As the production decreases the controller enables disconnection from grid. The same process continues as long as the solar generation system is operational.

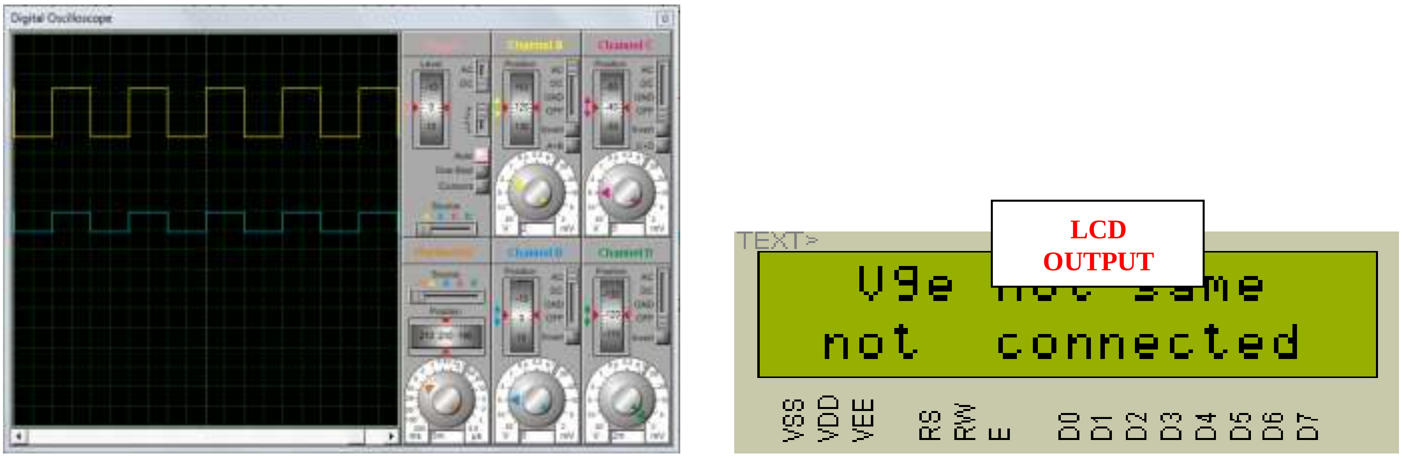


V & F & P not sa
not connected

4(b)

4(a)

Fig. 4.(a) Digital Oscilloscope showing two digital voltages corresponding to solar inverter and grid. (b) Output displayed on the LCD showing mismatch in voltage, frequency and phase.

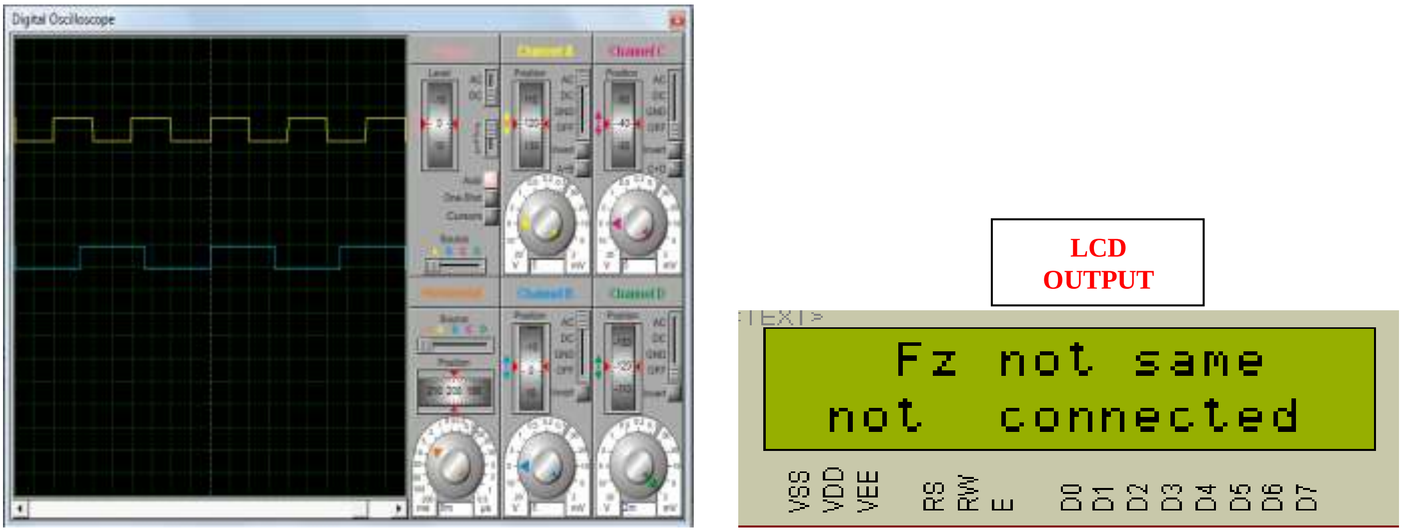


V9e not same
not connected

5(a)

5(b)

Fig. 5.(a) Digital Oscilloscope showing different voltage amplitudes corresponding to solar inverter and grid. (b) Output displayed on the LCD showing mismatch in voltage.

