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Design and Simulation of an Inverter Drive System with a Display for a Renewable Energy System in the Rural Isolated Communities of Uganda

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Abstract

In medical diagnostics, therapeutic, laboratory, intensive care unit devices, and machines application, two form of Electrical Energy is utilized. Alternatives current (AC) and Direct current (DC) form. In this paper an inverter driver system with a display model is made using MATLAB and its specific tool box of Simulink, the process will involve converting single phase alternating current power to direct current using rectifier made from ordinary normal diodes then converted to three phase using three-arm insulated gate bipolar transistors this is commonly known as inverter bridge which is sufficient enough to run three phase loads depending on the application requirement. The system uses a five-level inverter with low levels of distortions and ripples in the equipment output, this increase and improves the performance of the system. Using carefully selected passive and active elements such as capacitor resistors, inductors, diodes, and transistor system in inverter, decreases the number of switches and boosts the efficiency of the system. This inverter drive system helps us to run three phase machines in the health facility at the same frequency of single phase. The inverter system allows a smaller smoothing capacitor in the DC-AC link as proposed. Large smoothing capacitors are conventionally essential in such converters to absorb power ripple at twice the frequency of the power supply. The proposed network topology consists of an indirect matrix converter and an active snubber to absorb the power ripple, and does not necessitate a reactor or large smoothing capacitor. Simulation result is shown using MATLAB software and used to verify system operation principle as well as circuit development and their control mechanism for a single-to-three-phase power inverter system. The results from experiment show that for a 1 kW-class prototype circuit system, the power ripple at twice the frequency of the power supply can be adequately suppressed using a buffer capacitor of low values.

Keywords

Inverter, Renewable Energy, Simulink, Health Facilities, Uganda

1. Introduction

A wide variety of medical, commercial, emergency and industrial electrical devices needs three-phase energy. Electric power companies do not connect three-phase power due to cost because it is more costly compared to single phase installation procedures [1] [2]. As an alternative to utility installed three-phase, rotary phase converters, static phase converters and phase converting variable frequency drive have been used for many years to develop three-phase energy from a single-phase source and supply [3] [4] [5].

Single-phase electric power refers to the distribution of alternating current electric power using a system in which all the voltages of the supply vary in unison. Single-phase distribution is used when loads are mostly used temporarily and light loads, with few equipment.

The power of three-phase as a minimum of three live conductors and one neutral conductor which incidentally doesn't carry voltage which are offset in time by one-third of the period. A three-phase system may be organized in delta (Δ) or star (*) [6] [7] [8]. A delta arrangement system has only three live conductors, though it has a larger redundancy as it may continue to its normal operation which makes the system to be with a large value of faulty current and harmonics as compared to the star system which has fewer problems depending on the applications [9] [10]. We are going to assemble various power electronics equipment as below to come up with three phases without using bulky transformers. Power electronics is extremely important technology to yield a circuit of small size and scope used to produce large volumes of energy this was not the case in the older days where people used complicated, bulky, less efficient, low performance, costly circuit only to get little energy on top of high operation and maintenance requirement [5] [11] [12].

Power electronic system is nearly in every electronics device and equipment. For example, AC/DC converters (rectifiers) are used every time an electronic device is connected to television and computer. Inverter is broadly classified into two types namely voltage source inverter and current source inverter [5] [13] [14]. Converting a single phase to three phase power supply uses semiconductor devices such as BJT (Bipolar Junction Transistor) [15] [16] [17]. DC/AC converter are used primarily in uninterrupted power supply or emergency applications. During shutdown or failure time, the AC will be used to produce AC electricity at its output. The main disadvantage of using BJT is that it has a high switching loss but lower conduction loss.

Currently most of the electrical equipment's are functioning by the use of AC power. Starting current of a three-phase motor is less than the same rating single-phase motor starting current. Three-phase motor is preferred more than a single-phase motor in medical machines application due to its low ripple in output and better performance. For weighty duty and higher power rating three phase devices are used [18] [19]. It is very hard to obtain three phase supply in every palace in rural remote isolated areas of Uganda where low concentration of consumers are presents. Typically the three-phase power is not supplied due to sophisticated survey, installation cost and maintenance cost of transmission line [20] [21] [22]. In such a scenario most remote areas are supplied by single phase hence the need for the proposed system that can output three phases from single phase [7]. This system is based on the source, rectifier, DC-AC LINK filter, snubber, inverter and boost system. In order to run medical devices having induction motor from inverter, Total Harmonics Distortion (THD) must be lower for improved performance and less ripple in mechanical output of the machine. To decrease THD, Pulse Width Modulation (PWM) and multilevel network topology is used in this research. By using the two topologies in this project, THD should decrease better and output waveform should be sinusoidal [23] [24] [25]. Three phase Inverter is built by the connection of six transistors in the bridge form which are connected with the three-phase load without using three transformers. By using voltage and current measurement system values of power at any given point in time can be obtained depending on the application.

