Bulletin of Electrical Engineering and Informatics
Vol. 12, No. 1, February 2023, pp. 42~50
ISSN: 2302-9285, DOI: 10.11591/eei.v12i1.4276

Design and implementation of a driver circuit for three-phase induction motor based on STM32F103C8T6

Nahla Abdul Jalil Salih[1], Hayder Tareq Rajab Altaie[2], Waleed Khalid Al-Azzawi[3], Mohannad Jabbar Mnati[4]
[1]Department of Electronic, Medical Technical Institute/Al Mansour, Middle Technical University, Baghdad, Iraq
[2]College of Engineering, Al-Muthanna University, Samawah, Iraq
[3]Department of Medical Instruments Engineering Techniques, AL-Farahidi University, Baghdad, Iraq
[4]Department of Electronic Technologies, Institute of Technology, Middle Technical University, Baghdad, Iraq

Article Info

Article history:

Received Jun 17, 2022
Revised Aug 18, 2022
Accepted Oct 14, 2022

Keywords:

Driver circuit
Pulse width modulation
STM32F103C8T6
Three-phase induction motor
Three-phase inverter

ABSTRACT

A three-phase induction motor is an electrical machine that can be used for many industrial applications. A three-phase driver circuit, also known as a three-wire series circuit or three-wire delta circuit is an electrical power system. These motors typically rely on power supplied using electric cables, which carry alternating currents. The three-phase motor inverter driver circuit is a simple circuit consisting of three half-wave rectifiers, which are connected in a bridge. When the input voltage level of the DC power supply to the inverter is high enough, this arrangement can provide a large current through the induction motor. This paper will show how to build a three-phase inverter driver circuit from scratch for a threephase induction motor by using (transistors and diodes) for photovoltaic application. The paper will guide people through each step with diagrams and schematics that make it easy for anyone to understand every part of this project and ensure people's safety by learning how these components work before putting them into their own design. The focus of this project will be on the use of STM32F103C8T6 as microcontrollers to generate the pulse width modulation (PWM) signals.

Corresponding Author:

Mohannad Jabbar Mnati
Department of Electronic, Medical Technical Institute/Al Mansour, Middle Technical University
Baghdad, Iraq
Email: mohannad.mnati@mtu.edu.iq, m.j.mnati@gmail.com

1. INTRODUCTION

Electronic transducers are now widely used in a range of applications and enable variable speed driving of induction motors by adjusting the frequency of the applied voltages. As a consequence of substantial technological improvement in the field of power electronics in recent years. This amount of use indicates the ability of these transducers to enhance the efficiency of dynamic or static features and limit the specifications of machines [1]–[5]. Which is the scenario in the electromechanical switching series because of the inverter's high ability to ensure adaptive voltage and frequency change.

For the smooth operation of the speed and direction controller, several researchers have presented many types of controllers. The occurrence of torque ripples is dictated by a dip in torque between two consecutive phases, as stated in [6]–[8]. In [9]–[12] the authors proposed a model-based killed flux controller. Typically, the design of control system components for high-order systems includes significant computational problems and time-consuming activities. As a result, high-requirement controllers must be designed for such systems through appropriate order-reduction of the model [13]–[17].

In MATLAB/Simulink, the interpretation of sinusoidal pulse width modulation (SPWM) and SVPWM-based inverters was estimated using the metrics of speed organization, torque ripple, and total deformation of harmonics [17], [18]. We find AC signals that are used as control variables in AC systems to assess the system's performance. Performance is significantly enhanced when these ac control signals are switched out for DC values (referred to as AC/DC frame translation) since DC signals are more straightforward and have larger bandwidth. The foundation of this transformation theory is the conversion of AC signals to DC values, manipulation of these DC values, and subsequent return of the values to the AC domain and conversion of the values back to AC signals. There are a large number of electronic circuits that are used to control single-phase and three-phase induction motor motors. Each circuit differs from the other by the difference in the type of electric controller or the type of the inverter circuit and often these circuits are not available to everyone or it the difficulty of obtaining the main schematics with the control program.

In this paper, we designed a new, low-cost and easy-to-use circuit by using the STM32F103C8T6 as a microcontroller [19], which can be used to write the control program by using Arduino IDE [20]. Moreover, the design of a three-phase inverter with a driver circuit was designed to be easy to use for everyone, especially students and researchers. The final printed circuit board (PCB) circuit was designed by using an open-source PCB circuit design program. The complete system of the three-phase induction motor driver circuit consists of the following main major parts, all of which are open-source, inexpensive electronic components.

2. HARDWARE REQUIRED

In this section, all the necessary electronic items on the market that are available to everyone that will be used in this paper will be presented and discussed. STM32F103C8T6 will be used as a microcontroller in the final circuit design. IRF840 will be used for the power switch and IR2112S TRPBF as IGBT driver IC. MC7805CDTG and LD1117S33TR will be used as voltage regulators ICs.

