

SOLAR ENERGY CONVERSION USING LOW COST INVERTER

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ABSTRACT

This paper focuses on designing and implementing of an inverter and particularly focuses on developing a low cost transformer-less voltage source conversion that has a higher efficiency as well as compact in size. The complete design consists of DC-DC converter and a DC-AC inverter. The converter is dependent on switched capacitor techniques and steps 12Vdc to 240Vdc. The inverter is dependent on a full-bridge configuration which produces a 240Vac output from 240Vdc. To achieve the improvement in inverter efficiency and a reduction in cost, the power transformer and magnetic components such as inductors are eliminated. In addition, inverter voltage control techniques such as pulse width modulation (PWM) and switching of MOSFETs are optimized through digital control using ATtiny26L microcontroller unit.

KEYWORDS: solar energy conversion, inverter, MOSFET

1. Introduction

The inverter is an instrument having input of Direct Current (DC) while its output is Alternating Current (AC). The inverter desires to be manufactured to manage the necessities of an energy hungry family yet continue to be highly efficient at some point of intervals of reduced demand. Inverters may be manufactured in a wide variety of topologies based on the state of affairs and their necessities. The inverter efficiency is greatly structured on the switching device, topology and frequency of switching of the inverter (Nagarathna, Nikhil, Usha & Vinayaka, 2015).

Nowadays, the essential electricity dealer of the international economic system is fossil fuel. This then again has led to many troubles such as global warming and air pollution. Therefore, with regard to the global vogue of inexperienced energy, solar energy science has come to be one of the most promising strength resources. The quantity of photo-voltaic (PV) installations has had an exponential growth, commonly

due to widespread public, the governments and utility agencies who aid the idea of the inexperienced energy. The photo voltaic cell transforms the mild energy into electric powered energy. It represents a source with a properly strength density and excessive theoretical efficiency. From an electric factor of view, the solar cell is viewed as a voltage source. This source is despite the fact that imperfect. Therefore it is essential to insert an inverter between the photo voltaic cell and the community in order to reap the alternating electric source (Petreus et al., 2016). PV systems are related to domestic systems or the grid through inverters. Therefore criterions have to be defined to choose the inverter, taking into account the distinction of voltage values between a standard photo voltaic cell 12V and the required voltage for home functions which is 240V ac. In most of the modern systems, transformers are used in the inverter. In our paper however, one of the techniques used to limit power loss, fee and dimension of the inverter system is to keep

away from the use of power transformers (Shekhawata & Raob, 2016).

The quantity of electrical power produced by way of a PV device linked to a purchaser does not constantly coincide with the electricity demand of that consumer. Therefore, to use all the energy produced from such a system requires giant electricity storage potential to be used in conjunction with the PV generation. Alternatively, a greater cost-effective method would be to at once feed any extra strength from the PV gadget to the grid network. The gain of utility related PV technology over the stand-alone systems is that back-up generation and bulk storage are shared (Yildiran, 2016).

The major disadvantages of the use of PV energy are its capital fee in evaluation to that of the conventional sources of electricity and its conversion efficiency. High efficiency is perpetually required, due to the fact that cooling of inefficient power converters is hard and expensive. The best strength converter has a hundred percent efficiency; in practice, efficiencies of 70 % to 95 % are usually obtained. Consequently,

for utility related PV technology to end up a workable choice power supply not only have to the cost of the PV panels and the inverter gadget be decreased but additionally its efficiency needs to be improved (Asim & Aamir, 2019).

2. Design and Implementation

2.1. DC-DC Converter Design

The DC-DC converter is designed to provide a steady DC voltage of 240V to allow the implementation of the inverter stage. The topology chosen for implementing the converter is a multilevel switched capacitor (MMCCC) design based on the Makowski charge pump DC-DC converter. This topology is chosen because of several reasons. The design is modular in structure and hence can be designed to achieve any conversion ratio. Each modular block has one capacitor and three transistors leading to three terminal points. The schematic diagram of a 4-stage Makowski charge pump cell, which has 6 capacitors, is shown in Figure no. 1.

