SPEED CONTROL OF SINGLE PHASE INDUCTION MOTOR USING TRIAC AND DIAC

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ABSTRACT
Most commonly used industrial and domestic appliances are single phase induction motors (SPIMs). More research is going on to improve further on their drives. Because the SPIMs are readily available, various speed control techniques are being proposed. This paper looks into the use of TRIAC to control the speed of single phase induction motor. This method reduces the periodic nature of the input voltage to the motor and increases the motor efficiency. Especially for a single phase induction motors this method provides an easy speed control and most applicable for variable loads as in pump drives, air-conditioners, refrigerators and the like.

Keyword: TRIAC, Firing Angle, Single Phase Induction Motor, Waveforms.

I.0 INTRODUCTION
The single phase induction motors are the most familiar of all electric motors because they are used in home appliances and portable machine tools. In general they are employed when three-phase is not available. The construction is similar to that of the 3-phase induction motors composing of a squirrel cage rotor and the stator that carries the main winding. While basically the rotor is of cage type, some employ auxiliary windings that aid in their self-starting by creating N-S poles. The main winding on the other hand carries a group of four concentric coils, connected in series. The arrangement of these winding and the fluxes thus produced results in the required rotating field and the resultant torque.
As in the case of all 3-phase motors, the synchronous speed of all single phase induction motors is given by the equation:

$$n_s = 120f/p \qquad (1)$$

Where: n_s = synchronous speed
f = frequency of the source
p = no of poles
Practically, the rotor turns at a speed slightly less than the synchronous speed.

2.0 INDUCTION MOTOR
Figure 1 depicts the auxiliary wound single phase induction motor showing lines of fluxes and current at standstill when the main and auxiliary windings are energized. Rotation is anti-clock-wise as indicated in fig. 1. According to Karnika et al (2016), an induction or asynchronous motor is a type of AC motor where power is supplied to the rotor by means of electromagnetic induction, rather than a commutator or slip ring as in other types of motor. Single phase versions are used in small appliances. Their speed is determine by the frequency of supply current, so they are most widely used in constant speed applications, although variable speed versions, using variable frequency drives are becoming more common. The most common type is the squirrel cage motor, and this term is sometimes used for induction motors generally.

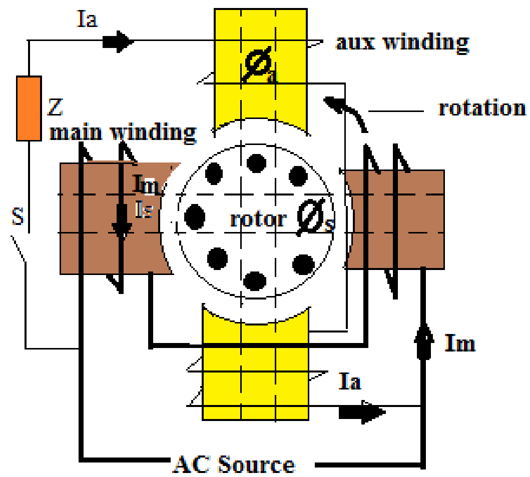


Figure 1: Single phase induction motor showing the main and auxiliary winding.

In both large induction and synchronous motors, the stator is powered by 3-phase alternating current and arranged to create a rotating magnetic field which rotates in time with the supply frequency. Usually to maintain some torque the induction motor the rotor rotates at a slower speed than the stator field. The rotor has winding in the form of copper bars bridged at the ends. The rotating magnetic flux induces current in the winding of the rotor as in a transformer and causes the rotor conductor to experience a force. These current in turn create magnetic fields in the rotor that interact with that of the magnetic field created the stator. The resultant produces a torque which force is in the direction of the rotating stator magnetic field and the speed of the rotor increases reaching the synchronous speed. Because no more emf is induced in the rotor at synchronous speed, the rotor speed drops below it. According to Karnika et al (2016), as the speed of the rotor drops below synchronous speed, the rotation rate of magnetic field in the rotor increases, inducing more current in the windings and creating more torque. The ratio between the rotation rate of magnetic field as seen by the rotor (slip speed) and the rotation rate of stator's rotating field is called *"slip"*. This slip increases as the load increases and the speed drops. The resultant is a sufficient torque that turns the motor on such load. For this reason, induction motors are sometimes referred to as asynchronous motor. An induction motor can be used as induction generator, or it can be unrolled to form the linear induction motor which can directly generate linear motion. Generally, induction motors are categorized based on the number of stator windings. They are Single-phase induction motor and Three-phase induction motor.

