

Modified Inverter Circuit For Maximum Energy Conversion Efficiency

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Abstract— This study developed an inverter circuit with improved maximum power output. Specifically, the inverter was built for electrical loads that serve significant practical applications and are critical during power shortages. The modified inverter circuit was successfully designed, developed, and built using locally available components such as two 1k ohm resistors, one 4.7k, 5.6k, and 120k ohm resistors, and two 0.01 microfarad capacitors and one 0.1 microfarads 470 microfarads electrolytic. These components are the best circuit options for their functionality and reliability. The inverter circuit was first evaluated using the Multisim Circuit Simulator. Based on the features and specifications required, the one that successfully gave the most reasonable results was the one used in the actual testing. Because the inverter was not a pure sine wave, the waveform is square, indicating that it is suitable for resistive and some inductive loads. The shown square wave has period 2 and levels $-1/2$ and $1/2$. There is an increase of about 6.28% up to 10.86% in efficiency and 2% up to 12% in the power output of the inverter circuit. The research was carried out with extensive analysis. Furthermore, the experiment results revealed that the desired data is greater than 86%, which is the average efficiency of an inverter circuit.

Keywords— inverter circuit, maximum power output, energy efficiency

I. INTRODUCTION

Power electronics is a technology that allows you to process and manage the flow of electric energy by supplying voltages and currents in the most appropriate form required for user loads. DC/AC inverters are a type of power electronics

that convert DC energy into AC energy which can be used in an electrical grid. Nowadays, traditional voltage-source inverters (VSIs) and current-source inverters (CSIs) have been widely applied in different fields. However, they still have some drawbacks, such as their limited load voltage and/or current ranges, output distortions due to dead times or overlap delays, and low efficiency [1]. This has now become a challenge for the power electronics industry, as many different inverter circuit designs are emerging, but only a few have focused on resistor and capacitor modifications.

A study on inverter testing for model validation covered model development and validation including but not limited to voltage transients, frequency deviations, grid disconnection, short circuits, harmonics generation, and voltage oscillations. To better understand the implications of this significant increase in inverter-based generation on the grid, a sample of inverters was tested so that numerical models could be developed and validated. The additional intent of this testing was to find out if these inverters are grid-friendly and help ease the integration of high penetrations of these devices into distribution circuits [2]. Under-voltage transients, over-voltage transients, and inverter disconnect from the grid are among the tests performed. Based on investigations of high-level testing and modeling penetration of solar PV inverters, various steady-state and temporary behaviors were suggested to make assimilation simpler. This includes harmonic generation whereas the existing IEEE 519 limits need to be applied to all inverters. More investigation needs to be done to establish acceptable harmonic limits for harmonics greater than the 50th

[2]. It also included voltage control which states that to assist in voltage stabilization during cloud crossings, inverters must be able to operate independently and dynamically in voltage control mode.

In recent years, it has been known that the frequency for switching to an alternative is required in conjunction with various other techniques for modulation to generate high-quality power output. However, when operating at higher frequencies, traditional two-level inverters always have limitations. This is due to the high-power ratings of the devices, which impact the voltage required for the applications. Considering the capacitors that are also overcharged or discharged, when the capacitor is completely discharged, the multilevel converter technically reverts to working as a level converter, unless and until an appropriate control strategy or technique is used to execute the charging progress [3]. The research demonstrates that using multiple inverters in conjunction with solar technologies would provide a significant benefit. This would not only improve the harmonic profile of the output but would also aid in sustainable development. This emphasized the direct relationship that as voltage levels increase, better power quality with lower THD is obtained. The paper provided an overview of the various modulation techniques that are available to pair with existing PV topologies in terms of suitability for low/ fundamental and high switching.

An outline of recent trends in the field of power quality shows that in comparison to a standard inverter, the most significant improvement and potential is the employment of photovoltaics in multilevel inverters to obtain voltages at multiple levels. Photovoltaics are found to generate low-voltage as necessary by appropriate power electronics converters to achieve much higher efficiency for geographical or weather difficulties [5]. Another study analyzes the performance of a standalone system based on solar PV as a DC source, whereas the simulation is carried out in SIMULINK/MATLAB software. The total harmonic distortion is the major factor determining the efficiency of any power electronic device, which the researchers were able to reduce to 0.19%. The components being cheap made the research cost-effective. Hence, the inverter design is reliable, smart, and has maximum efficiency [2].