2.1. STM32F103C8T6 microcontroller

STM32F10x is a low-cost, high-performance ARM Cortex® -M3 based microcontroller. It offers advanced features and peripherals, which make it ideal for embedded applications. The STM32F103xx series is one of the most popular platforms for emerging IoT applications such as connected home or smart city solutions.

This 32-bit microcontroller board has built-in 2D acceleration via video processing unit (VPU1) which can support MPEG2 decoding at up to 25 fps or MPEG4 encoding at up to 30 fps. It supports one time boot, on-chip debug store (OCDS), low power modes and 256 byte electrically erasable programmable read-only memory (EEPROM) for data retention during application development process. Atmel's STM32F103C8T6 is an ARM® Cortex™-M3 based with 256 K flash, 16 K RAM and a USB 2.0 connector. It has 51 general-purpose input/output (GPIO) pins, 10 analog I/O pins, 37 digital I/O pins, 128×8 software selectable I/O pins, 3.3 v operating voltage, 64/128 flash memory (KB), 20 KB SRAM, 72 MHz max frequency (clock speed) and inter-IC (I2C), serial-peripheral interface (SPI), universal asynchronous receiver/transmitter (UART), controller area network (CAN), USB communication, and see Figure 1(a) [20].

2.2. IRF840 power metal oxide semiconductor field effect transistor

The IRF840 is a general-purpose metal oxide semiconductor field effect transistor (MOSFET) semiconductor power switch designed for controlling DC loads. It has high power capacity and fast switching, making it suitable for use in battery chargers, uninterruptible power supplies (UPS), inverters, and other high-power applications [21]. The IRF840 is also offered with an SOT23 surface mount package that can be used to provide low-power circuit protection applications such as input overvoltage protection on the low voltage side of transformer isolated supply circuits. The small size of the SOT23 package enables these devices to be conveniently located near sensitive circuitry or out on a PCB track side, see Figure 1(b).

2.3. IR2112STRPBF metal oxide semiconductor field effect transistor

Power MOSFET and insulated gate bipolar transistor (IGBT) drivers with individually referenced high and low output channels comprise the IR2112(S), see Figure 1(c). Because of the distinct high-voltage integrated circuit (HVIC) and latch-resistant complementary metal–oxide–semiconductor (CMOS) technology, a ruggedized monolithic design is achievable. Up to 3.3 V logic, the logic inputs are suitable for CMOS or low power Schottky transistor transistor logic (LSTTL) model outputs. To reduce driver cross-conduction, the output drivers make use of a high pulse current buffer stage. High-frequency applications may be used more easily since the propagation delays are matched. In a high-side configuration, the floating channel may drive an N-channel power MOSFET or IGBT rated for 600 volts [22].

2.4. MC7805CDTG voltage regulators

The 7,805 voltage regulator is necessary for a lot of circuits. It was designed to regulate a steady 5 V output from a wall adapter with incongruities in input voltage. A common application is converting 12 volts from an automotive battery to 5 volts for powering micro-controller circuits. The 7,805 is one of the most popular voltages because it provides stable and reliable power on inexpensive, readily available components. It can convert as much as 1 ampere at up to 35 watts of power and 10 amperes at over 150 watts into regulated, constant voltage at up to 25% duty cycle, see Figure 1(d) [23].

2.5. LD1117S33TR voltage regulators

LD1117 is a low-voltage regulator with an adjustable release (VREF=1.25 V) and an output current of up to 800 mA. Fixed versions of the following output voltages are available: 1, 2, 5, 1, 8, 2, 85, 3, 3, and 5 volts. The device is presented in the formats SOT-223, DPAK, SO-8 and TO-220. The SOT-223 and DPAK surface mount packages have amended thermal properties while also taking up less space. Excellent competence is guaranteed by the negatif positif negatif (NPN) pass transistor. In reality, in contrast to positif negatif positif (PNP), the quiescent current in this scenario flows largely into the load. Only a standard 10 F minimum capacitor is needed for stability. The regulator may achieve an extreme tolerance for the output voltage of less than 1% at 25 °C gratitude for on-chip trimming. End-to-end adjustable LD1117 conforms to other standard. Figure 1(e) shows that adjustable voltage regulators have better tolerance and loss than fixed voltage regulators [24]. Deferent values of resistances and capacitors for the design of the full circuit, see Figure 1(f). Some of these resistors are used on the low-voltage side of the driver circuit and others are on the high voltage side.

2.6. Three-phase induction motor

An induction motor is a machine with electromagnetic components that induces currents in the rotor by electromagnetic forces. It is the most common type of AC motor. An induction motor's main components are stator coils, an iron core, and thin copper wire rotors called an armature. The stator coils are stationary with respect to the ground or another frame of reference, while the rotor moves inside them with respect to that frame, see Figure 1(g) [25].

