

Mitigation of Harmonics in Voltage flicker Compensation using STATCOM

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Abstract

Voltage flicker and harmonics are the power quality problems which are introduced to the power system as a result of nonlinear and stochastic behavior of the arc furnace operation. To analyze harmonic and flicker generated by an arc furnace, accurate arc furnace models are needed. Due to the latest achievement in the semiconductor industry and consequently the emergency of the compensators based on voltage source converters, FACTS devices have been gradually noticed to be used for voltage flicker compensation.

This paper covers the contrasting approaches; dealing with the voltage flicker compensation and mitigation of harmonics and assessing the related results in details. Initially the voltage flicker compensation using FCTCR (Fixed Capacitor Thyristor controlled Reactor) was simulated and studied the harmonics level during compensation. Secondly, the compensation for the static compensator (STATCOM) of six pulses and twelve pulses has performed. In this case injection of harmonics into the system caused some problems which were later overcome by using 12-pulse assignment of STATCOM with RLC filters. The obtained results show that STATCOM is very efficient and effective for the compensation and mitigation of voltage flicker and harmonics all the simulation has been performed on the MATLAB Software.

Keywords: Power quality, Voltage flicker, Static synchronous Compensator (STATCOM)

I. Introduction

Harmonics, inter-harmonics, voltage flicker and unbalance are the power quality problems which are introduced to the power system as a result of nonlinear and stochastic behavior of the arc furnace operation. The nonlinear voltage-current characteristic of the arc can cause harmonic currents which when circulating by the net can produce harmonic voltages which can affect to other users.

Voltage Flicker is the disturbance of lightning induced by voltage fluctuations. Very small variations are enough to induce lightning disturbance for human eye for a standard 230V, 60W coiled-coil filament lamp. The disturbance becomes perceptible for voltage variation frequency of 10 Hz and relative magnitude of 0.26%

Electric arc furnace, the main generator of voltage flicker, behaves in the form of a constant reactance and a variable resistance. The transformer-reactance system is modeled as a lumped reactance, a furnace reactance (included connection cables and busses) and a variable resistance [1] which models the arc. Connecting this type of load to the network produces voltage variation at the common point of supply to other consumers.

Voltage flicker mitigation depends on reactive power control. To limit the effects of these disturbing loads, compensation devices which are nothing but FACTS devices have usually to be connected for the compensation of the reactive power fluctuations which causes this voltage flickering [2]. Among all the FACTS devices, Static VAR Compensator (SVC) such as Thyristor Switched Capacitor TSC, Thyristor Controlled Reactor (TCR), and FCTCR are the most frequently used devices for reduction of voltage flickering, but they have problems such as injecting a large amount of harmonics. Beyond these, STATCOM (Shunt Structure) which is SVC device provides effective voltage flicker mitigation in power system which has the higher potential to be exceptionally reliable for voltage flickering and in reducing the THD [3]. The concept of instantaneous reactive power components is used in the controlling system which is nothing but 'd_q' components. A 6-Pulse converter based STATCOM [4] was used to mitigate the voltage flicker. With respect to the harmonic problem, a novel 12-pulse converter based STATCOM was designed to minimize the load harmonics and mitigate the propagation of voltage flicker in to the system. The obtained results clearly confirmed the efficiency of the 12-Pulse converter based STATCOM is more and it gives effective voltage flicker mitigation and THD reduction.