High-frequency operation of power semiconductor switches is required for high-performance power converters with reduced size and improved efficiencies. As a result, switching devices experience high switching stresses and losses [6]. Designers must consider high efficiency, maximum power capability, minimal weight, and high reliability, among other critical needs, to enable these critical string-inverter system attributes.

In reality, the commonly used inverters today operate poorly because of their low power output and efficiency. Inverter designs are also complicated, and costly, and the materials are scarce. With this, the researchers would like to propose a new approach to circuit integration on inverter circuits. The parameters of the inverter system and its key components will focus on resistors and capacitors that are properly selected for optimum performance and will be

improved based on the best results from the Multisim simulation. Lastly, the proposed system can be utilized for further advancement of power electronics study in different parts of the world.

II. RELATED WORKS

High power output in inverters plays a vital role in the conservation of energy. In general, driving a high-power output inverter with a variable speed drive saves a significant amount of energy. The benefit of increasing the maximum power output is that it lowers the rated current of a very large capacity load, allowing for simpler system construction and less expensive system components.

A recent study conducted presents the theoretical operation of inverter topologies which are Push-Pull and H-Bridge. As discussed, the Push-Pull and H-Bridge topology of the inverters has advantages and disadvantages. The design of the inverter in a PV system is based on the load applied to this system. These theoretical operations are important in designing the inverter to make solar technology more feasible. The Push-Pull topology is preferred to be used in designing the inverter for a small load application in a PV system [7].

Another study which is focused on the design and development of an MPPT charge controller for Photo-Voltaic (PV) power generation systems described how to implement MPPT using the most popular switching power supply topology. To keep their design simple, they used Arduino Nano. It has features like LCD and LED Indication and it is equipped with various protections to protect the circuitry from abnormal conditions. This design is suitable for a 50W solar panel to charge a commonly used 12V lead-acid battery. As the maximum power point (MPP) of photovoltaic (PV) power generation systems changes with changing atmospheric conditions (e.g., solar radiation and temperature), an important consideration in the design of efficient PV systems is to track the MPP correctly. They have implemented the most common MPPT algorithm named Perturb and Observe (PO) to control the output of a synchronous buck converter [8].

To achieve MPPT, the controller adjusts the voltage by a small amount from the solar panel and measures power; if the power increases, further adjustments in the direction are tried until power no longer increases. The voltage to the panel is increased initially, if the output power increases, the voltage is continually increased until the output power starts decreasing. Once the output power starts decreasing, the voltage to the panel decreases until maximum power is reached. This process is continued until the MPPT is attained. This result is an oscillation of the output power around the MPP [9].

The past studies can be further improved by reviewing the component blocks of the inverter circuit and the panel. The bulky components like the transformer can be replaced by a high-frequency transformer with the right ferrite core which is a lot smaller than what was used, allowing testing of the new design which may lead to better efficiency and high-power capabilities. However, the materials are limited, and the designs are intricate. With this, the researchers have decided to create their inverter circuit design based on the IEEE standard

inverter circuit design. This will then allow for conducting a comparison between the two or more designs and deciding which one is more efficient.

III. METHODS

A. Project Design and Specification

Fig. 1 shows the sequential movement of the whole process. The device consists of a 12V DC input connected to a 555 IC timer that serves as the brain of the inverter, controlling the switching of the switching devices. The MOSFET is then used in converting DC Voltage to AC voltage. Finally, the transformer steps up the 12V AC voltage from the driver circuit to 220 V AC output.

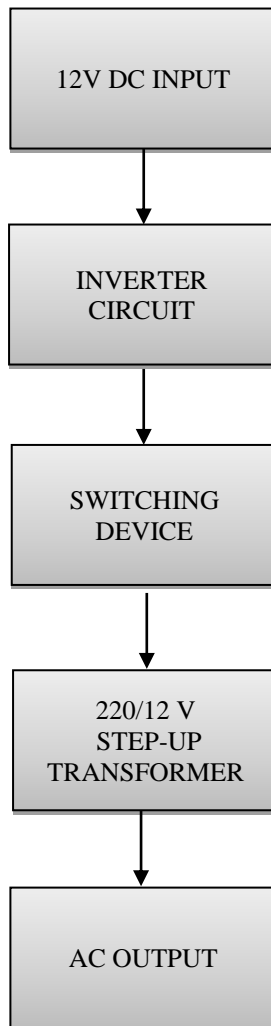


Fig. 1. Block Diagram of the Device.

