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DESIGN AND ANALYSIS OF SHUNT ACTIVE POWER FILTER FOR REACTIVE POWER COMPENSATION AND HARMONIC DISMISSAL FED TO INDUCTION MOTOR DRIVE

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Abstract: In this paper design and analysis of shunt active power filter for abolition of harmonics and reactive power compensation fed to induction motor drive is proposed. A control strategy of an Active Power Filter (APF) is introduced for harmonic mitigation in Variable Frequency Drives (VFD). In this paper Voltage Source Inverter (VSI) is used to supply a variable frequency variable voltage to a three phase induction motor drive in a variable speed application. One important complication is that, Voltage Source Inverter (VSI) used in VFD causes non-sinusoidal output voltage and current due to presence of harmonics. Shunt active filter with VSI topology is proposed for current harmonic elimination. PI controller for DC voltage balancing and Hysteresis current controller (HCC) for gating pulse generation is implemented. The analysis of simulation results are carried out in MATLAB/SIMULINK model.

Keywords: active power filter, reactive power compensation, hysteresis controller, harmonics

I.Introduction

In Variable Speed application, Voltage Source Inverter is commonly used to supply a variable frequency variable voltage to a three phase induction motor. In this PWM drives are more efficient and typically provide higher levels of performance. A suitable Pulse Width Modulation technique is employed to obtain the required output voltage of the inverter. The most common AC drives today are based on sinusoidal pulse-width modulation SPWM. . Induction motor is rugged, reliable, and single-fed machine; it can directly absorb the reactive power from the utility With this device, we can get two advantages: one is that we can get a low start current; the other is that we can change the motor speed conveniently by controlling the output frequency of the ASD.

Any power problem manifested in voltage, current, or frequency deviations that result in failure, disoperation or even damage of customer equipment is considered as a power quality problem [1], [2]. Different power quality problems are power frequency disturbances, power system transients, electromagnetic interference, electrostatic discharge, power system harmonics, poor power factor (PF), grounding and bonding problems etc. [3]. Many big industries, commercial and industrial electrical loads include power transformers, welding machines, arc furnaces, induction motor driven equipment such as elevators, pumps, and printing machines etc., which are mostly inductive in nature. These loads create serious power quality problems. Poor PF & harmonics are two most important & serious power quality problems nowadays. Poor PF has various consequences such as increased load current, large KVA rating of the equipment, greater conductor size, larger copper loss, poor efficiency, poor voltage regulation, reduction in equipment life etc. Therefore it is necessary to solve the problem of poor PF. There are different reactive power compensation techniques to improve the PF such as: synchronous condenser, capacitor banks, static VAR compensators (SVCs) [4], self-commutated VAR compensators [5] etc.

However, most of them have disadvantages: Synchronous machines are bulky, require strong foundation, instability problems being a low inertia synchronous machine, require significant amount of starting and protective equipment [5], capacitor banks generate high transients during connection and disconnection [6], SVCs are harmonic polluters. Second important power quality problem is harmonics. Modern semiconductor switching devices are being utilized more and more in a wide range of applications in distribution networks, particularly in domestic and industrial loads. These power electronics devices offer economical and reliable solutions to better manage and control the use of electric energy. However these semiconductor devices present nonlinear operational characteristics, which cause distortion in the voltage and current waveforms at the point of common coupling. These devices, aggregated in thousands, have become the main polluters, the main distorters, of themodern power systems. These nonlinear loads draw current in non-sinusoidal form which contains frequency components which are integer multiple of fundamental frequency. These frequency components which are integer multiple of fundamental frequency is known as harmonics. Various sources of harmonics are solid state power converters, HVDC converters, adjustable speed motor drives (ASDs), diode and thyristor rectifiers, uninterruptible power supplies (UPSs), computers and their peripherals, consumer electronics appliances (like TV sets, Printers, Fax Machine, Photocopiers etc.), SVCs, Compact Fluorescent Lamp (CFL) etc. Harmonics produced by these loads percolate into the system that causes excessive losses, heating, saturation in transformers, reduction of equipment life, blowing of capacitor fuses, malfunctioning of relays, nuisance tripping of circuit breakers, interference with