2. Proposed Model

The inverter drive is constructed on the principle of an indirect matrix, where the rectifier is operated as a current sourcing device, and the inverter stage is operated as a voltage sourcing mode. The buffer circuit consisting of a small resistor, capacitor, inductor connected in parallel and a switch is inserted into the DC-AC link to absorb the current and voltage ripples and prevent them from being applied to the next level. This is done by using a capacitor with value twice the frequency of the power supply and system [7] [26]. Note that the buffer circuit is also used as a snubber circuit for the purpose of circuit protection which is further used as a safety mechanism for excess current and voltage that would damage the entire circuit.

Zero-current switching of the switch of the buffer and diodes located inside the rectifier are attained by corresponding the switch timing to the zero-voltage vector output of the proposed system. In this way, switching losses at the buffer switch of the diode are minimized.

The proceeds of transforming single phase to three phase power, there are important concept required. These are: buffering, boost, conversion, filtering and inversion of voltages [21]. These will form the circuits to be used in the circuit development of the proposed system. It is further important to note that power system supply will have both ac and dc sources at low and high voltages. The circuits used in the prosed system include but not limited to the following:

1) Power circuit
2) Rectifier circuit
3) Two arms universal bridge Liner Transformer
4) Inverter circuit
5) Control circuit
6) Power supply circuit
7) PWM generator
8) Buffer circuit (dc-ac link)
9) Boost chopper circuit.

Control circuit is provided with three phase inverter. Power circuit is used to convert the single phase power supply to three phase power supply. It includes conversion of AC to DC supply using rectifier and DC to AC supply using inverter.

We are converting power from single phase AC supply into three phase AC supply [27]. Using these three-phase power supplies, we can drive any motor. Block diagram of converting single phase to three phase power supply units is shown in **Figure 1**, it consists of:

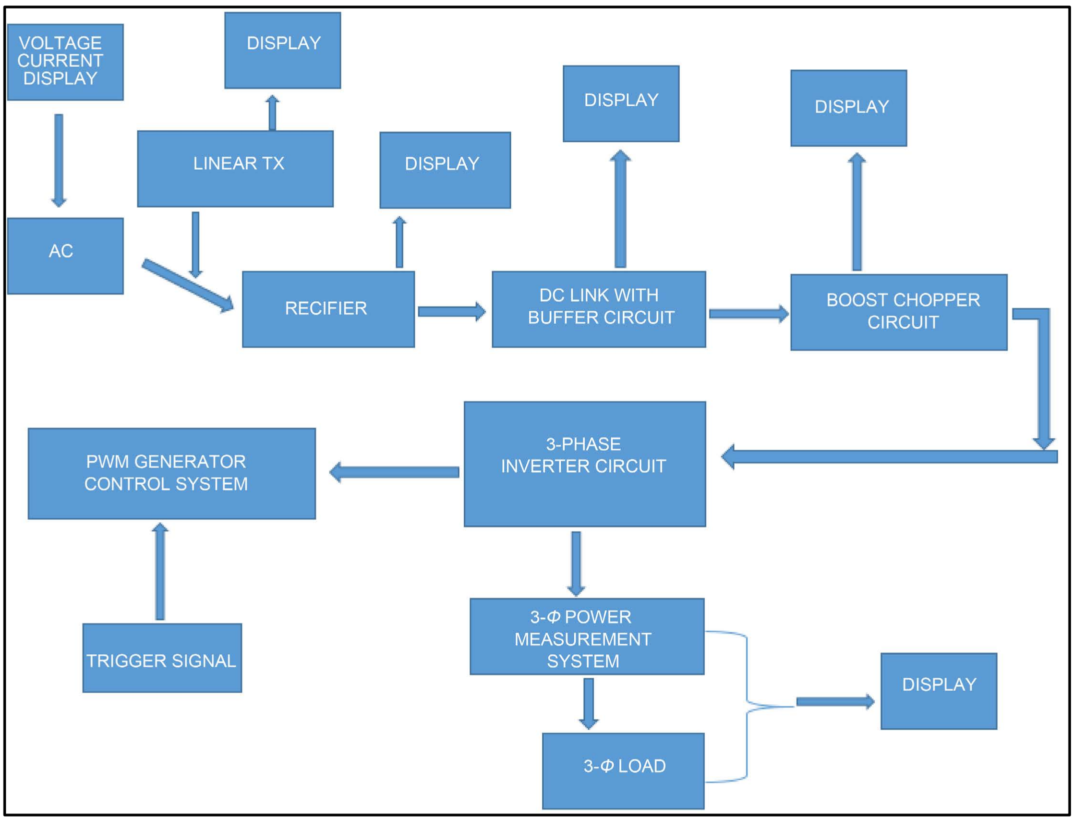

Figure 1. Block diagram of converting single phase to three phase power supply units.

- Single phase AC supply Liner transformer
- Two arm universal bridge Rectifier
- Three phase (3Φ) inverter
- 3Φ transformer
- Load

AC power supply of 240 volt is connected to liner transformer and liner transformer connected to two arms universal bridge rectifier, the AC voltage is converted to DC 100 V, the converted voltage is then changed to AC 415 V ready to be supplied to the loads. This inverter has three arms of insulated gate bipolar transistor.

