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Compensation of Voltage Flicker by Using Statcom and Facts Devices

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Abstract: Voltage flicker is considered as one of the most severe power quality problems (especially in loads like electrical arc furnaces) and much attention has been paid to it lately. Due to the latest achievements in the semiconductors industry and consequently the emergence 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 mitigation in three stages and assessing the related results in details. Initially, the voltage flicker mitigation, using FCTCR (Fixed Capacitor Thyristor Controlled Reactor), was simulated. Secondly, the compensation for the Static Synchronous Compensator (STATCOM) has been performed. In this case, injection of harmonics into the system caused some problems which were later overcome by using 12-pulse assignment of STATCOM and RLC filters. The obtained results show that STATCOM is very efficient and effective for the flicker compensation. All the simulations have been performed on the MATLAB Software.

Keywords: Fixed Capacitor Thyristor Controlled Reactor, STATCOM, Fact device, Voltage controller

I. INTRODUCTION

The relationship between power quality and distribution system has been a subject of interest for several years. The concept of power quality describes the quality of the supplier Voltage in relation to the transient breaks, falling voltage, harmonics and voltage flicker. 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% . Huge non-linear industrial loads such as the electrical arc furnaces, pumps, welding machines, rolling mills and others are known as flicker generators. In this respect, the quality of supplied voltage is significantly reduced in an electrical power system and the oscillation of supplied voltage appears to be a major problem.

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 which models the arc. Connecting this type of load to the network produces voltage variation at the common point of supply to other consumers. The relative voltage drop is expressed by equation (1.1):

$$\Delta U/Un = R\Delta P + X\Delta Q/Un \quad \textbf{Eq 1.1}$$

Where ΔP and ΔQ are the variation in active and reactive power; Un is the nominal voltage and R and X are short circuit resistance and reactance. Since R is usually very small in comparison to X, ΔU is proportional to Q (reactive power). Therefore, voltage flicker mitigation depends on reactive power control. Two types of structures can be used for the compensation of the reactive power.

Fluctuations that cause the voltage drop:

Shunt structure:
In this type of compensation, the reactive power consumed by the compensator is kept constant at a sufficient value.

Series structure:
In this type, all the efforts are done to decrease the voltage drop mentioned above, and finally the reactive power is kept constant despite the load fluctuations by controlling the line reactance.

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In addition to the aforesaid procedures for the compensators, the active filters are used for the voltage flickers mitigation as well. Furthermore, the mitigating devices based on Static VAR Compensator (SVC) such as Thyristor Switched Capacitor TSC, Thyristor Controlled Reactor (TCR), and FCTCR, are the most frequently used devices for reduction in the voltage flicking. SVC devices achieved an acceptable level of mitigation, but because of their complicated control algorithms, they have problems such as injecting a large amount of current harmonics to the system and causing spikes in voltage waveforms. Advent of FACTS devices make them ideal for use in a power system and especially in the voltage flicker mitigation. In this respect, the FACTS devices based on voltage-source converters have been able to improve the problems related to SVC. 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 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. 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 mitigation.

FACTS Devices:

Most of the world’s electric supply systems are widely interconnected. This is done for economic reasons, to reduce the cost of electricity and to improve its reliability, it must however be kept in mind that these inter connections are very complex and they emerged gradually based upon the requirements of various power utilities. These interconnections apart from delivering the power pool power plants and load centers in order to pool power generation and reduce fuel cost. Thus they reduce the overall generating sources, but as the saying goes a coin has two sides, like wise as the power transfer grows. The power system becomes increasingly complex to operate and system can become less secure for riding through major outages. It may lead to large power flows with inadequate control, excessive reactive power, and large dynamic swings between different parts of the system.

Thus the full potential of a transmission connection cannot be utilized. It is very difficult to control such transmission of power in such systems. Most of the controllers designed in the past were mechanical in nature. But mechanical controllers have numerous intrinsic problems. Many power electronics controllers have been designed to supplement the potentially faulty mechanical controllers. These power electronics are all grouped in a potentially mechanical category called flexible AC transmission controller or FACTS controllers.

