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Power Conversion from Solar Panels using a 3000-watt Inverter

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ABSTRACT

The advancement of inverter technology has seen rapid growth and widespread adoption across various industrial and commercial sectors. The output wave of the inverter has seen significant development since the introduction of the multilevel inverter. By utilizing multilevel inverters, the strain on switch components can be alleviated due to the low frequency of the power wave. This results in generating a voltage that closely resembles the desired output of the AC voltage. The study demonstrated the efficient utilization of resistive loads by the transformer, with the average sinusoid voltage source measuring 103.6%. When conducting inverter testing with a 60 Volt resource, the current input, output, voltage, and input and output efficiency measurements are obtained using a 10 Amper resource. After analyzing the data collected from the tests, it was found that the system's output voltage fell short of the anticipated 220 Volt. When a load of 60 W/220V is added, the system's output voltage is affected, resulting in an output of 740.5 Volts. When the light load is decreased to 60W/220V, the output voltage rises to 786.9 Volt with an average inverter efficiency of 77%. The input power efficiency ranges from 25.5% to 80.0% when calculated based on the inverter power capacity limit.

1. Introduction

Inverters are power electronics that convert DC electricity into either one—or three-phase AC electricity with adjustable voltage and frequency. They are commonly utilized in both households and industries to convert direct current (DC) energy into alternating current (AC) [1,2]. Inverter equipment is highly advantageous for devices that rely on an AC power supply. However, alternative resources are available for devices that operate on DC electricity. In the modern era, inverters have become an essential requirement due to the rapid development of electronic technology [3-6]. The high electricity demand necessitates the use of electrical energy conversion equipment. Inverters are

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commonly employed to facilitate the operation of electrical equipment that requires an alternating current power supply [7-10]. On the other hand, when there is no access to AC power sources, such as in rural or remote areas, during mountain climbing, in vehicles, or during power outages, DC power becomes the primary source of electricity [11,12].

An inverter device is necessary to power AC electrical equipment like heating systems, electric stoves, air coolers, refrigerators, and lighting lamps [13-15]. This device consists of a series of DC electric converters. UPS, or Uninterruptible Power Supply, is a prime example of equipment incorporating a sequence of inverters. UPS systems are commonly employed to provide backup power for computers and essential equipment in various settings such as homes, hotels, hospitals, and industrial facilities [16-18]. A wide range of inverter products is available, varying from single-phase to three-phase options. Inverters come in a wide range of power capacities, starting from as low as 100 W and going up to thousands of KW or MW. In the same vein, when it comes to the quality of the output wave, box waves, fixed sinus waves, and inverters are capable of generating pure sinusoidal forms. An electronic switch with a bridge configuration can create a single-phase inverter set, as seen in Figure 1 [12,19,20].

A simplified equivalent series can be derived for the inverter series, as illustrated in Figure 1. An inverter network can generate an AC power output by employing a DC power source. This is achieved by precisely controlling the activation of four electronic switches according to a specific rule. An inverter is a circuit that transforms a DC voltage source, typically derived from a battery, into an alternating current source with a precise frequency and voltage. The inverter is an essential component of the power supply system, serving as a backup power source during outages in vehicles and at home. Inverter chains are power semiconductors, such as SCRs, transistors, and MOSFETs, that function as switches and variables [21,22]. There are two main types of inverters: one-phase and three-phase. Based on the method of commutation on the SCR, the different types of inverters can be classified into four categories: pulse width modulation, resonance inverter, auxiliary commuting inverter, and complementary commutation inverter [23-25]. Different types of inverters are based on how they handle input voltage and current. One type is the voltage-fed inverter (VFI), which maintains a constant input voltage. Another type is the current-fed inverter (CFI), which keeps the input current steady. Lastly, there is the variable DC-linked inverter, which allows for adjustment of the input voltage. Examining the wave shape generated by an inverter with square, modified, and pure sine wave output. An exceptional inverter can create a waveform that perfectly mimics the sinusoidal wave of a power grid (grid utility) [26].

