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Original Article

Application of PI controller based DSTATCOM for improving the power quality in a power system network with induction furnace load

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Abstract

This paper presents the application of DSTATCOM in a distribution network with induction furnace load. Induction furnace is one of the common types of load used in industries like the steel industry. The problem with the induction furnace load is the generation of appreciable amount of harmonic distortion. This distortion results due to the design and operation of the induction furnace. This harmonic distortion can even affect the performance of other loads connected in the system. DSTATCOM is a shunt connected custom power device to improve the power quality. It does so by injecting a compensating current into the power system network. In this paper, the SIMULINK model representing the application of DSTATCOM with PI controller for reducing the harmonic distortion of the distribution network with induction furnace load is presented.

Keywords: distribution static synchronous compensator (DSTATCOM), induction furnace, harmonic distortion, power quality

1. Introduction

With the deregulation of the electric power energy market, power quality (Sankaran, 2002) has become an important issue of concern for both electric utilities companies and consumers. In this environment, electric utilities are expected to compete with each other for the customer. The power quality (Bollen, 2003) has serious economic implications for consumers, utilities and electrical equipment manufacturers. Modern industry involves the use of nonlinear and electronically switched devices in distribution systems. Integration of non-conventional generation technologies such as fuel cells, wind turbines, and photo-voltaic with utility grids often requires power electronic interfaces. These devices contribute the problems of power quality such as voltage fluctuations, flicker, harmonics, and asymmetries of voltages. Moreover, modern high-tech industrial equipments are more sensitive to these power quality problems. Therefore, there is a stringent need of better quality power supply because acceptable power quality levels if not achieved, may result in costly downtimes. In view of this, the concept of custom power was first introduced by Hingorani (1995).

Induction furnace (Dugan *et al.*, 1999) is one of the common loads in many industries like the steel industry. The problem with the induction furnace (Jabbar *et al.*, 2008) is that it deteriorates the power quality by introducing harmonic distortion in the power system network. The unbalance load currents with large reactive components results in voltage fluctuations and imbalance due to the system impedance. Its presence also affects the performance of other electric equipment connected in the power system network (Dugan *et al.*, 1999, Jabbar *et al.*, 2008). It is due to the fact that it produces very high levels of harmonic distortion in the power system network. So, it is of utmost necessity to take proper

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measures to reduce this power quality problem.

The one possible solution to the above-mentioned problem is the application of a DSTATCOM, which is a distribution static synchronous compensator. The load compensation by DSTATCOM helps to maintain unity power factor load while balancing the load. The general theory about the DSTATCOM operation and its main components is discussed in next part.

2. DSTATCOM

DSTATCOM (Jung *et al.*, 2002) is a voltage source converter (VSC) that is connected in shunt with the distribution system by means of a tie reactance connected to compensate the load current. In general, a coupling transformer is installed between the distribution system and the DSTATCOM for isolating the DSTATCOM from the distribution system. In addition, the device needs to be installed as close to the sensitive load as possible to maximize the compensating capability. Being a shunt connected device, the DSTATCOM mainly injects reactive power to the system. The role of DSTATCOM is specifically appreciated in case of a weak AC system (Ghosh *et al.*, 2003).

The structure of DSTATCOM along with its operating modes is shown in Figure 1. The main components of DSTATCOM are – a VSC (voltage source converter), controller, filter, and energy storage device. The system scheme of DSTATCOM is shown in Figure 2. These are briefly described as follows:

Isolation transformer: It connects the DSTATCOM to the distribution network and its main purpose is to maintain isolation between the DSTATCOM circuit and the distribution network.

Voltage source converter: A voltage source converter consists of a storage device and switching devices, which can generate a sinusoidal voltage at any required frequency, magnitude and phase angle. In the DSTATCOM application, this temporarily replaces the supply voltage or generates the part of the supply voltage which is absent and injects the compensating current into the distribution network depending upon the amount of unbalance or distortion. In this work, an IGBT is used as the switching device.