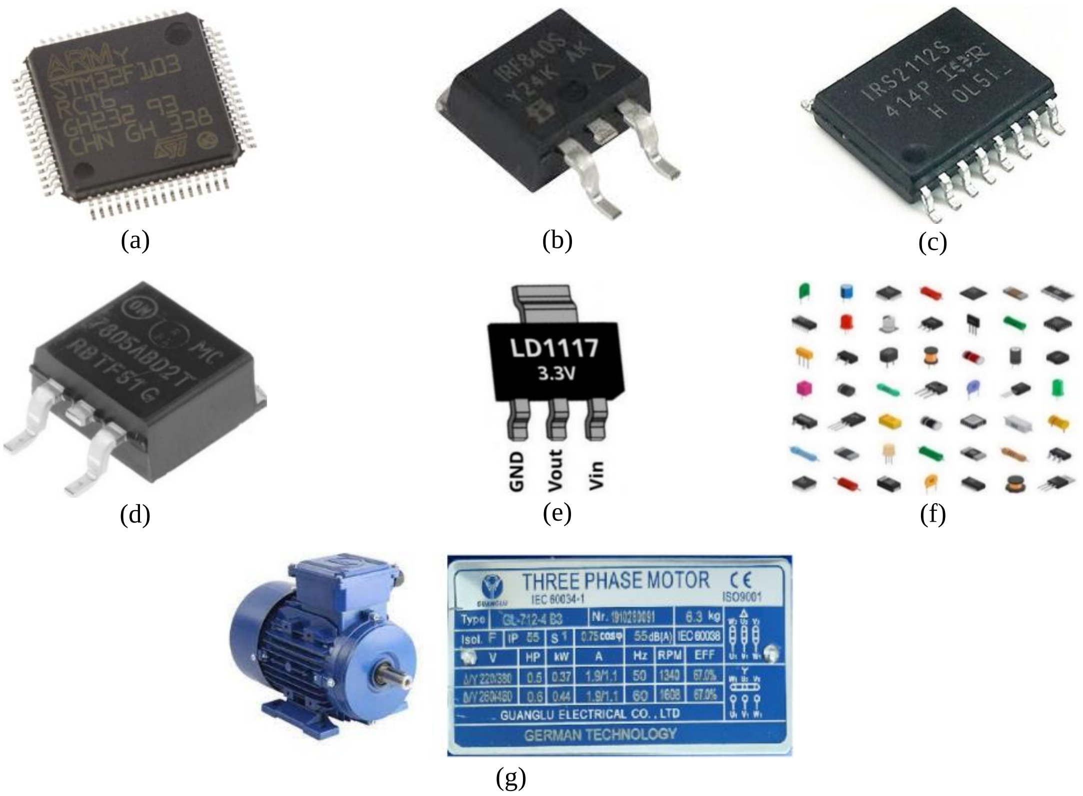


Figure 1. System hardware components (a) STM32F103C8T6, (b) IRF840 power MOSFET, (c) IR2112STRPBF, (d) MC7805CDTG voltage regulators, (e) LD1117S33TR, (f) electronic components, and (g) three phase induction motor

3. SYSTEM ARCHITECTURE

The electrical and electronic components need to be tested independently before the system can be entirely developed and built. The Diagrams in this part will be used to show the practical aspects of each electrical component in this section. Finally, the hardware for the final system design is given. Figure 2 shows how the PWM pins on the STM32F103C8T6 are used to generate six PWM signals to drive the three-phase inverter circuit, plus the digital pins for the purpose of controlling the direction of rotation and speed of the induction motor.

The IRF840 MOSFET transistor is seen in the circuit schematic for a three-phase inverter in Figure 3. A DC input voltage is transformed into an AC output voltage using this circuit. To provide a three-phase AC supply, it includes three arms that are typically 120 degrees apart. The switches in the inverter have a rate of 50%, occur every T/6 of the time, and have a 60° angle interval.

