Soft Start High Frequency Switched Variable Voltage Controlled Induction Motor Drive

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Abstract- Three phase VVVF drives are widely used for softstart and speed control purpose of three phase induction motor. Phase angle voltage controlled technique is implied for soft start of induction motor however it suffers from disadvantage of retardation of the firing angle which causes lagging power factor at the input side especially at lower speed. This paper presents, a new variable voltage control technique which uses only four high frequency PWM controllable switches. This method will be suitable for fan, pump or blower load coupled to a three phase induction motor. The advantages of proposed method are its high power factor, high efficiency and ease of control.

Keywords- *A variable voltage control scheme, High frequency PWM pulses, high power factor, three phase induction motor, VVVF drive.*

I. INTRODUCTION

Three phase Induction motor is most widely used in industries than other machines due to their advantages such as simplicity in construction, reliability in operation, and cheapness. The speed control of such motors can be achieved by controlling the applied voltage on the motor by the use of power electronic devices [1]. AC voltage controllers as power converters are also used as induction motor soft starter. But this suffers from several disadvantages such as retardation of firing angle, poor input power factor, complex control techniques and large no of switches.[2-3]

Three phase squirrel cage induction motors are used for fans, blowers and pumps coupled to induction motor in industries. Three phase VVVF drives are used for speed control of such motors but the controlled techniques used in VVVF drive is complex and costly [2-3]. A variable voltage control scheme is proposed in this paper employing with four high frequency PWM controllable switches instead of using six switches. The smooth starting and speed control of induction motor is possible with high efficiency and high power factor. The advantages of proposed scheme are high input power factor, high converter efficiency and only four number of controlled power semiconductor switches. The control technique is based on high frequency PWM technique which is more efficient and simpler to implement as compare to control techniques used in VVVF drive usually used and any other induction motor control techniques.

II. CIRCUIT DESCRIPTION AND PRINCIPLE OF OPERATION

A. *Circuit Description*

Fig 1.Shows the power circuit diagram of the proposed scheme. It consist of main power semiconductor controlled switch S_1 connected with three phase stator winding through a 3phase diode bridge rectifier. Three auxiliary switches S_2 , S_3 , S_4 connected in parallel with each stator winding respectively. Switches S_2 , S_3 , S_4 provides the freewheeling path.

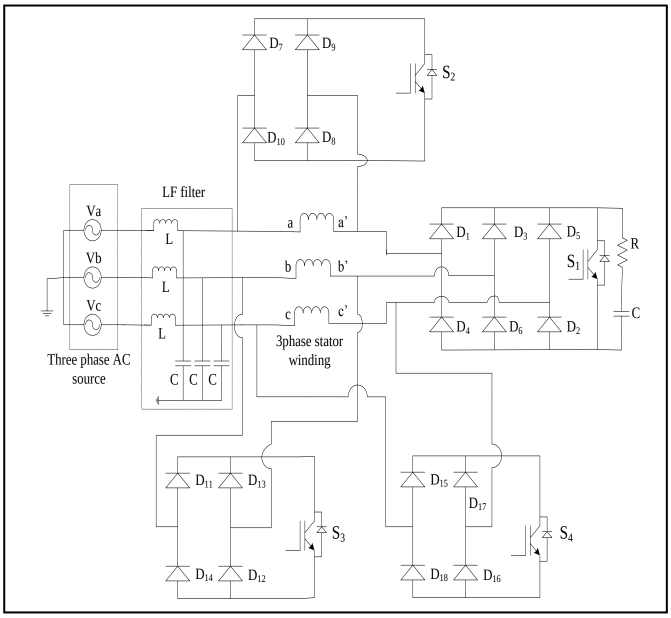

Figure 1. Power circuit of proposed scheme

The main power semiconductor controlled switch S_1 is used periodically to connect and disconnect the stator terminals to the ac source to regulate the power delivered to the motor. The parallel freewheeling switches S_2 , S_3 , S_4 provides a freewheeling path for the load current to discharge its stored energy when the forward main switch S_1 is turned off.

B. *Principle of operation*

The operation modes are divided into three modes active, dead time and freewheeling modes. The load current conducts through the input and output sides , providing energy to the load during the active mode, freewheels through the parallel switch during the freewheeling mode and by-passes during the dead time mode.

a) Active operating Mode

The active mode is corresponding to the onstate periods of the active main switch s_1 and during this mode the auxiliary freewheeling switches s_2 s_3 s_4 are OFF. When switch s_1 is made ON, the current flows from 3 phase supply to the 3 stator terminal through switch and diode bridge as shown in figure 2(a). The supply voltage appears across the terminals of the stator winding and the stator is connected in star.

