CONTROL OF AIR FLOW RATE OF SINGLE PHASE INDUCTION MOTOR FOR BLOWER APPLICATION USING V/F METHOD

Atul M. Gajare¹, Nitin R. Bhasme²
¹PG Student, ²Associate Professor,
Department of Electrical Engineering,
Government College of Engineering, Aurangabad, India.

ABSTRACT
This paper describes the control scheme of air flow rate of single phase induction motor (SPIM) with blower application including variable voltage and variable frequency control, its implementation and test result. This scheme is developed using PWM (Pulse Width Modulation) control circuit, driver circuit and H-bridge inverter circuit. The PWM control circuit is implemented by using the SG3525A PWM IC, driver circuit, gate logic circuit, and also using BC547 transistor. Here, IC SG3525A is used as pulse width modulation IC for frequency control purpose. For proposed system the operating frequency range is 25 to 71 Hz at variable voltage and constant voltage for changing the speed of induction motor.

In this paper, Vf scheme controlling the air flow rate of blower to change the speed of single phase induction motor blower drive. The hardware is implemented using PWM control circuit, driver circuit and H-Bridge inverter. The experimental tests are conducted on this drive which produces the alternating current to feed the SPIM. The practical result is verified using the above control scheme as presented in this paper.

KEYWORDS: Pulse Width Modulation (PWM) control circuit, driver circuit, H - Bridge inverter and single phase induction motor (SPIM), blower, variable voltage - variable frequency control circuit.

I. INTRODUCTION
Most of the drives in industrial applications require speed control at various stages of production. Depending upon the various applications, some of the systems may be operating on variable voltage and variable frequency control or at a constant and variable speed application. Induction motors are widely used in many commercial, residential, industrial and many other utility applications. Single-phase induction motors (SPIM) is widely used in home appliances and industrial control. Conventional air conditioner, ventilators, furnaces and heating systems for residential and industrial application, are using single phase induction motor with blower to regulate air flow. The outlet air from blower move vary with changing the speed of single phase motor operates at variable voltage and variable frequency, so its speed varies with speed of blower blade. The air flow rate controlled by V/F scheme implemented in low cost PWM circuit, H-bridge inverter [1].

Most of variable-frequency drive (VFD) is used for controlling the speed of a rotational or linear alternating current (AC) electric motor by controlling the frequency of the electrical power supplied to the motor. A variable frequency drive is a specific type of adjustable-speed drive. Hence they are also known as adjustable-frequency drives (AFD), variable-speed drives (VSD) or AC drives. The multispeed operation and multipurpose operation are provided by controlling the speed of these motors [2].

In early days, the variable speed drives had various limitations such as larger space, poor efficiencies, lower speed, etc. But, now with new techniques and invention in power electronics semiconductor devices has changed the situation. So now, variable speed drive is constructed in smaller size, high efficiency and high reliability [3]. One of mostly control scheme is variable voltage - variable frequency. With this method one can control speed of motor working under any circumstances.
Therefore, adjustable frequency and adjustable voltage of power is more flexible it can be economical operation of industrial and household appliances [4].

In this paper, variable frequency drive is implemented using permanent split capacitor run single phase induction type along with blower motor. The present paper analyzes the performance characteristics of SPIM (torque, speed, current, frequency, slip, air pressure of blower, etc.) when the drives are operated.

This paper explains the basic concept of speed control using V/f ratio control by changing the air flow rate of blower. Here, SPIM has been controlled by V/f ratio using variable voltage, variable frequency control method by using PWM control circuit and H-bridge inverter which produces the alternating current to feed the SPIM.

In section II, speed control of single phase induction motor and concept of V/f method are explained. The V/f controlling and hardware system described in Section III. The section IV, performance analysis results are obtained in present strategy. Finally, the paper is concluded in section V.

II. SPEED CONTROL OF SPIM

The working principle of single phase induction motor is based on the double revolving theory or cross field theory. The single phase induction motor is distributed winding is displaced by 90° namely auxiliary winding and main winding. The capacitor is connected in series with auxiliary winding.

