

Helios Smart Grid Connected Inverter

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Abstract—This paper presents a solar inverter with the IoT interface. The intention is to build an inverter, which is used to interface a solar energy module to the power grid/load. The single stage boost converter and inverter are built eyeing cost efficiency and reliability. The control strategy for the Inverter should be in a way that, the required voltage and frequency (50 Hz) has to be supplied by the system. The IoT module measures the voltage, current and frequency of both inverter and the grid. The module also measures the temperature and the humidity of the system. The smart system measures the output power of the inverter connected to the grid. If the grid supply is off, the smart system turns off the inverter supply to the grid. Every value that are measured by the module are updated to the server, hence maintaining the database. The DSP TMS320LF2407A is used to generate the PWM signals for the inverter and boost converter. The Renesas micro-controller is used in the IoT module for measurement of the parameters. A battery bank is used for storage purpose. The Amazon cloud server is constantly updated through the GPRS module.

Index Terms— Solar Power, Boost Converter, Inverter, MATLAB/Simulink, DSP TMS320LF2407A, Load (Resistive/Inductive), IoT Module, Renesas, Grid, Battery bank, Cloud Server, CubeSuite+, Renesas Flash Programmer.

I. INTRODUCTION

Solar power is the conversion of solar energy into an useful form of energy, like using a solar panel to get the electrical power. Solar energy, as a substitute for the fossil fuels, is renewable, widely distributed, abundantly available in the nature, which reduce pollution, lower the costs of the dangerous global warming, and keep fossil fuel prices lower than otherwise. The environment is less effected by the solar power usage.

Solar panel is connected to the grid so that solar energy can be utilized as a power source. Since the solar panel does not give a constant output, an MPPT algorithm is adopted for the system. This helps the inverter to receive a stagnant input.

This paper develops the smartness to the PWM converter and inverter module through IoT techniques. Cloud servers are used for the distance monitoring. The control strategy for the inverter should be in a way that, the required voltage and frequency (50 Hz) has to be rendered by the system. The controller is implemented with the help of a DSP TMS320LF2407A. And the IoT is handled by the Renesas micro-processor. In the absence of the sun light, the battery bank is used for the power supply, while it is being charged during the presence of the sunlight. The extra generated electricity is supplied to the grid. The IoT measures the voltage, current and frequency of both the inverter and the grid along with the temperature and the humidity of the surrounding [5][6].

The intention of this project is to build a module for solar energy conversion. The desire is to update new and economic solutions to get the electrical power from the solar power, by including the following technologies

1. Grid interface for the module.
2. Storage option for the energy in the battery bank.
3. IoT for hyper connectivity for power management.
4. Intelligent converter inverter module.

II. PROPOSED SOLUTION

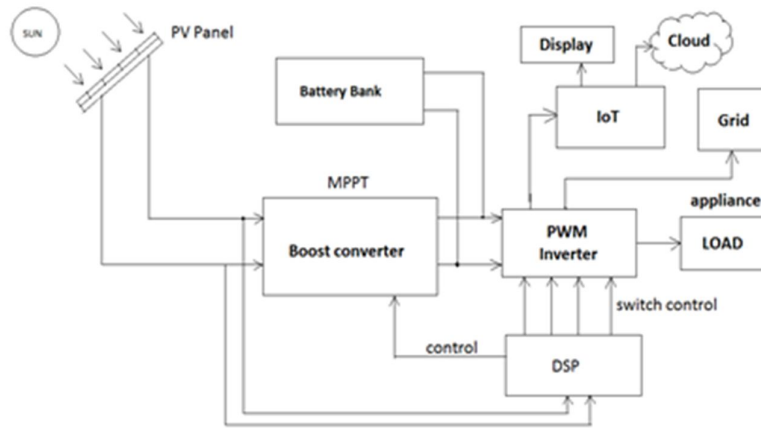


Figure 1: Top level block diagram of the smart grid connected solar inverter

The Figure 1 shows the top level block diagram of the smart grid connected solar inverter. The main components of the system consists of PV panel, Boost Converter, PWM Inverter, Digital Signal Processor, battery bank, Grid connectivity, IoT interface and cloud server with the display unit.