2.1. Circuit Explanation

Power supply units consist of the following as shown in **Figure 2**:

1) Single phase supply
2) Liner transformers
3) Bridge circuit

When AC voltage is applied to the primary of the transformer, it can be stepped up depending on the value of AC voltage needed. In our circuit the transformer is 380 volt and supply three phase power of 180 volt. Changing transformer rating, the phase power also changes. A commonly used circuit for supply AC source is bridge rectifier. A bridge rectifier of four diodes is used to achieve full wave rectification. Two diode will conduct during the positive half cycle and other two will conduct during negative half cycle. The AC voltage at the output terminals of bridge rectifier is less than 90% of RMS value.

The inverter converts DC supply to AC supply. Three winding transformer is connected with inverter to step up the voltage from the output and feed it to rectifier.

2.2. Three Phase Inverter

In three phase inverter there are three types they are:

- 2 Level output
- 3 Level output
- 5 Level output

The units and required components for modelling of single phase to three phase drive with a display for medical facility applications are given **Table 1** and

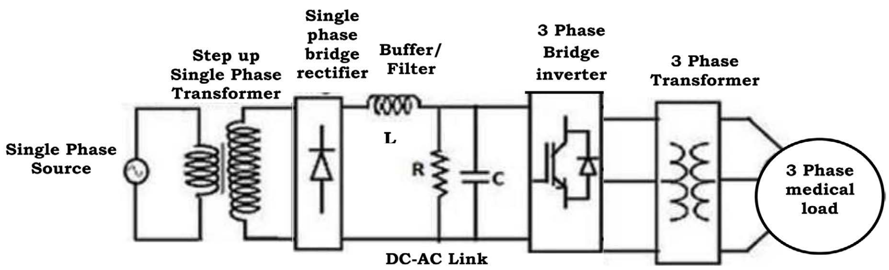

Figure 2. Power supply unit circuit.

the MATLAB tools and sub systems of the proposed circuit shown in Figure 3.

Single Phase to Three Phase Power Converter Simulation in Matlab Simulink is shown in Figure 4.

Table 1. Modelling of single phase to three phase drive with a display for medical facility applications.

Unit	Required components
AC source	Peak amplitude (V) 325, frequency (HZ) 50
Liner transformer	Nominal Power 1000 VA, frequency 50 HZ, primary winding voltage 220, resistance (pu) 0.01, inductance (pu) 0.002, secondary winding voltage 415, resistance (pu) 0.01, inductance 0.02, magnetization resistance 25 (pu) and reactance 25 (pu)
Two arm universal bridge	Snubber resistance 25 (ohms), snubber capacitance 0.1 (μF), power electronics diode
Three arms IGBT diode bridge	Snubber resistance 100 (ohms), forward voltage device I, forward voltage diode 1
Three phase Transformer	Nominal power 1000 VA, Power frequency 50 HZ, primary winding voltage 220, resistance 0.002, inductance 0.04, secondary winding voltage 770, resistance 0.002, and inductance 0.04

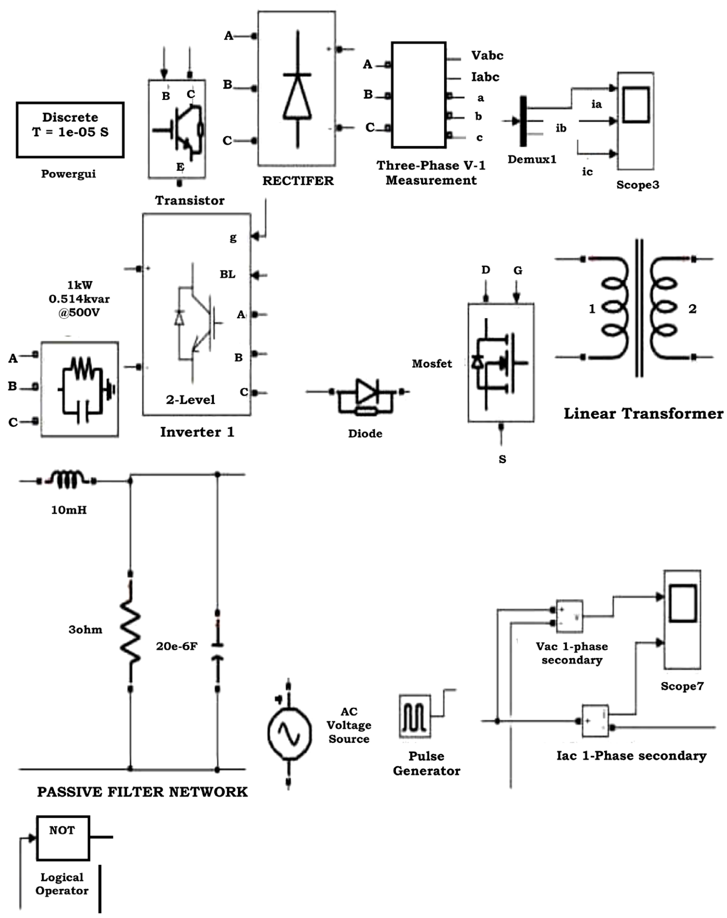

Figure 3. MATLAB tools and sub systems of the proposed circuit.

The AC input Curves for Single Phase Voltage and Current on the Primary side of the Linear Transformer 220/415 V is shown in Figure 5.

The output voltage and current on the secondary side of the linear transformer is shown in Figure 6.