DC charging unit: This unit charges the energy source after a compensation event and also maintains the dc link voltage at the nominal value.

Harmonic filters: The main function of harmonic filter is to filter out the unwanted harmonics generated by the VSC and hence, keep the harmonic level within the permissible limit.

Energy storage unit: Energy storage units like flywheels, batteries, superconducting magnetic energy storage (SMES) and super capacitors store energy. It serves as the real power requirements of the system when DSTATCOM is used for compensation (Molina *et al.*, 2006). In case, no energy source is connected to the DC bus, then the average power exchanged by the DSTATCOM is zero assuming the switches, reactors, and capacitors to be ideal.

Figure 3 represents the schematic scheme of DSTATCOM in which the shunt injected current I_{sh} corrects the voltage sag by adjusting the voltage drop across the

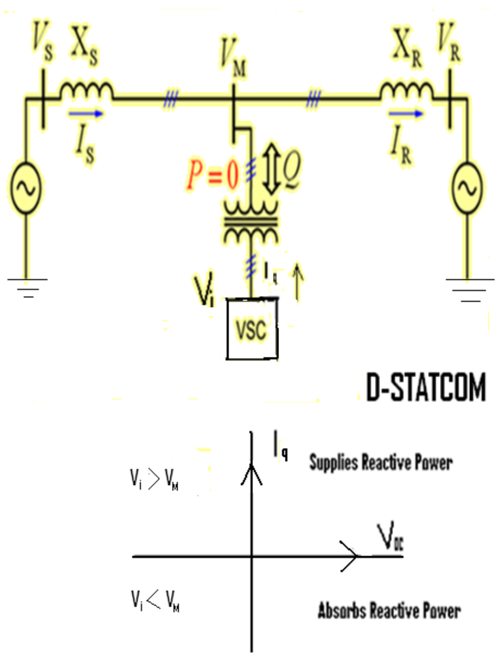

Figure 1. Structure and operating modes of DSTATCOM.

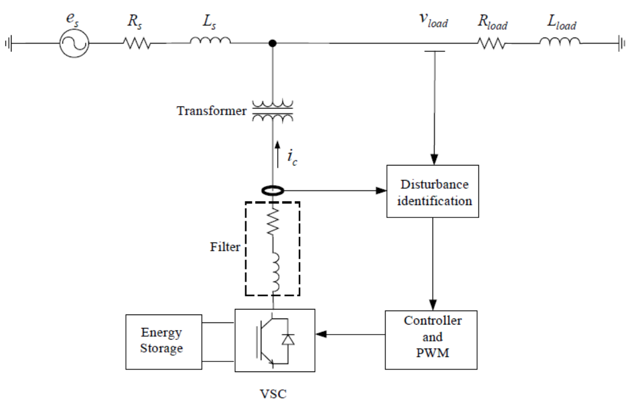

Figure 2. System scheme of DSTATCOM.

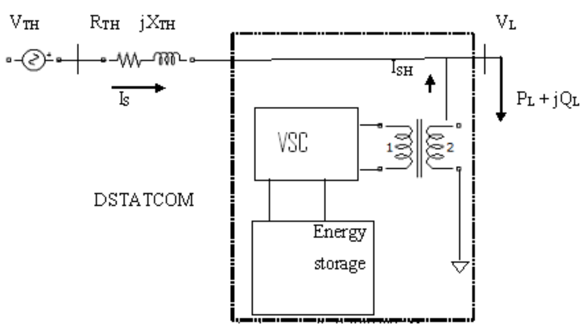

Figure 3. Schematic diagram of DSTATCOM.