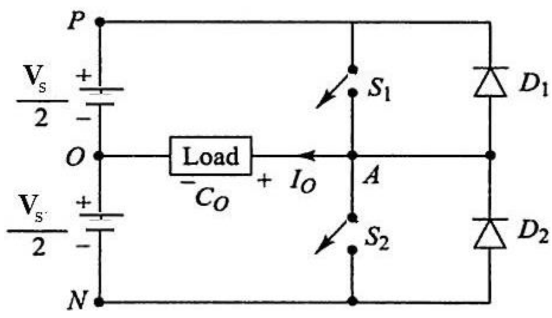

Fig. 1. Single-phase inverter network

An inverter is an electronic device that transforms direct current into alternating current. This inverter device converts fixed DC power into variable AC power, which can adjust both the frequency and voltage. Additionally, we can change the frequency output of this inverter to meet specific requirements, such as generating frequencies of 40HZ, 50HZ, and 60HZ. A voltage source inverter

(VSI) is an inverter that takes a DC input from a voltage source [13]. Typically, A half-bridge inverter only needs two switching devices, while an inverter requires four. You may get bridge inverters in two varieties: half-bridge and full-bridge. A comprehensive review of half-bridge inverters is given in this article. An inverter is a circuit that changes alternating current (AC) from direct current (DC). One half-bridge inverter uses two diodes and two switches linked anti-parallel, while the other half uses four switches [27,28]. Both switches work in tandem; when one is turned on, the other will be turned off as well. In a similar vein, the first switch will be turned off when the second switch is turned on. The schematic of a resistive-load, single-phase half-bridge inverter is shown in Figure 2.

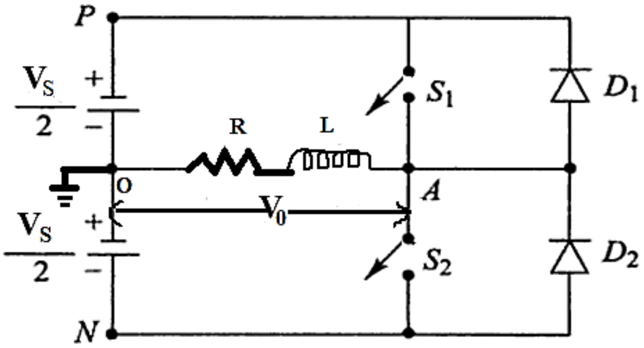

Fig. 2. Single Phase Half Bridge Inverter with R-L Load

Figure 2 shows a voltage source, two diodes, and two switches. Point A is usually considered positive, and point O is unfavorable; the R-L load is tied to these two places. A positive current flows from point A to point O, while a negative current flows from point A to point O. With an R-L load, the output voltage will lag by an angle, and the output current will follow an exponential function concerning time.

$$\phi = \tan^{-1}(\omega L/R) \quad (1)$$

The resistive load is denoted as RL, the voltage source as Vs/2, the two switches as S1 and S2, and the current as i0. In this configuration, the diodes D1 and D2 are linked in parallel with each switch. Switches S1 and S2 in the image above are examples of self-commuting switches. In the event of a positive voltage and a negative current, switch S1 will direct the current, and in the opposite case, switch S2 will lead the current. In the presence of a positive voltage and a negative current, diode D1 will take the lead, whereas diode D2 will act as the driver in the opposite situation.

Case 1 (when switch S_1 is ON and S_2 is OFF):

The diodes D1 and D2 are in a reverse bias state when switch S1 is ON from 0 to T/2, while the S2 switch is OFF. Applying KVL (Kirchhoff's Voltage Law)

$$V_s/2-V_0 = 0 \quad (2)$$

When the output voltage, V0, is equal to Vs divided by 2, Then the output current i0 is equal to V0 divided by R, which is equal to Vs divided by R. In the event of a supply current or a switch current, a current of iS1 = i0 = Vs/2R, iS2 = 0, and iD1 = iD2 = 0 would be found.