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communication facilities and motor controllers, erroneous measurements, series and parallel resonance with P.F. improving capacitors and so on [7]. With growing applications of harmonic producing devices it is necessary to filter out the harmonics. Different filtering techniques can be used to filter out the harmonics produced by nonlinear loads. There are various harmonic elimination techniques such as passive filters, active filters, hybrid filters etc. The Active power filter (APF) technology is now mature for providing compensation for harmonics, reactive power, and/or neutral current in ac networks [8]. It has evolved in the past quarter century of development with varying configurations, control strategies, and solid-state devices. AFs are also used to eliminate voltage harmonics, to regulate terminal voltage, to suppress voltage flicker, and to improve voltage balance in three-phase systems. This wide range of objectives is achieved either individually or in combination, depending upon the requirements, control strategy and configuration which have to be selected appropriately. The theme of this paper deals with the proposed topology, description of Instantaneous Reactive Power (IRP) theory, operation of PI controller, Hysteresis current control (HCC) technique and description of simulation results.

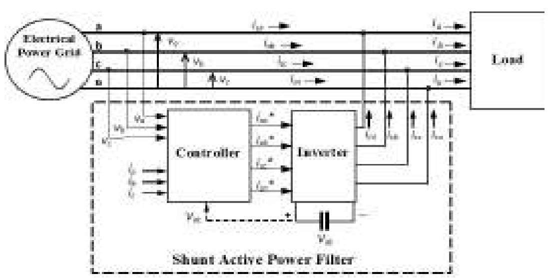

Fig.1. structure of APF and electrical topology

II. Main Circuit Design Of Apf

A. Power electronic devices selection of APF

Because of three – phase four – wire loads in industrial application, this project studied three – phase four – wire main circuit structure, which not only eliminate the harmonic component, positive sequence and negative sequence components of three – phase line current, but also can eliminate the zero sequence harmonic components in the three – phase line current, in order to improve the reliability of the system, and IGBT devices is selected as power electronic switching devices. In order to improve the reliability of the system, intelligent power module (intelligent power module IPM) was chosen, and according to system actual compensation requirements, Mitsubishi PM75RSE120 was selected as the main power devices of four – wire inverter. PM75RSE120 module is the mature fourth generation of high - frequency IPM product, and it has much technical advantages, such as $1\mu m$ step line process, a new type of fast recovery diode, built – optimized gate drive and protection circuit, and suitable for up to 15Khz power conversion occasions. The IPM module has the following characteristics:

- Fast switching speed, IPM IGBT chips have high-speed, and IGBT drive circuits have small delay time, so its switching speed is faster, and switching loss is smaller.
- Low power consumption. IPM within the IGBT of IPM has smaller conduction voltage drop and faster switching speed, so power consumption is lower.
- Anti- interface ability. IPM has optimized gate- level driver and integrated IGBT, and rational layout process, so it has more anti- interface ability.
- Soft recovery characteristics. IPM can effectively suppress the inrush current.
- Perfect protection circuit. IPM has short circuit, over-current, over- temperature, and other protection.

B. Design of APF coupled inductor

Because pwm control strategy in the present study is based on the hysteresis current space vector control method, coupled inductor of APF is designed in accordance with the control strategy. The tracking command current waveform of APM is shown in figure.2. In figure 3.2, I_c is tracking current, and I_c^* is reference current. It can be seen that in order to track the reference current, slope rate of tracking current must be larger than rate of reference current in each control cycle. Respect to other harmonic current, reactive reference current has most flat waveform, and minimum curvature in all of the command current. So, tracking reactive reference current required the largest inductance value. Based on above detail, maximum inductance value was analysed for tracking reactive reference current.