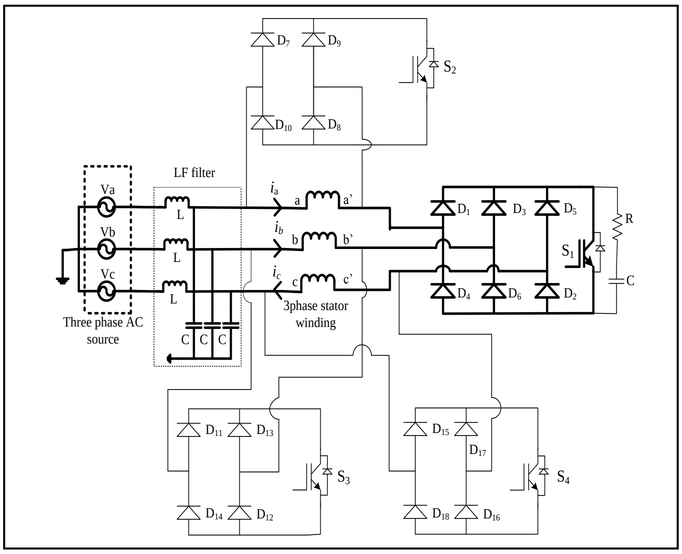

Figure 2(a). Active operating mode

b) Dead Time Mode

Dead time td is requisite to avoid current spikes arising from use of practical non-ideal switches and at the same time a current path of the motor current has to be provided to avoid voltage spikes.

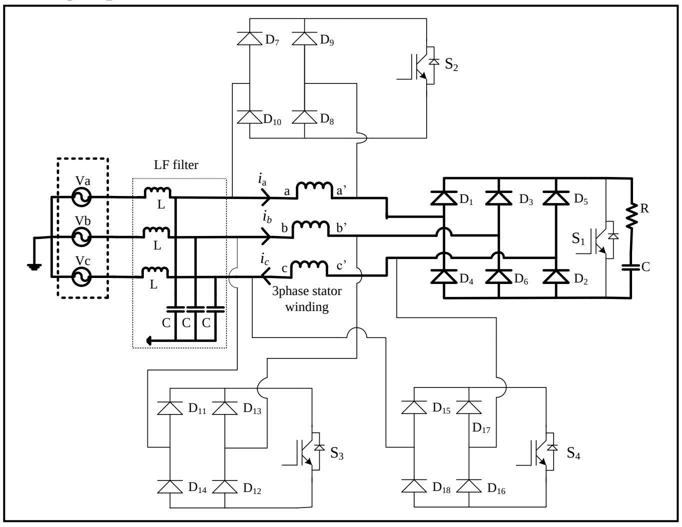

Figure 2(b). Dead time mode

Thus the dead time and the use of snubber circuits are necessary for safe commutation. During the dead time mode all the switches are turned off and the stator current flows through the by-pass capacitors C for very short time as shown in fig 2(b)

c) Freewheeling operating Mode

When switch s_2 s_3 s_4 are turned ON, the three stator currents will naturally decay through diode bridge rectifier and three freewheeling switches s_2 , s_3 , s_4 as shown in fig 2(c).

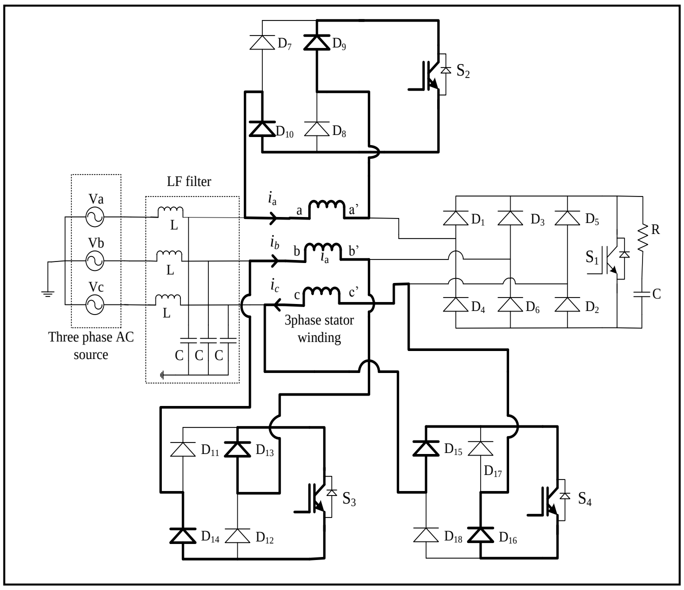

Figure 2(c). Freewheeling operating mode

During Mode III, switches s_2 , s_3 and s_4 simultaneously will be turned OFF before switch s_1 is again turned ON. The input line current and output voltage during this mode will be zero.