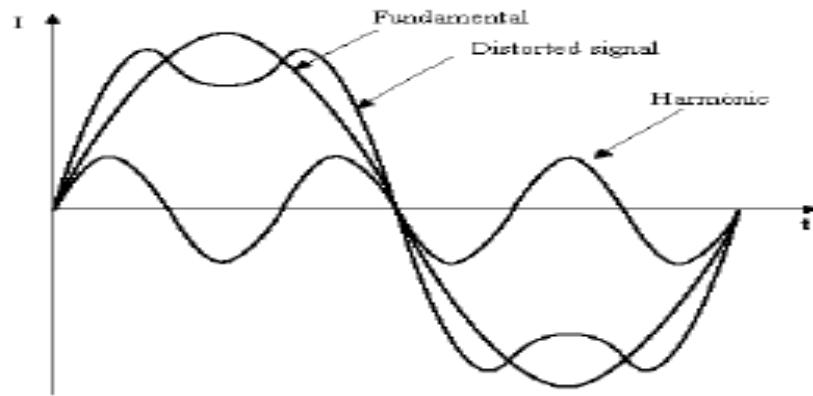
A new technique based on a novel control algorithm, which extracts the voltage disturbance to suppress the voltage flicker, is presented in this paper. The technique is to use STATCOM [1-4] for voltage flicker compensation to overcome the aforementioned problems related to other techniques. The concept of instantaneous reactive power components is used in the controlling system. A two-bus system is exploited to fulfill the investigation of the presented procedure. All the simulations are done according to the usage of MATLAB software [5]. The related compensation was performed first by FCTCR. Afterwards, a 6-pulse voltage-source converter STATCOM was used to compensate for the voltage flicker. With respect to the harmonic problem in this stage, a 12-pulse voltage-source converter STATCOM was designed to isolate load harmonics and mitigate the propagation of voltage flicker

to the system in the next stage. The obtained results clearly confirmed the efficiency of the 12-pulse STATCOM to complete the voltage flicker compensation and reduces the THD levels.

II. Harmonics-Definitions and related Parameters

A. Harmonic definition

According to EN 50160, a harmonic voltage is a sinusoidal signal whose frequency is multiple of the basic voltage frequency. The voltage or current waveforms in one point of the electric system can have the aspect of the figure 1 distorted signal. Analyzing the signals in this figure we can say that the distorted signal is the result of the addition of the harmonic with the basic component. In this example the harmonic frequency is Figure 1. Three times the basic frequency.



According to French mathematician Joseph Fourier, any periodic signal, can be decomposed in an sum of pure sine waves in which the frequency of each sinusoid is an integer multiple of the fundamental frequency of the distorted wave.

$$y(t) = Y_0 + \sum_{n=1}^{n=\infty} Y_n \sqrt{2} \sin (n\omega t - \phi_n) \quad 1$$

Where Y_0 represents the DC component amplitude that in steady state is normally null. The Y_n parameter represents the rms value of the order n harmonic, while ϕ_n represents the harmonic angle phase for $t = 0$. Therefore, we can define the harmonics as being sinusoidal oscillations whose frequency is multiple of the fundamental frequency.

B. Total harmonic distortion (THD)

There are several measures commonly used for indicating the harmonic content of a waveform with a single number. One of the most common is total harmonic distortion (THD). Two equations exist to calculate the THD

$$THD_f = \frac{\sqrt{(h_2)^2 + (h_3)^2 + \dots + (h_n)^2}}{h_1} \cdot 100\% \quad 2$$

$$THD_r = \frac{\sqrt{(h_2)^2 + (h_3)^2 + \dots + (h_n)^2}}{\sqrt{(h_1)^2 + (h_2)^2 + (h_3)^2 + \dots + (h_n)^2}} \cdot 100\% \quad 3$$

Where h_1, h_2, \dots, h_n represents the harmonics rms value for order 1, 2, ..., n. THD_r represents the total harmonic distortion relatively to the total signal, in this case, $0 < THD_r < 1$, while THD_f represents the total harmonic distortion relatively to the fundamental component, this definition is used by IEC 61000-2-2; in this case values above 100% are possible to the THD_f .

III. Controlling System

The concept of instantaneous reactive power is used for the controlling system. Following this, the 3-phase voltage upon the use of the park presented by Akagi [6] has been transformed to the synchronous reference frame (Park or dq0 transformation). This transformation leads to the appearances of three instantaneous space vectors: V_d on the d-axis (real or direct axis), V_q on the q-axis (imaginary or quadrature axis) and V_0 , from the 3-phase voltage of V_a, V_b and V_c . The related equations of this transformation, expressed in the MATLAB software, are as follows:

$$V_d = \frac{2}{3} (V_a \sin(\alpha t) + V_b \sin(\alpha t - \frac{2\pi}{3}) + V_c \sin(\alpha t + \frac{2\pi}{3})) \quad 4$$

