POWER FACTOR IMPROVEMENT IN SWITCHED RELUCTANCE MOTOR DRIVE USING PWM CONVERTER

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ABSTRACT

This paper presents the power factor improvement technique in the midpoint converter based Switched Reluctance Motor (SRM) drive using a AC-DC three level Pulse Width Modulation (PWM) converter. A conventional SRM drive produces very high levels of harmonics content and poor power factor at ac mains. The proposed converter with midpoint converter fed SRM drive improves the power factor at ac mains with low current harmonics. The SRM drive with converter is modeled and its performance is simulated in Matlab/Simulink environment.

Keywords: Midpoint converter, Power quality, THD, PFC, SRM, PWM converter

I. INTRODUCTION

Switched Reluctance Motor (SRM) have a simple and robust construction; they eliminate permanent magnets, brushes, commutators and windings on the rotor side. As a result of its inherent simplicity, SRM offers advantages of reliable and low cost variable speed drives [1-2]. This motor drive needs power converters for its operation. Many type of power converters for SRM drive is reported in literature [3-4]. These converters require stable DC supply as an input source. For this purpose if a conventional rectifier unit is used as front end converter, the supply current drawn is in pulse form. This supply current is of very low power quality.

The block diagram of conventional SRM drive is shown in fig-1. It can be divided into supply utility, AC/DC converter, Capacitor network, DC/DC machine converter and SRM.

The attractive features of these converters are constant DC bus voltage, low harmonic distortion of the utility current, bi-directional power flow & controllable power factor.

It is very difficult to maintain the balanced voltage across each capacitor at DC bus. Two capacitor split the DC link voltage into two equal voltages. Phase voltage of SRM is provided by each capacitor. By varying the conduction period of a phase, we can balance the capacitor voltage. Source current drawn by the motor is in pulse form so it induces ripple voltage across the capacitors.
Torque ripples and THD (Total Harmonics Distortion) of supply current are increased due to the unbalancing of voltages across capacitors. To improve the input power factor and DC capacitor voltage balancing, a power factor controller is needed at input side of the converter. For this a three level PWM converter fed SRM drive is designed, modeled and simulated in Matlab/Simulink.

![Fig-1 Bridge rectifier as front end converter fed SRM drive](image)

The proposed SRM drive system is capable of improving the power factor close to unity with low THD of supply current. The power quality is also within IEEE standard [5]

II. PROPOSED SYSTEM CONFIGURATION

In this paper, a non linear control technique for a PWM three level voltage source AC-DC converter associated with a mid point IGBT based machine converter is proposed.

To improve the power factor at the input ac mains, a PWM converter is used as front end converter for SRM drive. Fig-2 shows the schematic diagram of the proposed converter. The proposed system consists of a PWM converter which is an ac-dc boost converter and mid –point converter based SRM drive. In this system the mid-point converter will be used as a machine side converter & PWM will work as a front end converter.

![Fig-2 proposed PWM converter fed SRM drive](image)

The proposed converter has resistor-inductor series circuit on each input line & two capacitor on the DC link. The converter has a three level bridge of selected forced-commutated power electronics devices. The series RC snubber circuits are connected in parallel with each switch device. The IGBT bridge converter has a combination of universal bridge and discrete IGBT switches. These power electronic switches are controlled by gate pulses, which are given by PWM Gate pulse generator system. The PWM gate pulse generator has a combination of voltage & current regulator. The output of the controller is given to the discrete 3-phase PWM generator, which produces the controlled pulse as per requirement.
III. DESIGN & ANALYSIS OF CONVERTER

Traditionally Diode Bridge Rectifier (DBR) are used for rectification. This rectifier can only produce a constant DC voltage, which is a function of system voltage. A control rectification system can be used to produce variable dc output voltage. But both these rectifier behave as a non-linear load. A pulse width modulated (PWM) rectifier, shown in Fig-3, draws near sinusoidal current from the supply mains. Also the DC link voltage can be regulated & the supply power factor is adjustable.

By applying KVL on supply side and KCL on load side gives

\[ L \frac{di}{dt} = v_s - SV_o \]  \hspace{1cm} \text{(1)}

\[ C \frac{dv_o}{dt} = Si_s - \frac{1}{R} V_o \]  \hspace{1cm} \text{(2)}

where S is the switching function of the PWM converter & \( V_i = V_m \sin \omega t \) is the input ac source voltage with the amplitude of \( V_m \) and angular frequency of \( \omega \). Resistance on the ac side is neglected.