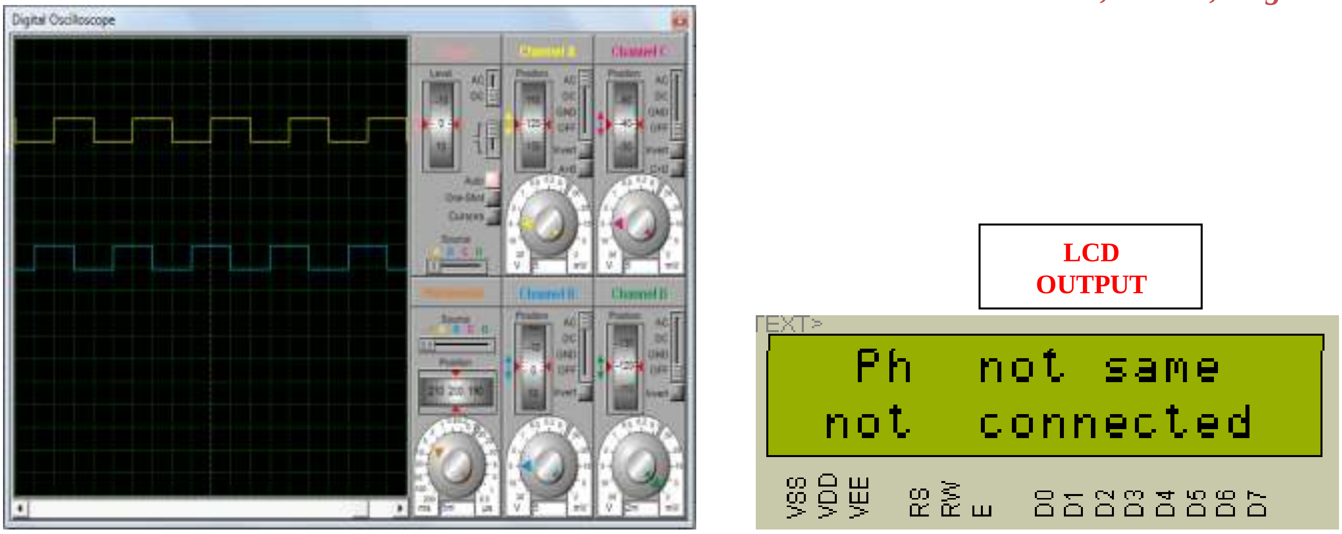


Fz not same
not connected

6(a)

6(a)

Fig. 6.(a) Digital Oscilloscope showing input waveforms having non similar frequencies corresponding to solar inverter and grid. (b) Output displayed on the LCD showing mismatch in frequency.



Ph not same
not connected

7(a) 7(b)

Fig. 7.(a) Digital Oscilloscope showing different voltage amplitudes corresponding to solar inverter and grid. (b) Output displayed on the LCD showing mismatch in phase of waveforms.

vge--Fz--Ph same
Connect to grid

8(a) 8(b)

Fig. 8.(a) Digital Oscilloscope showing different voltage amplitudes and frequency corresponding to solar inverter and grid. (b) Output displayed on the LCD showing mismatch in voltage, frequency and phase.

V CONCLUSION

The use of standard components and operating them within ratings promotes greater controller reliability. Exact reliability characteristics can be extracted with the help of detailed tests and analysis of the circuit. The anti-islanding feature and also reestablishment of connectivity to grid were demonstrated during test. In this work, a grid connection is possible only when the parameters of the two generating systems, the solar panels and the electric grid match. Though the system is designed to track the grid voltage, it is not fully equipped to catch the instantaneous voltage variations in the grid. This is a limitation of the system. More sophisticated additional circuitry is to be provided such as a compensation technique, which can continuously monitor the grid voltage and vary the parameters of the voltage from inverter, so the fluctuations in the grid parameters will not be a barrier to maintain connection as long as solar inverter is ready to feed the grid. Such a technique which is also economic is under investigation by the authors.

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