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Modified Single Phase Induction Motor Fed from the Solar Energy

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Abstract: The solar PhotoVoltaic (PV) power is a dc power and if compatible loads are available, we can build a simple and economic solar system at remote locations. The most important load is the electric motor which is capable of driving rotating loads such as pumps, washers and refrigerators and supplied directly from the solar energy. The single phase induction motor is commonly used in such domestic applications, so, we selected it as a base for our new solar drive, however, the motor will be redesigned for identical main and auxiliary stator windings and fed from the solar power via. a special two-phase inverter. In this study, we will design a novel simple programmed wave inverter which collects the advantages of the two commercially available inverters: low harmonics and low cost in addition to small size, so, it can be integrated with the motor as a reliable solar drive.

Key words: Electric drive, PV power, solar drive, two-phase inverter, two-phase induction motor

INTRODUCTION

Various motor types are available for photovoltaic applications (AC and DC motors). When direct coupling to PV module is selected the dc motors are the suitable choice where AC motors must be fed from the PV panels via. inverters. In general, AC motors are more reliable and cheaper than DC motors and brushed DC motors suffer from brushes and commutator wear (Agarwal *et al*., 2015). In this study, we concern with the basic household loads which contain electric motors such as fan, water pump, washing machine and refrigerator. All these appliances use single phase induction motors in their current design however it may not be the best solution in case of solar energy source.

The single-phase induction motors have been widely employed in low or middle power level fields, especially in household appliances where a three-phase supply is not available (Chaiyot *et al*., 2017). The single-phase induction motor requires an auxiliary winding to produce a suitable starting torque. For example, the capacitor starting moto produces the starting torque with the aid of the auxiliary winding and series-connected capacitor. Accordingly, it operates as asymmetrical two-phase induction motor at starting but operates as a pure single-phase induction motor while running after a centrifugal switch is opened (Jang and Yoon, 2003). However, single-phase induction motors suffer from electromagnetic torque ripple. In this research, we will introduce symetrical two phase induction motor as a solar drive which is suitable for target applications mentioned above. For this purpose, we need to design a controller for it to be compatible with solar PV power source. The available supply is DC source, so, we will convert it to two-phase power instead of single phase to avoid single phase motor draw backs. Single-phase induction motor can be modified to two-phase induction motor and supplied with a three-leg Voltage Source Inverter (VSI) in order to improve the motor performance (Choorak and Kinnares, 2014).

MATERIALS AND METHODS

Modified 1-phase induction motor drive: Conventional capacitor-start single-phase induction motor has two windings, the main winding and the auxiliary winding. A capacitor is placed in series with the auxiliary winding, thus, a 90° phase difference in current is obtained. Consequently, a torque is developed and motor becomes a self-starting motor. After the motor starts, the auxiliary winding is disconnected usually by means of centrifugal switch that operates at about 75% of synchronous speed. Finally, the motor runs by the main winding. Since, this is being single-phase, some level of humming noise is associated with motor during running. To run this single-phase induction motor with two-phase supply, modification will be done. Capacitor and centrifugal switch are removed. A change is made to the auxiliary winding to have the same thick copper wire and number of turns as the main coil (Khan and Ahsan, 2014). Normally, variable voltage variable frequency supply can be obtained from inverter with constant DC input voltage

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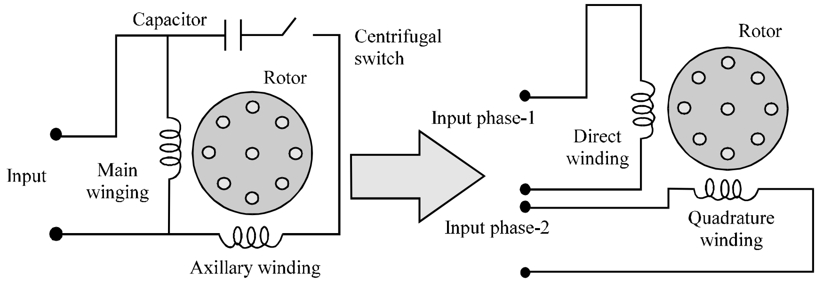


