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Performance Evaluation of Induction Motor Drive with D-STATCOM Using A Fast-Acting DC Link Voltage Controller

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Abstract

Adjustable speed drives (ASD) employing induction motors were widely used in the industrials and process control condition in the form of varied applications such as fans, compressors, pumps etc. They are energy efficient and can result in substantial energy saving when properly installed. However, they inject high harmonic content into current drawn from the ac system. The transient response of the distribution static compensator (DSTATCOM) is very important while compensating rapidly varying unbalanced and nonlinear loads. Any change in the load affects the dc-link voltage directly. In this paper, a fast-acting dc-link voltage controller based on the energy of a dc-link capacitor is proposed. The MATLAB / SIMULINK based models are developed for induction motor speed drive loads. The analysis is carried out with and without induction motor drive. The results shown in the paper with DSTATCOM can be used as a good harmonic filter.

Index terms: Adjustable speed drive (ASD), D-STATCOM system, DC-Link Voltage controller, Induction motor, non-linear loads.

1. Introduction

Harmonic disturbances and their study has been a topic of research and today we can find a whole array of devices used to extenuate such problems. The ever growing use of power electronic based systems has exasperated the harmonics problem. These devices themselves require clean and good power quality but inject unwanted harmonics into the supply system as well as the neighbouring loads. Indicate the problems, effects and solutions for harmonics in power systems. Different type of low voltage loads can also introduce harmonics in the power network and adversely affect on the overall performance and operation of the power system. In this paper, use of custom power device for harmonic reduction is studied.

Adjustable speed drives [7-12] employing the use of asynchronous motors was widely used in process control in varied applications. The main benefit from ASDs is that their energy efficiency to the tune of 30-50%. This feature alone makes them very attractive to consumers. ASDs also improve system efficiency, equipment reliability, enhance product quality and reduce product waste and the noise level. However, the ASDs use power electronic devices for their switching operation which inject harmonics into the connected system. The increased penetration of these drives in electric utility system produces high harmonic content in current and voltage. The harmonic currents result in excessive heating in rotating machines. The harmonic currents, depending on their frequency, cause additional rotating magnetic fields in the motor. The magnetic field due to fifth harmonic, being the most prevalent tries to weaken the main field and rotates the motor in the opposite direction as the fundamental. Harmonic currents also cause overheating due to high-frequency eddy currents and hysteresis losses in the stator and rotor core and skin-effect losses in the windings.

A comprehensive literature review is available on custom power devices which were invented by Hingorani [3] and are being used in distribution systems. Power quality problems in distribution system mainly include poor power factor, poor voltage regulation and harmonics. Also, additional problems due to neutral current and load unbalancing have to be studied and system design has to be through. The trend nowadays is shift focus from passive filters to active filters. Some problems related to passive filters include selective filtering, large sized inductors and capacitors are needed and they are prone to detuning and resonance problems. Custom power devices especially DSTATCOM can be used as very effective filter. It need not be designed to eliminate a particular harmonic; in fact a DSTATCOM unit can be designed to eliminate all lower order harmonics introduced by the drive system.

When the dc link of the DSTATCOM supplies the dc load as well, the corresponding dc power is comparable to the average load power and, hence, plays a major role in the transient response of the compensator. Hence, there are two important issues. The first one is the regulation of the dc-link voltage within prescribed limits under transient load conditions. The second one is the settling time of the dc–link voltage controller. Conventionally, a PI controller is used to maintain the dc-link voltage. It uses the deviation of the capacitor voltage from its reference value as its input. However, the transient response of the conventional dc-link voltage controllers is slow, especially in applications where the load changes rapidly. Some work related to dc-link voltage controllers and their stability is reported in [16]–[20]. However, the work is limited to rectifier units where switching patterns are well defined and analysis can be easily carried out. In this paper, a fast-acting dc-link voltage controller based on the dc-link capacitor energy is proposed. The detailed modelling, simulation, and experimental verifications are given to prove the efficacy of this fast-acting dc-link voltage controller. There is no systematic procedure to design the gains of the conventional PI controller used to regulate the dc-link voltage of the DSTATCOM. Herewith, mathematical equations are given to design the gains of the conventional controller based on the fast-acting dc-link voltage controllers to achieve similar fast transient response.

2. D-STATCOM Operation

The operation of Distribution Static Compensator is simple and similar to the synchronous machine. It is well known that a synchronous machine can provide a lagging or leading current wrt voltage by controlling the field current. In the same manner, we can vary the DC link voltage and control it. If the magnitude of voltage developed by DSTATCOM is larger than the three phase voltage, then the current shall flow from the DSTATCOM to the system. In this case, DSTATCOM acts as source of capacitive vars. In the second case, if the system voltage is larger than the voltage at the ac terminals of DSTATCOM, it behaves as an inductor. When if both the ac voltages at the system as well as the DSTATCOM are equal, then there is no reactive power exchange between the two.