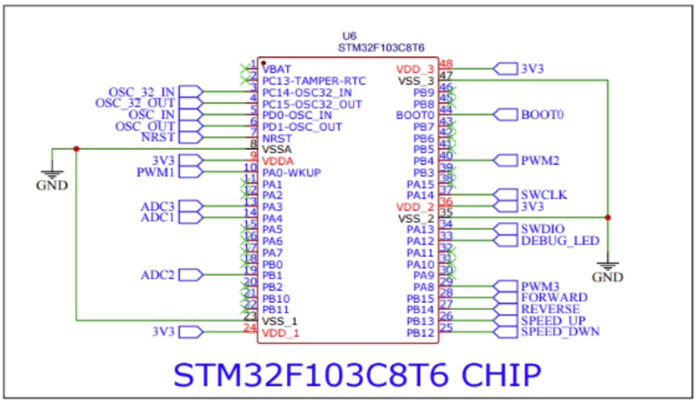


Figure 2. STM32F103C8T6 circuit diagram for generate PWM signals

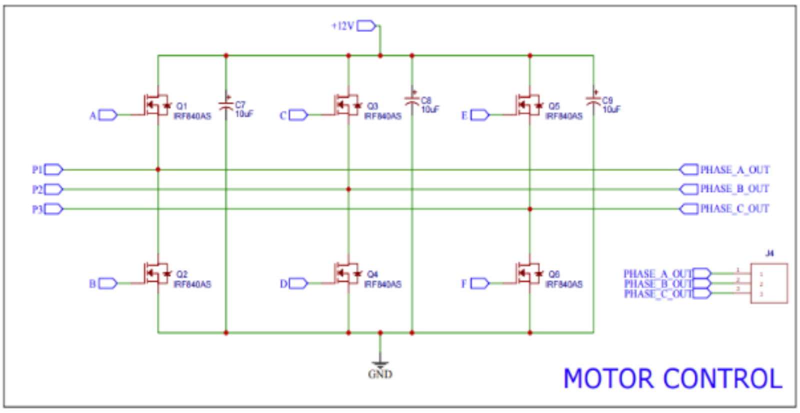


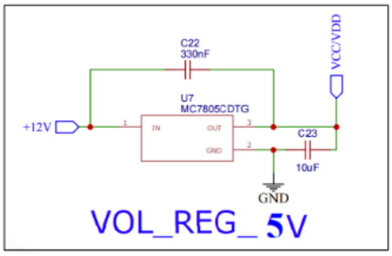
Figure 3. Three phase circuit diagrams for IRF840AS MOSFET transistor

A 5 volt regulator circuit that only requires three parts is shown in Figure 4(a). It is a straightforward, affordable, and simple method to obtain a current of up to 1 A and a voltage of more than 5 V. This circuit may also serve as a power source for breadboards. A circuit for 3.3 V @ 800 mA DC regulated supply is shown in Figure 4(b). This circuit employs the LM1117 low-dropout linear regulator. A voltage regulator with a low dropout of 3.3 V at 800 mA load current is the LM1117-3.3.

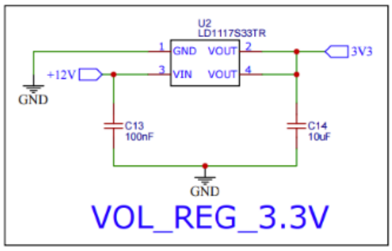
High and low side driver circuit diagram IR2112 popular integrated circuits and transistors is shown in Figure 5. The IR2112(S) is an IGBT and power MOSFET driver with separately referenced high and low output channels that operate at high voltages and speeds. Exclusive HVIC and latch-resistant CMOS technologies make it feasible to create robust monolithic architecture. A normal CMOS or LSTTL output may be used with logic Input down to logic 3.3 VIn drives output, via driver conduction is minimized by using a high pulse current buffer step. To make using high-frequency applications simpler, the propagation delays are matched. In a 14-DIP package, the floating channel can be used to power N-channel power

MOSFET or IGBT in high bypass configuration, operating up to 600 V. Figure 5(a) is shown the driver circuit diagram for phase A, Figure 5(b) is shown the driver circuit diagram for phase B and Figure 5(c) is shown the driver circuit diagram for phase C.

Figure 6(a) shows how to connect some electronic components necessary, such as capacitors, diodes and crystal oscillator to complete the final circuit of the three-phase inverter board. Figure 6(b) shows the terminals used how to connect the external switches that are used to change the direction of the motor (right - left) as well as control the speed of the induction motor. After all the electronic parts used in our project were shown, we assembled them and wrote one program to run them. Figure 7(a) presents the final PCB design of the entire system circuit and the driver circuit to drive the three-phase induction motor and the final hardware implantation circuit is presented in Figure 7(b).

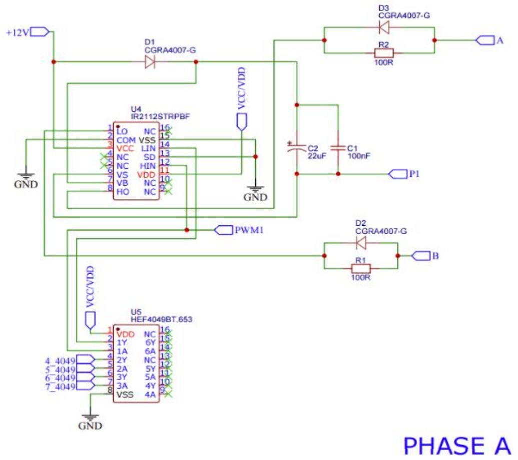


(a)