The DC Voltage and DC Current Curves and graph at the Output of the Boost Chopper Circuit are shown in Figure 7 and Figure 8 respectively. When the Boost Chopper is inserted, the output becomes greater than the input at the DC Link because the chopper steps it up. If the Pulse width is increased, the output also changes. For this case the Pulse Width or Duty Cycle is put to 80%. If the

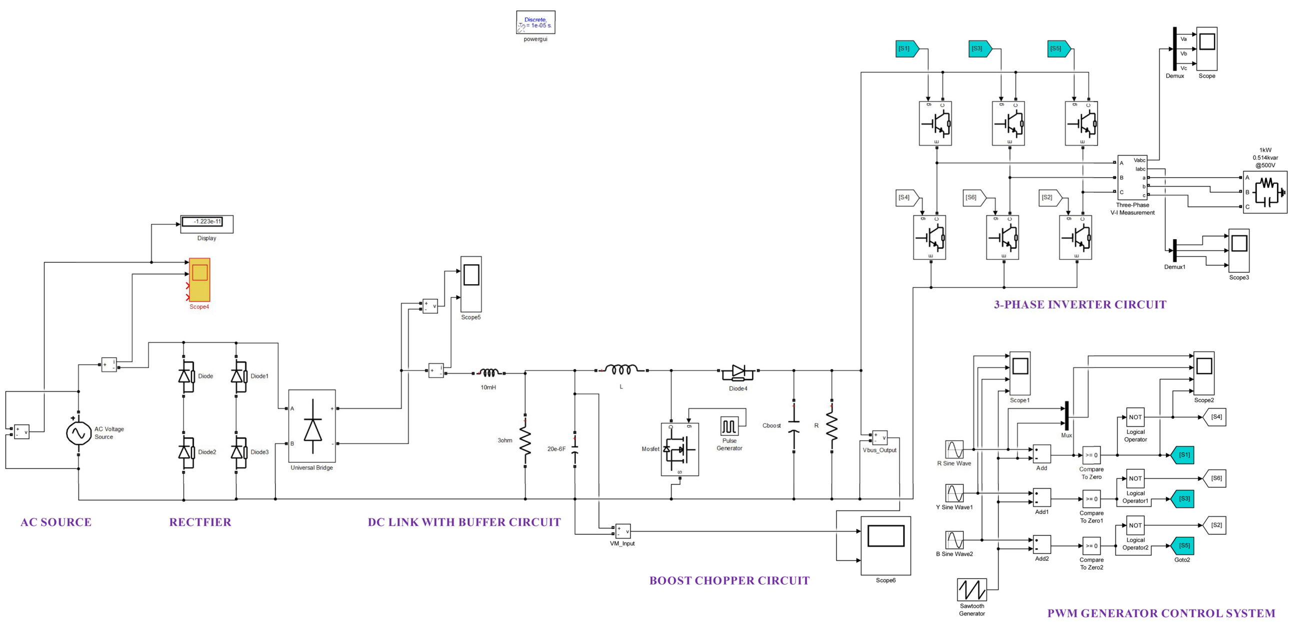

Figure 4. Single phase to three phase power converter simulation in Matlab Simulink.

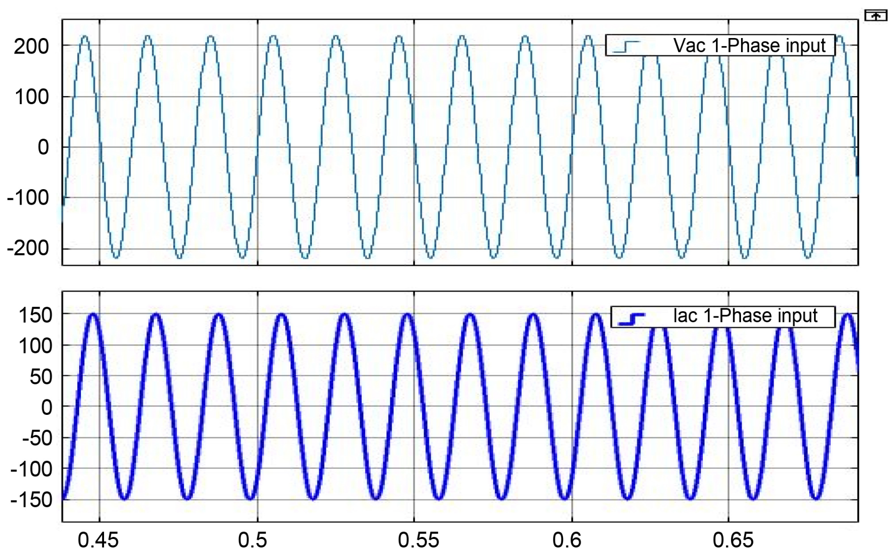

Figure 5. The AC input curves for single phase voltage and current on the primary side of the linear transformer 220/415 V.