system impedance Z_{th}. The value of I_{sh} can be controlled by adjusting the output voltage of the converter. The shunt injected current I_{sh} (Kumar *et al.*, 2007) is given by

$$I_{sh} = I_L - I_S = I_L - \frac{(V_{th} - V_l)}{Z_{th}} \quad (1)$$

$$I_{sh} < \eta = I_L < \theta - \frac{V_{th}}{Z_{th}} < (\delta - \beta) + \frac{V_l}{Z_{th}} < -\beta \quad (2)$$

The complex power injection of the DSTATCOM can be expressed as:

$$S_{sh} = V_L I_{sh}^{*} \quad (3)$$

It may be mentioned that the effectiveness of the DSTATCOM in correcting voltage sag depends on the value of Z_{th} or fault level of the load bus. When the shunt injected current I_{sh} is kept in quadrature with $V_{L,}$ the desired voltage correction can be achieved without injecting any active power into the system. On the other hand, when the value of I_{sh} is minimized, the same voltage correction can be achieved with minimum apparent power injection into the system.

The contribution of the DSTATCOM to the load bus voltage equals the injected current times the impedance seen from the device, which is the source impedance in parallel with the load impedance. The ability of the DSTATCOM to compensate the voltage dip is limited by this available parallel impedance. DSTATCOM is utilized to eliminate the harmonics from the source currents and also balance them (Blazic *et al.*, 2004; Blazic *et al.*, 2006) in addition to providing reactive power compensation. It helps to reduce the voltage fluctuations at the PCC (point of common coupling). Voltage dips can be mitigated by DSTATCOM, which is based on a shunt connected voltage source converter. VSC with pulse-width modulation (PWM) offers fast and reliable control for voltage dips mitigation. The topology of the DSTATCOM connected at distribution level is shown in Figure 4.

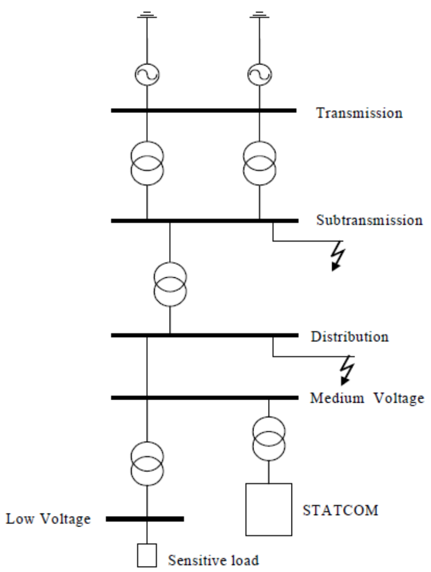

Figure 4. Topology of the power system with DSTATCOM.

In the proposed model, the application of DSTATCOM to improve the power quality in a distribution network with induction furnace load is investigated.

3. Control Philosophy

The SIMULINK model representing the compensation using DSTATCOM of a distribution network with induction furnace load is investigated in this work. The SIMULINK model of induction furnace load is taken from Icrepq (2003). Load current is sensed and passed through a sequence analyzer. The magnitude of load current is compared with reference current. Pulse width modulated (PWM) control technique is applied for inverter switching so as to produce a three phase 50 Hz sinusoidal current through the load terminals. Chopping frequency is kept in the range of a few KHz. PI controller is used with the IGBT inverter (shown in Figure 5) to reduce the harmonic distortion due to the induction furnace. Output from the controller block is in the form of an angle δ that is used to introduce an additional phase-lag/lead in the three-phase voltages, as shown in Figure 6.

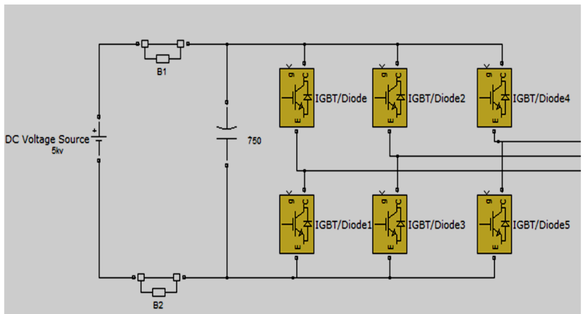

Figure 5. Basic inverter structure.