$$V_q = \frac{2}{3} (V_a \cos(\alpha t) + V_b \cos(\alpha t - \frac{2\pi}{3}) + V_c \cos(\alpha t + \frac{2\pi}{3})) \quad 5$$

$$V_0 = \frac{1}{3} (V_a + V_b + V_c) \quad 6$$

A dynamic computation shows that the voltage oscillations in the connecting node of the flicker-generating load to the network are created by 3 vectors: real current (i_p), imaginary current (i_q) and the derivative of the real current with respect to time. In general, for the complete voltage flicker compensation, the compensating current (i_c) regarding the currents converted to the dq0 axis is given as [4-6]:

$$i_c = f(i_q + i_p \frac{R}{X} f + \frac{1}{\omega} \frac{di_p}{d\omega} f + k) \quad 7$$

Where R and X are the synchronous resistance and reactance of the line and f is the correcting coefficient. The constant k is also used to eliminate the average reactive power of the network [7]. If the compensation current of the above equation is injected to the network, the whole voltage flicker existing in the network will be

eliminated. Regarding the equation, related to the dq-transformation of the 3-phase-voltages to the instantaneous vectors, it is obvious that under the conditions of accessing an average voltage flicker, V_d and V_0 , the obtained values are close to zero and V_q is a proper value adapting to the voltage oscillation of the network. This state of the 3-phase voltage flicker is presented in the following figures (simulated in the MATLAB Simulink package)

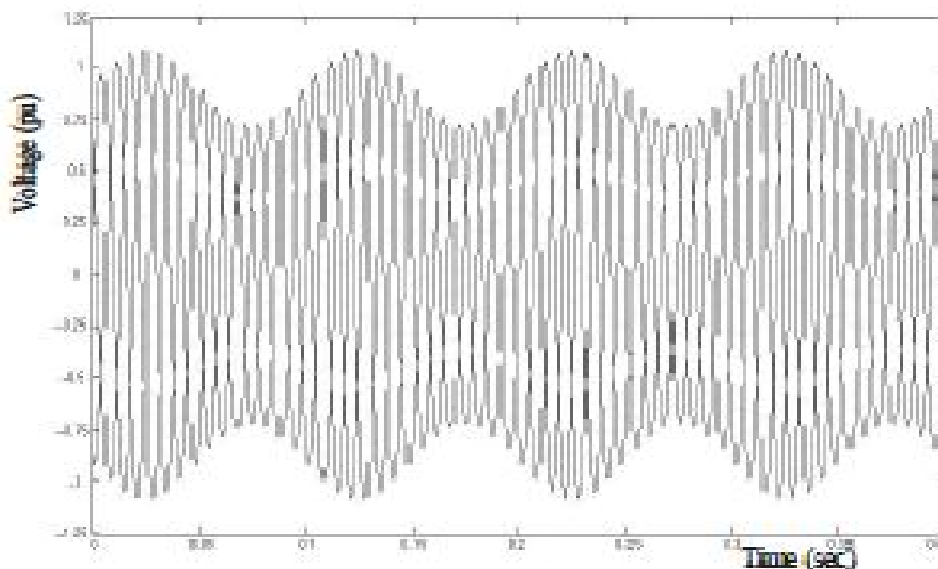


Figure 2

Then, we may conclude that the decrease of the voltage flicker of the network and the compensating control to decrease the voltage flicker can be limited only based on the amount of the imaginary component of the instantaneous voltage (V_q).

IV. Compensation System

A typical two-bus power system shown in figure 3 is simulated in MATLAB for this study. It can be seen that the voltage oscillation was produced by a 3-phase flicker source connected to the main bus-bar.

First, using a 3-phase converter to dq0, the instantaneous vectors V_d , V_q and V_0 , are evaluated from the output 3-phase voltages whose equations were explained in the previous section. Then, from the obtained instantaneous components, sampling is taken place. Since the controlling system uses just V_q to control the STATCOM, a de-multiplexer is used to extract V_q voltage from V_d and V_0 . The obtained V_q is then entered as an input to the controlling function upon the MATLAB software. The controlling function generates the amount of conducting angle, needed for the GTOs of the STATCOM. A phase shifting block is designed to control the appropriate phase angle of the exerting pulses upon the GTOs of the STATCOM. The outputs of this unit are entered into the STATCOM as inputs.