Case 2 (when switch S2 is ON and switch S1 is OFF):

From period T/2 to T, with switch S2 turned ON, diodes D1 and D2 are in a reverse bias state, and switch S1 is turned OFF. Using Kirchhoff Voltan Law (KVL)

$$Vs / 2 + V0 = 0 \tag{3}$$

Assuming that V0= -Vs. / 2, and that i0= V0/R= -Vs./2R, we may write this equation as an output voltage. Figure 3 shows the output wave structure of a single-phase half-bridge inverter. The currents in the power supply or switches are represented by iS1 = 0, iS2 = i0 = -Vs./2R, and the currents in the diodes are represented by iD1 = iD2 = 0.

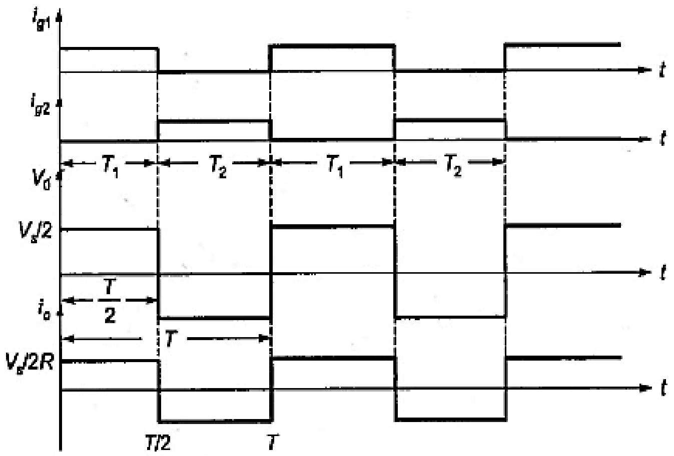

Fig. 3. Half Bridge Inverter Output Voltage Waveform

2. Power Inverters

Power inverters are crucial in solar power systems, enabling electrical equipment that requires high voltage alternating current (AC). Power inverters are ideal for solar power systems because they include significant electrical equipment. Engage in the maintenance and operation of high-voltage systems—significant alternating current. The total power an inverter can supply is essential as it is directly linked to its power consumption and capacity to deliver power to the load [27]. The 3000-watt power supply is designed to provide 220 volts AC at 50 Hz for this research. The inverter takes its input voltage from a 12-volt lead-acid battery. A middle-tapping arrangement load inverter is used in the circuit. You must think about the input power required by the inverter to get the output power you want. To attain the desired output power, it is crucial to consider the power needed as input to the inverter. Assuming an 80% efficiency level for the transformer and a 1 for the output power factor. An inverter is a tool for changing direct current (DC) power into alternating current (AC). You may choose between a modified sine wave, a square wave, or a sine wave as the inverter's output. Batteries, solar panels, or any number of other direct current (DC) power sources are all viable choices for the inverter's input voltage source.

The inverter relies on a voltage amplifier, which acts as a step-up transformer, to convert DC power to AC voltage [29]. An inverter's working principle is similar to a power source's; it converts direct current (DC) into alternating current (AC) and vice versa. A vehicle battery's DC (Direct Current) may be changed into AC (Alternating Current) by following a few simple procedures. The kind of battery and load that an inverter circuit is coupled to affects its endurance [30]. The inverter's operation is best understood by looking at the four switches shown above. The left-to-right direct current (DC) flow to load R is controlled by the activation of switches S1 and S2. Switches S3 and S4, in contrast, cause a right-to-left flow of DC to load R. The pulse width modulation (PWM) circuit is a typical component of inverters that transform DC power into AC voltage [31,32]. The following considerations are crucial when choosing a DC-to-AC inverter: Think about the load capacity in watts when you're picking an inverter. For optimal productivity, choose an inverter that is a good fit for the intended load. Inverters may accept either 12—or 24-volt DC as an input voltage. The inverter's waveform might be square or sine depending on the intended AC inverter output voltage. The DC-to-AC inverter's efficiency and appropriateness are at issue here.

3. DC-to-AC Inverter

Figure 4 shows the simple inverter circuit which is a device that changes the voltage from direct current (DC) to alternating current (AC). An inverter can generate alternating current (AC) voltage with various waveforms, including modified sine, square, and sine. Batteries, solar panels, or any number of other direct current (DC) power sources may provide voltage to the inverter. A voltage amplifier, such as a step-up transformer, must be present for an inverter to convert DC voltage to AC voltage. Here is a rundown of the many DC to AC inverter types: We classify the inverters according to their number of output phases. There is a subset of inverters called one-phase inverters that only have one phase of output. One kind of inverter that can provide a three-phase output is the two-phase inverter. Inverters are classified according to how they regulate voltage. Some examples of these types of inverters include voltage-fed (VFI), current-fed (CFI), and variable DC-linked (VDD) inverters. VFDs keep the input voltage constant, CFIs keep the input current constant, and VLDIs let you alter the input voltage [33,34].