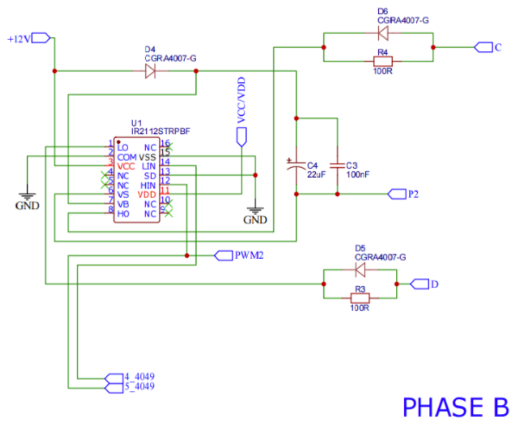


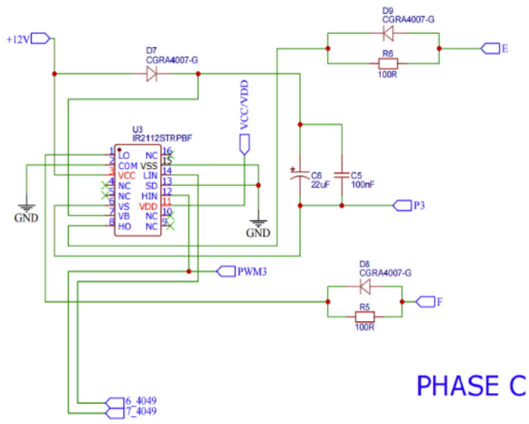
(b)

Figure 4. Voltage regulator circuit diagram (a) 5 V output and (b) 3.3 V output



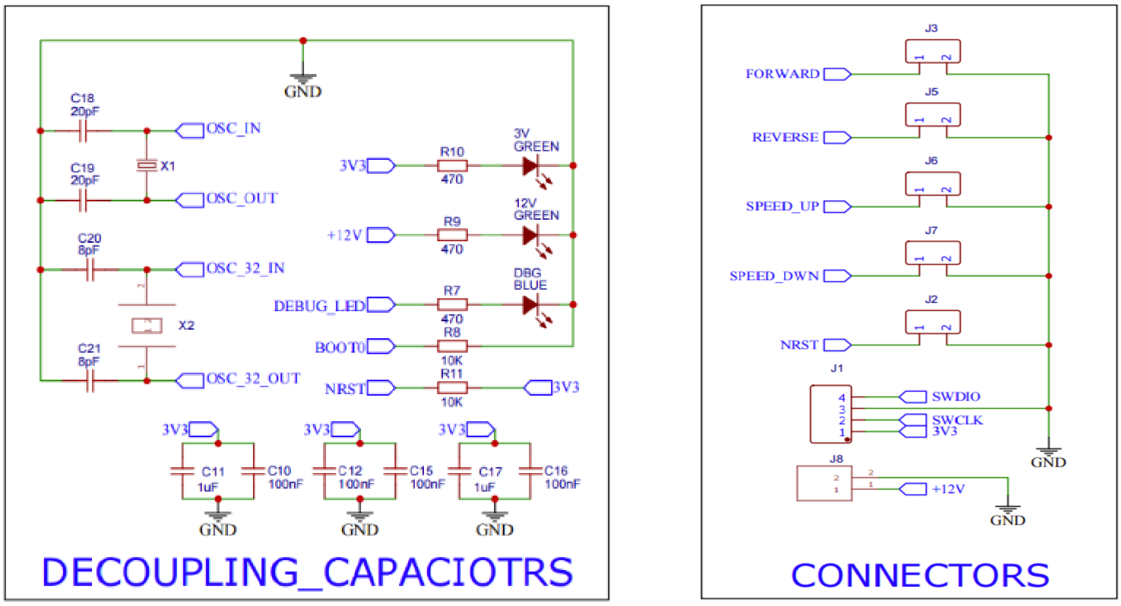
(a)





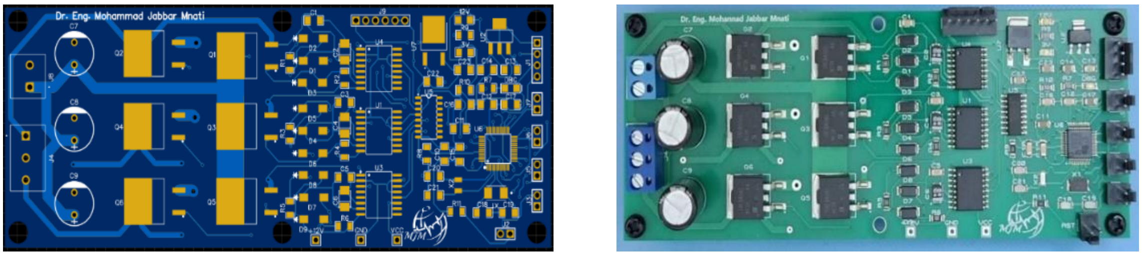
(b) (c)

Figure 5. IR2112 driver circuit diagram (a) phase A with HEF4049BT Hex IC INVERTER, (b) phase B, and (c) phase C



(a) (b)

Figure 6. Schematic diagram (a) decoupling capacitors circuit diagram and (b) connectors circuit diagram for switches



(a) (b)

Figure 7. PCB circuit (a) PCB top layer circuit layout designed by using (easy EDA software) and (b) final hardware circuit after printing

4. RESULTS AND DISCUSSION

The final simulation for the three-phase inverter and induction motor was done in the MATLAB/ Simulink program and the values of voltage and current were as in Figure 8. The final hardware setup of the system is presented in the Figure 9. This figure is present the full driver circuit with three-phase inverter, three phase induction motor and DC input power supply.

