Design of a Micro-Inverter for Solar Panels

Tennessee State University
Department of Electrical and Computer Engineering

Students: Emmanuel Safari and Richard Wiencek

Project Advisor: Dr. Sagnika Ghosh
Sponsor: GridEd by EPRI

Abstract:

The objective of this capstone project is to design an efficient DC to AC inverter for solar panels. With three alternative solutions namely string inverter, power optimizers. the micro-inverter is selected as the best alternative solution. With the proposed micro-inverter, the structure of H-Bridge MOSFETS based DC to AC converter, a transformer to step up the ac voltage, and filter which blocks all high frequency components and just lets the fundamental frequency 60 Hz signal to pass through system is designed. Finally, the circuit is simulated in MATLAB Simulink to check the system design specifications. The system produced ac voltage as desired. PV array simulation of 12V and 1.8A as the input DC voltage and it is inverted to 16 AC volts. After the transformer the output becomes 1.5 kV AC.

Introduction:

Solar energy produces electricity in a form that residential loads cannot use. It produces DC power, but residential loads use AC power. Therefore, a tool to change this form into a suitable form is required. This works like a traveler going around the world, so you cannot buy anything in another country unless you exchange your country's currency for local currency. According to Kelsey Misbrener, repots says that inverters are solely responsible for more operational functions than any other PV system component Electricity generated by solar panel is initially direct current (DC), so the inverter converts into alternating current (AC) which is suitable to be used by residential loads such as lamp, TV, computer, etc. This project will be designed in LTSpice and on board with hardware components.

A. Problem statement

In two or three decades ago, most of human work was done manually, but in this digital era, a lot of machines have been invented to do human work. For this machine to operate effectively; it requires electricity, and the most challenging issue is to generate the electricity to feed all residential loads. This high demand of electricity to run residential loads endangers the environment like air pollution and toxic water caused by coal-fired power plants and leads to high electricity bills. On average, electricity users in Tennessee spend about $195 per month on electricity. This adds up to $2,34 per year. Over the next 25 years you should expect to pay $74,100 on electricity bill in Tennessee [1].

B. Need Analysis

According to Energy Information Administration, the national average residential rate increased by 8% compared to 2021, and in Florida, Hawaii, and New York, consumers saw an increase of 15%. There are many reasons why electricity bills are too high nowadays including the ongoing pandemic, geopolitical conflicts affecting energy prices, and extreme weather event like those that impacted Texas grid. Electricity bills will continue to go higher and higher with the emerge of electric vehicles. Therefore, another form of energy is needed as the backup of grids. To withstand this high cost of electricity we should go for renewable energy sources like wind energy, solar energy, and hydropower which are sustainable forms of energy because they have a low environment impact and are widely available as well as naturally replenished. As the solution to this high demand of electricity and problems highlighted in the problem statement solar panel can play an important role as the saving of the planet.

Background:

A. H-Bridge Inverter

An inverter is one of the most important pieces of equipment in a solar energy system. It's a device that converts direct current (DC) electricity, which is what a solar panel generates, to alternating current (AC) electricity, which the electrical grid uses. In DC, electricity is maintained at constant voltage in one direction. In AC, electricity flows in both directions in the circuit as the voltage changes from positive to negative. Fundamentally, an inverter accomplishes the DC-to-AC conversion by switching the direction of a DC input back and forth very rapidly. As a result, a DC input becomes an AC output. H- bridge is an example of an inverter. Which is an electronic circuit that enables a voltage to be applied across a load in either direction. Its main purpose is to switch the polarity of the voltage applied to the load. Its name "H-bridge "is derived from its common schematic diagram representation, with four switches elements configured as the branches of the letter "H" and the load connected to it as the cross bar. The H-bridge can be built with transistor, which can operate as switch.

The H-bridge inverter's name is derived from its construction like H letter. It enables the voltage to be applied across the load and enables the voltage to be applied across the load. It alternates the polarity of voltage across the load operating two switches at the time. When MOSFET 1 and MOSFET 2 switched on for half period, the positive dc voltage appears across the load. When MOSFET 3 and MOSFET 4 switched off for another half period negative dc voltage appeared across the load. Figure 2 shows the H-bridge Inverter with MOSFET.