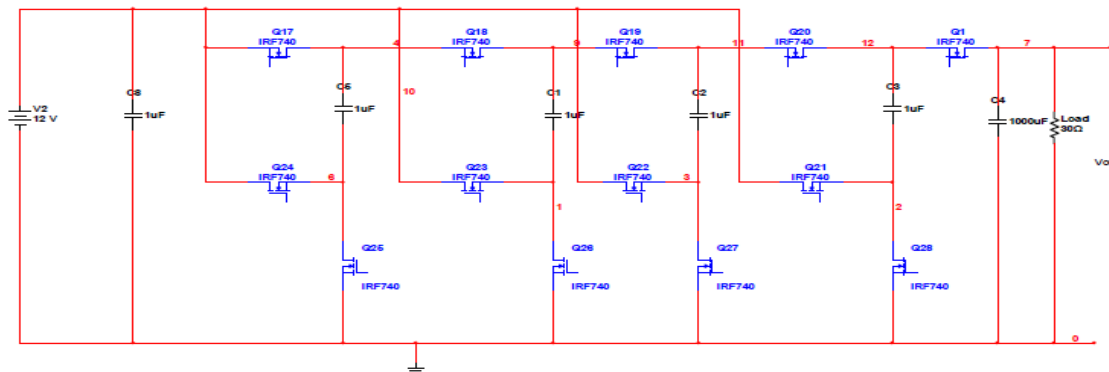


Figure no. 1: 4-stage MMCCC DC-DC converter

In addition, this topology can achieve high frequency operation, low input/output current ripple, and low ON-state voltage drop and bidirectional power flow management. Compared to other capacitor-clamped DC-DC converters, it is more compact, reliable, better component utilization as well simple switching scheme

with only two switching states. The simpler switching scheme enables high-speed operation for the multilevel switched capacitor converter. It is the maximum conversion ratio that can be attained from a switched capacitor DC-DC converter using capacitors. In other words, for a specified conversion ratio, the Makowski charge

pump requires the least number of capacitors and switches. The next question is how many modules are needed to achieve the 240V required. Since the design requires N-1 modules for N conversion ratio, 20 modules would be required to achieve the desired voltage considering the voltage drop across the MOSFETs.

2.1.1. Capacitor Selection

Two types of capacitors are popular in switched-capacitor (SC), DC-DC converter applications-integrated capacitors and external ceramic capacitors. The integrated capacitors are convenient for low power applications as they help create an ultra-compact final product. However, due to the higher power level in the work, ceramic capacitors are chosen. The selection of capacitors depends on both the capacitance and the output ripple current. Unlike other multilevel inverter topologies, such as flying capacitor multilevel inverters, in which the capacitor for the various levels have to be calculated separately, the MMCCC converter is modular in nature and allows for the use of capacitors of the same value in each module. Electrolytic capacitor used in each module is rated $1\mu\text{F}$, 300V while the output capacitor is rated $1000\mu\text{F}$, 300V. The reason for choosing an output capacitor of large capacitance value is so as to achieve a smooth constant DC voltage desired to be fed to the inverter stage.

2.1.2. MOSFET Selection

The selection of MOSFETs is determined by the current requirements and the voltage ratings as well as closely comparing their drain-source-resistances ($R_{DS(on)}$), power dissipation and switching

characteristics. Lower voltages ratings and higher current capabilities tend to drive down the conduction losses through reduced $R_{DS(on)}$ values, however, the switching losses are increased due to large gate charges and parasitic capacitances. Thus, a compromise has to be made between low conduction losses or low switching losses. In addition, the device must be rated above the maximum output voltage of the converter. As a result of the above consideration, fairly low cost MOSFETs is found to be made by Fairchild Semiconductor called IRF740. This MOSFET is 10A, 400V with a fairly low $R_{DS(on)}$ of 0.48Ω and good switching performance.

2.1.3. Gate Drive

Power MOSFETs have considerable gate capacitances that must be charged beyond their threshold voltage for MOSFET to turn ON. The output voltage from the ATtiny26L is 2.3V and this is not sufficient to turn on the MOSFET. As a result, a gate-driver is required to provide the gate with high enough currents to charge the gate capacitances within the time required to reduce switching losses. Two options are available to supply the required gate current. One of the methods is to use a gate drive IC and the other is to use an interface circuit such as totem-pole type arrangement using an npn and pnp transistor to achieve the required current. Whereas the gates drive ICs would have been ideal because of its capabilities and simplicity they were not available on time. The author settled for a simple interface gate driver circuit as shown in Figure no. 2.