1. The sunlight falls on the PV panel. The PV panel produces a DC output voltage corresponding to the intensity of the light on the solar panel.
2. The low DC voltage received from previous blocks is stepped up to required voltage level using a single-stage DC-DC Boost Converter.
3. A unipolar PWM switching technique is used to convert a DC input to AC output with the help of control switches. Two half bridges form a AC network that contains separate control signals.
4. We use DSP to receive, control, process and send signals to the various external connected peripheral devices.
5. Battery bank is an additional storage of power that can be used for the appliances in the absence of the sun light. It is a temporary source.
6. An electrical network for delivering electricity for the consumers. It is a high voltage transmission line.
7. The internet of things is a inter-networking of physical devices, smart devices and other embedded systems with electronic, software, sensors, etc. Here it is used to monitor the various parameters based on its requirements.
8. The cloud server is used for the distant viewing of the data pertaining to the inverter's parameters.

Figure 2 shows the block diagram of IoT module that is integrated with the inverter module. This module measures the voltage, current and frequency of both the inverter and the grid while displaying the values on the LCD screen simultaneously, also transferring the information to the cloud server, where the data can be monitored at any place with the access of the internet. This is also called as “**distance monitoring**”.

III. SOFTWARE IMPLEMENTATION

The simulation of the systems is done with the help of MATLAB/Simulink software. Simulink, is a graphical programming platform for modelling, simulating and analyzing multi-domain dynamic systems. Its primary

interface is a graphical block diagramming tool and a set of blocks' libraries. It offers right ideal integration with the rest of the MATLAB environment and can either run MATLAB or being run from it.

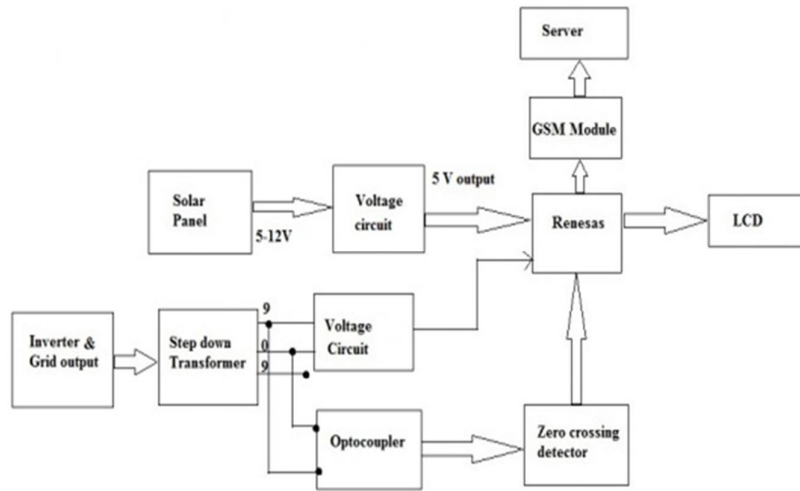


Figure 2: Block diagram of the interfacing IoT module

A. Boost Converter

From the Figure 3 the low voltage (range 8-15V) is boosted (stepped up) to a constant value (300V) to get the inverter output voltage as 230V (rms). The simulation results of the Boost Converter can be seen in Figure 4.