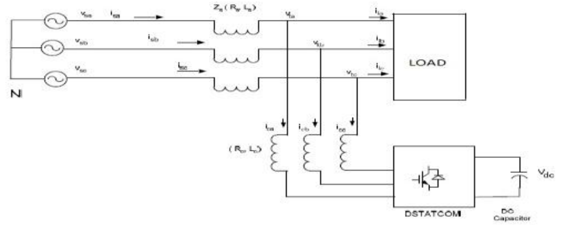

Figure 1: Diagram of D-STATCOM

Figure 1 shows the block diagram of the system with DSTATCOM connected in shunt configuration. Nonlinear load on the system is modelled in the form of adjustable speed drive feeding induction motor load. DSTATCOM is modelled as a three-phase IGBT (Insulated Gate Bipolar Transistor) bridge based VSI (voltage source inverter) with dc bus capacitor at the DC link. Switching ripples need to be eliminated so small capacitors (Cc) have been used. Figure 2 show the proposed three phase-four wire by using fast-acting dc link voltage controller D-STATCOM with induction motor drive. The VSI bridge is connected to the three phase, three wire system via three input inductors (Lc, Rc). The role of these inductors may also be played by transformer. The first mechanism is the converter operation which injects harmonic currents into the supply system by an electronic switching process. The second mechanism is the inverter operation which can introduce additional ripples into the DC link current. These ripples penetrate into the supply system side. The extent and the frequency of inverter-caused ripples depend on inverter design and motor parameters. The current analysis of the load current injected into the system shows a high THD of over 95% with a predominance of 5th and 7th harmonics. The most common three phase converter is a six-pulse unit. Its characteristic shows high 5th and 7th content.

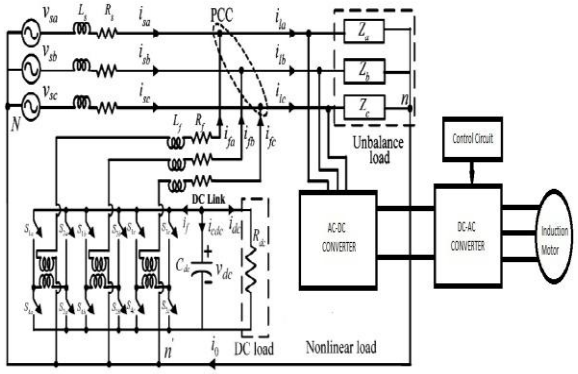

Figure 2: Proposed three phase-four wire system by using D-STATCOM with induction motor drive.

3. Proposed Control Technique

3.1 Conventional and fast-acting DC-link voltage controller

The conventional PI controller used for maintaining the dc-link voltage is shown in figure.2. To maintain the dc link voltage at the reference value, the dc link capacitor needs a certain amount of real power, which is proportional to the difference between actual and reference voltages. The power required by the capacitor can be expressed as follows:

$$P_{dc} = K_p\left(V_{dcref} - V_{dc}\right) + K_i \int (V_{dcref} - V_{dc})dt \qquad (1)$$

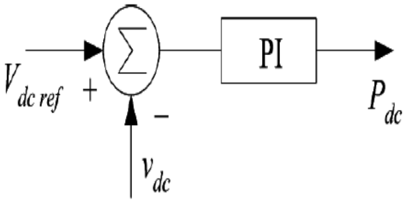

Figure 3: schematic Diagram of Conventional dc-link voltage controller.

To overcome the disadvantages of the aforementioned controller, an energy-based dc-link voltage controller is proposed. The energy required by the dc link capacitor (W_{dc}) to charge from actual voltage (V_{dc}) to the reference value (V_{dcref}) can be computed as.