- The operating the device does not require any great experience, because it was designed to work easily, especially when working on it by students, while providing all safety means in terms of operation and extinguishing.
- The devices were turned on and their performance tested, reaching a speed of 1,000 rpm during the test because the motor tested under open loop. In the future it may be used and test it under closed loop for research.

The driver circuit is designed for ease of use and control of a three-phase motor using an inexpensive driving circuit, especially for students. The user only needs to apply high voltage DC (more than 150 V DC) and then turn on the driver circuit, then the motor will be start to operate at a low speed. The four external switches that are connected with the driver circuit, as shown in the final circuit diagram control the speed and direction of the motor. The flowchart in Figure 10 is present the operation instruction of the full system.

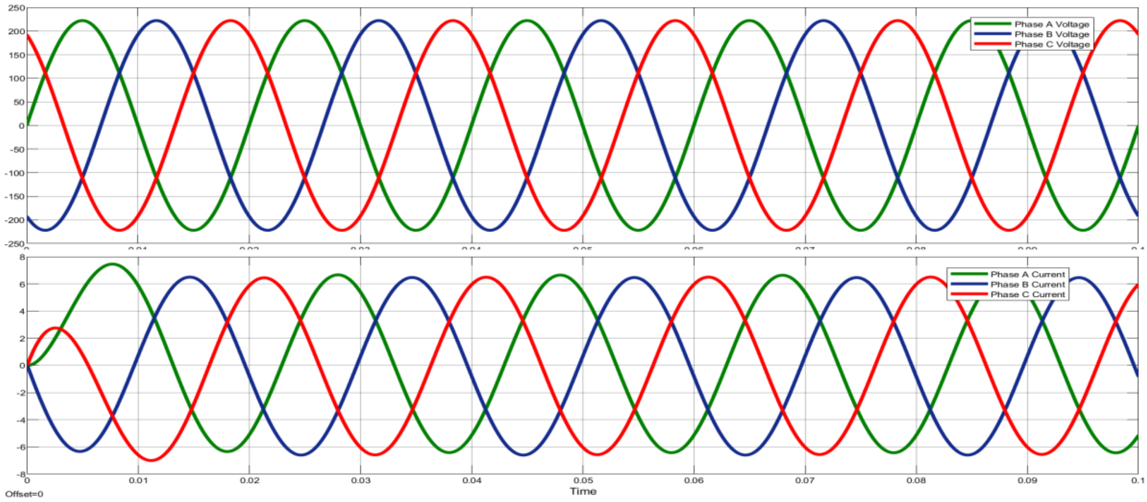


Figure 8. The final simulation results (three phase voltage and currrent)

Figure 9. The final hardware setup of the proposed system

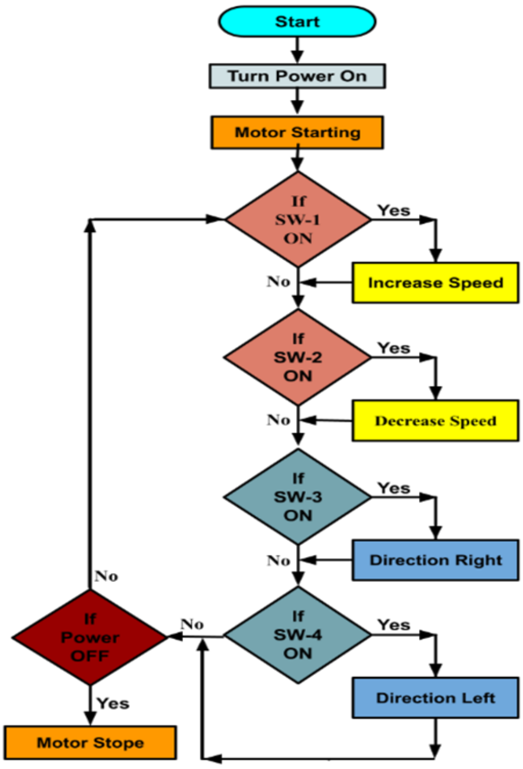


Figure 10. The flowchart of the final program

5. CONCLUSION

This paper demonstrated how to construct a three-phase inverter driver circuit from the ground up for a three-phase induction motor using (power transistors, diodes, and other components) for photovoltaic applications. The paper helps people through each stage with diagrams and schematics that will make it simple for anyone to grasp every aspect of the project. Also, this circuit provides protection and safety for people by teaching them how to use these components before incorporating them into their own designs. The final electronic circuit was tested and proved its efficiency in controlling the speed and direction of a three-phase induction motor by using STM32F103C8T6 as microcontrollers to generate the PWM signals.