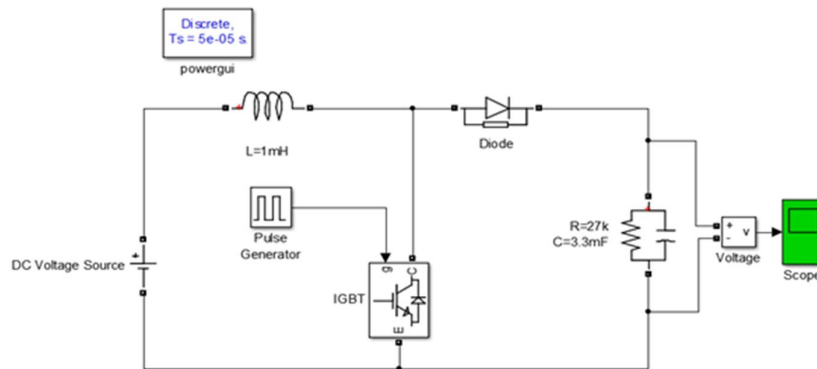


Figure 3: Simulink model of Boost Converter

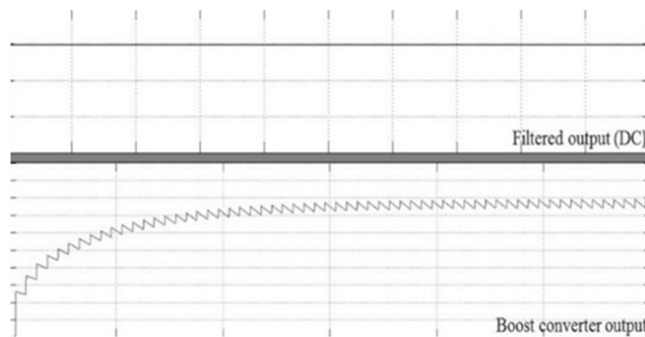


Figure 4: Simulation results of Boost Converter

In order to boost the input of Boost Converter to constant value irrespective of intensity of the sun light, Constant Frequency variable PWM control strategy is used. In this type of control strategy, the duty cycle is coded to the value obtained as per the design and the boost converter output is maintained constant(300V). Hence, this control strategy is also called as the pulse-width modulation control.

B. Inverter

The DC voltage from the boost converter is given to the inverter, whose switches are controlled by the PWM controllers from DSP and the inverter converts the DC into required AC output. The output from this inverter is passed through a ‘L’ filter, to obtain the sinusoidal AC output waveform of amplitude 230V(rms) and a frequency of 50Hz. The simulation results of the Inverter output can be seen in Figure 5a.

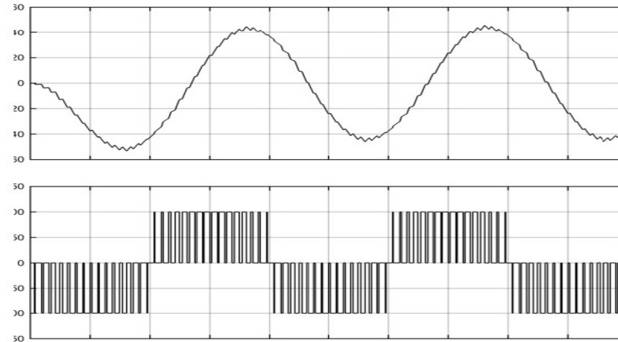


Figure 5a: Simulation results of Inverter

C. Unipolar control strategy

A Unipolar PWM switching technique is used to convert a DC input to AC output with the help of switches. Two half bridges form a AC network that contains separate control signals as shown in Figure 5b. For this case, the triangular carrier waveform is compared with two reference signals which are positive and negative signal as shown in Figure 6.

In Unipolar voltage switching, the output voltage switches between 0 and V_{dc} . The effective switching frequency is observed, when the load is doubled and the voltage pulse amplitude is halved. Therefore, the harmonic content of the output voltage waveform is reduced compared to bipolar switching. In Unipolar voltage switching case also, the amplitude of the harmonics and its sidebands is lesser for all modulation index, thus making filtering easier, and with its size being much smaller between 0 and $-V_{dc}$.

Algorithm: (summarized in table1)

The output voltage is generated by using the following logic:

If Switches S1 and S2 are ON, $V_{ab} = + V_D$

If Switches S3 and S4 are ON, $V_{ab} = - V_D$

If Switches S1 and S3 are ON, $V_{ab} = 0$

If Switches S4 and S2 are ON, $V_{ab} = 0$.

Table 1 shows the switching state of the unipolar PWM and the corresponding voltage levels. It can be observed from the table that when the two top and the two bottom switches are turned on the output voltage is zero [2], [7].