Fig. 1: 1-phase to 2-phase induction motor conversion

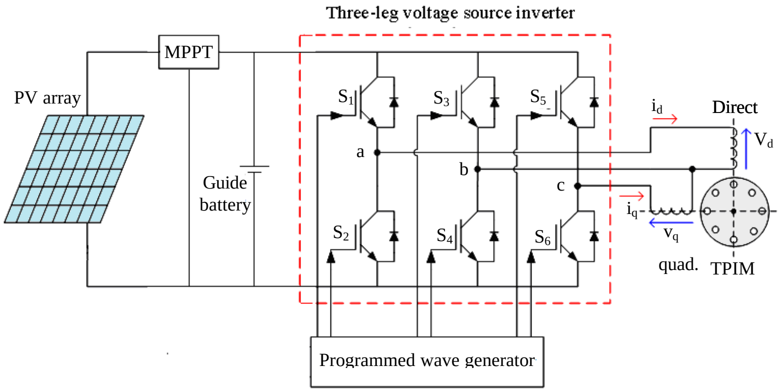


Fig. 2: 2-phase I.M. driven by PV powered VSI

which is provided by rectifier circuits or a PV array. However, it is necessary to obtain higher voltage for driving the Two-Phase Induction Motor (TPIM) with the rated flux, therefore, a boost converter is included to achieve sufficient DC link voltage and increase the system efficiency (Hayakwong and Kinnares, 2014). Figure 1 illustrates single phase to two phases conversion.

Figure 2 illustrates symmetrical TPIM fed from PV powered three-leg VSI schematic diagram, the Maximum Power Point Tracker (MPPT) includes the boost converter and the guide battery informs the MPPT by the required system voltage. The inverter is driven by programmed wave generator and feeds the direct and quadrature windings of the TPIM.

RESULTS AND DISCUSSION

Programmed wave inveter: Most of commercially available inverters are divided into two types, modified wave inverters and sine wave inverters. The modified wave inverter is designed using a simple oscillator to output a modified square wave which is a normal square wave with a dead band between positive and negative half cycles (Fig. 3).

The sine wave inverter is designed using Pulse Width Modulation (PWM) technique to give nearly pure sine wave output. However, this inverter cost is three to four times the modified wave one. Due to cost considerations commercial systems usually use the modified wave inverter with most applications which aren't affected by harmonic distortion like lighting, heating, static instruments as computers and also for light load motors as fans.

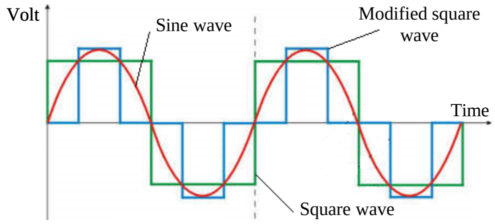


Fig. 3: Sine wave, square wave and modified wave

Programmed wave basic idea: The programmed wave idea is generated from the two previous ideas, the modified square wave and sinusoidal PWM (SPWM). The modified square wave uses one pulse per half cycle with duration less than 180s°, typically 120° duration is used to eliminate the third harmonic component. This operation angle can be applied in single phase or three-phase inverters, however, in case of two-phase inverters it can not be applied using a regular three-leg inverter. And the maximum pulse width in this case is only 90° per half cycle

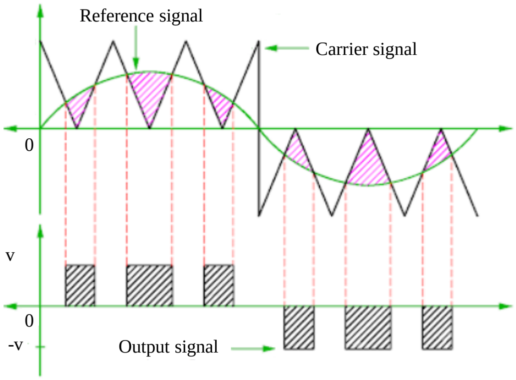


Fig. 4: Sinusoidal pulse width modulation

which will lead to sever harmonic distortion and low output V_{RMS} value. By Godbole and Fadnis (2017) a four leg inverter is introduced to avoid this case, however, the four leg inverter design is not standard and will increase the inverter cost.

On the other hand, true or pure sine wave generated by SPWM technique, depends on comparing two control signals to generate the gate switching signals. The two control signals are called the carrier signal and the reference signal. The carrier signal is a high frequency triangular signal and the reference signal is a sine wave with the required fundamental frequency (50 Hz).

As illustrated in Fig. 4, the number of pluses per half cycle is controlled by the ratio between carrier frequency to reference frequency (f_C/f_R) and the width of each pulse is determined according to the instantaneous reference signal magnitude (Rashid, 2011).