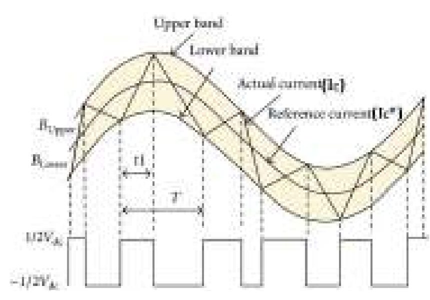

Fig.2 hysteretic current control sketch

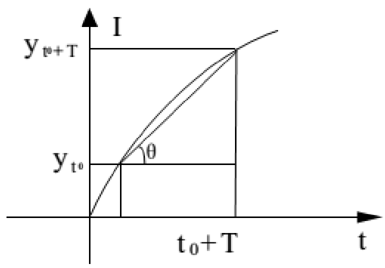

Fig.3. waveform fragment sketch

The practically enlarged waveform of sine current is shown in figure 3.3. T is the pwm switching cycle time, t_0 is optionally working time beginning. Due to high operating frequency of pwm, T is very small value, from t_0 to $t_0 + T$, sine wave curve can be regarded as an approximate straight line in this period. Therefore, the slope rate is:

$$\tan\theta = \frac{(y_{t_0+T} - y_{t_0})}{(t_0 + T - t_0)} = \frac{i^*_{c\max}[\sin(\omega(t_0+T)) - \sin\omega t_0]}{T}$$
$$= \frac{i^*_{c\max}[\sin\omega t_0 \cos\omega T - \sin\omega t_0 + \cos\omega t_0 \sin\omega T]}{T}$$
$$\max(\tan\ ) \quad (1)$$

So $I^*_{cmax}\omega\cos\omega t_0 \;\; \theta = \omega I^*_{cmax}$, in which I^*_{cmax} is the maximum value of reference current, ω is the frequency of reference current. The compensating current is generated from inductor on effect of voltage difference between the dc side of the main circuit capacitor and the ac side of the power supply. The main circuit (phase A) of the differential equations can be described as follows:

$$L\frac{di}{dt} = e_a + k_a U_C \quad (2)$$

Where k_a is switch coefficient, and e_a is system AC voltage, in a integration period, integration value of e_a is zero, and integration value of k_a is 4/9. So, we have:

$$L = \frac{e_a + k_a U_C}{di/dt} = \frac{4U_C}{9\,di/dt} \quad (3)$$

Because slope rate of tracking current must be larger than rate of reference current, in each sontrol cycle, we have:

$$\frac{di}{dt} > \max(\tan\theta) \quad (4)$$

Therefore,

$$L < \frac{4U_C}{9\max(\tan\theta)} = \frac{4U_C}{9\omega i^*_{c\max}} \quad (5)$$

And when we selected inductor, the actual output current ripple of APF must be considered, so L cannot be select too small. Assuming allowable output current fluctuation rate of APF isσ_0, and the actual output current fluctuation is $\sigma = I_1/I_1 < \sigma_0$. Where I_1 is ripple current amplitude of the fundamental current, and I_1 is fundamental current amplitude. So, we have$I_t = \frac{4U_C}{9L}t_s$, therefore,

$$L \geq \frac{4U_C t_s}{9I_1\sigma_0} \quad (6)$$

In summary, we can have

$$\frac{4U_C t_s}{9I_1\sigma_0} \leq L < \frac{4U_C}{9\omega i^*_{c\max}} \quad (7)$$

And in practical application, we select 4mH as the L value.

C. design of APF DC generator

In order to ensure that the APF compensation performance, the dc voltage must be maintained at a constant value. Capacitor value will affect the dc voltage fluctuations, and the greater the capacitance value, will get the smaller the voltage fluctuations, and better stability, but will result in increased costs. Determine the capacitance in engineering practice is based on the low frequency pulsation rate of dc voltage. Based on engineering experience, we have,

$$C = \frac{I}{\sigma f U_c}K \quad (8)$$

Where, I is RMS value of rated output current of APF, U_c is dc average voltage, f is minimum output frequency of APF, σ is allowable ripple factor of dc voltage, and K is control coefficient. In order to ensure the stable operation of the APF, the general dc- side voltage usually is set as 700-800V. In summary, we select six 450V/10000μF electrolytic capacitors, and three capacitors series connection then two parallel structure is selected in application.