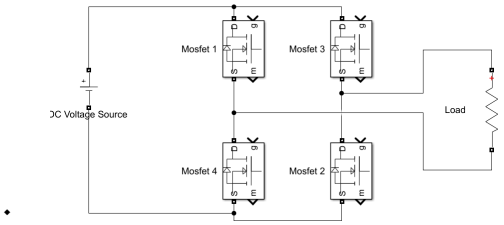

Figure 2. H-bridge Inverter with MOSFET as switch [2]

B. Transformer

Transformers are electrical devices consisting of two or more coils of wire used to transfer electrical energy by means of a changing magnetic field. "transformer, device that transfers electric energy from one alternating-current circuit to one or more other circuits, either increasing (stepping up) or reducing (stepping down) the voltage" [3]. In electric power transmission, transformers allow transmission of electric power at high voltages, which reduces the loss due to heating of the wires. In many electronic devices, a transformer is used to convert voltage from the distribution wiring to convenient values for the circuit requirements. For this project, a transformer will come into play to boost the voltage needed by the load after DC/AC converter process. The high the voltage level, the low current level with the same power, this reduces the power loss (I^2*R) in

transmission line. The coil of a transformer that is energized from an AC source is called the primary winding (coil), and the coil that delivers this AC to the load is called the secondary winding (coil). Figure 3 shows the schematic diagram for transformer.

$$Vs=-Ns\frac{\Delta\Phi}{\Delta t} \quad \text{..... (1)}$$

$$Vp=-Np\frac{\Delta\Phi}{\Delta t} \quad \text{.....(2)}$$

$$Pp=Ip*Vp=Is*Vs=P \quad \text{.....(3)}$$

$$\frac{Vs}{Vp}=\frac{Ip}{Is}=\frac{Ns}{Np}=N \quad \text{..... (4)}$$

where N is the turn ratio

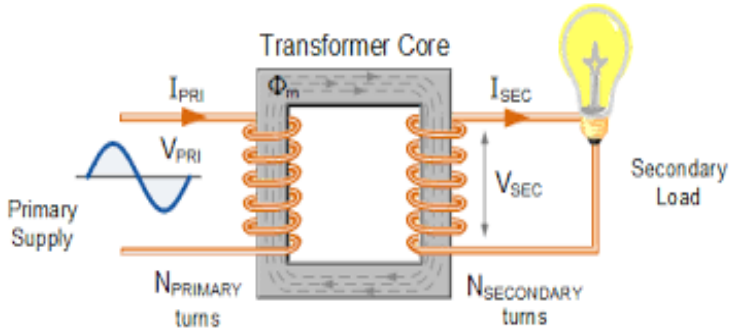

Figure 3. Transformer [4]

Design Goal and Objectives:

Solar panel collects energy from the sun and starts generating electricity for residential loads. Therefore, the goal of this project is to increase the efficiency of solar panels by stepping up the dc voltage of the solar panel. "According to Marc Johnson, the Photovoltaic (PV) industry is working to overcome several technical challenges to become a trusted and reliable energy provider on a truly large scale. Among these challenges are the needs for improving PV system reliability and maximizing total energy harvest. The key element for the solution is the inverter technology."

Though solar panel generates electricity, it is not capable of generating alternative current that residential loads use; instead, it produces direct current. Therefore, the objective of the project is to design an efficient DC to AC inverter for solar panel to take care of this shift from dc to ac.

Design Specifications:

Design Specification are technical requirements that deal with the technical functionality of the system design. As far as the design specification is concerned.

1. The system design must step-up the solar input voltage at least by the gain of 10.
2. The system design must provide power to the load connected to it.
3. The system design must generate output voltage with fluctuating polarity.

System Decomposition:

The system design is composed of H-bridge inverter, transformer, and fed to the load. The H-bridge inverter function is a covert dc voltage source from the PV array. The inverted dc will be fed to the transformer to step up the ac voltage to desirable voltage rating of the load. Figure 4. shows the physical decomposition of the system.