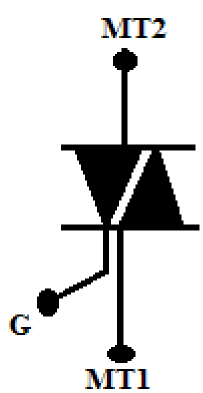
According to Kavya et al (2016), by the improvement of the power electronics devices, the flow of power to the motor is controlled by the switching action of the power switches (MOSFET, TRIAC, IGBT, etc). The nature of the speed control requirement for an industrial drive depends upon its type. Some drives may require continuous variation of speed throughout the operation, which ranges from zero to full speed, or over a portion of the range. For most of the drives, however a control of speed within the range of ±10% of rated speed may be suitable. Kavya et al, stated that the existing methods for the speed control of induction motor are voltage control, frequency control, vector control, changing stator poles, rotor resistance, doubly fed motor, Kramer circuit etc. The characteristics of a single phase induction motor are identical to three phase induction motor except that single phase induction motor has no inherent starting torque and some special arrangement have to be made for making it self-starting.

2.1 THE TRIAC

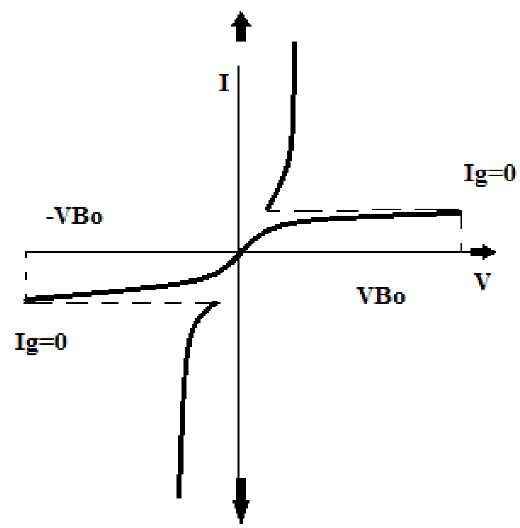
The Triac as defined by Kharagpur (online) is a member of the thyristor family. But unlike a thyristor which conducts only in one direction (from anode to cathode), a triac can conduct in both directions. Thus a triac is similar to two back to back (anti parallel) connected thyristors but with only three terminals. As in the case of a thyristor, the conduction of a triac is initiated by injecting a current pulse into the gate terminal. The gate loses control over conduction once the triac is turned on. The triac turns off only when the current through the main terminals become zero. They are extensively used in residential lamp dimmers, heater control and for speed control of small single phase series and induction motors.

2.2 CONSTRUCTION AND OPERATING PRINCIPLE

Fig. 2: shows the symbol and the voltage – current characteristic of a triac respectively.
The three terminals are marked as MT_1 (Main Terminal 1), MT_2 (Main Terminal 2) and the gate by G. a TRIAC can conduct in both directions and is normally used in AC phase control. [Kavya (2016)]. It can be considered as two SCRs connected in antiparallel with a common gate connection as shown in Figure 2. Because of the bidirectional characteristic of a TRIAC, its terminals cannot be designated as anode and cathode and it can be used for controlling the power in AC load.



(a)



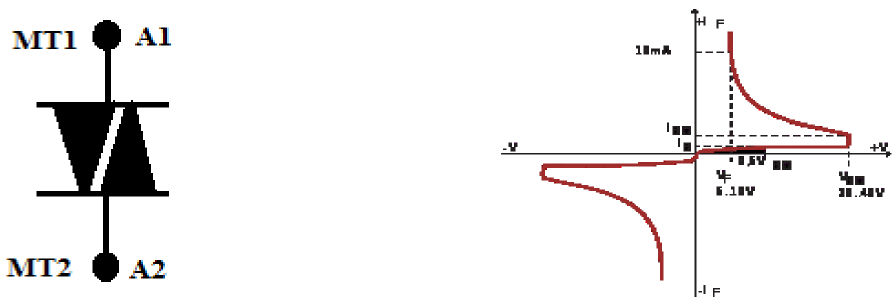
(b)

Figure 2: TRIAC symbol (a) and (b) V-I characteristic of a triac

If terminal MT2 is positive with respect to terminal MT1, the TRIAC can be turn on by applying a positive gate signal between gate G and terminal MT1. If terminal MT2 is negative with respect to terminal MT1, it is turned on by applying a negative gate signal between gate G and terminal MT1. It is not necessary to have both polarities of gate signals, and the TRIAC can be turned on with either a positive or a negative gate signal. In practice, the sensitivities vary from one quadrant to another, and the TRIACs are normally operated in quadrant I+ (positive gate voltage and gate current) or quadrant III- (negative gate voltage and gate current).

2.3 DIAC

DIACs are also called symmetrical trigger diodes due to the symmetry of their characteristic curve, because DIACs are bidirectional devices, their terminals are not labeled as anode and cathode but
as A1 and A2 or main terminal MT1 and MT2.



