Analysis of PI Based Predictive Control Techniques for 8-Pulse Active Power Filter for Asynchronous Motor

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Abstract: Active power filters are used for reducing harmonics in the power system. This paper deals with different control techniques of active power filter discussed along with their performance. The control techniques implemented in this paper are Unit vector control technique and PI based predictive control technique. Both the techniques are implemented for reference current to be maintained in the system at the un-balanced loading conditions. The unit vector template technique generates the reference current from magnitude and shape from the system. But the PI based predictive control technique generates the reference current from the rotator frame with 16 problem possibility conditions which suppress the harmonic by optimizing the 49 rules based PI. This technique reduces the cost and size of active power filter considerably; at the same time the problems associated with unit vector technique are also eliminated. With this study a comparison of different control techniques of active power filter is presented on different indices such as THD, complexity and cost and topology-II has been proven to be superior. The effectiveness of this topology is tested with induction motor; its performance characteristics are studied and shown by using Matlab/Simulink software.

Keywords: Active Power Filter, Unit Vector Template Control Technique, PI Based Predictive Control Technique and Induction Motor.

I. INTRODUCTION

The general use of power electronic devices in our daily applications, disturbances occur on the electrical supply network. These disturbances are due to the use of non-linear devices. These will introduce harmonics in the power system thereby causing equipment overheating, damage devices, EMI related problems etc. Active Power Filters (APF) is extensively used to compensate the current harmonics and load unbalance. Power quality is one of the most important topics that electrical engineers have been noticed in recent years. Current harmonics is one of the problems related to power quality. This phenomenon happens continuously in distribution systems. The presence of harmonics does not mean that the factory or office cannot run properly. Like other power quality phenomena, it depends on the “stiffness” of the power distribution system and the susceptibility of the equipment. As shown below, there are a number of different types of equipment that can have disoperation or failures due to high harmonic voltage and/or current levels.

In addition, one factory may be the source of high harmonics but able to run properly. This harmonic pollution is often carried back onto the electric utility distribution system, and may affect facilities on the same system which are more susceptible. Some typical types of equipment susceptible to harmonic pollution include Excessive neutral current, resulting in overheated neutrals. Generally, current controlled voltage source inverters are used in distributed system. Recently, a few control strategies for grid connected inverters incorporating PQ solution have been proposed. In [3] an inverter operates as active inductor at certain frequency to absorb the harmonic current. But the exact calculation of network inductance in real-time is difficult and may deteriorate the control performance. A similar approach in which a shunt active filter acts as active conductance to damp out the harmonics in distribution network is proposed in [4]. In [5], a control strategy for renewable interfacing inverter based on theory is proposed.

In this strategy both load and inverter current sensing is required to compensate the load current harmonics. Here, the main idea is to control the inverter at extreme loading conditions. It is shown in this paper that the grid-interfacing inverter can effectively controlled by: 1) Unit vector template control technique; 2) PI based predictive control technique; for the proposed 8 pulse APF shown in fig.1 By using the effective control technique of these 2 topologies the PQ constraints at the PCC can therefore be strictly maintained within the utility standards without additional hardware cost. Among these events, harmonics are the most dominant one. The effects of harmonics on PQ are specially described in [4]. According to the IEEE standard, harmonics in the power system should be limited by two different methods; one is the limit of harmonic current that a user can inject into the utility system at the point of common coupling(PCC) and the other is the limit
of harmonic voltage that the can supply to any customer at the PCC.

Fig.1. Components configuration of 8 pulse APF.

II. UNIT VECTOR TEMPLATE CONTROL TECHNIQUE

The main aim of the Unit Vector template control technique is to generate reference source currents to control the 8 pulse APF. The block diagram of the control scheme is shown in Fig. 2. The control strategy applied to the grid side inverter consists mainly of two cascaded loops. Usually there is a fast internal current control loop, which regulates the grid current and an external voltage loop which controls the DC-link voltage. Conduction and switching losses of diodes and IGBTs in inverters increase voltage ripple in DC-link which affects the performance of the filter. The control scheme approach is based on injecting the currents into the grid using hysteresis current controller.