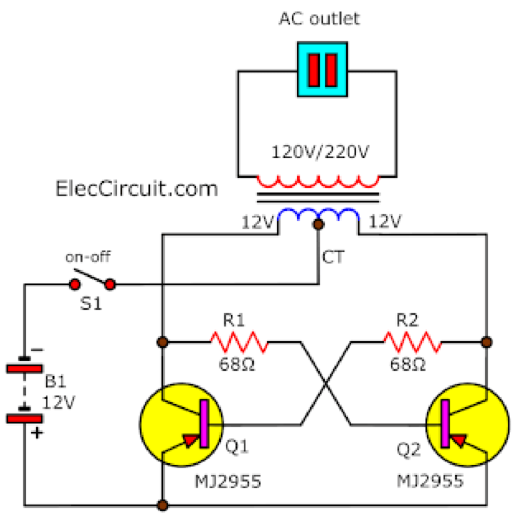

Fig. 4. Example of a Simple Inverter Circuit

4. Materials and Method

The research spanned over two semesters, totalling 12 months, and was divided into two distinct phases: the preparatory and planning phases. This study was conducted at the UMSU Engineering Faculty laboratory and focused on the design and collection of load data. The methodology adopted was experimental, involving the design and measurement of systems under strict supervision. This experimental approach aimed to ensure precise data collection and accurate results. The groundwork for the experimental study was laid out in the preparatory phase. This involved setting up the laboratory, procuring necessary equipment, and designing the experimental setup. The primary goal was to ensure that all the instruments were calibrated correctly and that the environment was conducive to conducting precise measurements. Additionally, detailed planning was undertaken to outline the steps for the experimental procedures, ensuring that each aspect of the study was meticulously planned and accounted for. The planning phase focused on executing the experimental research. The non-electric quantities measured included the intensity of sunlight striking the surface of the solar cells, which is crucial for understanding how much solar energy can be harnessed. This step involved placing solar cells in strategic locations to capture maximum sunlight and measuring the intensity of the sunlight throughout the day. By doing so, researchers could gather data on how sunlight intensity varies and how it affects the performance of the solar cells. The study also involved measuring various electrical quantities such as power, voltage, current, and power factor. These measurements are essential for evaluating the efficiency and performance of the solar power system. By analysing these electrical parameters, researchers could determine how effectively solar cells convert sunlight into electrical energy and how stable and reliable the power output is [35].

The research extended to observing and analysing the daily demand for electricity. This involved monitoring the daily load, measured in Watts, and the energy consumption, measured in Watts-hours. By assessing these parameters, the researchers could calculate the solar power capacity needed for residential structures using PV off-grid systems. This analysis was crucial for designing an effective off-grid solar power system that meets the daily energy requirements of a household. Designing the off-grid roofing system was another critical part of the research. This included analysing the household's energy needs, determining the capacity and number of solar panels required, and designing the layout for installing these panels on the roof. The design process also took into account factors such as the orientation and tilt angle of the panels to maximize sunlight exposure and energy generation. The final part of the research involved the installation of solar panels and devices to monitor power data. This practical implementation was essential for validating the experimental design and ensuring that the system worked as intended. The monitoring devices provided real-time data on power generation, allowing researchers to assess the solar power system's performance and make any necessary adjustments to optimize efficiency. Overall, the research methodology was comprehensive, involving both theoretical planning and practical implementation. By conducting detailed measurements and analyses, the study aimed to develop an efficient and reliable off-grid solar power system for residential use. The insights gained from this research could contribute to the broader adoption of solar energy, promoting sustainable and renewable energy solutions [36,37]. This research has been divided into different stages.