(a) (b)

Fig 3: (a) Symbol and (b) Characteristics of DIAC

2.4 TRIAC SWITCHING AND GATE TRIGGER CIRCUIT

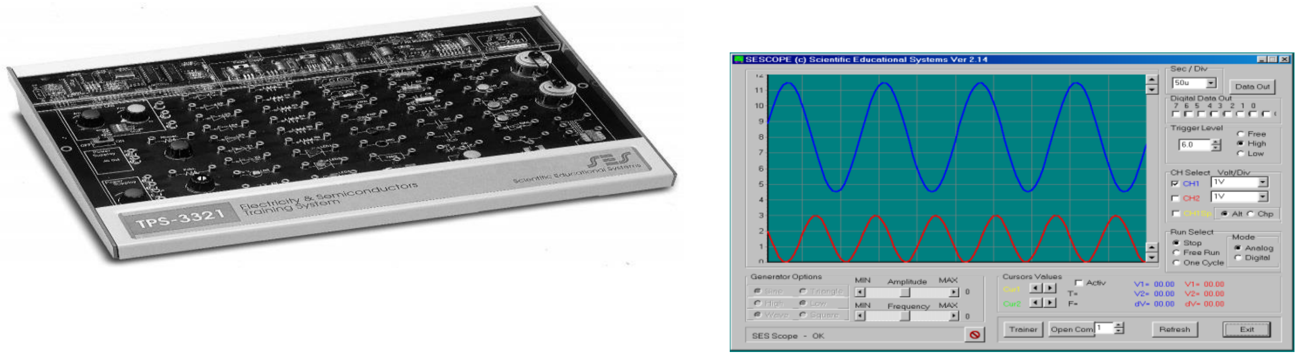
The triac has smaller time duration to turn off due to its bidirectional conduction. As a result the triacs are operated only at power frequency. Switching characteristics of a triac is similar to that of a thyristor. However, turn off of a triac is extremely sensitive to temperature variation and may not turn off at all if the junction temperature exceeds certain limit.[Kharnika et al].
The triac should be triggered carefully to ensure safe operation. For phase control application, the triac is switched on and off in synchronism with the mains supply so that only a part of each half cycle is applied across the load. To ensure 'clean turn ON' the trigger signal must rise rapidly to provide the necessary charge. A rise time of about 1 μs will be desirable. Such a triac gate triggering circuit using a "diac" and an R-C timing network is shown in Fig 5.

3.0 EXPERIMENT

Equipment Required:

We have set up an experiment using the TPS-3321 Scientific Education System (SES) which incorporates among other components a DC and AC supply voltages, motor, generator (dynamo), diac and triacs. The TPS is also connected to a PC aided SESSCOPE software and the waveforms seen on a monitor.

- TPS-3321
- Power supply
- Banana wires



(a) (b)

Figure 4: (a) TPS-3321 (b) SESLAB displaying 2-chanell SESCOPE waveforms

3.1 Circuit Diagram

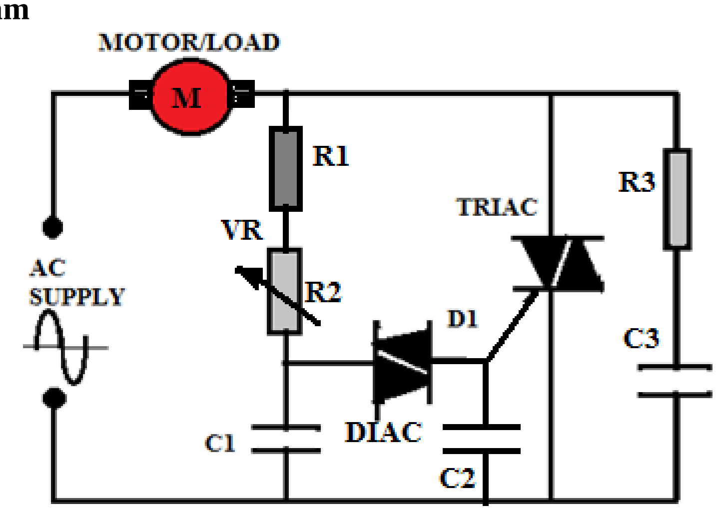


Fig. 5: Triac triggering circuit using a diac.

Figure 5 depicts the speed control circuit of a single phase induction motor using the triac in addition to a diac. With the increase of the input voltage magnitude, the voltage across C1 increases and consequently the voltage across Di increases until it reaches break over voltage. A large current pulse from the diac then triggers the triac at its gate terminal. Variable resistor R2 is used to control the firing from virtually zero to 100%. According to Karnika et al (2016), when pulse to gate are delayed then reduced voltage is applied to the induction motor stator terminals and thus as voltage and torque are proportional to each other torque decreases and simultaneously speed of the motor gets reduced.