Fig.2. Block diagram representation of Unit vector control scheme.

A. Magnitude of the Reference Current

A PI controller is used to maintain the DC link voltage at specified value. The DC link voltage is sensed and compared with reference value and the error is passed through a PI controller.

\[ V_{dcref} = V_{dc} - V_{dc} \]

Thus the output of dc link voltage regulator results in current \( i_m \).

B. Current Control of VSI

Unit vector templates are generated as

\[ U_a = \sin(\phi) \]
\[ U_b = \sin(\phi - 2\pi/3) \]
\[ U_c = \sin(\phi + 2\pi/3) \]

The multiplication of current \( I_m \) with unit vector template \( U_a, U_b, U_c \) generates reference grid currents \( I_a^*, I_b^*, I_c^* \). The instantaneous values of reference grid currents are computed as

\[ I_a^* = I_m \cdot U_a \]
\[ I_b^* = I_m \cdot U_b \]
\[ I_c^* = I_m \cdot U_c \]

The neutral currents present if any due to the loads connected to the neutral conductor should not be drawn from the grid. Thus reference grid neutral current is considered as zero and can be expressed as \( I_n^* = 0 \). Current errors are obtained by comparing reference grid currents \( I_a^*, I_b^*, I_c^* \) with actual grid currents \( I_a, I_b, I_c \). These current errors are given to the hysteresis current controller.

\[ I_{aerr} = I_a^* - I_a \]
\[ I_{berr} = I_b^* - I_b \]
\[ I_{cerr} = I_c^* - I_c \]
\[ I_{nerr} = I_n^* - I_n \]

C. Switching Control of IGBTs

Switching pulses are generated using hysteresis current controller. There are various current control methods for active power filter configurations but hysteresis method is preferred among other current control methods because of quick current controllability, easy implementation and unconditioned stability. The conventional current control scheme is the hysteresis method where the actual filter currents are compared with their reference currents with a predefined hysteresis band in their respective phases. Thus the actual currents track the reference currents generated by current control loop. The switching pattern of each IGBT is formulated as,

If \( (I_n^* - I_n) = +h_b \) then the upper switch S I will be ON in the phase a leg of inverter.
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If \((I_a^* - I_a) = -h_b\) then the lower switch S4 will be ON in the phase a leg of inverter.

Where, \(h_b\) width of hysteresis band. Similarly switching pulses are derived for other three legs.

III. PI BASED PREDICTIVE CURRENT CONTROL

The block diagram of the proposed digital predictive current control scheme is shown in Fig. 3. Consequently, the analysis has to be developed using discrete mathematics in order to consider additional restrictions such as time delays and approximations. The main characteristic of predictive control is the use of the system model to predict the future behavior of the variables to be controlled. The controller uses this information to select the optimum switching state that will be applied to the power converter, according to predefined optimization criteria. The predictive control algorithm is easy to implement and to understand, and it can be implemented with three main blocks, as shown in Fig. 3.

1. Current Reference Generator: This unit is designed to generate the required current reference that is used to compensate the undesirable load current components. In this case, the system voltages, the load currents, and the dc-voltage converter are measured, while the neutral output current and neutral load current are generated directly from these signals (IV).

2. Prediction Model: The converter model is used to predict the output converter current. Since the controller operates in discrete time, both the controller and the system model must be represented in a discrete time domain [12]. The discrete time model consists of a recursive matrix equation that represents this prediction system. This means that for a given sampling time \(T_s\), knowing the converter switching states and control variables at instant \(kT_s\), it is possible to predict the next states at any instant \([k + 1]T_s\).

A. Current Reference Generation

A dq-based current reference generator scheme is used to obtain the active power filter current reference signals. This scheme presents a fast and accurate signal tracking capability. This characteristic avoids voltage fluctuations that deteriorate the current reference signal affecting compensation performance. The current reference signals are obtained from the corresponding load currents as shown in Fig. 4. This module calculates the reference signal currents required by the converter to compensate reactive power, current harmonic and current imbalance.