FACTS technology opens up new opportunities for controlling power and enhancing the usable capacities of present, as well as new and upgraded lines, the possibility that current through a line can be controlled at a reasonable cost enables large potential of increasing the capacity of existing lines with large conductors. Also, the use of one of the FACTS controllers to enables corresponding power flow through such lines. Under normal and contingency conditions. These opportunities arise through the ability of FACTS controllers to control the interrelated parameters that govern the operation of transmission system. “Series Impedance, Shunt Impedance, Current, Voltage, Phase angle etc.,” are some of the interrelated parameters that are controlled. These constraints cannot be overcome while maintaining the system reliability by mechanical means without lowering the usable transmission capacity. By providing added flexibility FACTS controllers can enable a line to carry power closer to it thermal rating. It must however be emphasized that FACTS is an enabling technology, and not a one to one substitute.

The FACTS technology is not a single high power controller but rather a collection of controllers, which can be applied individually or in co-ordination with others to control one or more of the inter related system parameters mentioned above. A well chosen “FACTS” controller can overcome specific limitations of designated transmission line on a corridor. But all FACTS controller represent applications of some basic technology, their production can eventually take advantage of technologies of scale. Just as the transistor is the basic element for whole variety of microelectronic chips and circuits, the thyristors or high power transistors is the basic element for a variety of high power electronic controllers. FACTS technology also lends itself to extending transmission limits in step-by-step manner with an incrementing investment as and when required. A planner could force a progressive scenario of mechanical switching means and enabling FACTS controllers such that the transmission lines will involve a combination of mechanical and FACTS controller to achieve the objective in an appropriate, stage investment scenario. It is also worth nothing that in implementation of the FACTS technology, we are dealing with base technology, proven through HVDC and high power industrial drives. Nevertheless, as power semiconductor devices to improve, particularly the devices with turn off capability cost of FACTS controller tend to decrease.

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Basic Types of FACTS Controllers:
Basically the FACTS controllers are four types:-

1. Series Controllers
2. Shunt Controllers
3. Combined Series-Series Controllers
4. Combined Series-Shunt Controllers

1. Series Controller: By means of controlling impendence or phase angle or series injection of voltage a series FACTS controller can control the flow of current. Hence, the series controller could be variable impendence, such as capacitor, reactor or power electronics based variable source to serve the desired need. But generally all series controllers inject variable voltage in series with line. Even variable impendence multiplied by current flow through it represents an injected series voltage. As long as voltage is in quadrature with the line current, the series controller only supplies or consumes variable reactive power. Any other phase relationship will involve real power as well.

2. Shunt Controller: As in the case of series controller, shunt controllers may be variable impedance, variable source or a combination of these. In principle all shunt controller inject current into the system. Even variable shunt impendence causes a variable current injection into the line. As long as injected current is in phase quadrature with the line voltage it supplies or consumes variable reactive power. Any other phase relationship will involve real power exchange also.

3. Combined Series-Series Controller: This could be a combination of separate series controllers which are controlled in a co-ordinate manner, or it could be a unified controller. The series controllers could provide independent series reactive compensation but also could transfer real power among the lines via the power link (D.C. link). The real power transfer capability of the unified series-series controller, referred to as interline power flow controller, makes it possible to balance both the real and reactive power flow in the lines. And there by maximize the utilization of the transmission system. Note that the term “unified” here means that the DC terminals of all controller converters are all connected together for real power transfer.

4. Combined Series-Shunt Controller: This is a combination of series and shunt controllers which are controlled in a coordinated manner or a unified power flow controller with series and shunt elements. In principle, combined shunt and series controller inject current in to the system with the part of the controller and voltage in series in the line with the series part of the controller. However when the shunt and series controllers are unified, there can be a real power exchange between the series and shunt controllers via the power link.

After All Above Discussion FACTS Can Be Defined As:-
Alternating current transmission systems incorporating power electronic base and other controllers to enhance controllability and increase power transfer capability.

FACTS Controller Can Be Defined As:-
A power electronic based system and other static equipment that provide control of one or more AC transmission system parameters. Below a list of FACTS controllers that fall into the four categories discussed has been given. The working of each has not been discussed as their general principal of working has already been discussed.