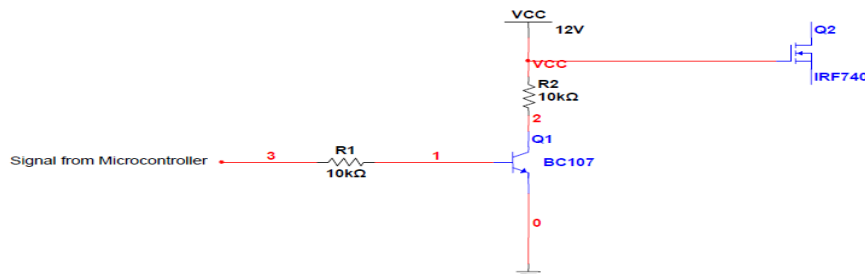


Figure no. 2: Gate driver circuit

2.2. DC-AC Inverter Design

The DC-AC inverter layout chosen is constructed round a standard full-bridge topology due totally to its high power coping with capabilities and the potential to supply bi-polar PWM and as a result

successfully double the switching frequency of the output. The enter voltage is supplied with the aid of the DC-DC stage and is assumed to be 240V. This circuit is designed as shown in Figure no. 3.

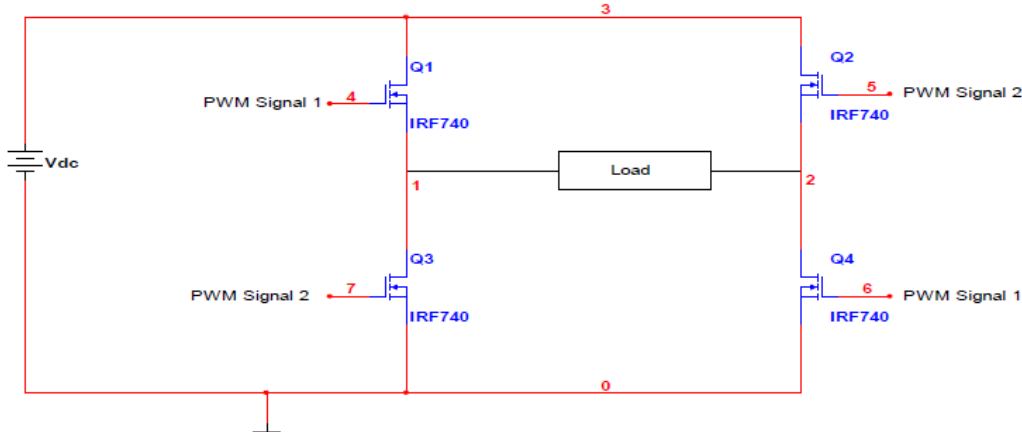


Figure no. 3: *H-bridge Inverter Circuit*

The circuit of inverter is an H-bridge that composed of 4 N-channel enhancement MOSFETs. The MOSFETs considered are International Rectifies IRF740, that maintains a high drain to source voltage of 400V and skips a high current of 10A. The MOSFET makes switching with a most frequency of switching of about 16MHz. Since the producer built-in an inverse parallel diode to the MOSFETs, there is no want for external inverse parallel diodes even though they can be included for brought safety. The inverter of full-bridge is selected as the output stage of inverting for a variety of causes. It is preferably selected over the inverter of half-bridge since for an equal entering voltage, the inverter of full-bridge may supply double the output voltage, which means that for equal electricity output, the coming out current is reduced to halve. The inverter of full-bridge is additionally considerably most controllable. The MOSFET ON-state resistance causes a loss of conduction. This resistance is not only the solely cause of dissipation of electricity in the MOSFET. Other source occurs when there is switching between states in MOSFET.

In case of brief duration of time, the MOSFET is 1/2 ON and 1/2 OFF. The longer state is when the MOSFET is neither ON nor OFF, the extra electricity is dissipated. Due to this dissipation of electricity and to avoid breaking of MOSFETs by means of heat, warmness sinks are required.

2.3. Control Circuit

To generate sine PWM signal, an Atmel ATtiny26L microcontroller is used. The ATtiny26L is low voltage, high-performance, low-power AVR 8-bit microcontroller. The gadget is manufactured with the use of Atmel's high density nonvolatile memory technology and is well matched with the industrial fashionable MCS-5 one guidelines set. It also has two 8-bit timers that supply the characteristic used in this application. By combining a versatile eight-bit Central Process Unit (CPU) with flash on a monolithic chip, the ATtiny26L is powerful microcomputer which presents exceedingly bendy and cost fantastic answer to many embedded manipulate applications. The selection of frequency of switching is a tough one in

that losses of switching and equipment sizes minimize with frequency of switching at the fee of noise boundaries and higher speed switching instruments. This selection is made less complicated via the wide vary of high pace MOSFETs available. Since two square waves are required to generate the 10 KHz signal for switching in the DC-DC converter stage and a 50Hz signal for the inverter stage and the two must run concurrently, the use interrupts is the high-quality solution to better gain the desired waveforms. Atmel ATtiny26 microcontroller has built-in interrupt structures with their timer enter modules. In place of continually polling for a flag, a microcontroller plays other responsibilities and is predicated on its interrupt device to observe the programmed event. The mission of computing the length and the frequency is the same as that of polling approach, barring that the microcontroller will no longer be tied down continuously checking the flag, growing the efficient use of the microcontroller assets.