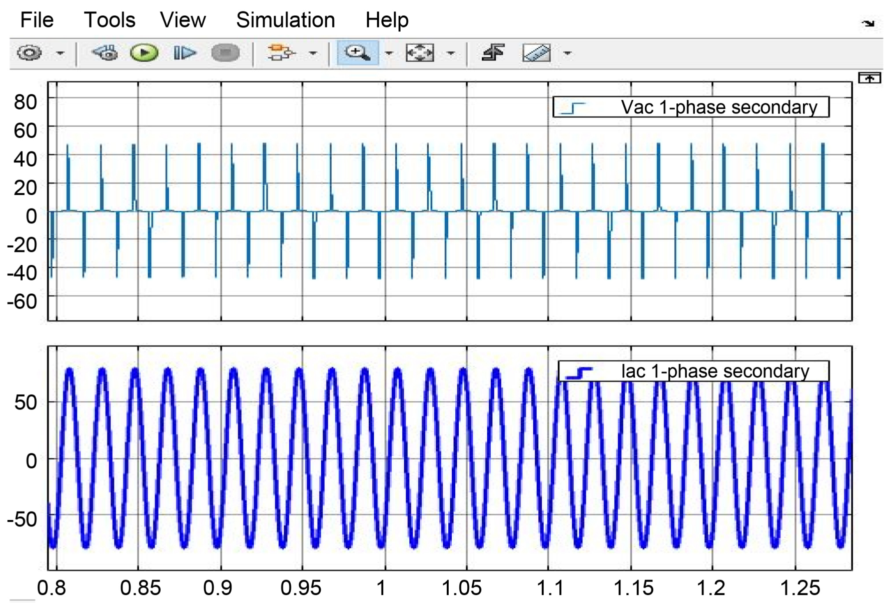

Figure 6. Output voltage and current on the secondary side of the linear transformer.

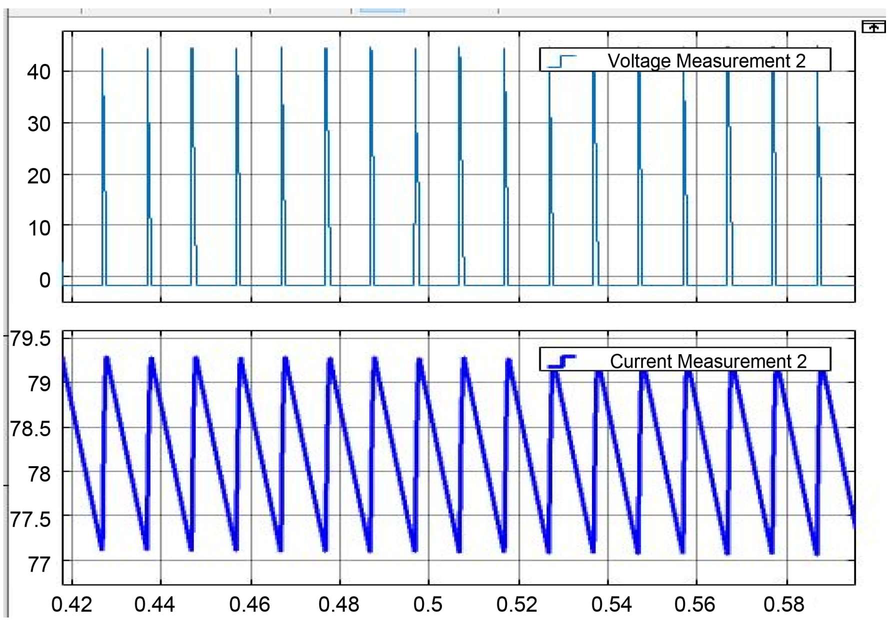

Figure 7. DC voltage and DC current curves at the output of the boost chopper circuit.

pulse width is reduced, the output of the step-up Chopper or Boost Chopper will reduce too. Thus, in controlling the Pulse width input to the MOSFET in the Circuit, we can step up the Voltage of the Chopper Circuit and the MOSFET will be used as the Switching Device.

Load Voltages and Currents for the Side of the three phase Inverter output are shown in Figure 9.

Three Phase Load Voltages and the Curve for Combination of the Individual Phase Voltages are shown in Figure 10.

Curve for Combination of the Three Phase Voltages Received at Three Phase

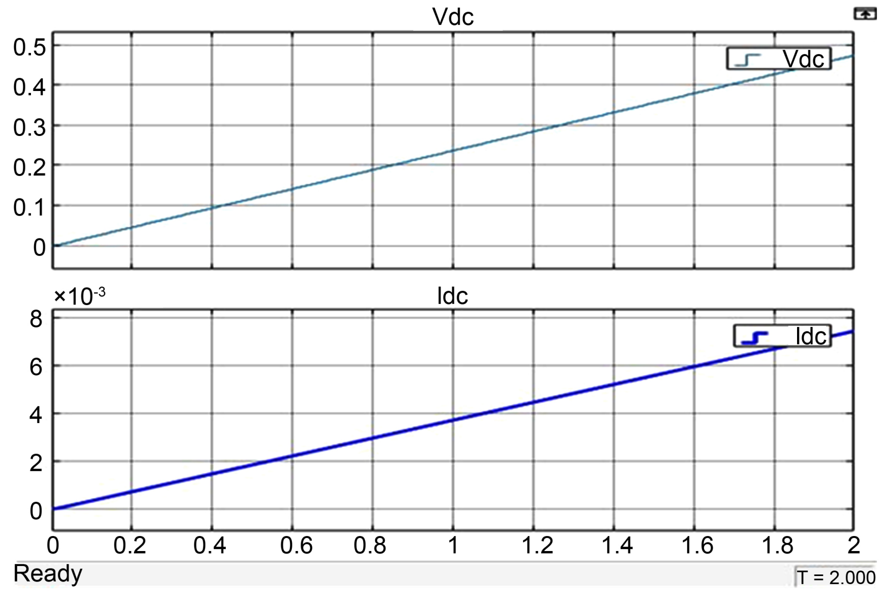

Figure 8. DC voltage and DC current at the output of the boost chopper circuit.