There are two speed terms are synchronous speed and rated speed used in the electric machine. Synchronous speed is the motor’s theoretical speed if there was no load on the shaft and friction in the bearings. The two factors affecting synchronous speed are the frequency of the electrical supply and the number of magnetic poles in the stator [5]. The synchronous speed equation 1 is given by,

\[ N_s = \frac{120f}{p} \]  

Where,

\( f = \) Frequency in Hz  
\( p = \) Number of Poles

The rotor speed of an Induction machine is different from the speed of Rotating magnetic field. The shaft speed (rotor speed) of induction motor when driving load will always be less than the synchronous speed. The percent difference in synchronous speed and shaft speed is called slip as shown in equation 2.

\[ S = \frac{N_s - N_r}{N_s} \]  

\( N_s = \) Synchronous speed  
\( N_r = \) Rotor speed

The synchronous speed of induction motor is directly proportional to the frequency and inversely proportional to the number of poles of the motor from the equation 3.Since the number of poles is fixed by design, the best way to vary the speed of the induction motor is by varying the supply frequency [2].

\[ N_s \alpha \frac{f}{p} \]  

The speed of the motor shaft with rated voltage and line frequency applied at full load is so called base speed. By changing the frequency to the motor above or below frequency; the motor can operate above or below base speed.

The relationships between the applied voltage (V), frequency (f) and torque (T) of the motor are represented by below equation 4.

\[ \text{Torque}(T) = \frac{\text{Voltage}(v)}{\text{Frequency}(f)} \cdot I \]  

1) When the ratio of V/f is constant, the torque is constant.
2) When the voltage (V) is constant and only the frequency (f) varies, the torque is inversely proportional to the frequency if the motor current is constant.
Relationships between the voltage and torque to the frequency are shown in Figure 1. The relationship between the output voltage and output frequency of an inverter is called the "V/f pattern" which is an important factor in controlling a motor.

![Graph showing relationships between voltage, torque, and frequency](image)

**Figure 1.** Speed-torque characteristics by V/f control

### 1.1 Concept of V/f Ratio

This theory or term it can be describes a relationship that is fundamental to the operation of motors using adjustable frequency control. An ac induction motor produces torque by virtue of the flux in its rotating field. Keeping the flux constant will enable the motor to produce full load torque. Below base speed, this is accomplished by maintaining a constant voltage-to-frequency ratio applied to the motor when changing the frequency for speed control. For 460 and 230 Volt motors, the ratio is $460/60 = 7.6$ and $230/60 = 3.8$. If this ratio increases as the frequency is decreased to reduce the motor speed, the motor current will increase and may become excessive. If it reduces as the frequency is increased, the motor torque capabilities will decrease. There are some exceptions to this rule which are described below.

The base speed of the motor is proportional to supply frequency and is inversely proportional to the number of poles. So, by changing the supply frequency, the motor speed can be changed. Above base speed, this ratio will decrease when constant voltage (usually motor rated voltage) is applied to the motor. In these cases, the torque capabilities of the motor decrease above base speed. At approximately 30 Hertz and lower, the Volts-per-Hertz ratio is not always maintained constant. Depending on the type of load, the voltage may be increased to give a higher ratio, in order for the motor to produce sufficient torque, especially at zero speed. This adjustment is usually called "Voltage Boost" [2].

At base speed and below, the Volts-per-Hertz ratio can be adjusted lower to minimize motor current when the motor is lightly loaded. This adjustment, which lowers the voltage to the motor, will reduce the magnetizing current to the motor. Consequently, the motor will produce less torque which is tolerable. This control is the most popular in industries and is popularly known as the constant V/f control.