III. Analysis Of Proposed Scheme

This section deals with the operation of proposed scheme with three phase balanced supply. The three phase balanced supply voltage to load terminals is given by

$$v_{sa} = V_m \sin \omega t \tag{1}$$

$$v_{sb} = V_m \sin(\omega t - 120°) \tag{2}$$

$$v_{sc} = V_m \sin(\omega t + 120°) \tag{3}$$

This can be written as

$$v_s(t) = \left[v_{sa} \quad v_{bs} \quad v_{sc} \right]^t \tag{4}$$

where, ω and V_m are the angular frequency and the peak value of the phase voltage respectively.

The gating time sequences of the IGBT switches uses symmetrical PWM technique or constant duty cycle method. High frequency fixed PWM is generated by comparing triangular wave of fixed frequency and amplitude v_c with dc value of variable amplitude v_r . The ratio of v_c and v_r is called as duty cycle. The duty cycle is defined as the ratio of on time T_{on} to the total time T .The average output voltage is varied by changing through the variable v_r to control the duty cycle D.

The output voltage that appears across the load terminals can be written as

$$v_0(t) = [v_{oa} \quad v_{ob} \quad v_{oc}]^t \tag{5}$$

$$v_{0a} = D * V_m \sin \omega t$$

Where, $v_{ob} = D * V_m \sin(\omega t - 120°)$

$$v_{oc} = D * V_m \sin(\omega t + 120°)$$

The value of the fundamental component can be adjusted according to the required duty cycle, which can be obtained by comparing a triangular carrier waveform with a dc reference signal, having variable amplitude.

By assuming the switching frequency is sufficiently high and an inductive load, the load currents can be considered to be nearly sinusoidal in all phases and it can be written as

$$i_{oa} = I_o \sin(\omega t - \phi) \tag{6}$$

$$i_{ob} = I_o \sin(\omega t - 120° - \phi) \tag{7}$$

$$i_{oc} = I_o \sin(\omega t + 120° - \phi) \tag{8}$$

and $i_0(t) = [i_{oa} \quad i_{ob} \quad i_{oc}]^t$ (9)

where $\cos\phi$ is load power factor and $\phi = \tan^{-1}(\omega L / R)$

$$i_s(t) = [i_{sa} \quad i_{bs} \quad i_{sc}]^t \tag{10}$$

$$i_{sa} = D * I_o \sin(\omega t - \phi)$$

Where, $i_{sb} = D * I_o \sin(\omega t - 120° - \phi)$

$$i_{sc} = D * I_o \sin(\omega t + 120° - \phi)$$

During the freewheeling mode, the load terminals are shortcircuited and the load currents naturally decay in the freewheeling path. The corresponding input line currents are equal to the load currents as given by Eq. (6), (7) and (8) during the active mode while it is equal to zero during the freewheeling mode. More detailed analysis for the harmonic contents of the output voltage and input and output currents can be found in references [3]

Snubber circuits provide by-pass current to ensure safe and successful commutation of the power semiconductor devices. The snubber capacitor is designed such that the peak voltage rise across it does not exceed the device rating. The snubber resistor is designed such that the capacitor discharges completely during the minimum on time of the switch.

Since the by-pass mode lasts for only few micro seconds, it is reasonable to assume that the line voltages are assumed to be constant during this mode and thus the load current is shared by-pass capacitors. The maximum value of the by-pass current is equal to the maximum value of the output line current. Then, the by-pass capacitor or snubber capacitor is determined from:

$$C = \frac{\sqrt{2}}{3} I_O \frac{t_d}{\Delta V_c} \tag{11}$$

Where ΔV_c is the small voltage increment produced on capacitor by the load current during the dead time interval.

The snubber resistance can be determined by

$$R \leq \frac{9\sqrt{3}}{4\sqrt{2}\pi} * \frac{V_{sm}}{I_o} \frac{1}{t_d f_s} \tag{12}$$

Where, V_{sm} is the maximum supply voltage.

f_s is the supply frequency.

IV. MATLAB SIMULATION OF THE PROPOSED SCHEME

This section presents the performance evaluation of the proposed scheme with the high frequency PWM technique by simulation using MATLAB Simulink. The complete simulation model for soft starting and speed control of 3 phase induction motor using IGBT is shown in Figure 3. The simulated circuit parameters are shown in table I