Shunt Controllers:-

1. Shunt Synchronous Compensator (STATCOM)
2. Static Synchronous Generator (SSG)
3. Battery Energy Storage System (BESS)
4. Super Conducting Magnetic Energy Storage (SMES)
5. Static VAR Compensator (SVC)
6. Thyristor Controlled Reactor (TCR)
7. Thyristor Switched Reactor (TSR)
8. Thyristor Switched Capacitor (TSC)
9. Static VAR Generator or Absorber.

Series Controllers:-

1. Static Synchronous Series Compensator (SSSC)
2. Inter Line Power Flow Controller (IPFC)
3. Thyristor Controlled Series Capacitor (TCSC)
4. Thyristor Switched Series Capacitor (TSSC)
5. Thyristor Controlled Series Reactor (TCSR)
6. Thyristor Switch Series Reactor (TSSR)

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Advantages of FACTS:-

The following are the benefits that are principally derived by using the FACTS controllers.

1. The flow of power is ordered. It may be as per the contract or as per the requirements of utilities.
2. It increases the loading capability of the lines to their thermal capability. This can be accomplished by overcoming their limitations and sharing of power among lines.
3. It improves the stability of the system and thus makes the system secure.
4. Provides secure tie line connections to neighboring utilities and regions, thereby decreasing over all generation reserve requirements on both sides.
5. Provides greater flexibility in sitting new generation.
6. Upgrade of lines.
7. Reduce loop flows.
8. Minimizes the cost of transmission and hence the overall cost of generation.

Organization of the Report:-

The report of the work done is organized on as follows. After this introductory chapter1, chapter 2 gives a brief overview of static synchronous compensator, in this chapter the circuit arrangements; operation, basic control functions and characteristics of the upfc are discussed.

The chapter3 discussed the proposed control strategy. In this chapter 3-phase to D-Q transformation and mathematical modeling of the control strategy for independent control of STATCOM are discussed. The chapter4 presents an introduction to SIMULINK and modeling of STATCOM for MATLAB/SIMULINK.

II. STATIC SYNCHRONOUS COMPENSATOR

This shunt connected static compensator was developed as an advanced static VAR compensator where a voltage source converter (VSC) is used instead of the controllable reactors and switched capacitors. Although VSCs require self-commutated power semiconductor devices such as GTO, IGBT, IGCT, MCT, etc (with higher costs and losses) unlike in the case of variable impedance type SVC which use thyristor devices, there are many technical advantages of a STATCOM over a SVC. These are primarily:

1. Faster response
2. Requires less space as bulky passive components (such as reactors) are eliminated
3. Inherently modular and relocatable
4. It can be interfaced with real power sources such as battery, fuel cell or SMES (Superconducting Magnetic Energy Storage)
5. A STATCOM has superior performance during low voltage condition as the reactive current can be maintained constant (In a SVC, the capacitive reactive current drops linearly with the voltage at the limit (of capacitive susceptance).

It is even possible to increase the reactive current in a STATCOM under transient conditions if the devices are rated for the transient overload. In a SVC, the maximum reactive current is determined by the rating of the passive components – reactors and capacitors. A ±80 MVA STATCOM using 4.5 kV, 3000 A GTO devices was developed in Japan in 1991. A ±100 MVA STATCOM, also based on GTOs (4.5 kV and 4000 A (peak turn off)) was commissioned in late 1995 at Sullivan substation of Tennessee Valley Authority (TVA) in U.S.A. The major objective of the prototype installation is to regulate the 161 kV bus voltages. During daily load variations so that the duty on the tap changers on the transformer banks is minimized. (The failure of tap changers is a common problem when they are forced to act continuously).The STATCOM was originally called as advanced SVC and then labeled as STATCON (Static Condenser).

Principle of Operation of STATCOM:

A STATCOM is comparable to a Synchronous Condenser (or Compensator) which can supply variable reactive power and regulate the voltage of the bus where it is connected. The equivalent circuit of a Synchronous Condenser (SC) is shown in Fig.6.1, which shows a variable AC voltage source (E) whose magnitude is controlled by adjusting the field current. Neglecting losses, the phase angle (±) difference between the generated voltage (E) and the bus voltage (V) can be assumed to be zero. By varying the magnitude of E, the reactive current supplied by SC can be varied. When E = V, the reactive current output is zero. When E > V, the SC acts as a capacitor whereas when E < V, the SC acts as an inductor. When Del = 0, the reactive current drawn (Ir) is given by

$$Ir = \frac{V - E}{X'} \qquad \text{……….} \mathbf{Eq\ 2.1}$$

A STATCOM (previously called as static condenser (STATCON) has a similar equivalent circuit as that of a SC. The AC voltage is directly proportional to the DC voltage (Vdc) across the capacitor.