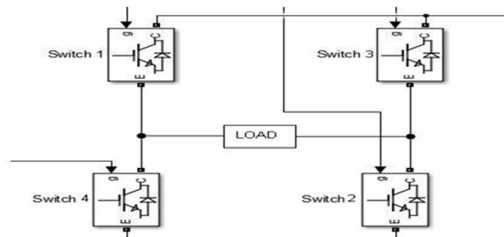


Figure 5b: Unipolar switching circuit

TABLE I: SWITCHING STATE OF THE UNIPOLAR PWM AND THE CORRESPONDING VOLTAGE LEVELS.

S1	S2	S3	S4	V_{an}	V_{an}	$V_o = V_{an} - V_{an}$
ON	ON	-	-	V_D	0	V_D
-	-	ON	ON	0	V_D	$-V_D$
ON	-	ON	-	V_D	V_D	0
-	ON	-	ON	0	0	0

Figure 6 shows the waveforms of PWM control (PWM1, PWM2, PWM3 and PWM4) with Unipolar switching using Simulink

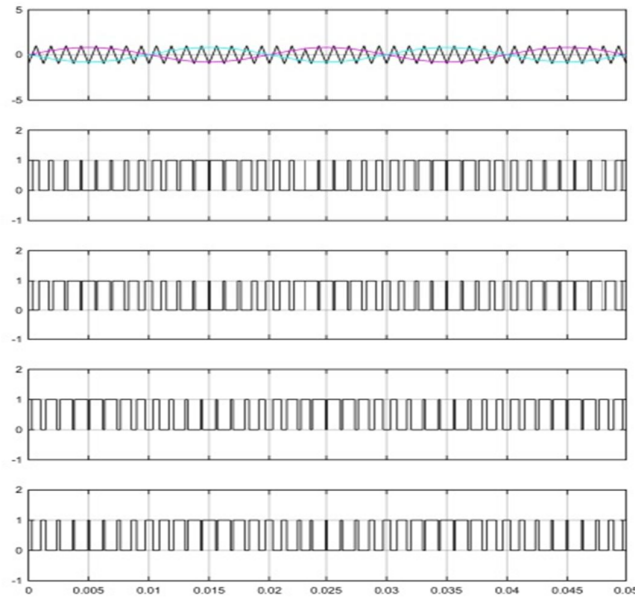


Figure 6: Simulation result of Unipolar Control strategy for inverter switches (4 nos).

D. CubeSuite+ and Renesas Flash Programmer

CubeSuite is an Integrated development platform that is designed to perform repetitive editing, building and debugging operations. The program provides a high user-friendly development platform featuring formidable shorter build times and graphical debug functions.

Renesas Flash Programmer is a software package used to dump the program to the on-chip flash memory of Renesas micro-controllers. It provides usability and functionality specifically designed for flash programming.

The required model of the Renesas(RL78) is selected and the code is written for the required message to be displayed on the LCD, using the Cubesuite+ software. All the pins of Port 7 are changed to output pins. The 5th and the 6th pin of Port 0 are also set as output pins. Watchdog timer is changed to unused. The files generated along with the main file are compiled and the project is built.

IV. HARDWARE IMPLEMENTATION

A. Experimental Setup

An experimental prototype consists of three boards:

1. eZdsp™ TMS320LF2407A Board.

2. Experimental board consisting of Boost converter with gate driving circuit, two-level single phase PWM inverter with gate driving circuit for four IGBTs.
3. Experimental board consisting of Renesas micro-controller, GSM module, LCD display, relay and other voltage circuits.

B. The eZdsp™ TMS320LF2407A

The details of this eZdsp™TMS320LF2407A is available in Technical Reference. Figure 7 shows eZdsp™TMS320LF2407A Evaluation Board. The eZdsp™TMS320 LF2407A is a 5.25 x 3.0 inch, multi-layered PCB, powered by an external 5V power supply.