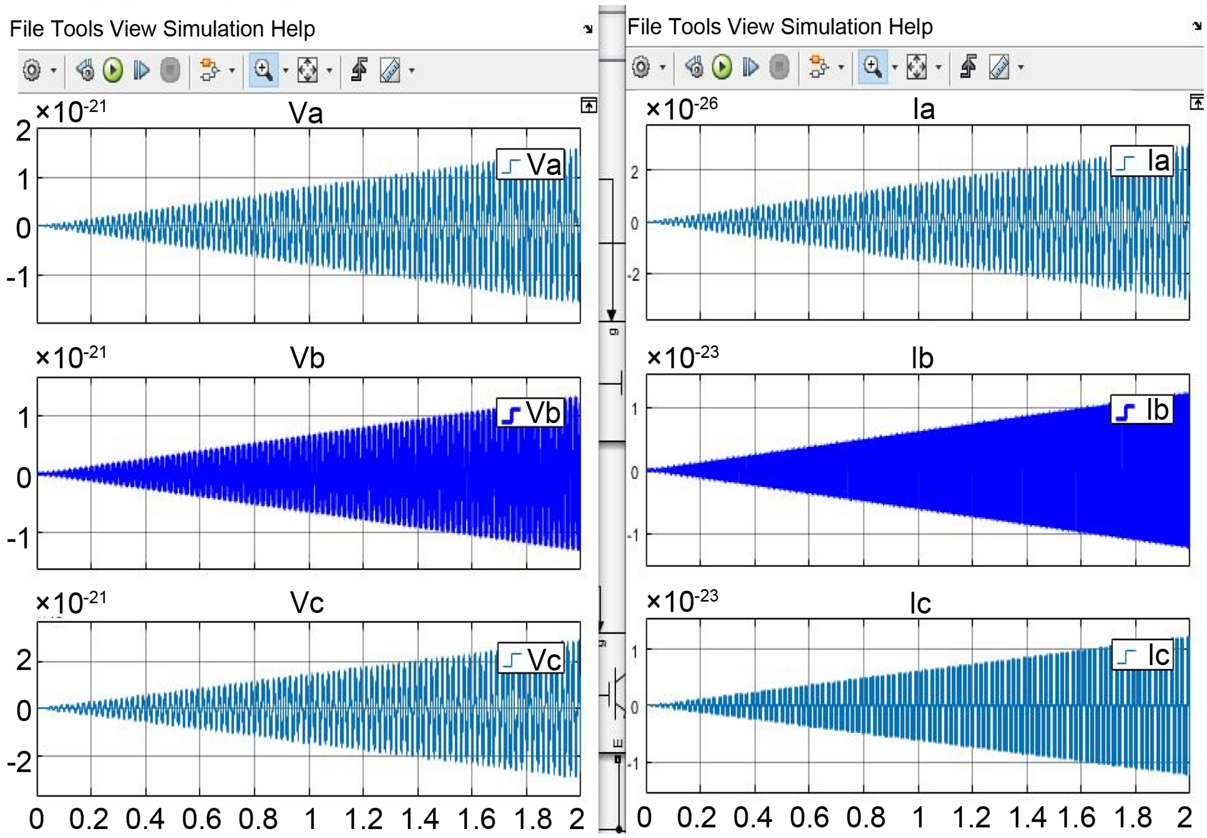

Figure 9. Load voltages Va, Vb, Vc on the left and load currents Ia, Ib, Ic on the right for the three phase inverter output.

Load is as described in Figure 11.

Figure 12 depict the Sinusoidal Curves for the Three Phase Voltages and currents on Three Phase Inverter Output (Three Phase V-I measurement) of the Phase load.