(i) The study's first phase, focused on material and tool analysis, is a crucial foundational step in any experimental research. This phase ensures that the researchers comprehensively understand the materials and tools they will use throughout the study, enabling them to select the most appropriate and effective ones for their specific experimental needs.
(ii) The second phase involves Preparing to develop a 3000-watt solar inverter involves the following specifications for an H-Bridge PWM single-phase inverter: it will have an input voltage range of 12-30 VDC and an output voltage of 25.96 VAC. The inverter will accept an input voltage range of 220-230 VAC and provide an output power of 30 W with an efficiency of 81%. It will operate at a frequency of 50 Hz with a work cycle of 50% and a current draw of 1 A. The inverter will produce a square wave output.
(iii) The evaluation of inverters subjected to a resistive load involves testing their performance when connected to a load that purely resists electrical current (such as a heater or

incandescent bulb). This assessment includes measuring the inverter's output voltage, current, efficiency, and overall stability. By analyzing these parameters, the effectiveness and reliability of the inverter in delivering consistent power to resistive loads are determined. This testing ensures the inverter can handle real-world applications where resistive loads are common, providing valuable insights into its operational capabilities and performance under standard conditions.

(iv) Determining each inverter's overall and mean energy production involves measuring the total amount of energy generated over a specific period and calculating the average energy output. This process includes monitoring the inverter's daily, weekly, or monthly energy and aggregating the data to find the total energy produced. The mean energy production is then calculated by dividing the total energy by the number of days or relevant time units. This evaluation provides insights into the efficiency and consistency of each inverter's energy generation capabilities, helping to assess their performance and suitability for various applications.

(v) The comparison involves analyzing the energy outputs of an optimal energy string array, focusing on the top 75% of its energy production. These results are then compared with the energy outputs of inverters with the highest 75% output ratios. Additionally, other data processing findings related to energy production are considered. This comparison aims to evaluate and contrast the performance and efficiency of different energy systems, identifying which setup provides the best energy output and reliability. The insights gained help optimize energy production strategies and select the most effective inverters and configurations.

5. Results and Discussions

Prior researchers have made significant contributions to the advancement of the industrial sector. Specifically, they have developed an inverter training module that enables the adjustment of electric motor speed for both phase 1 and phase 3. An inverter is a type of circuit that is designed to convert direct voltage into alternating voltage. The switching technique is employed by alternately turning on and off a switch to generate pulses or square waves in both negative and positive directions. When a DC voltage is repeatedly applied, it will transform into a square signal with varying densities and voltages. The production of the inverter is reliant on the utilization of the component code [38]. The components are then assigned letters and placed in the code. Once placed, each component is soldered securely, and any unused elements are trimmed. Next, it is essential to thoroughly inspect the soldered network path for any potential issues. In a breakage, the solder plays a crucial role in restoring functionality. After installing the inverter electronic network, the subsequent procedure involves connecting the electronic network to the step-up transformer. This connection is made from the end of the 12V-CT-12V terminal to the transistor amplifier network. Additionally, the voltage input terminal of 12V needs to be connected to the battery, which serves as the power source [39]. When a square wave is in a closed state, the voltage will register as high, and when it is in an open state, it indicates a low voltage. As a result, a quarter wave with a rare periodic density will also generate a periodic sinusoidal wave. Based on this concept, the direct current (DC) voltage would manifest as alternating sinusoidal waves, commonly called alternating current (AC). The Modified Sine Wave shape is also displayed for comparison. The sine wave exhibits a smooth voltage transition, changing the phase angle continuously. Additionally, the polarity of the wave changes instantaneously as it crosses the 0 Volts threshold.

The modified wave beam exhibits sudden voltage fluctuations and abrupt changes in phase angle. After reaching zero volts, the phase angle remains constant before switching polarity [40,41]. So, any device that uses a control circuit that detects a phase (for voltage/speed control) or an instantaneous zero intersection voltage (with a timer) will not work correctly from the voltage it has [42].