The main control objectives for such PWM converter are to produce an input ac current \( i_s \) with low harmonics content at a high power factor and to control the average DC voltage \( V_o \). It is clear that unity pf can be achieved , if the ac input current tracks the following reference current.

\[ I_s^* = I_m \sin \omega t \]  \hspace{1cm} \text{(3)}

By combining the equations \( (1), (2) \) & \( (3) \) , we can write

\[ S_o (t) = \frac{1}{V_{sto}} (v_s - L \frac{di_s^*}{dt}) \]

\[ S_o (t) = \frac{1}{i_s} (\frac{V_{sto}}{R} + C \frac{dv_{os}}{dt}) \]  \hspace{1cm} \text{(4)}

where \( V_{sto} = V_o + V_{hr} \) is the steady state output voltage with a DC reference voltage \( V_o \) and a harmonic ripple content \( V_{hr} \).

Now let

\[ X_1 = i_s - i_s^* \ , \ X_2 = V_o - V_{sto} \ , \ S = S_o + \Delta S \]  \hspace{1cm} \text{(5)}

Where \( x_1 \) & \( x_2 \) are the state variables and \( \Delta S \) is the perturbation of the switching function \( S \). By using the above equations the following resulting equations are obtained.

\[ L x_1 = -S_o x_2 - \Delta S (V_{sto} + x_2) \]  \hspace{1cm} \text{(6)}

\[ C x_2 = S_o x_1 - \Delta S (i_s^* + x_1) - \frac{x_2}{R} \]  \hspace{1cm} \text{(7)}

With the switching function variable \( (6) \) & \( (7) \) are non-linear & time varying.
A. Control strategy

According to the Lyapunov stability theory, any linear or non-linear system must eventually settle down to an equilibrium point means every system is stable if there exists a positive definite Lyapunov function $V(x)$, whose time derivative is negative definite\[^5\]. Then the equilibrium point at the origin ($X_1=0, X_2=0$) is globally asymptotically stable. Now consider the following positive definite Lyapunov function for the converter

$$V(x) = \frac{1}{2}Lx_1^2 + \frac{1}{2}Cx_2^2$$

------------------------- (8)

Taking the derivative of eq(8) with respect to the time gives

$$V'(x) = x_1Lx_1 + x_2Cx_2$$

------------------------ (9)

If we put the value of $Lx_1$ & $Cx_2$ from eq(6),(7) to eq (9)

$$V'(x) = (x_1i_s^* - x_1V_{so})\Delta S - \frac{x_2^2}{R}$$

-------------(10)

By the equation (10), we can conclude that derivative of $V(x)$ along with any system trajectory becomes negative definite, if $\Delta S$ is chosen to be

$$\Delta S = \beta (x_1i_s^* - x_1V_{so}) , \beta < 0$$

where $\beta$ is an arbitrary real constant number. In order to generate the switching function $S$ (or compute in a digital implementation), it is necessary to predict the time varying steady state output voltage $V_{ss}=V_o+V_{hr}(t)$ for the present operating point of the converter. In this method there is a problem for calculation of $V_{hr}(t)$ because the methods for finding the ripple component $V_{hr}$ is complex and less accurate so if we neglect this component, the calculation will be simple.

$$\Delta S = \beta (x_1i_s^* - x_1V_o) , \beta < 0$$

There are three criterion for selection of arbitrary real constant ($\beta$)

(i) It gives a stability region as large as possible.

(ii) Satisfactory dynamic response is obtained over the operating range of the converter.

(iii)Ripple content should be minimum.

A typical range of the $\beta$ for the converter in this study is found to be $-0.002 \leq \beta \leq -0.00015$

B. PWM gate pulse generation

For the purpose of triggering pulses the input supply voltage $V_{abc}$, supply current $I_{abc}$ & generated DC link voltage $V_{dc}$ are filtered through low-pass filters. The normalized supply voltage are fed to the Phase Locked Loop (PLL) system. This PLL can be used to synchronize on a set of variable frequency, three phase sinusoidal signals. The output of this PLL system are fed to current & voltage regulator incorporate with normalized supply currents & voltages. The signal generated by the combination of these regulators is fed to the discrete 3-phase PWM generator in series with delay function. The block diagram are shown in Fig-3 & Fig-4
A discrete 3-phase PWM generator block generates the pulse for carrier based pulse-width modulation converter. The block can be used to fire the forced-commutated devices (FET’s, GTO’s or IGBT’s) of 2-level or 3-level converters. By using a single bridge or twin bridges connected in twin configuration vectorized outputs $P_1$ & $P_2$ which contains either 6-pulses(2-level) or 12-pulses(3-level) are used for triggering.