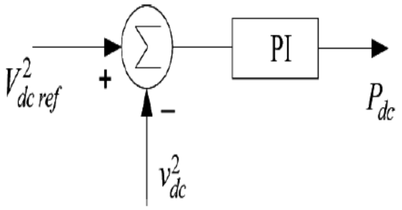

Figure 4: Schematic Diagram of fast-acting dc-link voltage controller.

$$W_{dc} = 1/2C_{dc}\left({V_{dcref}}^2 - {V_{dc}}^2\right) \qquad (2)$$

In general, the dc link capacitor voltage has ripples with double frequency, that of the supply frequency. The dc power (P_{dc}) required by the dc link capacitor is given as

$$P_{dc} = \frac{W_{dc}}{T_c} = (1/2)T_c C_{dc}\left({V_{dcref}}^2 - {V_{dc}}^2\right) \qquad (3)$$

Where is the ripple period of the dc link capacitor voltage, some control schemes have been reported in [7] and [9].However, due to the lack of integral term, there is a steady-state error while compensating the combined ac and dc loads. This is eliminated by including the integral term. The input to this controller is the error between the squares of reference and the actual capacitor voltages. This controller is shown in figure.3 and the total dc power required by the dc link capacitor is computed by the following equation:

$$P_{dc} = K_{ps}\left(V_{dcref} - V_{dc}\right) + K_{is} \int (V_{dcref} - V_{dc})dt \qquad (4)$$

The coefficients K_{ps} and K_{is} are proportional and integral gains of the proposed energy-based dc-link voltage controller. Energy based controller gives fast response compared to the conventional PI controller. Thus, it can be called a fast acting dc link voltage controller. The ease in the calculation of the proportional and integral gains is an additional advantage. The value of the proportional controller gain K_{ps} can be given as

$$K_{ps} = {C_{dc}}/{2T_c} \qquad (5)$$

For example, if the value of dc link capacitor is 2200μF and the capacitor voltage ripple period is 0.01 s, then K_{ps} is computed as 0.11 by using (5).

3.2 Proposed Shunt Controller method using PQ-Theory

The control algorithm for series active power filter (APF) is based on unit vector template generation scheme, where as the control strategy for shunt APF is discussed in this section. Based on the load on the 3P4W system, the current drawn from the utility can be unbalanced. In this paper a new control strategy is proposed to compensate the current unbalance present in the load currents by expanding the concept of single phase p—q theory (8), (9). According to this theory, a signal phase system can be defined as a pseudo two-phase system giving π/2 lead or π/2 lag, that is each phase voltage and current of the original three-phase system can be considered as three independent two phase systems. These resultant two phase systems can be represented in α—β coordinates, and thus, the p—q theory applied for balanced three phase system can also be used for each phase of unbalanced system independently. The actual load voltages and load currents are considered as α—axis quantities where as the π/2 lead load or π/2 lag voltages and π/2 lead or π/2 lag load currents are considered as β—axis quantities. In this paper π/2 lead is considered to achieve a two phase system for each phase. The major advantage of p—q theory is that it gives poor results under distorted and/or unbalanced input/utility voltages. In order to eliminate these limitations, the reference load voltage signals extracted for series APF are used instead of actual load voltages. By using the definition of three phase p—q theory, for balanced three-phase system mathematical forms taken from (6)

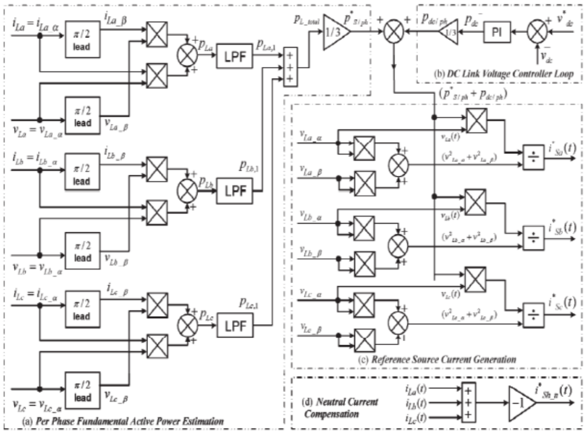

Figure 5: Shunt active filter control block diagram. (a) Proposed balanced per-phase fundamental active power estimation. (b) DC-link voltage control loop. (c) Reference source current generation. (d) Neutral current compensation.

3.3 Induction Motor

In this paper three phase induction motor as a load. The equivalent circuit for one phase of the rotor is shown in figure 6.

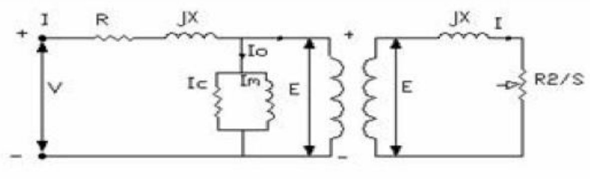

Figure 6: Steady state equivalent circuit of induction motor

The induction motor is modelled using these equations (9-12) based on the standard d-q voltages and currents (e_q', e_d', i_d, i_q)

$peq' = -wos\, ed' - \{eq' - (X - X')id\}/To'$ (6)

$ped' = -woseq' - \{ed' + (X - X')iq\}/To$ (7)