3. Results

3.1. Calculated Efficiency

To calculate the efficiency, the power loss which occurs mainly through each MOSFET is calculated and then the result multiplied by the number of MOSFETs

used in the research. In addition, the power supply losses are included in determining the overall efficiency of the inverter. The losses can be summarized as follows:

$$\begin{aligned} \text{Total MOSFET conduction} \\ \text{loss} = i^2 R_{ds(on)} = (100/240)^2 \times 0.48 \times 65 = \\ 5.42\text{w} \end{aligned}$$

$$\text{Total switching loss} = 2.3\text{w}$$

$$\text{Total power supply losses} = 0.4\text{w}$$

$$\text{Total losses} = 8.12\text{w}$$

Therefore, for 100w inverter this translates to an overall efficiency of:

$$\eta = (100 - 8.12) / 100 \times 100 \% = 91.88 \%$$

3.2. Simulation Results

Simulations are performed using Multisim Software from National Instruments (NI) Inc.

3.2.1. DC-DC converter stage

Simulation of four modules of the DC-DC converter stage gives an output of between 46.92V and 49.98V which is around the expected 48V as shown in Figure no. 4.



Figure no. 4: Four modules simulation result of the DC-DC converter stage

3.3. Testing of the Gating Signal

The output of the ATtiny26L from the output port is tested and the waveforms

obtained from the oscilloscope as shown in Figure no. 5 for 50Hz and Figure no. 6 for 10KHz.