### III. SYSTEM DEVELOPMENT DESCRIPTION

#### 3.1 Implementation for V/f Control of SPIM

The block diagram design considerations for speed control system using variable voltage and frequency control have been divided into PWM control circuit, AND gate driver circuit, opto isolator signal amplifier circuit and H-Bridge inverter is shown in figure 2. Variable speed drive by using variable voltage and frequency control method is commonly used to control and change the speed of the single-phase induction motor. It can vary the desired speed by changing the V/f ratio using the variable resistance. Due to compact integrated circuit, low cost high performance speed control is obtained. In this project, two separate power supplies has been used which is 300 V DC and 12 V DC.
The 300 V DC is used to feed to H-bridge inverter while 12 V DC is used in PWM control circuit and driver circuit as shown in Figure 2.

3.2. H-Bridge inverter using MOSFET

The inverter, also known as DC to AC converter, converts dc power to ac power at desired output voltage and frequency. An H-Bridge or full bridge converter is a switching configuration composed of four switches in an arrangement that resembles an H. By controlling different switches in the bridge, a positive, negative, or zero potential voltage can be placed across a load. The H-Bridge configuration implemented using four MOSFET IRF840 N channel. Its arrangements as shown below figure 3.

The device pair M1-M4 and M2-M3 is switched alternatively. Only two MOSFET are able to switch ON and OFF at the same time. The driver circuit fed to the triggering pulses for four MOSFET’s it will turn ON and OFF continuously. The operation of this inverter is explained as below:

1) M1-M3 ON: Both create short circuits across the DC source and are invalid.
2) M2-M4 ON: Both create short circuits across the DC source and are invalid.
3) M1-M4 ON: Applies positive voltage to the load. The positive current passes through M1-M4 and the negative current is through D1-D4.
4) M2-M3 ON: Applies negative voltage across the load. The positive current flows through D2-D3 and returns energy to the DC source. The negative current flows through M2-M3 and draws energy from the supply.
5) M1-M2 ON: Applies zero volts across the load. The positive current’s path is M1-M2 and the negative current’s path is D1 – M2.
6) M3 - M4 ON: Applies zero volts across the load. The positive current’s path is through D3 – D4 and the negative current’s path is M3 - M4.

### 3.3. Controller circuit using PWM SG3525 IC

Pulse width modulation use technology and use sophisticated power electronics to accomplish the same Frequency and voltage control. The pin configuration of controller as shown below figure 4.

![Figure 4. Pin Configuration of Controller](image)

The switching frequency used in this project is 25 to 71 Hz. It is desired to control the inverter with proper switching signals. The turn on and turn off time of the switches is determined by this PWM control signal generated by the 3525A IC controller. The turn ON and OFF for M1 and M3 are controlled by PWM A generated at pin 11. While the turn ON and OFF for M2 and M4 are controlled by PWM B generated at pin 14. Both PWM A and PWM B use the same control signal generated by the IC. It produces PWM pulses which are provided to the MOSFET switches such that the MOSFET gates can be triggered ON and OFF. This is responsible for generating oscillating signals that controls the ON and OFF action of the MOSFET switches. The control circuit as a whole is made with a SG3525A PWM IC and combination of some passive components. The oscillation from its output pins is controlled by a timing resistor and capacitor connected to pins 5 and 6 terminal of the IC. The SG3525A is a 16-pin device and included in it are all the control necessary for PWM. They include reference an error amplifier, voltage regulator, an oscillator, a comparator, under-voltage lockout, soft start circuit, and output drivers. The PWM controller circuit IC design is easy, more reliable and requires less components.

### IV. PERFORMANCE TEST AND ANALYTICAL RESULT

The output of PWM pulses are used to trigger the power MOSFET switches. Figure 5 shows the square wave as a result of PWM.
Here, the turn on and turn off time of the power MOSFET switches are controlled by PWM control signal shown in the figure 5 above. Power MOSFET switches are denoted by transistor M1, M2, M3 and M4 out of which M1 and M3 are controlled by PWM A generated at pin 11. Whereas M2 and M4 are controlled by PWM B generated at pin 14 of SG3225IC. The result timing wave form for M1, M3 and M2, M4 are shown in figure 6 and 7 respectively.

The output result of H-Bridge inerter across of the load is shown in figure 8 when driving fractional horse power single phase induction motor inductive load is connected.
Figure 8. Output result of H-Bridge Inverter across of the Load.