6. Inverter Input Power Calculation

The input power capability can hold a load of:

$$Pinv = V_1 \times I \tag{4}$$

If calculated from the transformation equation of the ratio of the input to the voltage output voltage, then the output current is:

$$V_1 = V_2 = I_2 : I_1 \tag{5}$$

Connecting the inverter working factor cos = 0.9 then the secondary current is:

$$I_1 = Cos\Theta \times I_2 \tag{6}$$

Then, the secondary power that can be loaded to the maximum is:

$$Pout_1 = Vout_1 \times Iout_1 \tag{7}$$

From the design process data, the device has a power of 1300 watts, calculated from the current and voltage output. Then, the power is [43]:

$$Pout_2 = Vout_2 \times Iout_2 \tag{8}$$

Thus, the maximum remaining power that can be loaded is:

$$Pout_3 = Pout_2 - Pout_1 \tag{9}$$

The power calculation from the current and input voltage measurement data is the size:

$$Pin_1 = Vin_1 \times Iin_1 \tag{10}$$

Inverter with the calculation of output power based on current and voltage references and working factors, then the output energy can be calculated as [44][45]:

$$Pout_1 = Vout_1 \times Iout_1 \times Cos\Theta \tag{11}$$

The load installed variably has an inverter input power efficiency of:

$$F = \frac{pn}{120}$$

$P = \frac{E_0 E}{X_2} \sin \emptyset$

$\emptyset = \frac{pa}{2}$

$X_2 = \frac{En}{I_{Sc}}$

Regulation % = $\frac{E_{NL} - E_{FL}}{E_{FL}}$ x 100%

$$\eta = \frac{\text{Pin V} - \text{Pin}}{\text{Pin V}} \times 100\% \quad (12)$$

Then:

$$\eta = \frac{\text{P Oout} - \text{P Out1}}{\text{P Out}} \times 100\% \quad (13)$$

7. Weighted Inverter Measurement Result Data

Inverter testing of an accumulator power source of 12V/70AH tested using variable loads of 200-1400 watts as shown in Figure 5. Table 1 shows an average input voltage of 12 Volts and an average input current of 40 Amps, an average output voltage as large as 211 Volts, a mean output current of 3 Amps, and an average working factor with a load variation of 0.8.

Table 1
Wighter Inverter the measurement results

S.No	Vin (Volt)	I In (Amper)	V Out (Volt)	IOut (Amper)	Load (Watt)	Work Factor (Cos)
1	13.8	13.9	225	0.9	200	0.9
2	12.5	27.5	220	1.8	400	0.87
3	11.8	37	210	2.59	600	0.82
4	11.6	46	208	3.2	800	0.80
5	11.2	53	205	4.3	1000	0.78
6	11	65	200	5.2	1200	0.75