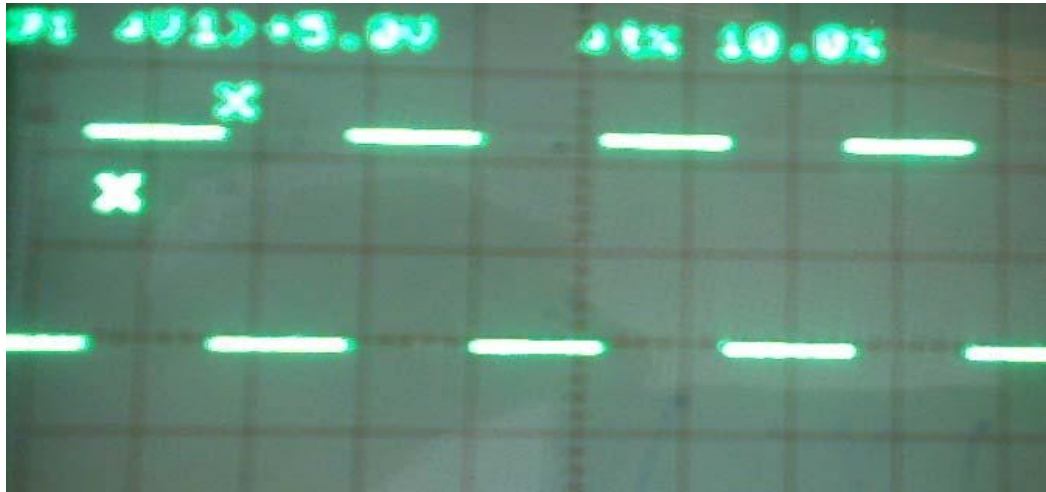


Figure no. 5: 50Hz gating signal

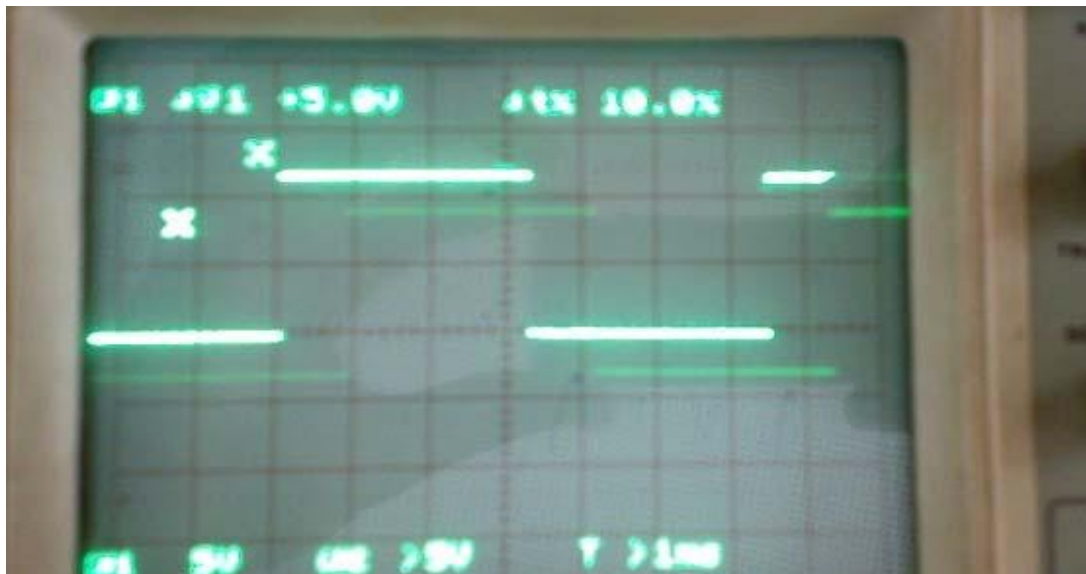


Figure no.6: 10KHz gating signal

3.4. Prototype Results

The prototype of the system outlined above is implemented and tested both on breadboard as shown in Figure no. 7. The figure consists of the microcontroller power supply unit, the microcontroller, the MOSFET driver circuit and the DC-DC converter stage. Testing of both stages show that the hardware design is valid. The DC to DC stage is tested using four modules and an output of 46.8V is

obtained. This value is quite acceptable since the expected output is 48V. The difference in the two values can be attributed to the losses in circuit components and the accuracy of the converter power supply unit. The inverter stage is tested using a load of 30Ω and the input being the output of the converter stage. A square wave output, though not perfect is obtained with a peak to peak value of 45.6V.

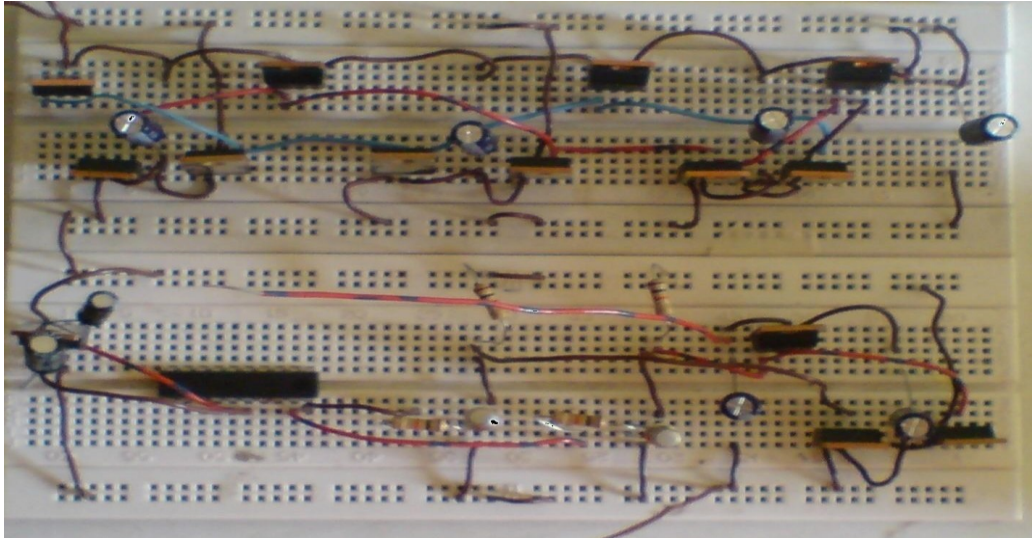


Figure no. 7: The prototype circuit

4. Conclusion

The main objective of this paper was to design and build a 12Vdc to 240Vac inverter for solar energy. Attempts have been made to develop a low cost transformer-less inverter using switched capacitor circuits in the DC-DC step up converter stage and a H-Bridge design in the inversion stage. Whereas the complete

implementation was not achieved, the prototype that was built showed that the design principles of hardware and control software were valid. The method used to control the switches, sinusoidal PWM, was very accurate since the switching signal obtained was as desired. This justifies the choice of the microcontroller used.

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