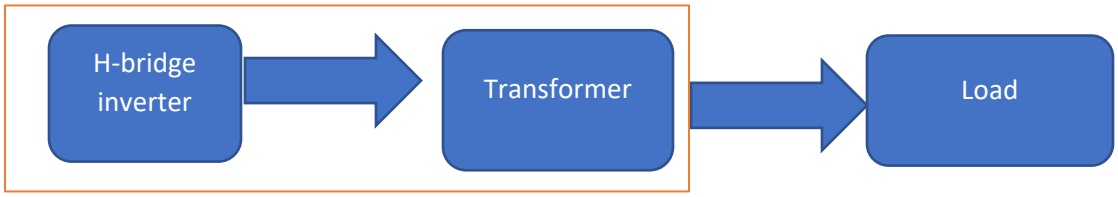

Figure 4. System Physical decomposition

Results:

A. Detailed Circuit Design and System Integration

The system Design started with a PV array fed with 1000W/m^2 at 25°C Temperature. The PV array gives a dc voltage and feeds it to H-bridge MOSFET based inverter to shift dc voltage to ac voltage. The output ac voltage is fed to the RLC filter and stepped up by a variable ratio transformer and finally fed to an RLC load. Table 1 shows the parameters of RLC filter and load. Figure 4 shows the entire integrated system design in MATLAB/Simulink environment. The sine wave is a shape or pattern the voltage makes over time, and it's the pattern of power that the grid can use without damaging electrical equipment, which is built to operate at certain frequencies and voltages. Therefore, the filter in this project is used to produce a sin wave voltage.

Table 1. Circuit Parameter

Parameter	Symbol	Value
Transformer Turn ratio	N	10
Resistor	$R_1 = R_2 = R_3$	1kΩ
Inductor	$L_1 = L_2 = L_3$	10H
Capacitor	$C_1 = C_2 = C_3$	0.1μF

As the system design aims to convert the dc to ac, the variable dc voltage is fed to the inverter. Figure 5 shows the simulation of variable PV array to be fed to the inverter. The inverter the dc to dc, and Figure 6 shows the output voltage after

conversion. After dc to ac conversion, the transformer comes into play to step up the voltage to desirable load voltage. Figure 7 shows the output voltage after the transformer has stepped it up.