V. Simulation And Analysis of the Results

In order to investigate the influence of the STATCOM as an effective compensation device for voltage flicker, three types of compensators are simulated in MATLAB. First, the voltage flicker compensation is adopted using FCTCR. Then a 6-pulse voltage-source converter STATCOM is used and finally for a complete voltage flicker mitigation a 12-pulse voltage-source converter STATCOM is designed. The compensation techniques and their results are presented in this section.

1) Compensation using FCTCR

In this stage a FCTCR; one of the FACTS devices being controlled by a thyristor is used to mitigate the voltage flickering. In this case, the exerted voltage flicker into the system and the compensated voltage are shown in figures5

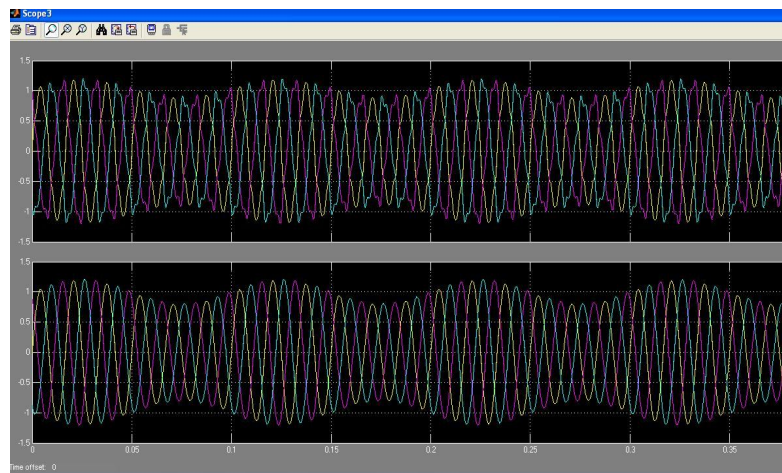


Figure 4

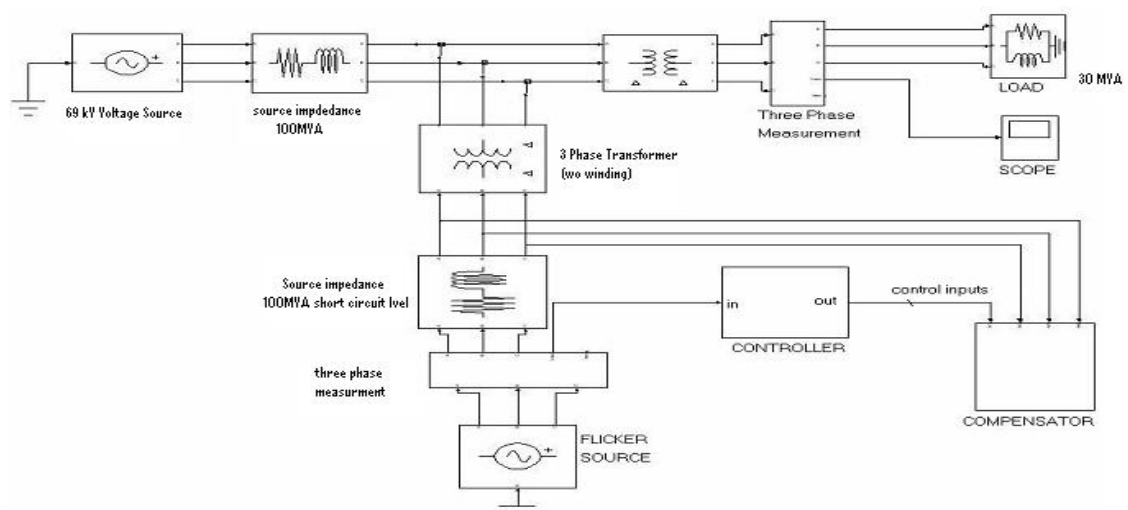


Figure 3 Two bus System

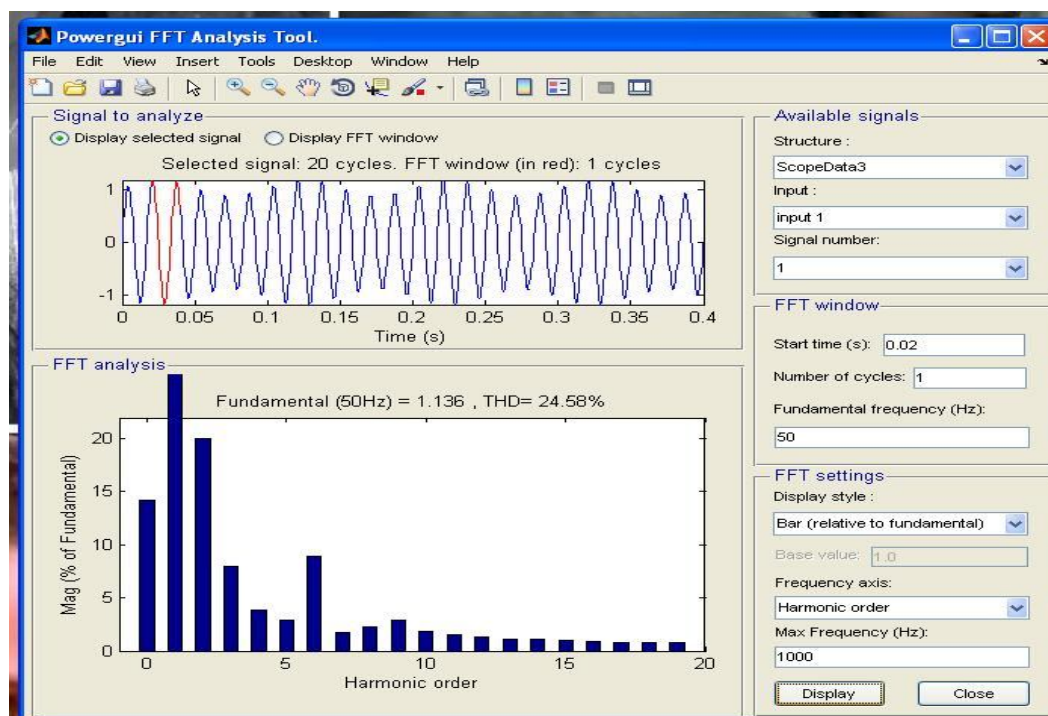


Figure 5

It is obvious from the output voltage waveform controlled by FCTCR that this technique achieves a reasonable level of mitigation but is incapable to be perfectly successful. Furthermore, in spite of using a snubber circuit [8-10] to eliminate voltage spikes caused by the huge TCR reactor switching, there are still distortions in the output waveform.

During the compensation of voltage flicker THD level is also very important that is measured during process. THD is 24.58% by using FCTCR as shown in figure 5

2) Compensation using 6-pulse voltage-source converter STATCOM

The circuit diagram of a three-phase 6-pulse voltage source converter STATCOM is shown in figure 6. Six valves compose the converter and each valve is made up of a GTO with a diode connected in anti-parallel. In this type of STATCOM, each GTO is fired and blocked one time per line voltage cycle. In this case, each GTO in a single branch is conducted during a half-cycle (180 degree) of the fundamental period. The combined pulses of each leg have a 120 degrees phase difference to produce a balanced set of voltages. By adjusting the conducting angle of the GTOs, the generated voltage and then the injected or absorbed power of the STATCOM are controlled [11-13]. In this respect, the compensated output voltage by 6-pulse voltage-source converter STATCOM is presented in figure 7.