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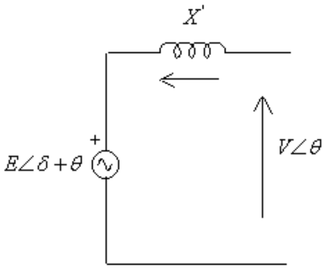

Figure 2.1: A synchronous condenser

Voltage Source Converters:
The basic building block of a high power GTO based STATCOM is a six pulse circuit shown in Fig. 3.1. The circuit consists of six switches, made up of six GTO thyristors with anti parallel diodes connected as a

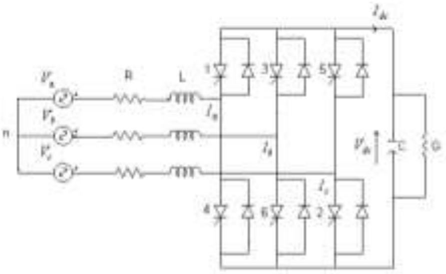

Fig 2.2: A Six Pulse VSC Circuit

Six pulse Graetz Bridge. The analysis of the circuit assumes that each switch is turned on only once in a cycle of supply voltage and conducts for 180deg each. The switches (or valves) are numbered in the sequence in which they are turned on (fired). Also, the two switches connected in series in each leg operate in a complementary fashion. Only one of the switches is conducting at any given time to prevent short circuit of the capacitor. Thus, before switch 4 is turned on, the switch 1 must be turned off and vice versa. To simplify the analysis, to derive the equations describing the steady state performance; we assume (initially) that
1. The capacitor size is infinite (very large) and therefore the DC side voltage is constant
2. The losses in the circuit are neglected.

The waveform of the voltage (EaN) is as shown in Fig. The waveforms of EbN and EcN are also similar except that they are displaced from one another by 120deg. (EbN lags EaN by 120deg and EcN lags EbN by 120deg).The voltages Ean, Ebn and Ecn (measured with respect to the source neutral) can be obtained from the following equations

$$E_{an} = E_{an} + V_{Nn} \text{ ....}\textbf{Eq 2.2}$$

$$E_{bn} = E_{bn} + V_{Nn} \text{ ....}\textbf{Eq 2.3}$$

$$E_{cn} = E_{cn} + V_{Nn} \text{ ....}\textbf{Eq 2.4}$$

From the symmetry of the circuit, it can be shown that

$$E_{an} + E_{bn} + E_{cn} = 0 \text{ ....}\textbf{Eq 2.5}$$

Substituting Eq. (3.1) in (3.2) to (3.3), we get

$$V_{Nn} = -\frac{E_{aN} + E_{bN} + E_{cN}}{3} \text{.....}\textbf{Eq 2.6}$$

$$E_{an} = \frac{2E_{aN}}{3} - \frac{E_{bN}}{3} - \frac{E_{cN}}{3} \text{...}\textbf{Eq 2.7}$$

$$E_{bn} = \frac{2E_{bN}}{3} - \frac{E_{cN}}{3} - \frac{E_{aN}}{3} \text{ ......}\textbf{Eq 2.8}$$

$$E_{cn} = \frac{2E_{cN}}{3} - \frac{E_{aN}}{3} - \frac{E_{bN}}{3} \text{ ....}\textbf{Eq 2.9}$$

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The fundamental frequency component (rms value) of Ean is obtained as

$$E_{a1} = \frac{\sqrt{2}}{\Pi} V_{dc} = 0.45\, V_{dc} \quad \text{...}\mathbf{Eq\ 2.10}$$

The harmonic component (Eah) is obtained as

$$E_{ah} = \frac{E_{a1}}{h} = \frac{0.45\, V_{dc}}{h} \quad \text{...........}\mathbf{Eq\ 2.11}$$