The performance test and results of variable frequency drive of single phase induction motor (SPIM) are expressed as below table 1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply voltage</td>
<td>220 volts</td>
</tr>
<tr>
<td>Supply frequency</td>
<td>50 Hz</td>
</tr>
<tr>
<td>Motor rating</td>
<td>0.18 hp (0.134kw)</td>
</tr>
<tr>
<td>Normal speed</td>
<td>2800 rpm</td>
</tr>
<tr>
<td>No. of pole</td>
<td>2</td>
</tr>
<tr>
<td>Maximum frequency</td>
<td>71 Hz</td>
</tr>
<tr>
<td>Minimum frequency</td>
<td>25 Hz</td>
</tr>
<tr>
<td>Maximum speed</td>
<td>3510 rpm</td>
</tr>
<tr>
<td>Minimum speed</td>
<td>1440 rpm</td>
</tr>
<tr>
<td>Aux. Winding</td>
<td>71.0 Ω</td>
</tr>
<tr>
<td>Main Winding</td>
<td>70.0 Ω</td>
</tr>
</tbody>
</table>

Speed up test of variable frequency drive of single phase induction motor (SPIM).

<table>
<thead>
<tr>
<th>Volt.</th>
<th>Time base (10ms)</th>
<th>Freq. (Hz)</th>
<th>Speed (rpm)</th>
<th>Current (Amp.)</th>
<th>Torque N-m</th>
<th>Air Flow (CMM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>230</td>
<td>4.0</td>
<td>25</td>
<td>1480</td>
<td>0.6</td>
<td>0.86</td>
<td>527</td>
</tr>
<tr>
<td>230</td>
<td>3.4</td>
<td>29</td>
<td>1550</td>
<td>0.6</td>
<td>0.82</td>
<td>556</td>
</tr>
<tr>
<td>230</td>
<td>3.0</td>
<td>33</td>
<td>1780</td>
<td>0.6</td>
<td>0.71</td>
<td>600</td>
</tr>
<tr>
<td>230</td>
<td>2.8</td>
<td>35</td>
<td>2090</td>
<td>0.5</td>
<td>0.61</td>
<td>778</td>
</tr>
<tr>
<td>230</td>
<td>2.0</td>
<td>50</td>
<td>2740</td>
<td>0.4</td>
<td>0.46</td>
<td>998</td>
</tr>
<tr>
<td>230</td>
<td>1.8</td>
<td>55</td>
<td>3040</td>
<td>0.3</td>
<td>0.42</td>
<td>1130</td>
</tr>
<tr>
<td>230</td>
<td>1.4</td>
<td>71</td>
<td>3510</td>
<td>0.3</td>
<td>0.36</td>
<td>1227</td>
</tr>
</tbody>
</table>

Table 2. Practical Result of system at constant voltage and variable frequency

<table>
<thead>
<tr>
<th>Volt.</th>
<th>Time base (10ms)</th>
<th>Freq. (Hz)</th>
<th>Speed (rpm)</th>
<th>Current (Amp.)</th>
<th>Torque N-m</th>
<th>Air Flow (CMM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>110</td>
<td>4.0</td>
<td>25</td>
<td>1440</td>
<td>0.3</td>
<td>0.89</td>
<td>445</td>
</tr>
<tr>
<td>130</td>
<td>3.9</td>
<td>26</td>
<td>1470</td>
<td>0.3</td>
<td>0.87</td>
<td>478</td>
</tr>
<tr>
<td>150</td>
<td>3.4</td>
<td>29</td>
<td>1520</td>
<td>0.3</td>
<td>0.84</td>
<td>500</td>
</tr>
<tr>
<td>195</td>
<td>2.8</td>
<td>35</td>
<td>1955</td>
<td>0.4</td>
<td>0.65</td>
<td>655</td>
</tr>
<tr>
<td>210</td>
<td>2</td>
<td>50</td>
<td>2290</td>
<td>0.4</td>
<td>0.55</td>
<td>768</td>
</tr>
<tr>
<td>230</td>
<td>2</td>
<td>50</td>
<td>2730</td>
<td>0.4</td>
<td>0.46</td>
<td>820</td>
</tr>
<tr>
<td>230</td>
<td>1.4</td>
<td>71</td>
<td>3510</td>
<td>0.4</td>
<td>0.36</td>
<td>1195</td>
</tr>
</tbody>
</table>