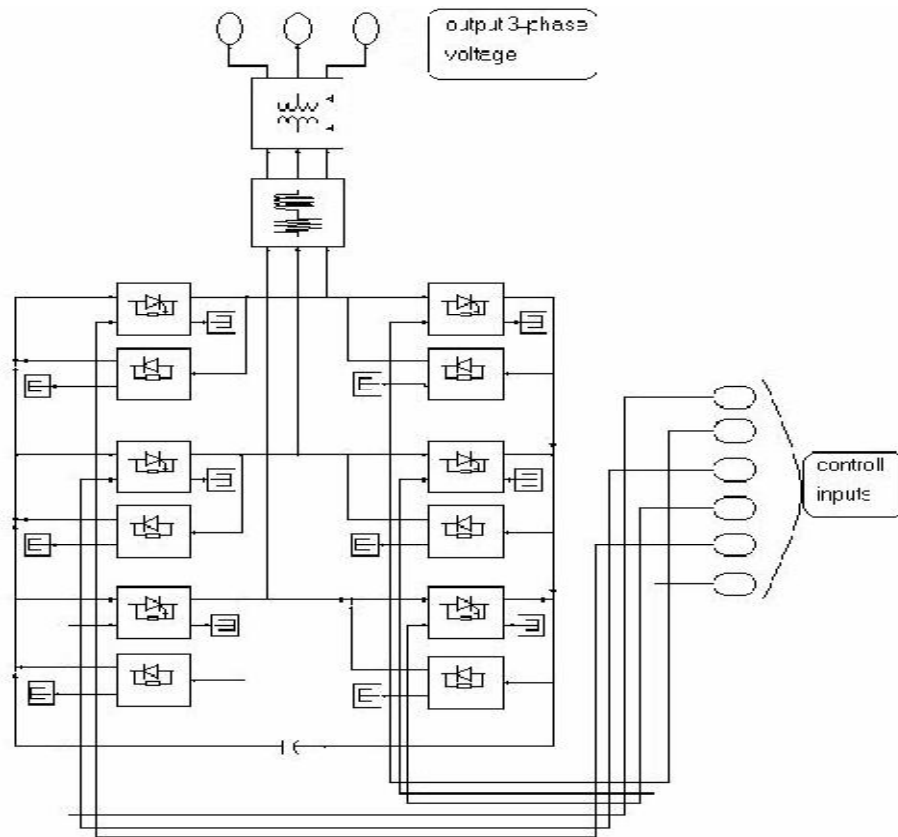


Figure 6

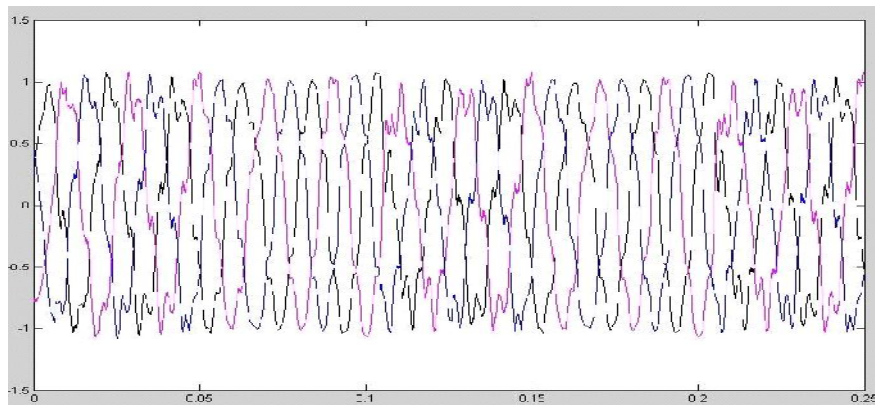


Figure 7

It can be seen that the mitigation effects of this compensator is better than that of FCTCR and effectively mitigate the voltage flicker; but the output voltage waveform has some considerable harmonics. THD level is 7% has been shown in figure 9 during flicker compensation by using 6pulse statcom.