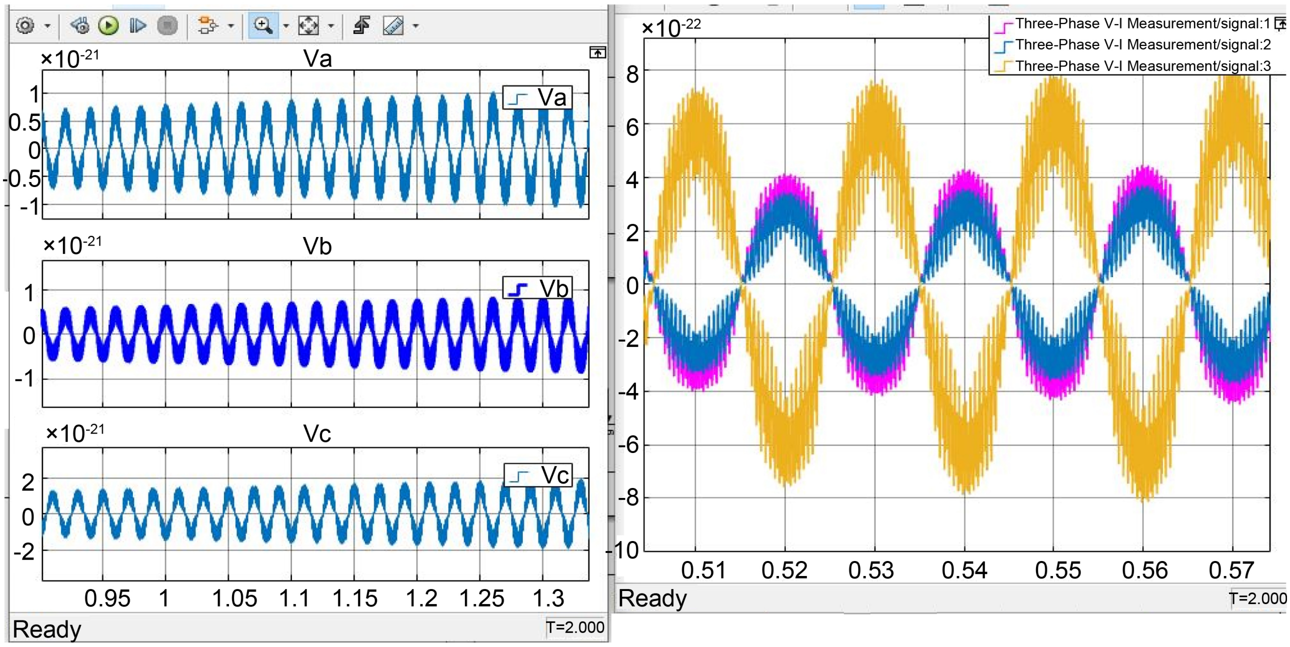

Figure 10. Three phase load voltages on the left and the curve for combination of the individual phase voltages on the right.

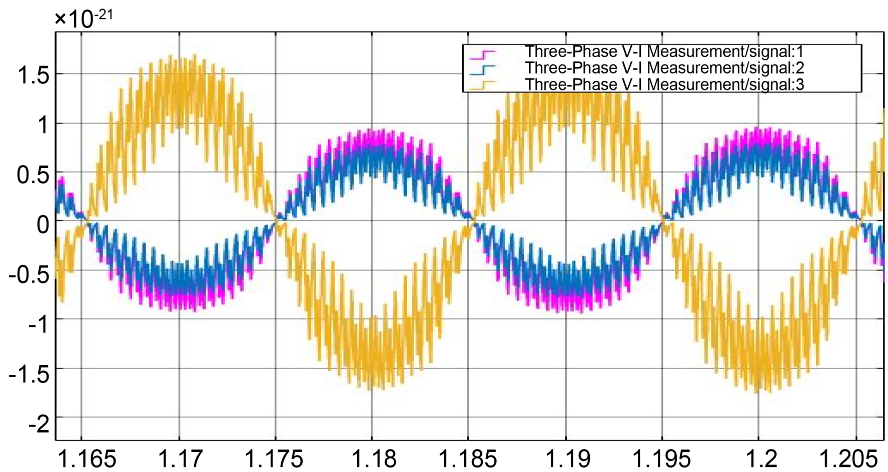

Figure 11. Curve for combination of the three phase voltages received at three phase load.

3. Result and Discussion

The Proposed system is simulated in MATLAB "Simulink". This proposed device is able to run a three phase portable loads from a single-phase AC supply power system. It has been clearly seen and shown that changing the input frequency changes the output frequency of the inverter system as well. It is advised to use the proposed system for loads up to a maximum of 15 Hp, or else a huge amount current will be drawn from the single-phase source. All the three-phase magnitude is unbalanced only one phase has big magnitude because of ripple that manifests at the output of the rectifier. Phase 1 output has no phase difference with the input signal so due to ripple of rectified output only phase 1 output is high. Output voltage and current were both seen to be in sinusoidal form.