The rms value of the fundamental component of (reactive) current, Ir is calculated from

$$I_r = \frac{V - 0.45\, V_{dc}}{\omega L} \quad \text{............}\mathbf{Eq\ 2.12}$$

The harmonic current (rms) is obtained as

$$I_h = \frac{0.45\, V_{dc}}{h^2 \omega L} \quad \text{..................}\mathbf{Eq\ 2.13}$$

III. SIMULATION AND ANALYSIS OF THE RESULTS

Simulink is a software package for modeling, simulating and analyzing dynamically system. It supports linear and non linear systems, modeled in continuous time, sampled time, or a hybrid of the two; systems can also be multirate, i.e. have different parts that are sampled or updated at different parts. For modeling, simulink provides a graphical user interface (GUI) for building models as block diagram, using click and drag mouse operations. SIMULINK includes a comprehensive block library of sinks, sources, linear and non linear components, and connector. One can also customize and create his own block. Models and hieratical, so we can build models using both top-down and button-up approaches. We can view the system at a high level, and then double click on blocks to go down through the levels to see increasing levels of own blocks.

Synchronized Pulse Generator:

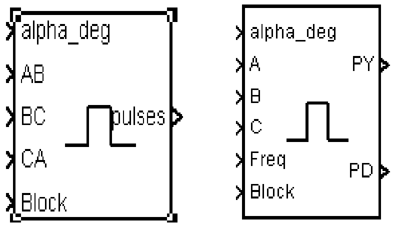

Figure 3.1: 6 pulse and 12 pulse synchronized generator

The Synchronized 6-Pulse Generator block can be used to fire the six thyristors of a six-pulse converter. The output of the block is a vector of six pulses individually synchronized on the six thyristor voltages. The pulses are generated alpha degrees after the increasing zero crossings of the thyristor commutation voltages. The Synchronized 6-Pulse Generator block can be configured to work in double-pulsing mode. In this mode two pulses are sent to each thyristor: a first pulse when the alpha angle is reached, then a second pulse 60 degrees later, when the next thyristor is fired. The pulse ordering at the output of the block corresponds to the natural order of commutation of a three-phase thyristor bridge.

When you connect the Synchronized 6-Pulse Generator block to the pulses input of the Universal Bridge block (with the thyristors as the power electronic device), the pulses are sent to the thyristors. When you build your own three-phase thyristor bridge with single thyristor blocks, you need to connect the pulse signals of the Synchronized 6-Pulse Generator block to the gate inputs of the corresponding thyristors and similar to synchronized 12 pulse generator In order to investigate the influence of the STATCOM as an effective mitigating 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.

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. 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 (Ip), 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 (Ic) regarding the currents converted to the dq0 axis is given as

$$i_c = j(i_q + i_p \frac{R}{X} f + \frac{1}{\omega} \frac{dip}{d\omega} f + k) \quad \text{……Eq 3.1}$$

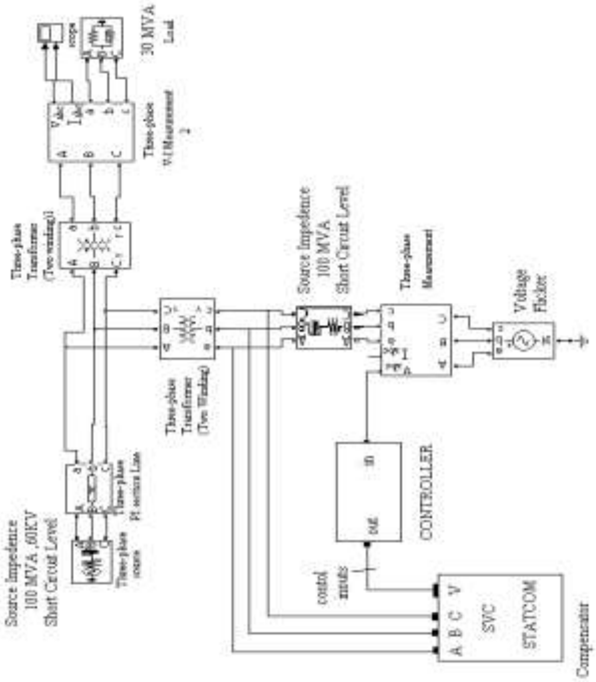

Figure 3.2 The Studied Power System

The complete STATCOM control system scheme implemented on MATLAB is shown in figure first, using a 3-phase converter to dq0, the instantaneous vectors V_d, V_q and V_o, 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_o. 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.