$pwm = w0\{T - Tm\}/(2Hm)$ (8)

$pid = \{Rs(vd - ed') + X'(vq - eq')\}/(Rs2 + X'2)$ (9)

$iq = \{Rs(vq - eq') - X'(vd - ed')\}/(Rs2 + X'2)$ (10)

The torque can be calculated using

$T = ed'id + eq'iq$

where‘s’ is the slip, T is torque

$s = (wm - wo)/ wm$

4. Modelling & Simulation Results

Various component models of the system are developed and simulated in MATLAB environment using Simulink and SPS toolboxes. The performance of the system is studied with shunt compensator using fast-acting dc-link voltage controller. The load and the compensator are connected at the PCC. The ac load consists of a three-phase unbalanced load and a three-phase diode bridge rectifier feeding a highly inductive R-L load. A dc load is realized by an equivalent resistance (Rdc) as shown in the figure. The dc load forms 50% of the total power requirement.

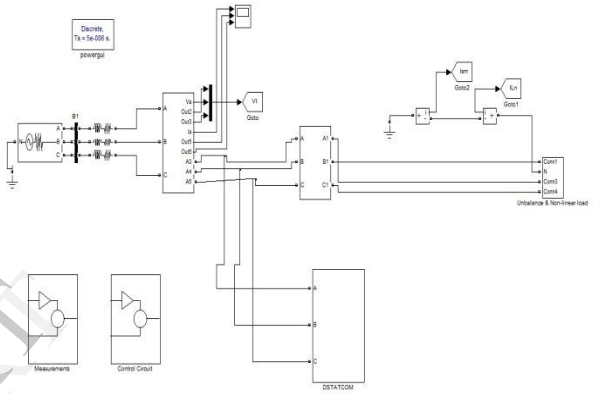

Figure 7: Modelling Circuit of fast-acting dc-link voltage controller with D-STATCOM under non-linear and unbalance loads.

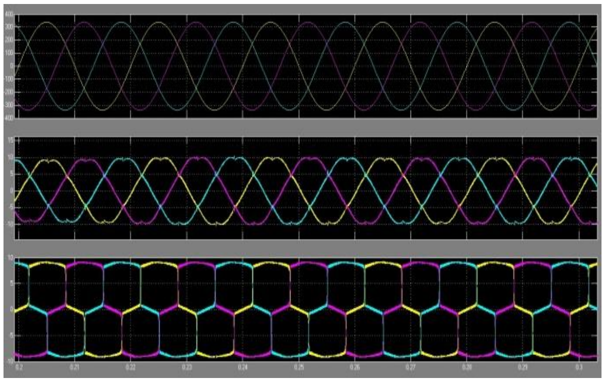

Figure 8: Simulation results (a) Supply Voltage, (b) Source Current, (c) Load Current.

The performance of the fast acting dc link voltage controller is tested by using the transient load used in the previous section. Figure 10 shows the source currents during the transients in load by using this fast acting dc link voltage controller. From the close observation of the figure, it is found that the response time is very less compared to that of the conventional dc link voltage controller. Though, in simulation studies, the fast acting voltage controller corrects the actual dc link voltage in a half cycle, the experimental results do not fully validate the same. This is due to the use of the mechanical switch for the change of load, which cannot connect/disconnect the load in all three phases simultaneously at the instants t_1 and t_2 due to other non-idealities in the system.

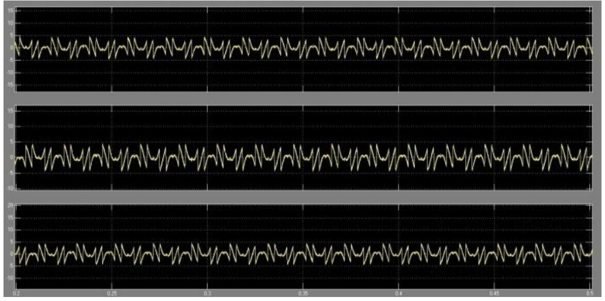
Figure 9: Three Phases Compensated Current

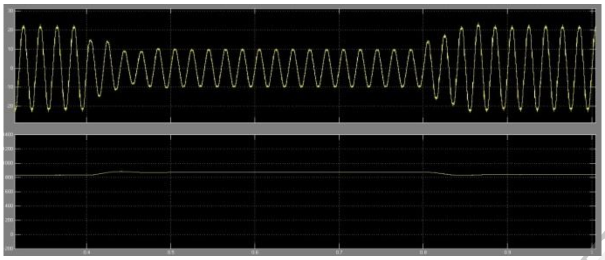
Figure 10: Transient response of the fast-acting controller. (a) Compensated source current in phase a. (b) DC-Link voltage.