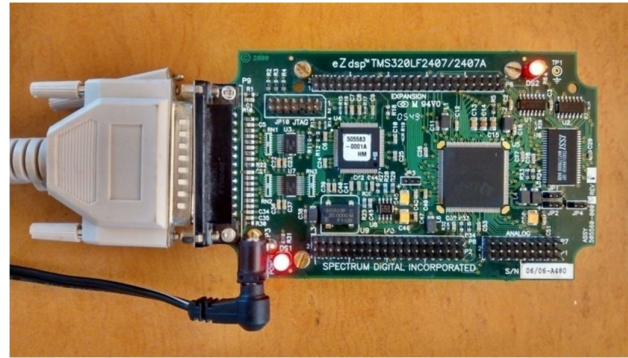


Figure 7: eZdsp™TMS320LF2407A used for SPWM gating signal generation

The Table 2 shows the Pin Configurations used in the project for PWM outputs and ADC input.

Table II: Pin Details for eZdsp™ TMS320LF2407

Pins	Description
9	PWM1
10	PWM2
11	PWM3
12	PWM4
30	PWM7
39	Ground
Analog Pin 3	Ground
Analog Pin 4	Analog input to ADC (ADCIN1)

C. Renesas micro-controller

Renesas micro-controller is a 16-bit CPU core by Renesas Electronics with a CISC architecture for microcontrollers. The features of the RL78 is available in technical reference.

D. The experimental set-up of the module

A prototype of Converter-Inverter module for solar power generation system was designed and the required components were assembled in the laboratory. The circuit consists of:

- Boost Converter
- Inverter circuit
- IoT module

The experimental setup includes the DSP for generating control signals, Boost converter and inverter. The setup is shown in Figure 9

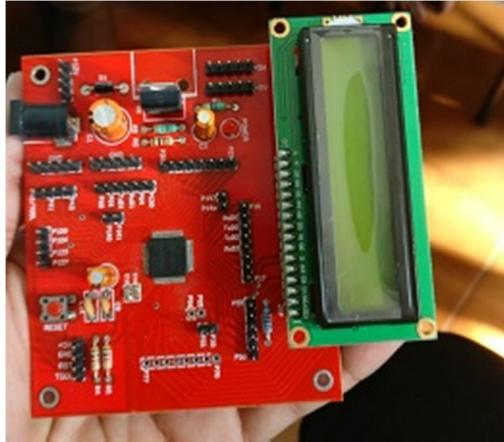


Figure 8: LCD inserted to the Renesas micro-controller port



Figure 9: Experimental set-up of the solar inverter module

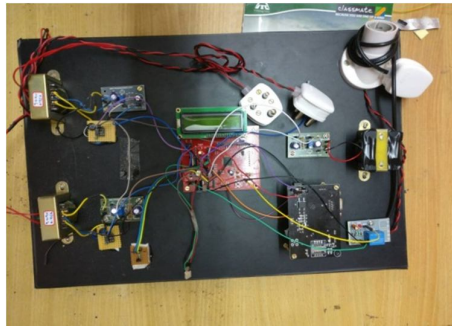


Figure 10: Experimental set-up of the IoT module

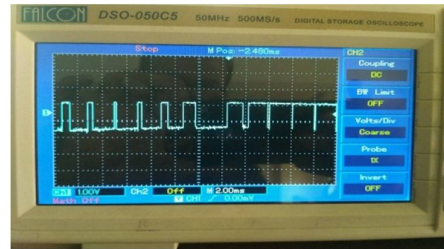


Figure 11: The PWM wave generated at pin No.9 of the DSP

The experimental set-up includes the Renesas micro-controller, the GSM module, 9-0-9 transformer, opto-coupler and temperature and humidity sensors.

Experimental Results of Hardware implementation : The Control signals for converter-inverter module is generated using DSP TMS320LF2407A. The four PWM signals for inverter are generated by DSP using unipolar control strategy.