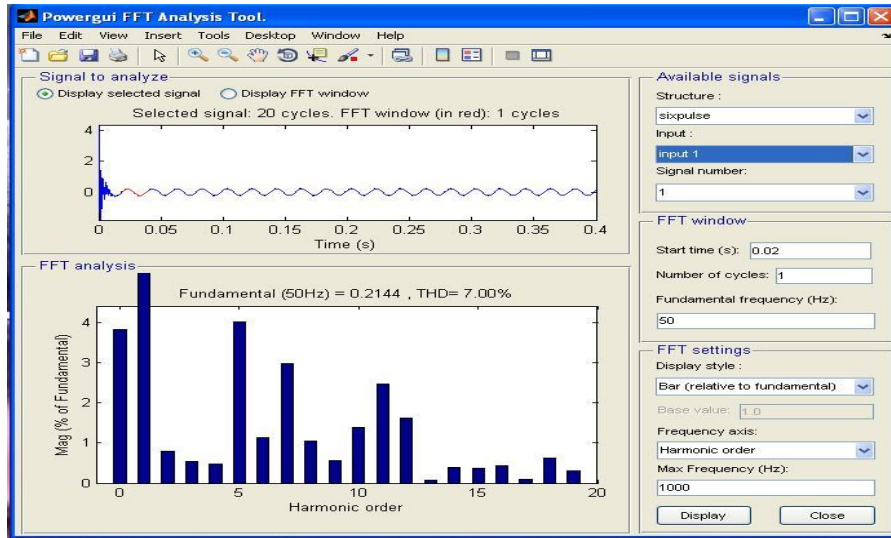


Figure 8

3) Compensation using 12-pulse voltage-source converter STATCOM

The number of pulses can be increased, forming a multi-pulse configuration. Multi-pulse converters are composed by n ($n=2, 4, 8 \dots$), where n is the number of pulses. 6-pulse bridges connected in parallel on the same DC bus and interconnected in series through transformers on the AC side. Depending on the number of pulses, these transformers and their connections can become very complex.

Two 6-pulse bridges are connected, forming a 12-pulse converter for a complete voltage flicker compensation design. In this case, the first converter is connected with a wye-wye transformer and the second one with a wye-delta transformer. These are linked together using a three winding transformer[17]

Moreover, the delta-connected secondary of the second transformer must have 3 times the turns compared to the wye-connected secondary and the pulse train to one converter is shifted by 30 degrees with respect to the other[14-16]. The 12-pulse voltage-source converter STATCOM circuit diagram is shown in figure 9.