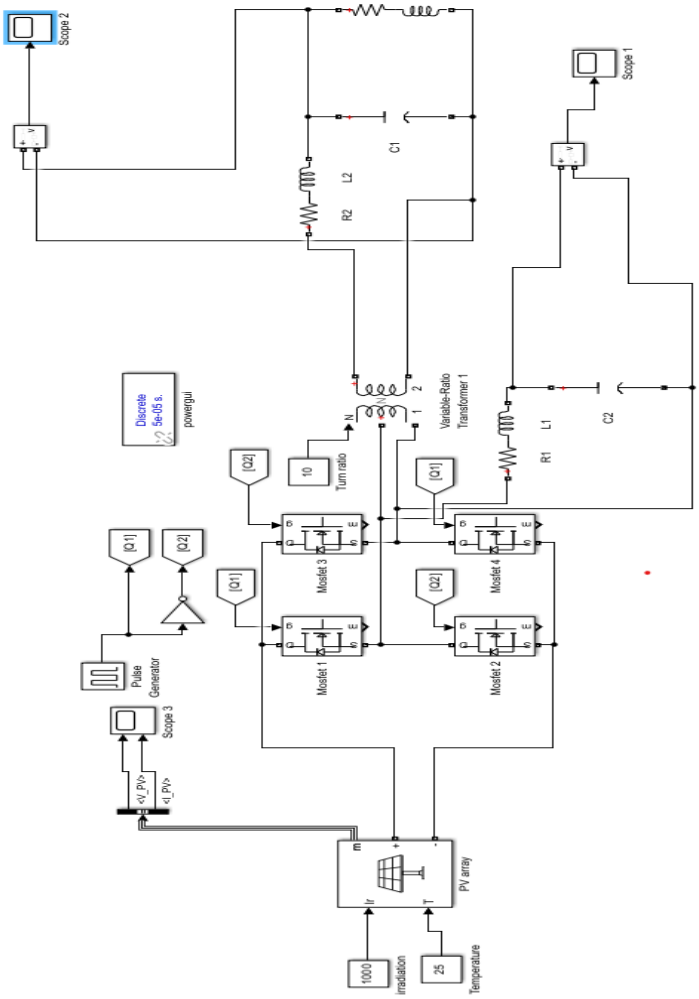

Figure 4. System Implementation in MATLAB Simulink

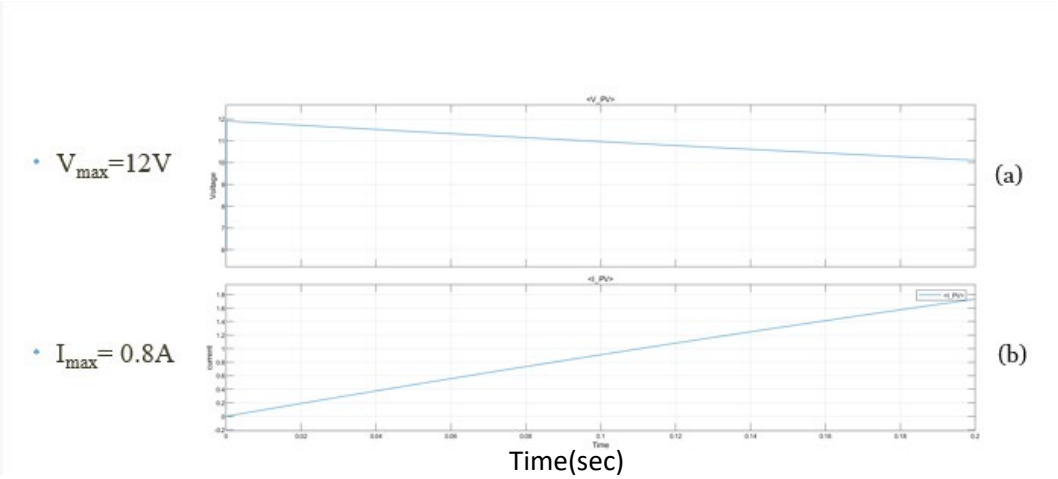

Figure. 5 Simulation of array a) Voltage across PV array b) current across PV array