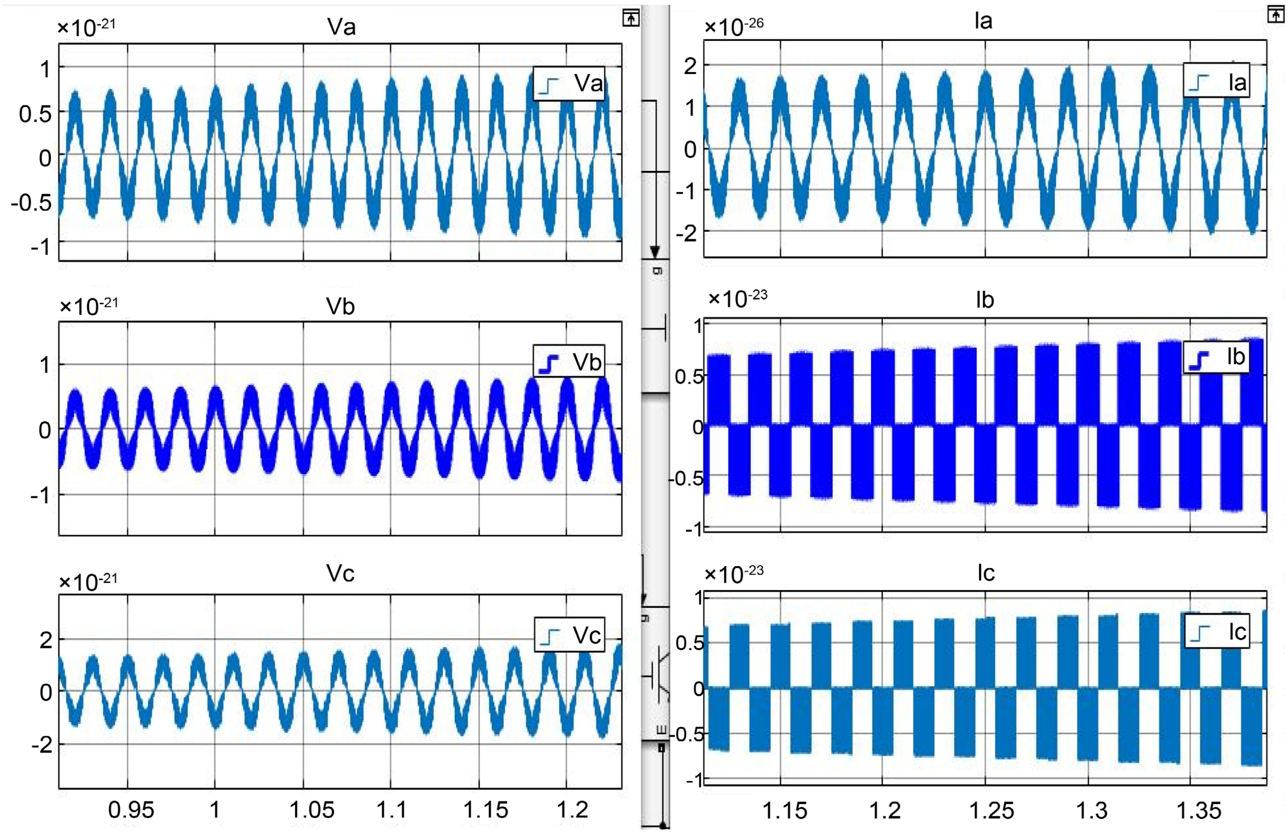

Figure 12. Sinusoidal curves for the three phase voltages and currents. Voltage on left and current on right.

However, the Output of the inverter is stepped up in nature and spike contain due to PWM.

In order to demonstrate the proposed system, a 1 kW class prototype circuit has been tested and used. The experimental conditions are the same as the simulation. Note that three-phase R-L load is used to confirm the principle of the proposed system.

The curves in this paper (**Figures 4-12**) illustrate the operation waveforms of the proposed circuit system. Decent sinusoidal waveforms are gotten for the single-phase current and three-phase current, with a single-phase power factor of over 99%. The proposed system can realize high efficiency because the current distortion of the system is extremely low.

The graphs further show single-phase waveforms and capacitor voltage waveform. The capacitor voltage is controlled form 400 V to 150 V of twice the frequency of the input voltage according to the proposed strategy of the total harmonics distortion (THD) of the output and input current for the conventional circuit with a similar capacitor and that of the proposed circuit system. The THD is calculated by less than 1 kHz harmonics. When the output power is reduced, the input current THD of the conventional circuit increases this is so because the source current in the conventional circuit only flows at around the peak of the source voltage. The input current THD in the conventional circuit progresses according to the increase of load power. The logic behind this, is that the time for the movement of source current rises as the load power rises. The reason is because the period for the flow of input current becomes long as the output power increase. Consequently, the conventional circuit switches the character of the THD between source current and load current. Nevertheless, the proposed circuit has a low THD in both results by using the active buffer control. At the output power of 1 kw which is the maximum value, the input and output current THD recorded are 3.9% and 5.1% respectively. The load current THD in the proposed circuit shrinks to less than 1/10 times in comparison with that of the existing conventional circuits which are similar. The results gotten during the experiment gave a strong confirmation that the proposed circuit system can compensate the power ripple of two times the power supply frequency. Despite the low voltage, the efficiency was recorded to be at 88.1% and power factor at close to unity. Results further showed that there was no switching loss in the buffer switch, booster, and rectifier diodes circuit, it should be noted that the inverter conduction loss was 40% of the entire systems loss. This is so because of an increased inverter current since all the current from the buffer flow through the inverter. In the proposed system the power factor correction circuit is not present because of the electrical and electronics connection, the circuit is even smaller in size than the existing conventional ones.

Thus, these results from the design, modelling and simulations experiment using MATLAB confirmed the validity, reliability and consistency of the circuit proposed for system.

4. Conclusion

The proposed model of inverter drive system with a display is mainly to be used in powering three phase loads in emergency situation and in remote isolated healthy facilities. The main benefit of this model is input AC single phase source but output is three phase supply with high level of convenience, efficiency less THD and other related losses. The output of the proposed model can be varied by changing the ratings of output components. Simulation result is shown using MATLAB software and used to verify system operation principle as well as circuit development and their control mechanism for a single-to-three-phase power inverter system. The results from experiment show that for a 1 kW-class prototype circuit system, the power ripple at twice the frequency of the power supply can be adequately suppressed using a buffer capacitor of low values. The current input THD of 3.9% and high value of power factor which is unity power factor are obtained.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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