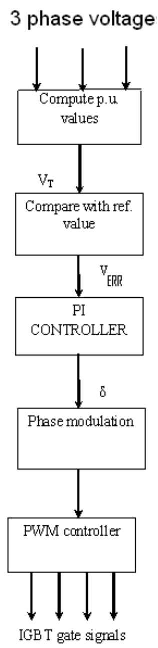

Figure 6. Control algorithm of DSTATCOM with PI controller.

The sinusoidal signal $V_{control}$ is phase-modulated by means of the angle δ.

i.e., $V_A = \text{Sin}(\omega t + \delta)$ (4)

$V_B = \text{Sin}(\omega t + \delta - 2\pi/3)$ (5)

$V_C = \text{Sin}(\omega t + \delta + \pi/3)$ (6)

The modulating angle is applied to the PWM generators in phase A. The angles for phases B and C are shifted by 240º and 120º, respectively. In the PWM generators, the sinusoidal signal, $V_{control}$, is phase modulated by means of the angle δ or delta as represented in the Figure 7. The pulses generated by PWM for VSC valves are represented in Figure 8.

4. Parameters of the Test System

Simulation model of the test system is shown in Figure 9. System parameters of the test system are given in Table 1. An induction furnace load is connected in the system. The secondary winding feeds a 12-pulse thyristor-controlled rectifier and the tertiary winding another identical rectifier. Both rectifiers are connected in series including filtering coils as shown in the SIMULINK model of induction furnace in Figure 10. Two parallel feeders are drawn from the source. In one feeder, induction furnace is fed without any compensating device, while in the second one, induction furnace is fed through the same source but with DSTATCOM in the circuit.

Table 1. System parameters.

S. No.	System Quantities	Standards
1	Source	Yn, 3-phase, 25 kV, 50 Hz
2	Inverter parameters	IGBT based, 3 arms, 6 Pulse, Carrier frequency = 475 Hz
3	PI controller	Kp = 0.5, Ki = 50, Sample time = 50 µs
4	Transformer 1	Δ/Y/Y 25/11/11 kV
5	Transformer 2	Δ/Yg 25/11 kV
6	Transformer 3	Δ/Yg 25/11 kV

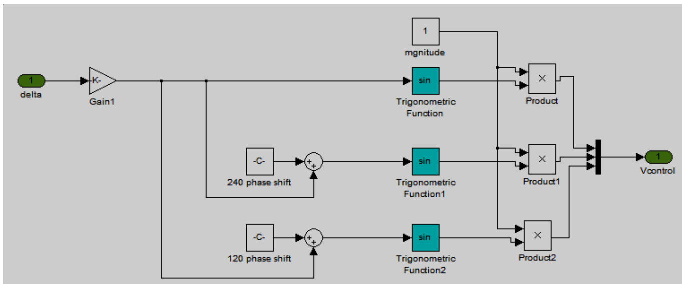

Figure 7. Phase-modulation of the control angle δ.

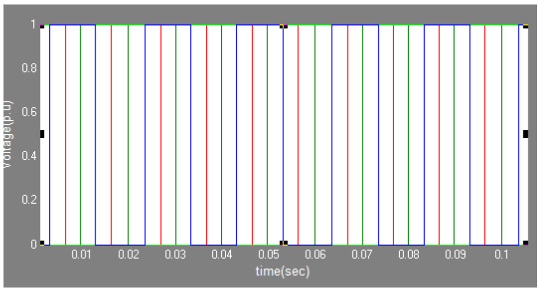

Figure 8. Pulses generated by PWM for VSC valves.