The circuit which is responsible for carrier signal and reference signals generation and comparing them to get the gate switching signals is the cause of sine wave inverter high cost. So, if the required switching pattern is mathematically identified and programmed on a single chip (IC), we will get a low harmonic distortion and low cost inverter design. This task may be done by reverse engineering (comparing sine wave with periodic triangular wave) or you can make your own design and calculate the corresponding harmonic contents until reach the best solution (pattern). To implement this method you can start with 3 pulses per half cycle, 5 pulses per half cycle or 7 pulses per half cycle and so on. Note that one pulse per half cycle is considered a modified square wave technique as mentioned above. Figure 5 illustrates a proposed 7 pulses per half cycle pattern which we use in our project.

Two-phase inverter design: The proposed controller (programmed wave inverter) is consisted of power module and control module. The power module is a regular six MOSFETs or IGBTs power module which is standard and commonly used in three phase inverters. The control module is a simple microcontroller based circuit which contains a microcontroller IC (PIC16F628A) driver IC (7414) six opto-couplers (TLP250) and three voltage isolators (B1212S-1W). The microcontroller single chip is programmed to directly generate the required timing control signals which will be applied to IGBTs gates in order to produce the required wave form via. the power module. These signals are conditioned via. inverter/buffer IC and sent to power module via. opto-coupler/driver ICs.

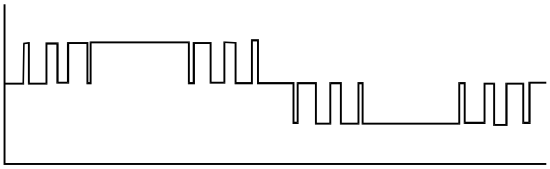


Fig. 5: Programmed wave pattern

The circuit is designed to operate by 12/5 V DC power supply where the 5 V will supply the microcontroller circuit and 12 V to supply opto-coupler isolation circuit. The microcontroller IC (PIC16F628A) has eighteen pins. We will use only six as follows:

Pin 14 is 5 V, pin 5 is 0 V, pin 3 and 4 are input high via. 10 k• resistors and pin 17 and 18 are the outputs. These two outputs are the direct and quadrature signals which are capable of driving the two phase programmed wave inverter. The program which is installed on the microcontroller is written by assembly language. The next stage is the Hex Schmitt-trigger inverter (IC 7414) which will do three functions.

It will generate the complementary signals for the direct and quadrature signals, it is an essential part of dead time circuit and it will drive the opto-coupler circuit without affecting the microprocessor IC, i.e., it will act as a buffer.

After complementary generation the direct and quadrature signals became four signals: direct, complementary direct, quadrature and complementary quadrature signals. These four signals will feed the six IGBT gates as follows:

- Direct signal feeds gate 1 and gate 6
- Complementary direct signal feeds gate 2 and gate 5
- Qadrature signal feeds gate 3
- Complementary quadrature signal feeds gate 4

However, these signals will pass through isolation/driver circuits which are consisted of six opto-isolators ICs TLP250. Each photo-coupler or opto-isolator will transfer one gate signal to one IGBT gate or will drive one IGBT.

For n-channel IGBT and MOSFET switches when gate to source voltage is more than threshold voltage for turn-on, the switch turns on and when it is less than threshold voltage the switch turns off. Usually from 10-20 V DC is used to turn on IGBT or MOSFET, typically, we used 12 V in our project.

Dead time/shoot through protection: The high-side and the low-side switches of a bridge on the same leg should never ever be turned on at the same time. If that happened, you would create a very low resistance path between your power supply and ground. A lot of current will start flowing through your circuit which is called a shoot through and often leads to two MOSFETs burn out typical case. Avoiding shoot through is fairly simple: just make sure that you never close both MOSFETs on the same leg at the same time. Normally in VSI design the two switches of an inverter-leg are controlled in a complementary manner. When the upper switch of any leg is 'on', the corresponding lower switch should remain 'off' and vice-versa.

However, the more serious problem when you turn one MOFET off while turning the other on for a short period both the low and high-side MOSFETs are potentially conducting to a certain degree, creating a relatively low resistance path between supply to ground which is called dynamic shoot through. To prevent this, you have to delay the turn-on of the low-side FET by at least as much as the turn-off time of the high-side FET. The same goes of-course for the other transition when you switch from low-side to the high-side. This technique is called dead time, shoot-through protection or no-overlap. Many modern microcontroller PWM implementations give a programmable no-overlap zone between outputs.

The other option is an external dead time circuit. External dead time circuits uses the R/C circuits to delay the edges of the two outputs and the diodes to make sure only one of the two edges gets delayed. The Schmitt-trigger inverters are needed to clearly define the point where the output switches due to the slow changing of the output of the R/C circuit which is set at 1/3 and 2/3 way between 0 and Vcc value. Figure 6 illustrates the proposed dead-time circuit and its output diagram. Figure 7 illustrates the dead time interval on the oscilloscope. However, such a blanking or dead time can cause problems such as output waveform distortion and fundamental voltage loss in VSI (Chen and Fang, 2007) if its period is more than required.