According to Arieh, before igniting the triac, a very low current flows at the load and all the source voltage drops on the double RC filter. This voltage is divided and moves at the supply frequency. When gate voltage Vg passes the ignition voltage, the triac ignites and conduct until the input voltage half cycle is finished. When the input voltage drops to 0V, the triac is shut down and the ignition procedure is repeated in inverted half-cycle. The potentiometer VR reduces the wave power at the gate and the ignition angle, thus reducing the average current in the load. In other words. The triac can be used to reduce power wastage in a load.
To increase the triac ignition voltage we use in addition a component called diac. Adding a diac to the triac gate increases substantially the ignition voltage of the triac and thus enables a much better power control at higher voltages. According to Arieh, a coal potentiometer is not designated for high voltages. When the potentiometer is set to a very low resistance (almost a short circuit), a relatively high current flows, which causes the potentiometer to heat up. Therefore, resistor R_1 is included to prevent this low resistance state.

(a) (b) (c) (d)

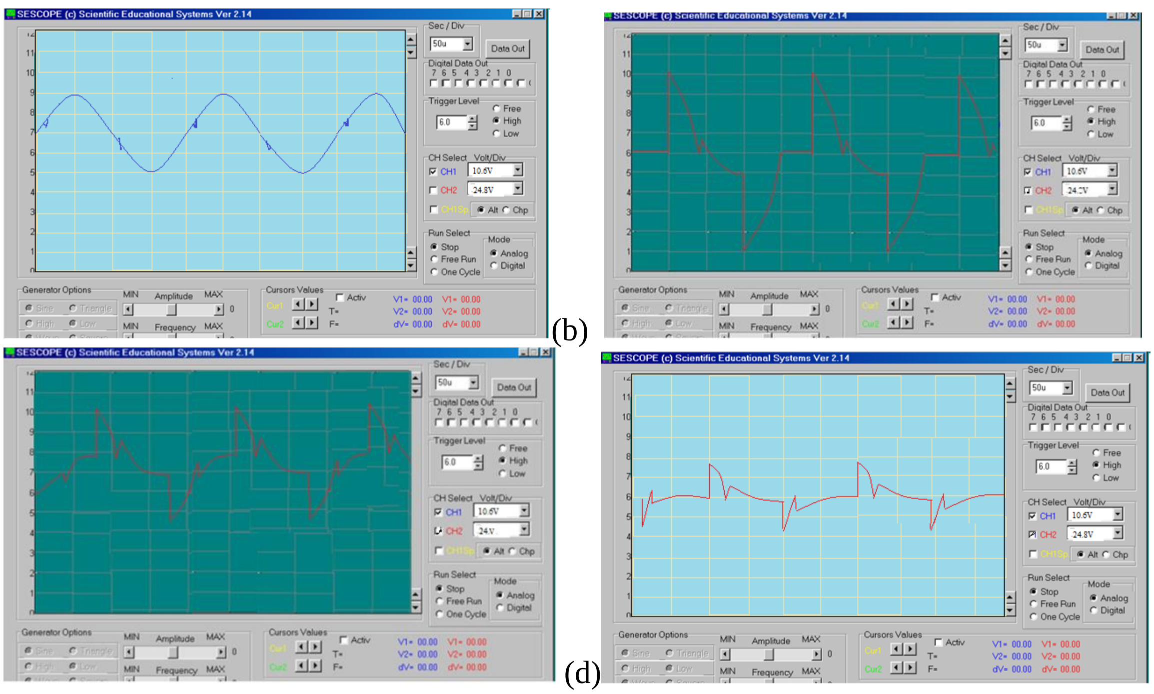


Figure 6: (a) plot between Voltage and Time at angle α 32.3°; (b) α = 127.30°; (c) α =182.4°; (d) α = 212.9°

3.2 Speed Measurement

We connected the electrical output from the dynamo (the second motor in the module that we coupled to the controlled motor) to a voltmeter. The dynamo supplies voltage proportional to its rate of rotation or in other words proportional to the speed of the motor being driven by the circuit. So we inferred the voltmeter reading as speed. Therefore, by varying the triac firing angle, we were able to regulate the speed of the motor.

Table 1: Result of varying output voltage and firing angle with input supply kept constant.
Table 2: Result of motor speed corresponding to different firing angle.

Table 1

S/.No	Input voltage (V)	Output voltage (V)	Firing angle (α) in deg.
1.	24	20	32.3
2.	24	18.2	127.3
3.	24	16.6	182.4
4.	24	14.5	212.9

Table 2

S/.No	Firing angle (α) in deg.	Speed (RPM) (inferred)
1.	32.3	20
2.	127.3	18.2
3.	182.4	16.6
4.	212.9	14.5

CONCLUSION

Both tables show that the speed of the motor is maximum when the firing angle is minimum. Though the experiment was a very clumsy one it actually show the activeness of the triac and diac in such speed control circuit.

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