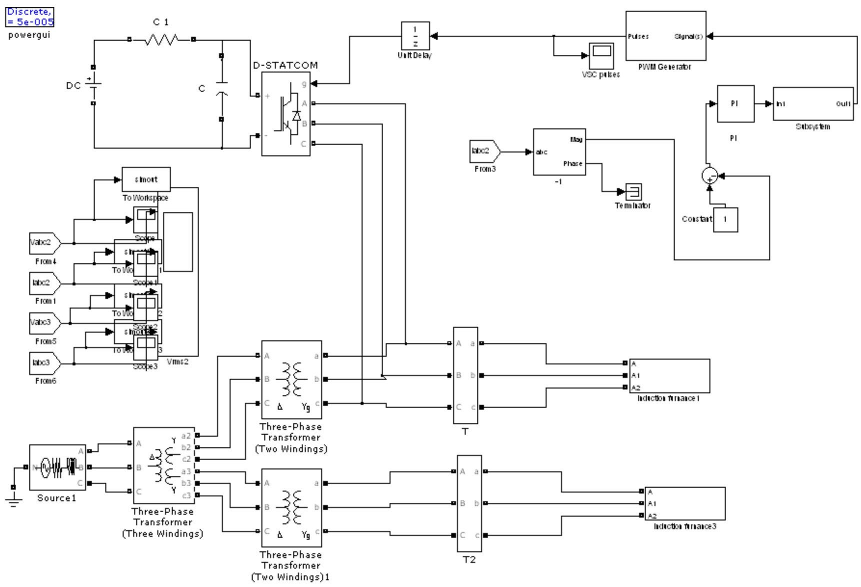

Figure 9. DSTATCOM test model.

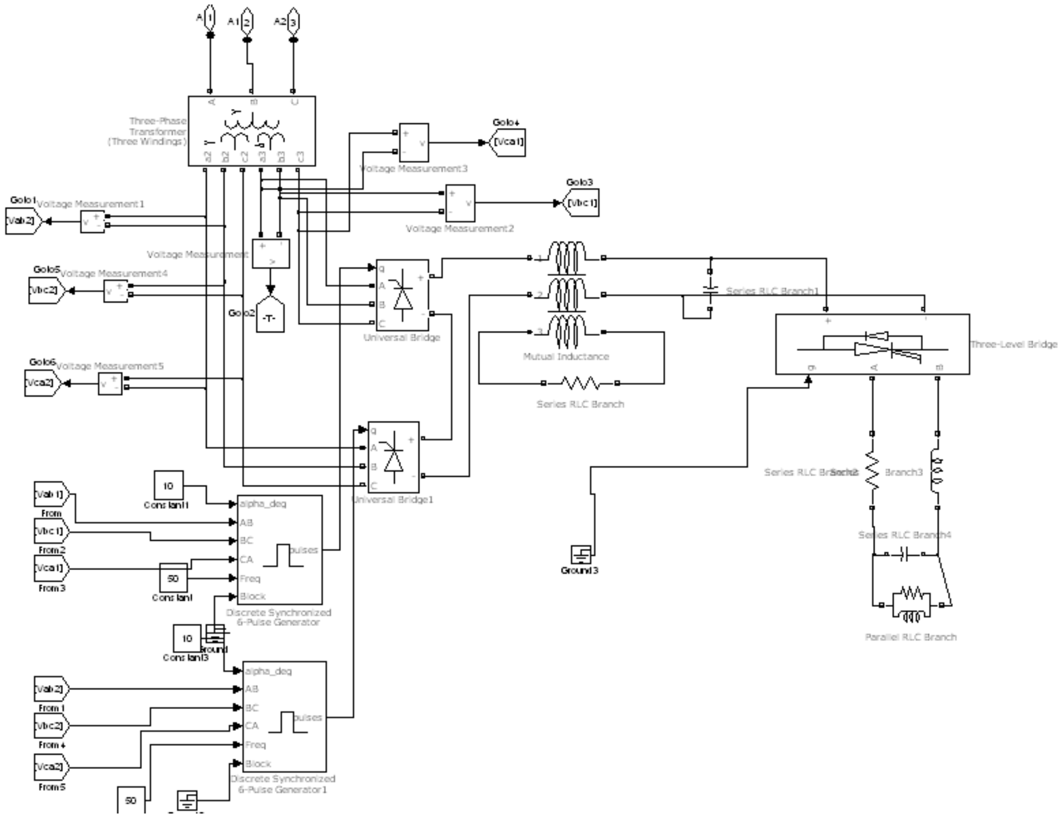

Figure 10. Induction furnace model.