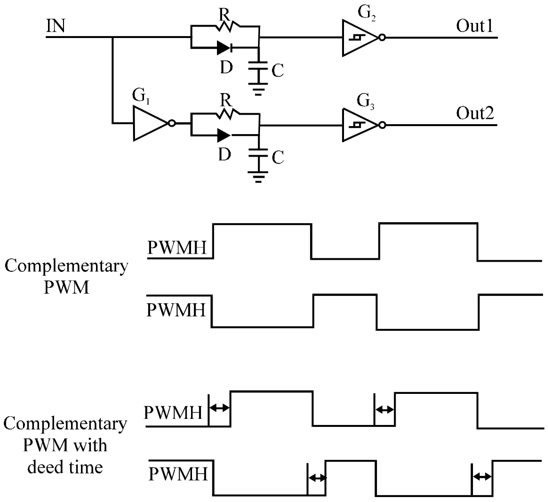


Fig. 6: Dead time circuit and output diagram

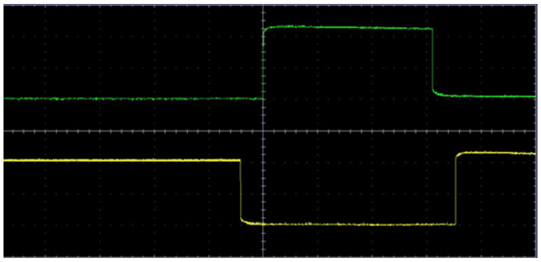
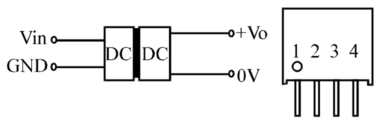


Fig. 7: Dead time between signals on the oscilloscope

Floating power supplies: When a switch is 'on' its emitter and collector terminals are virtually shorted. Thus, with upper switch 'on', the emitter of the upper switch is at positive DC bus potential. Similarly, with lower switch 'on', the emitter of upper switch of that leg is virtually at the negative DC bus potential. Emitters of all the lower switches are solidly connected to the negative line of the DC bus. Since, gate control signals are applied with respect to the emitter terminals of the switches, the gate voltages of all the upper switches must be floating with respect to the DC bus line potentials. This calls for isolation between the gate control signals of upper switches and between upper and lower switches. Only the emitters of lower switches of all the legs are at the same potential (since, all of them are solidly connected to the negative DC bus) and hence the gate control signals of lower switches don't need isolation among themselves. As should be clear from the above discussion, the isolation provided between upper and lower switches must withstand a peak voltage stress equal to DC bus voltage. Gate-signal isolation for inverter switches is generally achieved by means of optical-isolator (opto-isolator) circuits. The circuit on the output side is connected to a floating dc power supply. The control circuit supply ground is isolated from the floating-supply ground of the output. This configuration necessitates four control power supplies, one supply for control circuit in addition to all the lower IGBTs and three individual supplies for the upper IGBTs with proper isolation circuit.

The transformer based power supplies take up a significant weight and space on the control circuit board. Bootstrap power supplies can be used to reduce the number of isolated power supplies or DC to DC converters. This helps to reduce cost and the PCB space as compared to transformer based power supplies. The bootstrap output power supply circuit is used to power the top-bridge gate drives by making use of the inverter operating conditions to store (in a capacitor) and deliver the necessary power charges. The third method is DC/DC converter isolator which we used in our project. A three of the above mentioned IC B1212S-1W are used to get a three floating power supplies for the three upper IGBTs. Figure 8 illustrates the proposed isolator converter.



Footprint details	
Pin	B_s-1w
1	GND
2	Vin
3	0V
4	+Vo

Fig. 8: DC/DC converter or isolator IC

Circuit wiring and output waveforms: Figure 9 illustrates the direct and quadrature timing signals which output from the microcontroller to dead time conditioning circuit. The later outputs four firing signals. As illustrated in Fig. 10, these four signals are the input for the IGBTs driver circuit and the output are six firing signals for the six IGBTs gates. When these signals are transferred to IGBTs gates of switches (S1-S6) of Fig. 2, they will convert the DC input power into two phase AC power on terminals U, V, W. terminal V will be neutral for phases U and W which are shifted by 90°.