Table 3. Practical Result of system at variable voltage and variable frequency
The experimental results are divided into two parts. The first part, which is shown in Table 2, shows the behavior of the machine when the torque and current is reduced, while changing the frequency with constant voltage. The table 3 shows decreasing the torque and quite raised current by varying the V/F.

Figure 9. Experimental results of the V/f control method for motor speed under different frequencies

In the figure 9 speeds gradually increases by varying the frequency from 25 Hz to 71 Hz. But, in figure 10 when the speed is above the base speed, with increasing frequency the current decreases because frequency is inversely proportional to magnetic flux (See Equation 5).

\[ \text{magnetic flux}(\phi) \propto \frac{\text{Voltage}(v)}{\text{Frequency}(f)} = \text{constant} \]  

(5)

Figure 10. Frequency-Current Characteristics of SIPM with constant voltage, variable frequency

Note that from the relation in the equation 4 the behavior of the motor is described as frequency increases, torque decrease. From the above characteristics it can also concluded that at the starting period as the frequency increases current remains constant for some period and then current decreases with increase in frequency. This can be justified by table 2. It also shows the magnetic flux is inversely proportional to frequency (See Equation 5).

The next figure 11 is obtained for constant voltage variable frequency. By means of torque is inversely proportional to frequency from the equation 4 and also this can be justified by table 2.
Similarly, the next figure 12 of voltage - torque characteristics is obtained for various frequencies, variable voltages. But in this experimental result changing the V/F method, the current will gradually increase up to the still constant rated current as shown in given figure 13.
Figure 14. Frequency–Airflow and speed Characteristics of SIPM with Constant voltage, variable frequency

From the above figure 14 air flow rate is linearly increases with the frequency, blower fan speed also changes. Volume of blower air flow at can be described by the equation below

\[ Q \alpha N \]  

Where,

\( Q \) – Air flow rate  
\( N \) - Motor Speed  

In the figure 15 variations in air flow with respect to voltage at variable frequency is shown. Comparing the both characteristics in figure 14 and figure 15 yields slow increase in air flow at constant voltage and variable frequency (In Figure 14) as compared to that of at variable frequency and voltage(In figure 15).

Figure 15. Voltage – Airflow Characteristics of SIPM with Variable Voltage, Variable frequency

V. CONCLUSION

The SPIM can be successively driven by the variable voltage, variable frequency or changing the V/F ratio. Using V/f technique, the speed can be easily and smoothly adjusted. Single phase induction motor with air flow rate control of blower for domestic application is developed and presented in this paper using with variable voltage variable frequency (VVF) or V/f. From the experimental results, the air flow rate can be changed or made constant at desired frequency for various applications.

The inverter is compacted by reducing the H-bridge inverter. The open loop PWM control circuit is used to control the V/F ratio. The variable speed drive with variable frequency control method will offer new, low-cost solutions for light commercial and consumer applications. The frequency range of the constructed circuit is 25 Hz to 71 Hz at variable voltage and constant voltage for changing the speed of SPIM between speed 1440 rpm to 3510 rpm for smooth operation of blower in various domestic application.
REFERENCE


AUTHOR

Atul M. Gajare received the B. Engg. Degree in Electrical Engineering from North Maharashtra University, Jalgaon, India in 2004. He is pursuing M.E. (Electrical Machine and Drives) from Government College of Engineering, Aurangabad, Maharashtra.

N. R. Bhasme is working as an Associate Professor in Electrical Engineering at Government College of Engineering, Aurangabad-India since 1998. His research area is related to Electrical Drives, Power Electronics and Renewable Energy Technologies. He is associated with various activities in engineering field at national level.