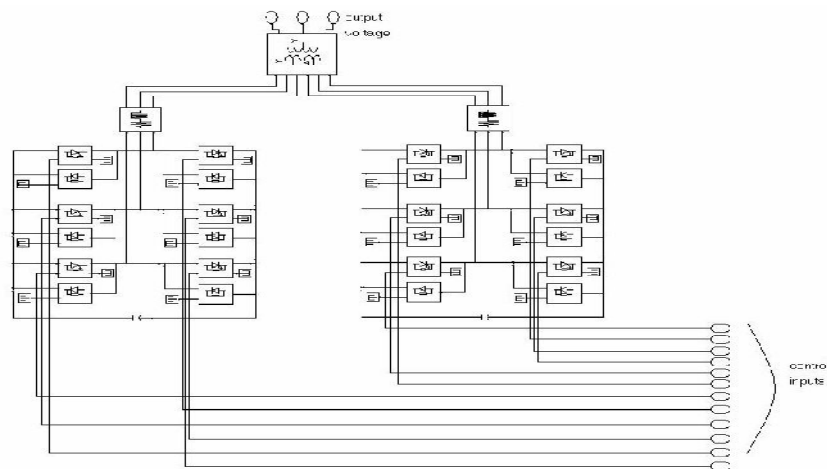


Figure 9

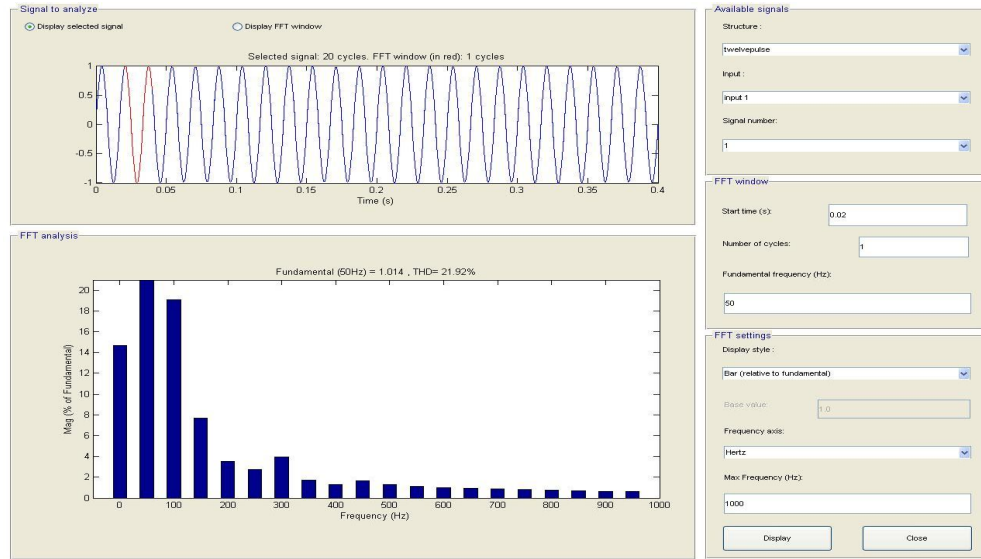


Figure 10

THD level for the 12 pulse STATCOM is 21.92% which is shown in figure 10 for voltage flicker compensation.

THD level is reduced when we use 12 pulse statcom with the help of RLC filter. THD level is shown in figure 11 which is 1.33%.

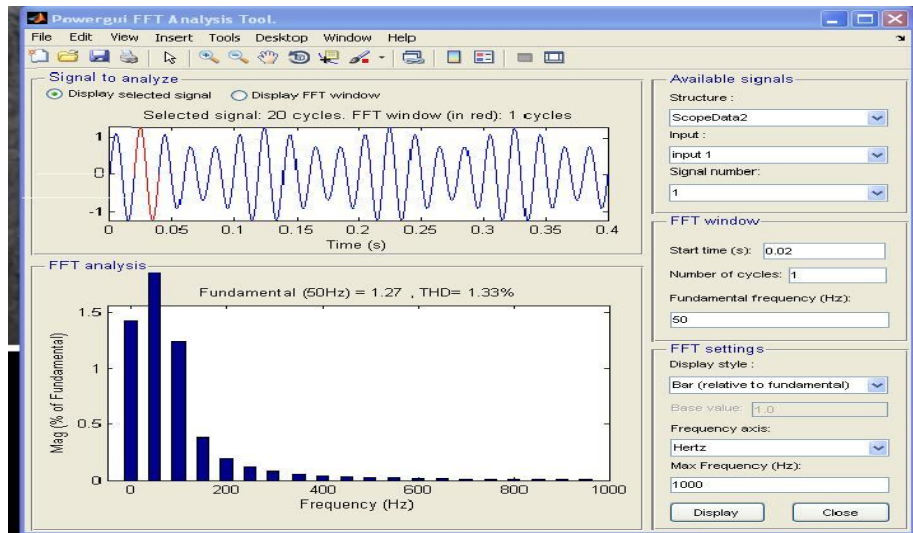


Figure 11

Conclusion

The design and application of STATCOM technology based on voltage-source converters for voltage flicker mitigation is discussed in this paper. Mitigation is done in three stages and the results are compared and contrasted. First, FCTCR is used to compensate for the voltage flicker, then a 6- pulse voltage-source converter STATCOM and finally a 12- pulse STATCOM based on voltage-source converter

equipped with an RLC filter are designed for complete voltage flicker compensation without harmonics.

All the simulated results which have been performed in MATLAB show that a 6-pulse STATCOM is efficiently effective in decreasing the voltage flicker of the generating loads. However, there is injection of the harmonic from STATCOM into the system which can be improved with the increase of the voltage source converters of STATCOM using a 12-pulse STATCOM equipped with an RLC filter. The obtained results clearly demonstrate that 12-pulse STATCOM equipped with an RLC filter can reduce the voltage flicker caused by nonlinear loads such as electric arc furnaces.

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