These two voltages will be applied to the motor stator windings and generate a rotating magnetic field in the air gap which lead to starting torque production same as three phase motor without any extra equipments. Figure 11 illustrates the direct and quadrature timing signals on the oscilloscope and Fig. 12 illustrates the output voltages waveforms U and W with respect to V on the oscilloscope. This inverter will be cheap and small enough to be integrated with the motor. On the other hand the TPIM torque performance will be better than single phase motor as the two phases now contribute in running torque production and there is no starting problem.

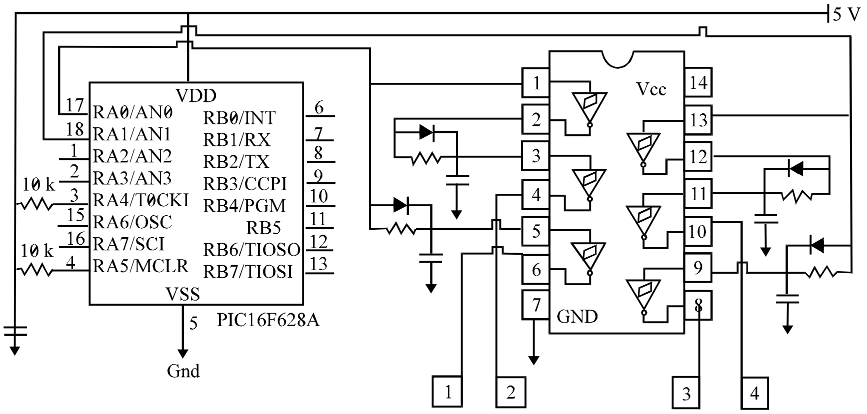


Fig. 9: Micro controller/dead time circuit

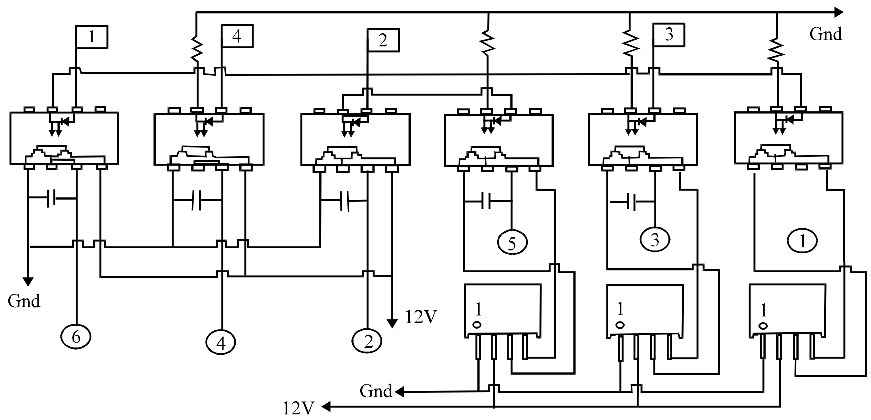


Fig. 10: IGBTs driver circuit

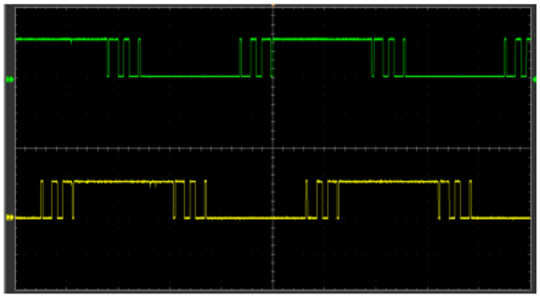


Fig. 11: Direct and quadrature timing signals

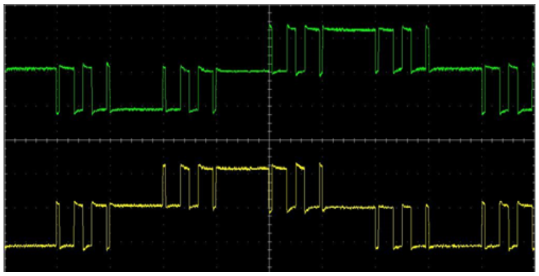


Fig. 12: 2-phase output voltages from the inverter

CONCLUSION

In this study the two-phase induction motor is presented as a solar drive. The drive is based on a novel two-phase programmed wave inverter. The two-phase induction motor has better developed torque than single phase one where the two phases contribute in the running torque production. The proposed programmed wave inverter is an intermediate design between modified square wave and sine wave inverters which collects their advantages. A practical inverter circuit is implemented. To avoid the floating power supplies problem a new DC/DC converter IC is used for ground isolation. The circuit is small enough to be integrated with the motor as a simple solar drive.

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