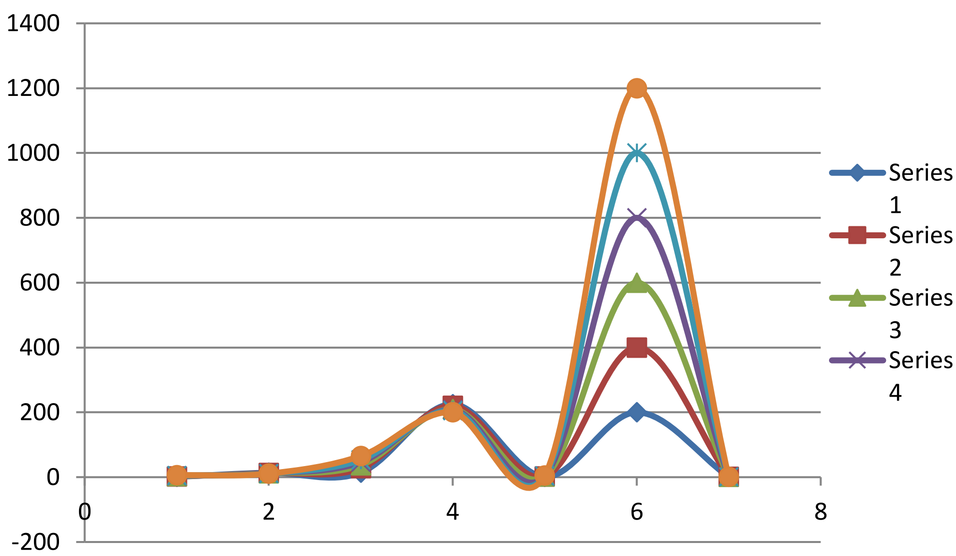

Fig. 5. Graph Measurement Results

The inverter is designed to operate at a maximum power of 3000 watts. It has an input voltage of 12Vdc and an output voltage of 220Vac. The inverter has a maximum input power capacity of 2750 watts as shown in Figure 6. According to the data collected from all conducted tests, it has been determined that the system's output voltage cannot reach the desired level of 220 Volts. When a load of 60 W/220V is added to the system, it causes a change in the output tension. As a result, the output voltage drops to 740.5 Volts. When the light load is decreased to 60W/220V, the Output Volt increases to 786.9V with an average inverter efficiency of 77%.

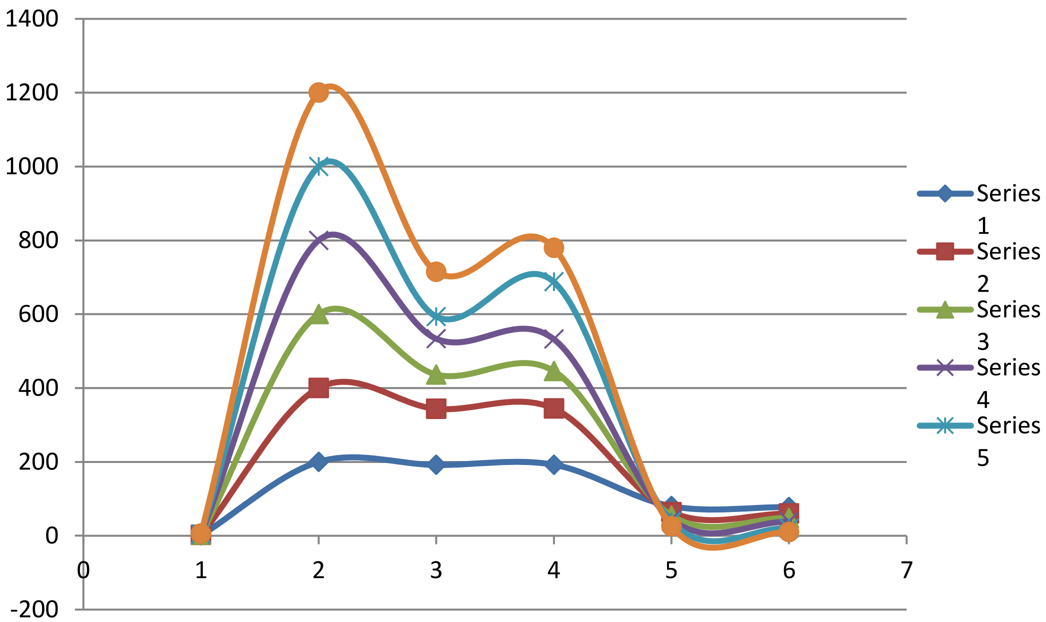

Fig. 6. Graph of voltage, current, and power test results

8. Conclusion

Electric devices that change the voltage from Direct Current (DC) to Alternating Current (AC) are known as inverters. Inverters may produce alternating current (AC) voltage in a variety of waveforms, including modified sinusoidal, square, or sinusoidal. You may power the inverter by using solar electricity, batteries, or any other DC voltage source. It is common practice for inverters to use a step-up transformer in order to change DC electricity into AC voltage. When the transformer is run with a resistive load and an average sinusoidal voltage source, its efficiency is measured at 103.6%. To evaluate the inverter's input, output, and current-voltage efficiency, a 60-volt power source is used. In order to assess the input and output efficiency, a 10-amp power source is used. Results from each test indicated that the system's output voltage would fall short of the target value of 220 volts. This disparity exists because the system's output voltage is sensitive to variations in the load. To be more precise, 740.5 V was the voltage output recorded with the addition of a 60 W/220V load. The average inverter efficiency is 77% when the light load is reduced to 60W/220V, resulting in an output voltage increase of 786.9 Volts. The inverter's power capacity limit is used to determine the input power efficiency. Somewhere between 25.5% and 80.0% is appropriate.

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