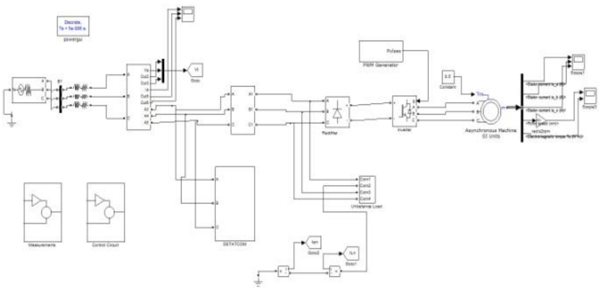
Figure 11: Modelling Circuit of fast-acting dc-link voltage controller with D-STATCOM under Induction Motor.

Fig.11 shows the response of DSTATCOM with Induction motor drives. It shows three–phase supply voltages (vs), supply currents (is), ‘a’ phase load current (ila,), DSTATCOM currents (ica, icb, icc) and dc link voltage (Vdc) along with reference value and torque and speed of the motor. It is observed that DSTATCOM is able to reduce harmonic content from 96.25% in load current.

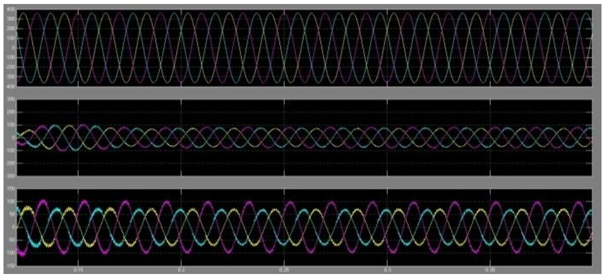
Figure 12: Simulation results under Induction motor (a) Supply Voltage, (b) Source Current, (c) Load Current.

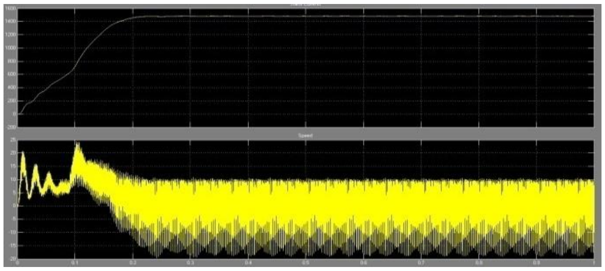
Figure 13: Induction motor (a) rotor speed, (b) Electromagnetic torque.

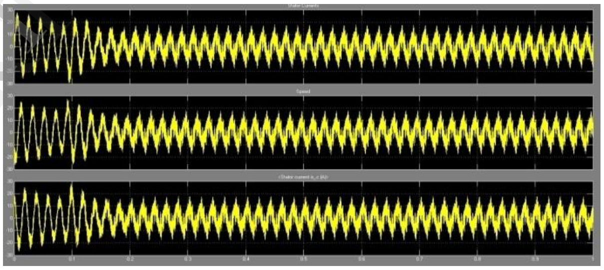
Figure 14: Induction motor Stator current.

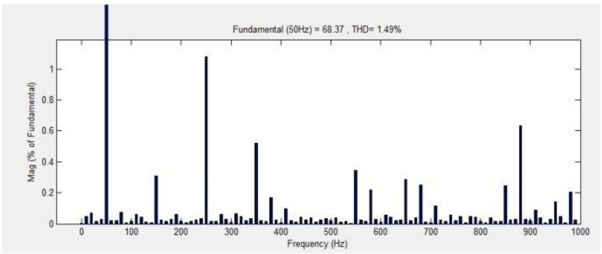

Figure 15: THD in load current.

Harmonic spectra and waveforms for the load current are shown are shown in Figure 15 and Figure 12(c). It is observed that DSTATCOM is able to reduce the level of harmonics in load current is 1.9% THD.

5. Conclusion

The application of DSTATCOM by using fast-acting dc link voltage controller as a compensator has been demonstrated with induction motor drive. Models have been developed for an adjustable speed drive system feeding induction motor. This harmonic injection in the neighboring loads can create problems. DSTATCOM in the form of a 3-leg VSI bridge has been modelled and controlled for harmonic reduction. Simulation analysis of the load currents with nonlinear loads and unbalance loads, the efficacy of the proposed controller over the conventional dc-link voltage controller is established through the MATLAB/simulink simulation under transient conditions. It is concluded that such a compensator can be effectively designed to meet the IEEE-519 standard for regulating the level of harmonics below 5% limit with speed drives.

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