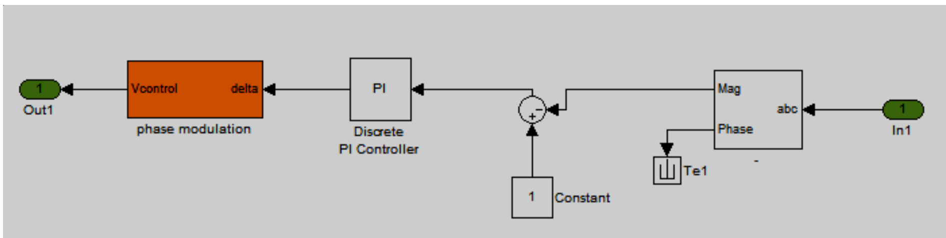

Figure 11. SIMULINK model of PI controller.

Load current is sensed and passed through a sequence analyzer. The controller used in the proposed test model is PI controller. The SIMULINK model of PI controller is shown in Figure 11. The load currents through and load voltages across the induction furnaces in both the feeders are monitored and studied.

5. Simulation Results

The simulation is performed on the test system with induction furnace load using MATLAB SIMULINK. The simulations are performed for the cases: (i) without DSTATCOM and (ii) with DSTATCOM - in the circuit. The system performance is analyzed. These cases are summarized below:

Case I: In the distribution network with induction furnace, the current initially takes time to have a steady value and is distorted as shown in Figure 12. Moreover, the FFT analysis of the load current wave as shown in Figure 13 indicates the presence of current harmonics and its THD level observed is 152.50% at 50 Hz fundamental frequency which is relatively high.

Case II: In the second feeder of the distribution network, the system is compensated using DSTATCOM. In this case, the current wave takes no time to attain its steady value and the distortion in the wave is negligible as shown in Figure 14. Moreover, the FFT analysis of the load current wave as shown in Figure 15 indicates that the current harmonics are almost compensated and its THD level observed is only 11.78% at 50 Hz fundamental frequency.

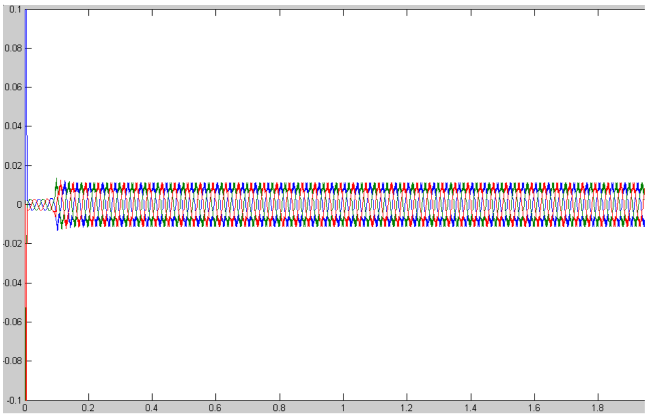

Figure 12. Load current without DSTATCOM.