Compensation using FCTCR:

In this stage a FCTCR; one of the FACTS devices being controlled by a thyristor is used to mitigate the voltage flicking. In this case, the exerted voltage flicker into the system and the compensated voltage are shown in figures 3.3 and3.7 respectively.

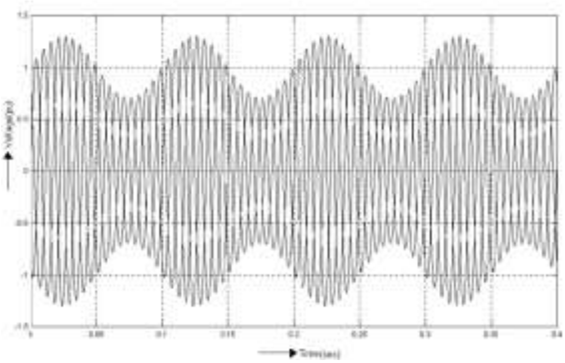

Figure 3.3: Simulation Result for Generated Voltage Flicker Source

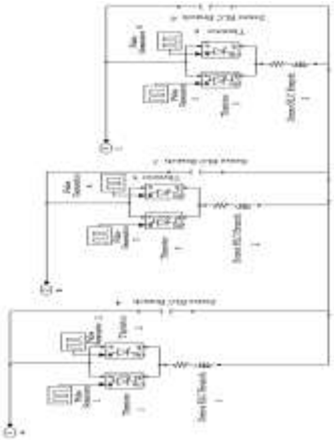

Figure 3.4: Sub Circuit of FCTCR

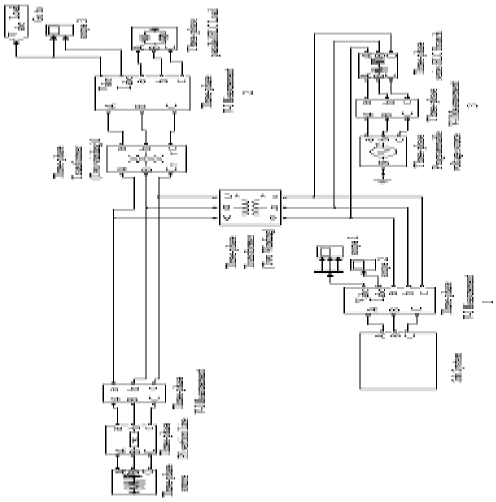

Fig 3.5: Simulink Model of Voltage Flicker Compensation

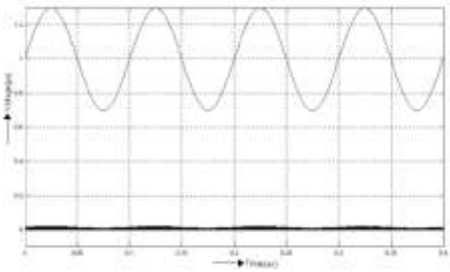

Figure 3.6: Simulation Result for Instantaneous Components of 3 Phase Voltage Flicker Waveform

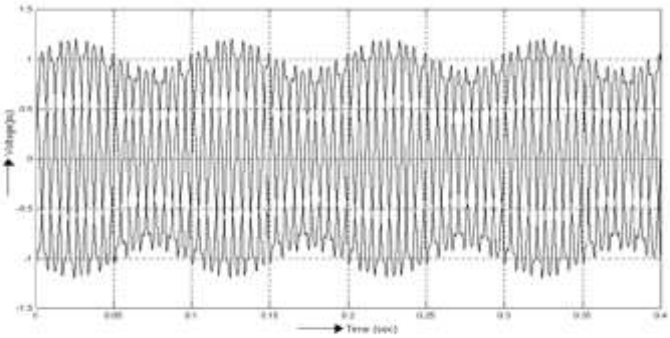

Figure 3.7: Simulation Result for The compensated voltage by FCTCR

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 to eliminate voltage spikes caused by the huge TCR reactor switching, there are still distortions in the output waveform.

IV. 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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