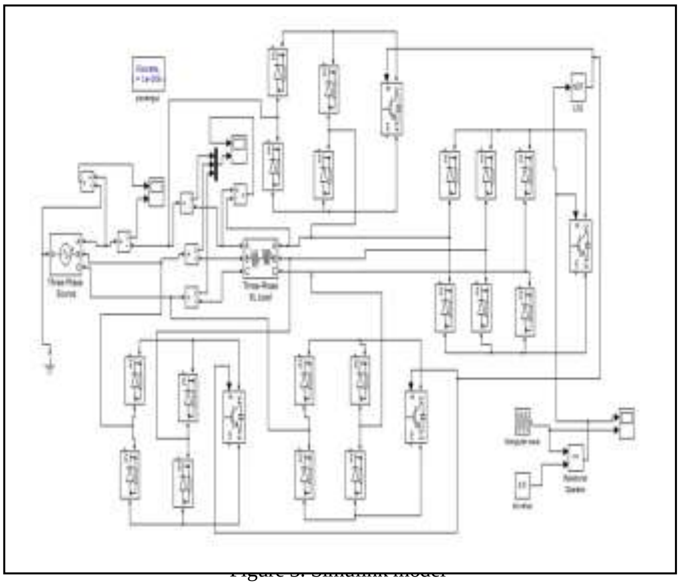

Figure 3. Simulink model

TABLE 1 SIMULATION PARAMETER

Parameter	Value
Maximum supply voltage	400V
Supply frequency	50Hz
Switching frequency	2kHz
Duty cycle	0.5
Load resistance	18Ω
Load inductance	26.5mH

High frequency fixed PWM is generated by comparing triangular wave and dc value. The switching signals have either 0 (turn off) or 1 (turn on). The load is taken as a simple R-L load. The three phase RL load represents three phase stator winding resistance and inductance. Simulation is carried out to

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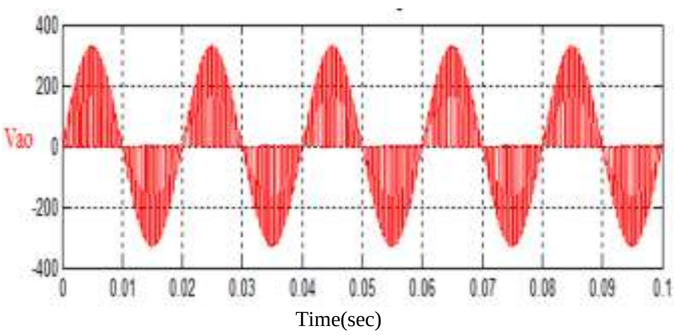
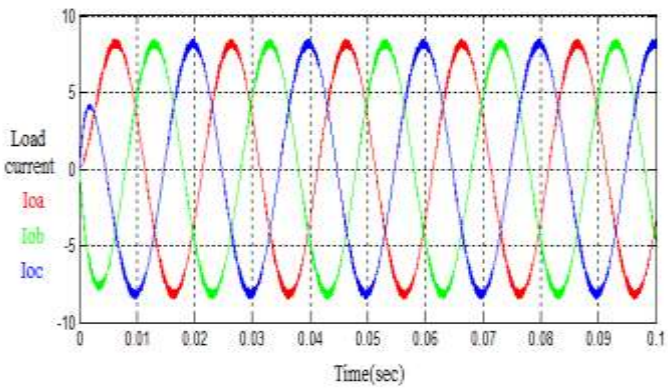
determine input current, load voltage and load current for R-L load.

V. SIMULATED RESULTS

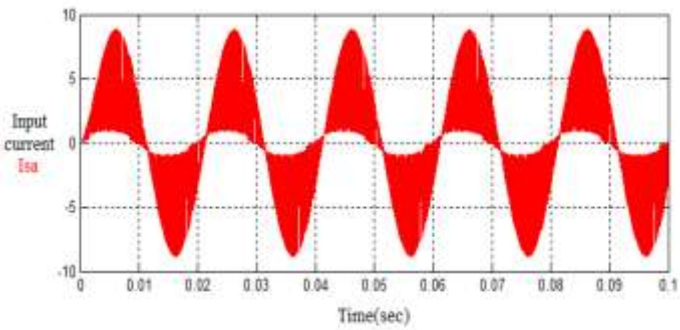
The results that have been obtained from the simulation model are presented in this section. Fig. 4 shows the voltage and current operating waveforms of the load voltage (phase a), three phases load currents and supply current (phase a) at a duty cycle D = 0.5



(a) Output load voltage, phase a



(b) Three-phases output load currents



(c) supply line current, phase a

Figure 4. Simulated voltage and current waveforms.

VI. CONCLUSION

This paper presented the detailed description of the newly proposed scheme of 3phase ac voltage control using single main power semiconductor switch connected across three phase diode bridge and three auxiliary power semiconductor switch across the single phase diode bridge comprising of four diodes. The voltage control could be achieved by varying the duty cycle of the switching function of the forward switches as a suitable means for controlling the effective voltage applied to the load terminals.

The actual scheme in the present paper uses IGBTs as controlled switches, the other active switches can alternatively be used depending upon the power handling capability. Gating pulse sequences of switches is based on equal PWM technique which is efficient and simple to implement. The advantages of proposed method are its high power factor, high efficiency and ease of control and requires only four switches. This method will be suitable for fan, pump or blower load coupled to a three phase induction motor.

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