III. Research On Current Detection And Pwm Control Strategy Of Apf

In order to better realize the function of APF, it is necessary to reasonably design the harmonic current detecting, to real- time, accurately detect harmonic and reactive current. In 1932, a German scholar fryze S initially proposed the idea of FBD algorithm, and the initial definition was in single phase system. Then, after improvement of some scholar such as buchholz F and Dpenbrock M, the algorithm has been generalized in the universal multiphase system, and amended some detect, so the algorithm evolved to be a system, and emended some defect, so the algorithm evolved circuit to be a system, and was called FBD method. The actual circuit in the equivalent load for each phase was substituted as equivalent series conductance in each phase in FBD algorithm. Circuit power is no other energy loss. According to the equivalent conductance of the current decomposition, the compensation of current can be calculated. Fig 3.4 shows FBD algorithm overall detection diagram.

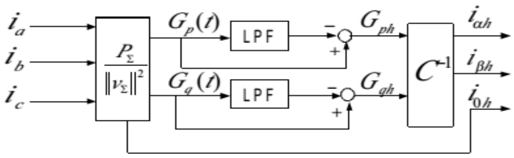

Fig. 4. FBD algorithm principle

After the compensation command current was calculated, based on relationship between the command reference current and the actual output of APF, the current tracking control circuit generate the on- off signals to control the main circuit power device, and drive IGBT device to output require the actual compensation current. Therefore, the current tracking control strategy is an important part of APF device. So, pwm control strategy based on the hysteresis current space vector control method is proposed. The principle of the algorithm is shown in figure 3.5. The difference between the output current and the reference current. Corresponding to different voltage vectors, the switching state is selected to achieve tracking pwm control of APF.

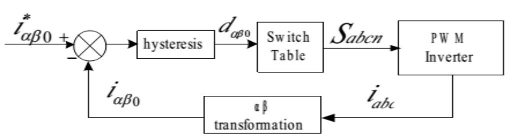

Fig.5 hysteretic space vector control principle

IV.Induction Motor

Induction Motor (1M) An induction motor is an example of asynchronous AC machine, which consists of a stator and a rotor. This motor is widely used because of its strong features and reasonable cost. A sinusoidal voltage is applied to the stator, in the induction motor, which results in an induced electromagnetic field. A current in the rotor is induced due to this field, which creates another field that tries to align with the stator field, causing the rotor to spin. A slip is created between these fields, when a load is applied to the motor.

Compared to the synchronous speed, the rotor speed decreases, at higher slip values. The frequency of the stator voltage controls the synchronous speed [12]. The frequency of the voltage is applied to the stator through power electronic devices, which allows the control of the speed of the motor. The research is using techniques, which implement a constant voltage to frequency ratio. Finally, the torque begins to fall when the motor reaches the synchronous speed. Thus, induction motor synchronous speed is defined by following equation,

$$n_s = \frac{120f}{p}$$

Where f is the frequency of AC supply, n, is the speed of rotor; p is the number of poles per phase of the motor. By varying the frequency of control circuit through AC supply, the rotor speed will change.