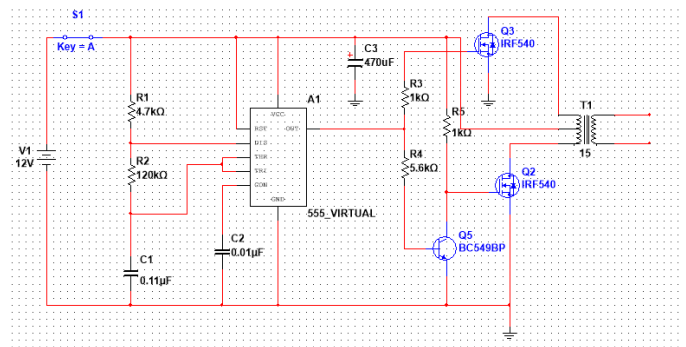


Fig. 2. Circuit Diagram of an Original Inverter Circuit.

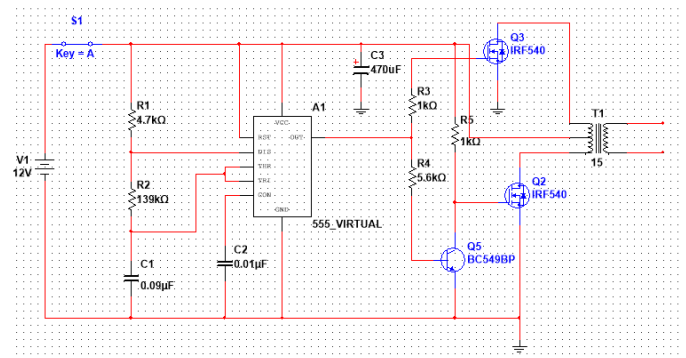


Fig. 3. Circuit Diagram of a Modified Inverter Circuit.

TABLE I. ELECTRIC COMPONENTS USED IN THE ORIGINAL INVERTER

Component	Quantity
IC 555 Timer	1
Transistor: NPN BJT BC549	1
NPN MOSFET IRF540	2
Transformer: 220 V/ 12 V Center tap	1
Resistor: 1kohm	2
4.7k, 5.6k, 120k	1 each
20k variable resistor	1
Capacitor: 0.05 microfarad	1
0.01 microfarad	5
470 microfarads electrolytic 25V	1

TABLE II. ELECTRIC COMPONENTS USED IN THE MODIFIED INVERTER

Component	Quantity
IC 555 Timer	1
Transistor: NPN BJT BC549	1
NPN MOSFET IRF540	2
Transformer: 220 V/ 12 V Center tap	1
Resistor: 1kohm	2
4.7k, 5.6k, 120k	1 each
Capacitor 0.1 microfarad	1
0.01 microfarad	2
470 microfarads electrolytic 25V	1

The electrical components for the two circuits are shown in Table I and Table II. The circuit designs in Fig. 2 and Fig. 3 were first simulated using the Multisim Circuit Simulator to ensure the quality and feasibility of the output voltage and current waveforms. To enhance the power output, the values of the capacitors and resistors in the original circuit in Figure 2 were changed using the RC Series discharge current and capacitor voltage formula given by (1).

$$I(t) = \frac{V_s}{R e^{(-\frac{t}{RC})}} \quad (1)$$

Such that I(t) is the instantaneous current and Vs is the voltage source. The power output increases as the value of the capacitor increases and increasing the capacitor which is in series with the resistor will increase the AC. The modified design that produced the best results (Figure 3) was used and studied. Following the simulation, actual testing was performed to demonstrate that the modified circuit has a higher maximum power output. The same wattage of loads was used to measure the actual maximum power output and efficiency of the two circuits. The data were then collected and compared with each other.

IV. RESULTS AND DISCUSSION

The most common performance metric used in the design of solar circuit inverters is collecting the maximum power output and efficiency. Based on Tables III and IV, it is evident that the maximum power output of the modified circuit (circuit 2) is higher than the original circuit, in any load variation. The measured maximum energy conversion efficiency has also shown an increase in number, and it is supported by the principle of energy efficiency, which may be calculated using $\eta = (\text{Power Output} / \text{Power Input}) \times 100 \%$.



(a) (b)

Fig. 4. Actual Implementation of the (a) original circuit and (b) modified circuit.