REFERENCES

[1] Q. Yang, J. Lou, S. Liu, and A. Diao, "Literature review of permanent magnet AC motors and drive for automotive application," *Bulletin of Electrical Engineering and Informatics*, vol. 1, no. 1, pp. 7–14, Mar. 2012, doi: 10.12928/EEI.v1i1.28.

[2] H. A. Mohamed and H. M. D. Habbi, "Power quality of dual two-level inverter fed open end winding induction motor," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 18, no. 2, pp. 688–697, May 2020, doi: 10.11591/ijeecs.v18.i2.pp688-697.

[3] J. Sabarad and G. H. Kulkarni, "Novel switching technique for five leg inverter in dual motor control," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 19, no. 2, pp. 644–651, Aug. 2020, doi: 10.11591/ijeecs.v19.i2.pp644-651.

[4] D. V. Bozalakov, J. Laveyne, J. Desmet, and L. Vandevelde, "Overvoltage and voltage unbalance mitigation in areas with high penetration of renewable energy resources by using the modified three-phase damping control strategy," *Electric Power Systems Research*, vol. 168, pp. 283–294, Mar. 2019, doi: 10.1016/j.epsr.2018.12.001.

[5] A. van den Bossche, D. V. Bozalakov, T. Vyncke, and V. C. Valchev, "Programmable logic device based brushless DC motor control," *Proceedings of the 2011 14th European Conference on Power Electronics and Applications, EPE 2011*, pp. 1–10, 2011.

[6] M. J. M. Al-Rubaye, A. Hasan, D. Bozalakov, and A. van den Bossche, "Smart monitoring and controlling of three phase photovoltaic inverter system using lora technology," in *Sixth European Conference on Renewable Energy Systems (ECRES2018)*, 2018, pp. 1–7.

[7] G. Joshi and P. P. A J, "ANFIS controller for vector control of three phase induction motor," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 19, no. 3, pp. 1177–1185, Sep. 2020, doi: 10.11591/ijeecs.v19.i3.pp1177-1185.

[8] M. Z. Ismail, M. H. N. Talib, Z. Ibrahim, J. M. Lazi, and Z. Rasin, "Experimental simplified rule of self tuning fuzzy logic-model reference adaptive speed controller for induction motor drive," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 20, no. 3, pp. 1653–1664, Dec. 2020, doi: 10.11591/ijeecs.v20.i3.pp1653-1664.

[9] J. Y. Khadouj, E. M. Lamiaà, and A. Saad, "Squirrel cage induction motor fault diagnosis using lissajous curve of an auxiliary winding voltage: Case of broken bars," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 24, no. 3, pp. 1332–1341, Dec. 2021, doi: 10.11591/ijeecs.v24.i3.pp1332-1341.

[10] M. J. Mnati, D. V. Bozalakov, and A. van den Bossche, "PID control of a three phase photovoltaic inverter tied to a grid based on a 120-degree bus clamp PWM," *IFAC-PapersOnLine*, vol. 51, no. 4, pp. 388–393, 2018, doi: 10.1016/j.ifacol.2018.06.097.

[11] P. N. Phuc, H. Vansompel, D. Bozalakov, K. Stockman, and G. Crevecoeur, "Data-driven online temperature compensation for robust field-oriented torque-controlled induction machines," *IET Electric Power Applications*, vol. 13, no. 12, pp. 1954–1963, Dec. 2019, doi: 10.1049/iet-epa.2019.0309.

[12] M. J. Mnati, D. V. Bozalakov, and A. van den Bossche, "A new synchronization technique of a three-phase grid tied inverter for photovoltaic applications," *Mathematical Problems in Engineering*, pp. 1–13, Jul. 2018, doi: 10.1155/2018/7852642.

[13] V. T. Ha, T. L. Nguyen, and V. T. Ha, "Hardware-in-the-loop based comparative analysis of speed controllers for a two-mass system using an induction motor drive with ideal stator current performance," *Bulletin of Electrical Engineering and Informatics*, vol. 10, no. 2, pp. 569–579, Apr. 2021, doi: 10.11591/eei.v10i2.2370.

[14] I. J. Hasan, N. A. J. Salih, and N. A. Abdulkhaleq, "Three-phase photovoltaic grid inverter system design based on PIC24FJ256GB110 for distributed generation," *International Journal of Power Electronics and Drive Systems*, vol. 10, no. 3, pp. 1215-1222, 2019, doi: 10.11591/ijpeds.v10.i3.pp1215-1222.