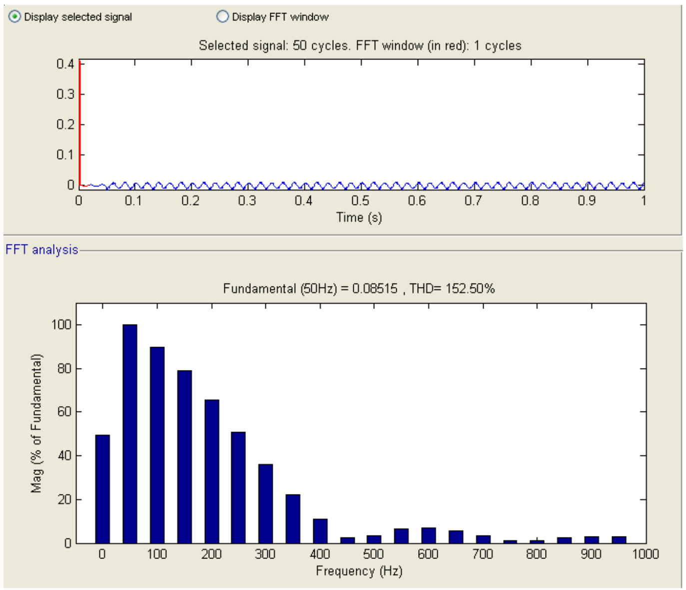

Figure 13. Current harmonics without DSTATCOM.

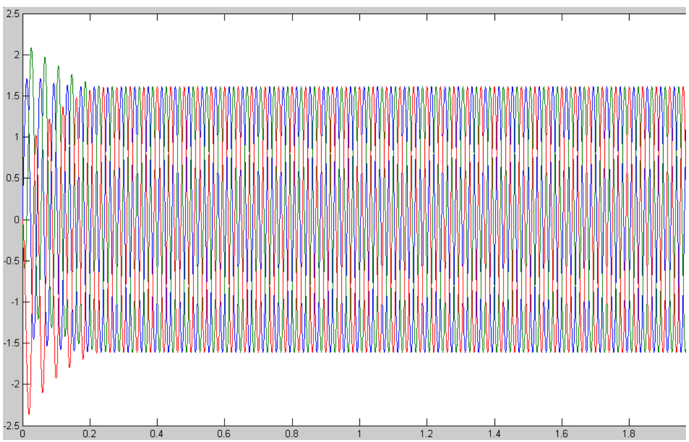

Figure 14. Load current with DSTATCOM.

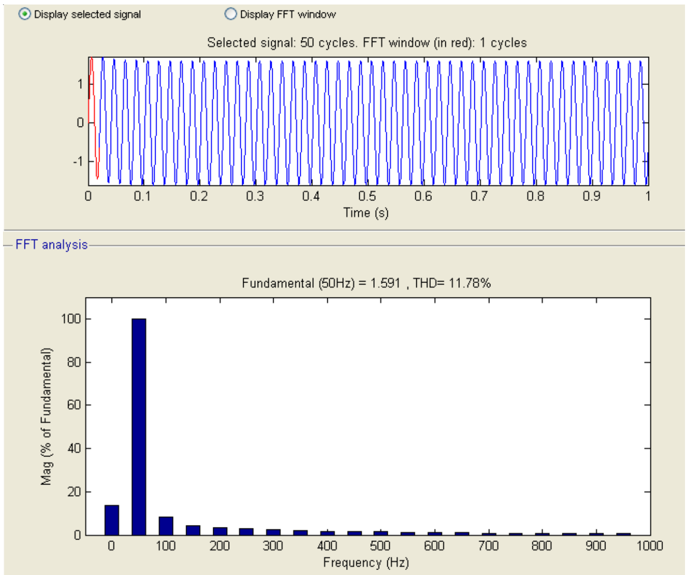

Figure 15. Current harmonics with DSTATCOM.

6. Conclusions

In this paper, the behavior of induction furnace is investigated. The induction furnace introduces appreciable amount of current harmonics into the distribution system network, which can even affect the performance of other equipments connected in the network. Also, the effectiveness of DSTATCOM with PI controller to reduce the current harmonics introduced by the induction furnace load is also investigated. The proposed DSTATCOM test model effectively reduces the current harmonics injected by the induction furnace load in to the distribution network.

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