TABLE III. MEASURED PARAMETERS OF THE ORIGINAL CIRCUIT

Parameters	Load Rating			
	No load	24W	35W	47W
Input Voltage	13.13 V	13.07 V	13 V	12.97 V
Input Current	0	1.79 A	2.98 A	5.06 A
Power Input	0	23.4 W	38.74 W	65.62 W
Output Voltage	245 V	218 V	198 V	173V
Output Current	0	0.09 A	0.16 A	0.23 A
Actual Power Output	0	19.62 W	31.68 W	39.79 W
Efficiency	-	83.85%	81.77%	60.64%

TABLE IV. MEASURED PARAMETERS OF THE MODIFIED CIRCUIT

Parameters	Load Rating			
	No Load	24W	35W	47W
Input Voltage	13.2 V	13.15 V	13 V	12.93 V
Input Current	0	1.79 A	3 A	5 A
Power Input	0	23.54 W	39 W	64.65 W
Output Voltage	245 V	220 V	202 V	185 V
Output Current	0	0.1 A	0.17 A	0.25 A
Actual Power Output	0	22 W	32.34 W	46.25 W
Efficiency	-	93.46%	88.05%	71.50%

Comparing the standard average efficiency of inverter circuits in Table III and Table IV, the modified inverter circuit has increased by about 6.28% to 10.86%.

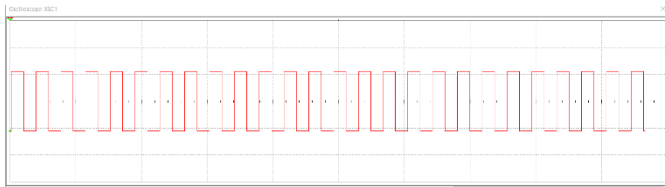


Fig. 5. Voltage Waveform of the Modified Inverter Circuit

Fig. 5 shows the waveform of the original and modified inverter circuits. The inverter was not a pure sine wave therefore the waveform is a square wave which is an indication that it is compatible with resistive load and some of the inductive load. The square wave illustrated has period 2 and levels $-1/2$ and $1/2$. The formula for the square wave of the circuit is defined by:

$$S(x) = A(-1)^{\lfloor 2(x-x_0)/T \rfloor}$$

$$= A \operatorname{sgn} \left[\sin \left(\frac{2\pi(x-x_0)}{T} \right) \right]$$

$$= A \frac{2i}{\pi} \left[\tanh^{-1} \left(e^{-i\pi(x-x_0)/T} \right) - \tanh^{-1} \left(e^{i\pi(x-x_0)/T} \right) \right],$$

$$a_0 = a_n = 0 \text{ and}$$

$$b_n = \frac{2}{L} \int_0^L \sin \left(\frac{n\pi x}{L} \right) dx$$

$$= \frac{4}{n\pi} \sin^2 \left(\frac{1}{2} n\pi \right)$$

$$= \frac{2}{n\pi} [1 - (-1)^n]$$

$$= \frac{4}{n\pi} \begin{cases} 0 & \text{for } n \text{ even} \\ 1 & \text{for } n \text{ odd.} \end{cases}$$

The frequency of the circuit is defined as $F = 1.44 / (R1 + 2 \times R2) C$. The overall improvement of the modified inverter circuit is also shown in Table V.

TABLE V. IMPROVEMENT CALCULATION

Calculation [P = (P2/P1) x (100)]	Power output Improvement [P-100]	Efficiency Improvement [N2 - N1]
(22 W / 19.62W) * 100 = 112 %	12 % improvement	[93.46% - 83.85 %] = 9.61%
(32.34 W / 31.68 W) * 100 = 102 %	2 % improvement	[88.05% - 81.77 %] = 6.28%
(46.25 W / 39.79 W) * 100 = 116 %	16 % improvement	[71.5% - 60.64 %] = 10.86%

The actual power output increased as well as the efficiency. The higher the maximum power output, the higher the energy conversion efficiency. And the higher the efficiency, the more economical it will be.

V. CONCLUSION

In this study, it is presented that the modified design is more efficient than the standard average efficiency of inverter

circuits. The maximum output power is more in all the load domains in which the experiment was carried out. The modified inverter circuit has been verified to address issues such as low maximum power output and low energy conversion efficiency. The Multisim model of the proposed topology is developed and simulated under dynamic conditions and the performance of the system is found to be satisfactory.

Therefore, the researchers recommend using the inverter circuit with the modified resistors and capacitances. It has been noted that power quality can be maintained with an increased level of an inverter. The proposed scheme can be tested for real-time application. However, due to the unavailability of some materials and equipment, other variations of the circuit design were limited; so, further research and tests should be explored to open the possibilities of a more reliable design system.

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