The PWM inverter output is obtained and is shown in the figure 12 showing the sinusoidal PWM wave. Also figure 11 shows the PWM wave generated by the pin no.9 of the DSP which are generated as per the design values

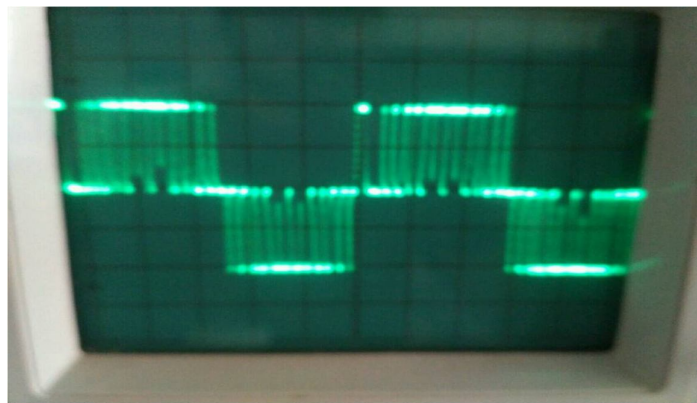


Figure 12: The output wave of the inverter module

The solar panel collects the solar energy and has an output of 5 to 12 volts DC. This voltage is provided as an input to the “voltage circuit”. This is a voltage regulation circuit and hence provides a constant output of 5V. This output of the voltage circuit is provided to the Renesas for measurement purposes.

The output from the grid ie the Power supply lines from the main power supply and also the outputs of the Inverter is stepped down. The step down of this voltage is done using the (9-0-9)V transformer or a (12-0-12)V transformer. The step down is a necessary step as the Renesas works on a 5V platform. And any input to the Renesas has to be in the range of 0-5V volts. The measurements are done on the stepped down voltage and then the measured parameter is later displayed in the actual/ stepped up format for convenience purposes. This output of the step-down transformer is again given to a voltage circuit for the same reasons and is given as an input to the Renesas for grid parameters measurements.

The frequency of the output from the grid or the inverter is also under consideration. Hence to measure this parameter of the signal, an opto-coupler along with a zero crossing detector is used. The opto- coupler is used for protection. Incase of high current flow the zero crossing detector along with Renesas itself is protected using the opto- coupler. The zero crossing detector generates a square pulse for every zero crossing and the Renesas counts the total number of such crossings per second and hence the frequency is determined with the value of time ‘T’ obtained. The frequency is measured in the Renesas with the input from the zero crossing detector.

As the voltages are stepped down to below 5V for measurement in the renesas, these again have to be converted to the input scale before they are displayed for the user convenience.

The output obtained from the Renesas is multiplied with a predetermined constant factor. This is determined using the factor by which it is stepped down at the input stage. Each output before displaying is multiplied by this factor and then is sent to the display unit.

The data hence determined also has to be updated to the Amazon cloud server. The server stores the data sent by the GSM unit embedded in the system. This system is programmed to send the data such as the voltage, current and frequency values to the server at predefined intervals. These values can be used when and where required at the given point of time.

The GSM module is a GSM-900 model which is used to send the data to the server. The Amazon cloud unit has a predefined amount of space for the data storage. The GSM unit used here uses a 2G cellular data for the data transfer.

The outputs of the Renesas , after it has been converted to the input scale has to be displayed on the display unit. The values of the voltage, current and frequency along with the temperature and humidity values are displayed on the LCD display unit attached with the unit. These values are continuously read and are updated and displayed on the unit.

V. CONCLUSION

The need for renewable energy resources inspired us to develop a Power Electronic system to convert solar power into electrical power for domestic usages. The control strategy was developed for the converter and Inverter to get a sinusoidal output for the applications.

The control strategy was first verified on simulink software, and based on the successful results, it was implemented using the DSP. The IoT module measures and successfully communicates the information of the parameters to the cloud storage and that could be viewed from any place. Parameters like temperature and humidity can also be measured ensuring a high standard inverter with multiple functions. Hence, these aspects add the “**smartness**” to the system.

The experimental results were observed by connecting CFL bulbs, filament lamps and universal motor as loads. The system supplied the required voltage and frequency to the load indicating the validation of the control algorithm and application of IoT for smart renewable energy conversion.

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