[15] S. Shashibhushan and S. Sonoli, "Starting torque and torque ripple reduction using SVPWM based vector control of induction motor with nine-level cascaded multilevel inverter fed with solar PV power," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 10, no. 2, pp. 1123–1132, Jun. 2019, doi: 10.11591/ijpeds.v10.i2.pp1123-1132.

[16] Y. K. Jelbaoui, E. M. Lamiaà, and A. Saad, "Fault diagnosis of a squirrel cage induction motor fed by an inverter using lissajous curve of an auxiliary winding voltage," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 21, no. 3, pp. 1299–1308, Mar. 2021, doi: 10.11591/ijeecs.v21.i3.pp1299-1308.

[17] M. J. Mnati, Di. V. Bozalakov, and A. van den Bossche, "New pulse width modulation technique to reduce losses for three-phase photovoltaic inverters," *Active and Passive Electronic Components*, pp. 1–10, Aug. 2018, doi: 10.1155/2018/4157614.

[18] D. V Bozalakov, M. J. Mnati, A. van den Bossche, and L. Vandevelde, "Voltage unbalance mitigation by using the three-phase damping control strategy in active rectification mode," in *Young Researchers Symposium (YRS2018)*, 2018, pp. 1–6.

[19] M. Mazzillo et al., "Timing Performances of Large Area Silicon Photomultipliers Fabricated at STMicroelectronics," *in IEEE Transactions on Nuclear Science*, vol. 57, no. 4, pp. 2273-2279, Aug. 2010, doi: 10.1109/TNS.2010.2049122.

[20] O. E. Amestica, P. E. Melin, C. R. Duran-Faundez and G. R. Lagos, "An Experimental Comparison of Arduino IDE Compatible Platforms for Digital Control and Data Acquisition Applications," *2019 IEEE CHILEAN Conference on Electrical, Electronics Engineering, Information and Communication Technologies (CHILECON)*, 2019, pp. 1-6, doi: 10.1109/CHILECON47746.2019.8986865.

[21] Siliconix, Vishay. "Power mosfet." IRF510/SiHF510 Datasheet S15-2693-Rev C (2015).

[22] Rectifier, I. I. "Datasheet IR2112." vol 2112: 1-18.

[23] LD1117, "Adjustable and fixed low drop positive voltage regulator," pp. 1-45, 2019, [Online]. Available: https://www.mouser.fi/datasheet/2/389/ld1117-974075.pdf.

[24] Texas Instrument, "Linear & low-dropout (LDO) regulators," [Online]. Available: http://www.ti.com/lit/ds/symlink/tlv1117-50.pdf.

[25] S. A. S. Alkadhim, "Three-phase Induction Motor: Types and Structure," *SSRN Electron. J.*, p. 11, 2020, doi: 10.2139/ssrn.3647425.

BIOGRAPHIES OF AUTHORS

Nahla Abdul Jalil Salih is a member of the Department of Electronic Techniques in the Institute of Technology in Middle Technical University in Iraq. She received his B.Sc in control and systems Engineering from University of Technology, Baghdad, Iraq in 1992. Her interests are control and systems, fractal coding technique, and digital image coding. She can be contacted at email: nahla.alchalaby@yahoo.com.

Hayder Tareq Rajab Altaie is a member of Sociology Department/Art College in Al-Muthanna University in Iraq. He received his B.Sc in Electronics and Communications Engineering from University of Technology-Baghdad-IRAQ in 2007, he received his M.Sc in Information technology and Communication Systems from ITMO University (Saint Petersburg State University of Information Technology, Mechanics and Optics)-Russia in 2015 his interests is new trends in Information Technology and gis. He can be contacted at email: hayderaltaie@mu.edu.iq.

Waleed Khalid Al-Azzawi his Ph.D in control engineering from De Montfort University/Leicester/UK/2013 and received his M.Sc and B.Sc in control and automation from the University of Technology Baghdad, Iraq. Currently worked as a Dean of Medical Technical College/Al-Farahidi University. He can be contacted at email: waleed.khalid@alfarahidiuc.edu.iq.

Mohannad Jabbar Mnati was born in Baghdad, Iraq in 1975. He received his B.S. degree in electrical and electronics engineering in 2000 and his M.S. degree in electronic engineering in 2005, both from the Faculty of Electrical and Electronic Engineering, University of Technology, Baghdad, Iraq, and he received his Ph.D. degree in electromechanical engineering in 2019 from Ghent University, Belgium. He is Faculty member at the Department of Electronic Technologies, Institute of Technology–Baghdad, Middle Technical University, Iraq. He has research interests are in electrical drives, power electronics, renewable energy, photovoltaic systems, IoT, and smart control systems. He can be contacted at email: mohannad.mnati@mtu.edu.iq or mohannad.mnati@gmail.com.