IV. PERFORMANCE OF THE INDUCTION MOTOR

The sinusoidally-distributed flux density wave produced by the stator magnetizing currents sweeps past the rotor conductors, it generates a voltage in them. The result is a sinusoidally-distributed set of currents in the short-circuited rotor bars. Because of the low resistance of these shorted bars, only a small relative angular velocity, \(r\), between the angular velocity, \(s\), of the flux wave and the mechanical angular velocity of the two-pole rotor is required to produce the necessary rotor current. The relative angular velocity, \(r\), is called the slip velocity. The interaction of the sinusoidally-distributed air gap flux density and induced rotor currents produces a torque on the rotor. The typical induction motor speed-torque characteristic is shown in Fig. 5.

In a DC motor this power is supplied to the armature directly from a DC source, while in an induction motor this power is induced in the rotating device by means of electromagnetic induction. An electric motor convert’s electrical power to mechanical power in its rotor. There are several ways to supply power to the rotor.
induction motors, which are frequently used in industrial drives. When induction motors are given supply, they draw the current as $I_a = \frac{E_a - E_b}{R_a}$. As initially $E_b = 0$. Motor draws a very high current initially; due to which voltage dip will forms, which show the effect on the power system network. In order to avoid such problems a effective controlled APF is placed without effecting the power quality or the motor performance characteristics.

![Fig.5. Speed-torque characteristics of induction motor.](image)

**V. MATALB/SIMULINK RESULTS**

Matlab/Simulink model of 8 pulses Active Power Filter with Unit vector and PI based Predictive Control techniques and results of this paper is shown in bellow Figs.6 to 20.

**Case-I: With Filter Connected To Non-Linear Load**

![Fig.6. Matlab/Simulink model of Unit vector Controlled 8-pulse Active Power Filter connected to Un-balanced loads.](image)

![Fig.7. Simulink model of Unit Vector Control technique.](image)

![Fig.8. Simulated output wave forms of the Unit Vector template controlled APF (a) Source voltage. (b) Load Current. (c) Neutral Current. (d) Source Current. (e) Compensating Current. (f) Dc Voltage.](image)
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Case-II: Without Filter When Connected To Induction Motor

Fig.9. shows the matlab/simulink model of the PI controlled based system with out filter when connected to induction motor.

Fig.10. shows the source current waveform of the proposed converter when connected to induction motor without filter.

Fig.11. Simulated output wave form of Stator currents drawn by Induction motor without filter.

Fig.12. Simulated Speed wave form of the Induction motor without filter.

Fig.13. Simulated output Torque wave form of the Induction motor without filter.

Fig.14. Total Harmonic Distortion of Source Current showing 29.88% without filter.

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Case-III: With Filter When Connected To Induction Motor

Fig.15. Matlab/Simulink model of PI based Predictive control technique Controlled 8 pulse APF connected to the Induction motor.

Fig.16. Simulated output wave forms of the PI based Predictive Current controlled APF (a) Source voltage. (b) Load Current. (c) Neutral Current. (d) Source Current. (e) Compensating Current. (f) Dc Voltage.

Fig.17. Total Harmonic Distortion of Source Current showing 0.17% with PI based Predictive Current controlled 8 pulse Active Power Filter connected to Unbalanced loads.

Fig.18. Simulated output wave form of Stator currents drawn by Induction motor.

Fig.19. Simulated Speed wave form of the Induction motor.

Fig.20. Simulated output Torque wave form of the Induction motor.

VI. CONCLUSION

The power quality of the power system network has been increased with the 8 pulse Active Power Filter and its performance has studied while controlling with Unit Vector template control technique and PI based predictive control technique. Based upon the theoretical analysis it is proven that PI based predictive control technique will effectively controls the 8 pulse Active power filter. Hence this system is tested under simulation with the Induction motor. These results shown that the high initial stator currents drawn by the Induction motor does not effects the power system network with effective controlling the 8 pulse Active power filter.

TABLE I:

<table>
<thead>
<tr>
<th>Controller</th>
<th>Source Current Harmonics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Predictive Current Control without shunt active filter</td>
<td>29.88%</td>
</tr>
<tr>
<td>PI based Predictive Current Control with shunt active filter</td>
<td>2.17%</td>
</tr>
</tbody>
</table>
VII. REFERENCES