C. Control of SRM

The model used in this scheme is a current-controlled 60-kW 6/4 SRM drive using the SRM specific model based on measured magnetization curves. The SRM is fed by a three-phase asymmetrical power converter having three legs, each of which consists of two IGBTs and two free-wheeling diodes. During conduction periods, the active IGBTs apply positive source voltage to the stator windings to drive positive currents into the phase windings. During free-wheeling periods, negative voltage is applied to the windings and the stored energy is returned to the power DC source through the diodes. The fall time of the currents in motor windings can be thus reduced. By using a position sensor attached to the rotor, the turn-on and turn-off angles of the motor phases can be accurately imposed. This switching angle can be used to control the developed torque waveforms. The phase currents are independently controlled by three hysteresis controllers which generate the IGBTs drive signals by comparing the measured currents with the references. The IGBTs switching frequency is mainly determined by the hysteresis band.

IV. MATLAB SIMULATION

The PWM converter along with midpoint converter based SRM drive is modelled and it is simulated in Matlab/Simulink environment shown in fig-5. Three phase 600V, 50Hz ac supply is given to the PFC converter & the DC link voltage is controlled to 260V. The IGBT based midpoint machine converter is considered for 60kW, 6/4 SRM in this simulation. Object of this paper to reduce the input current harmonics and give the almost unity power factor on supply side. The concerned waveforms of simulation are shown in fig-6 & table-I.
Fig-5: Matlab simulation model

Fig-6 Steady State Response Of Input Supplied Current, Voltage Waveform, Dc Link Output & Thd Of Supplied Current
TABLE I
PERFORMANCE PARAMETERS OF PROPOSED PFC FOR SRM DRIVE

<table>
<thead>
<tr>
<th>Speed (rpm)</th>
<th>Torque (N-m)</th>
<th>V_{dc} (Volts)</th>
<th>THD (%)</th>
<th>Power factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>81.78</td>
<td>263.3</td>
<td>1.5</td>
<td>0.9988</td>
</tr>
<tr>
<td>2500</td>
<td>88.65</td>
<td>262.7</td>
<td>1.2</td>
<td>0.9989</td>
</tr>
<tr>
<td>3000</td>
<td>79.01</td>
<td>269.7</td>
<td>1.01</td>
<td>0.9989</td>
</tr>
<tr>
<td>3500</td>
<td>76.1</td>
<td>264.1</td>
<td>0.99</td>
<td>0.9990</td>
</tr>
<tr>
<td>4000</td>
<td>68.28</td>
<td>262.5</td>
<td>0.70</td>
<td>0.9990</td>
</tr>
<tr>
<td>4500</td>
<td>49.64</td>
<td>262.7</td>
<td>0.46</td>
<td>0.9992</td>
</tr>
<tr>
<td>5000</td>
<td>18.18</td>
<td>262.7</td>
<td>0.36</td>
<td>0.9992</td>
</tr>
</tbody>
</table>

V. RESULT & DISCUSSION

The performance of the proposed PWM converter fed SRM drive has been simulated in Matlab/Simulink environment.

The results are compared with the conventional converter fed SRM from the bridge rectifier. The current drawn by the conventional converter is non-sinusoidal, distorted & containing high level of harmonic distortions. The percentage THD of supply current is 61.65% with fundamental current 3.614(r m s). AT 20% of rated load, THD of supply current is 92.39% with fundamental current of 1.149 %(r m s). As the load torque reduced the THD of supply current is increased. This shows that the conventional bridge rectifier fed SRM has a very high THD & low power factor of supply current [6].

Fig-6, Show the results of Steady state & dynamic performance of supply current, THD & dc link voltage for the proposed PWM converter based SRM.

VI. CONCLUSION

The PWM converter along with midpoint converter based SRM drive is designed & simulated in Matlab/Simulink environment. Three phase 600V, 50Hz ac supply is given to the PFC converter & the DC link voltage is controlled to 260V. The IGBT based midpoint machine converter is considered for 60kW, 6/4 SRM in this simulation. The obtained results have been compared with conventional rectifier. Using this technique, the power quality has been improved as compared to the conventional bridge converter. It has been seen that this scheme can withstand under wide range of speed with almost unity power factor. The THD of supply current and power factor are well within IEEE 519 standard limits [7].

REFERENCES