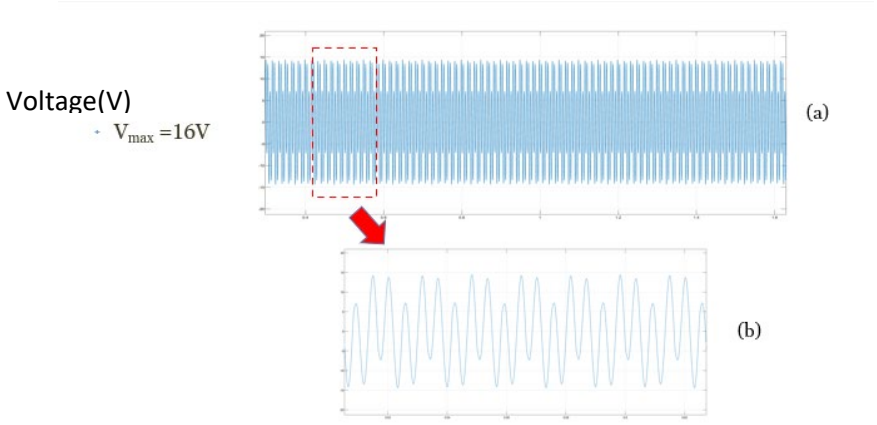

Figure 6. (a) Result after Inverter, (b) Zoomed in result

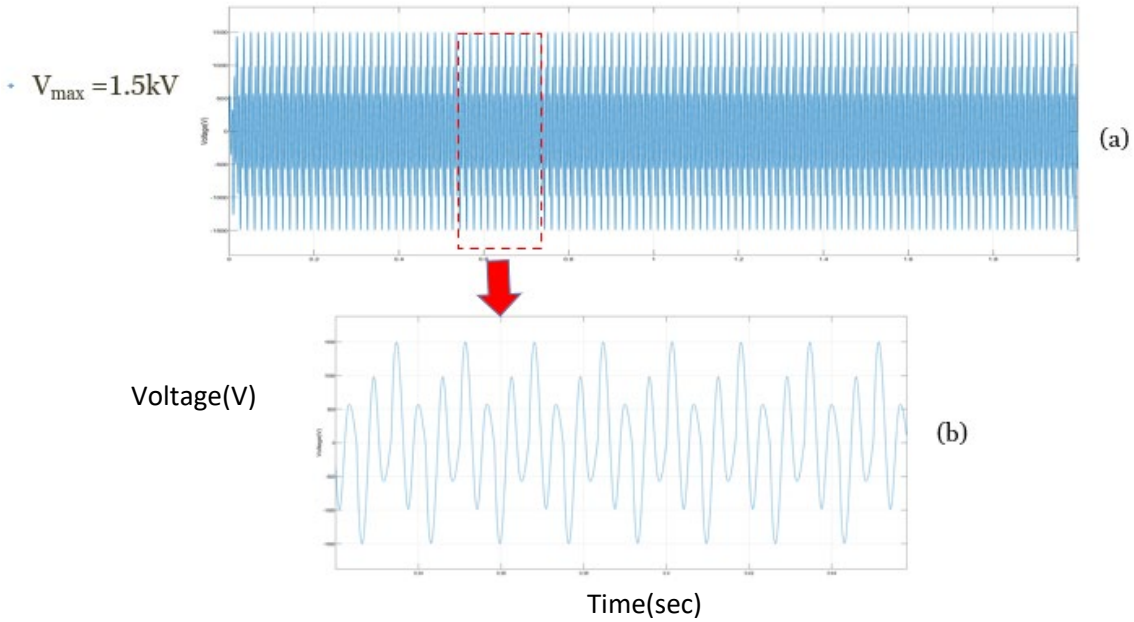

Figure 7. (a) Result after Transformer, (b) Zoomed result.

In Figure 8, The PV array box with DC variable voltage is fed to the inverter system design to give the AC output voltage on the display. Table 2 shows the DC input voltage of the PV array and their respective AC output voltage.

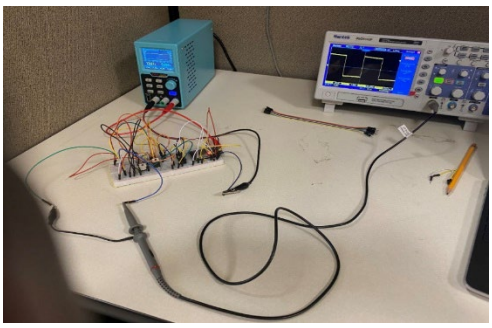
Figure.8 Hardware results

Table 2. Hardware Results

DC voltage	AC voltage
10V	10V
12V	12V
15V	15V

Conclusion and Recommendation:

A. Conclusion

The objective of this project is to design an efficient DC to AC inverter for solar panels. The system design was built with software and hardware components. All the design specifications were met, and the system design successfully completed its intended purpose, the design objective is successfully achieved. Software simulation results and the hardware results correlate, and it signifies that the design Goal and objective are met.

B. Recommendation

This capstone project has helped me in acquiring important experiences in the demands and responsibilities of the working world, practical experience, and incorporates all theoretical material I leant throughout the four years of college into one significant project. Therebefore, my recommendation to the faculty would be to add another capstone project in junior year because small project to junior students to be confident for big project the senior year. Also, a silicon carbine inverter would be another alternative of an inverter.it allows for saving in AC connection and high voltage cables. It delivers a high voltage range of 450V-850V and proves maximum power of up to 300 KW.

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