V. Matlab/Simulink Results

Case 1: Performance of SAPF for linear and nonlinear load

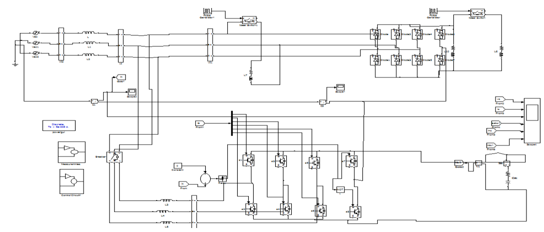

Fig.6. Matlab/Simulink circuit for proposed system

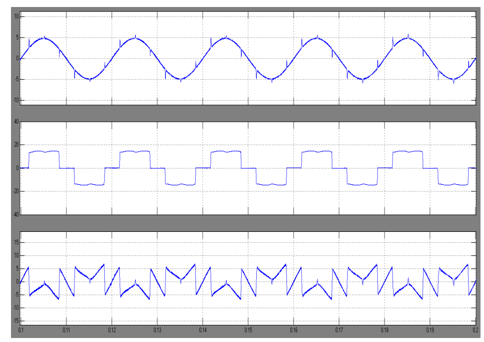

Fig.7. Simulation results for source current, load current and compensation current

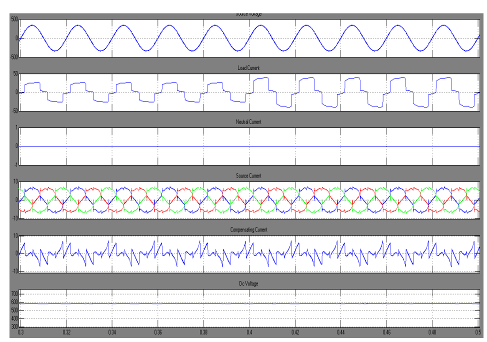

Fig.8. Simulation results for source voltage, load current, neutral current, source current, compensation current and dc link voltage

Case 2: Performance of SAPF for induction motor load

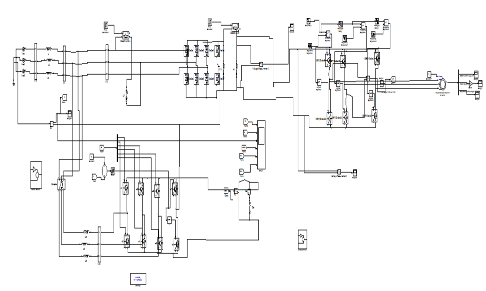

Fig.9. Matlab/simulink circuit for proposed system under induction motor load

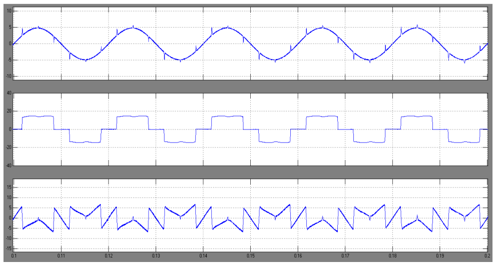

Fig.10. Simulation results for source current, load current and compensation current

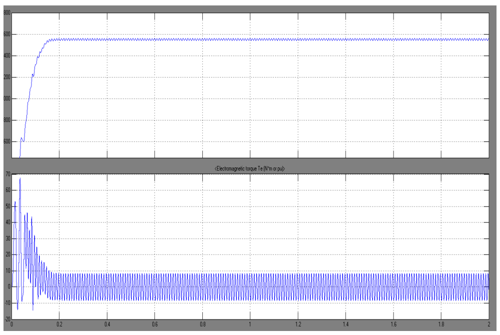

Fig.11. Simulation results for speed and torque of induction motor

VI. Conclusion

In this paper Shunt Active Power Filter is developed for harmonic reduction in VSI based Induction motor drive. A topology for reactive power compensation and harmonic mitigation of distribution system using SAPF is presented. Instantaneous Reactive Power is used for the reference current generation. PI controller is used to maintain the constant voltage of DC link capacitor. Hysteresis current controller is used for the generation of gating signals to the inverter. After compensation, the source current is in phase with the source voltage and THD on source side is well below the harmonic limit of 5%, imposed by IEEE std. 519-1992. This is due to the fact that the SAPF alone performs task of reactive power compensation and harmonic mitigation. The scheme developed is most suitable for highly nonlinear, inductive, fast changing and harmonic generating loads.

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