Modelling and Simulation of STATCOM Device for Voltage Flickering Mitigation

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Abstract— Voltage flicker occurs when heavy loads are periodically turned on and off in a weak distribution system. If the distribution system's short circuit capacity is not large enough, voltage fluctuations will occur. Voltage flickering can be extremely harmful to sensitive electronic equipment. Computerized equipment requires stable voltage to perform properly. This paper covers the contrasting approaches; dealing with the voltage flicker mitigation in three stages and assessing the related results in details. The compensation of voltage flickering 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 SATCOM 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.

Key words: Voltage Flickering Mitigation, STATCOM Device

I. INTRODUCTION

Electric Arc Furnace (EAF) is high power industrial load which has unbalanced, non-linear and time-varying characteristics with a strongly fluctuating consumption of reactive power. The fast, stochastic large variations in reactive power required by the EAF causes voltage drops, rapid voltage variation and harmonics across the ac supply network [1]. Voltage fluctuations which is known as flicker not only have negative impact on the power system quality and other loads, but also have an effect on the arc furnace operation, power output and efficiency. Flicker is an observable variation in brightness of a lamp as a result of quick fluctuations in the voltage of the power supply. The voltage drop is generated over the source impedance of the grid by the changing load current of an EAF. These fluctuations in time produce flicker. The amount of flicker depends on the size of the EAF in relation to the short circuit power of the grid at the point of common coupling.

The concept of power quality includes the quality of the supplying voltage with respect to for instance voltage sag, voltage swell, harmonics, interruptions and voltage flicker [1]. Voltage Flicker is the disturbance of lightning induced by voltage fluctuations. Causes for voltage flicker are huge non-linear industrial loads such as the electrical arc furnaces, pumps, welding machines, rolling mills. Consequences of voltage flicker are the quality of supplied voltage is significantly reduces, the most perceptible consequence is the flickering of lighting and screens, giving the impression of unsteadiness of visual perception. Very small variations are enough to induce lightning disturbance for human eye, the disturbance becomes perceptible for voltage variation frequency of 10 Hz and relative magnitude of 0.26% [1]. 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 modelled 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. To limit the effects of these disturbing loads, compensation devices have usually to be connected. Since the EAF does not have any built-in compensation for regulating voltage variations like an electrical motor or drive system, which consumes more current when voltage drops so that sustain the same torque, the power input to the furnace is very sensitive to flicker and because of nonlinear voltage-current characteristic of an EAF, efficient operation of an EAF requires the voltage to be kept high and stable. Because of the reasons that mentioned before, Flexible AC Transmission Systems (FACTS) technologies are used to mitigate the flicker and harmonics caused by EAF. Voltage flicker is considered as one of the most severe power quality problems and much attention has been paid to it lately. Voltage Flicker is the disturbance of lightning induced by voltage fluctuations.

If the distribution system's short circuit capacity is not large enough, voltage fluctuations will occur. Starting large motors require an inrush of current, which causes a decrease in voltage. This voltage depression may cause a visible flicker on lighting circuits connected to the same power system. Voltage flickering can be extremely harmful to sensitive electronic equipment. Computerized equipment requires stable voltage to perform properly. For this reason, voltage flicker is a major power quality problem. The magnitude of the voltage flicker depends upon the size and type of the electrical load that is producing the disturbance. A sag in voltage can also cause a voltage flicker; sudden voltage drops in the electrical distribution system can generate inrush current which can travel to sensitive equipment. The FACTS device that commonly be used in electrical device is Static Var compensator (SVC) which can reduce the flicker and harmonics to some levels. By installing an SVC on the bus bar to instantaneously compensate the electrical equipment's large and continuously varying reactive power demand, troublesome voltage drops and fluctuations can be avoided. The mean power input to the electrical equipment is raised, and nearby electrical equipment can operate as usual. However, it cannot do its compensation task very well because of delays relevant to reactive power measurement and thyristor ignition. Static Synchronous Compensator (STATCOM) is a high performance candidate for SVC in compensating the undesirable characteristics of electrical equipment. The response time of a STATCOM is shorter than that of an SVC, mostly by reason of the fast switching times provided by the IGBTs.

Voltage flicker is considered as one of the most severe power quality problems and much attention has been paid to it lately. 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. Voltage flicker occurs when heavy loads are periodically turned on and off in a weak distribution system. If the distribution system's short circuit capacity is not large enough, voltage fluctuations will occur. Starting large motors require an inrush of current, which causes a decrease in voltage. This voltage depression may cause a visible flicker on lighting circuits connected to the same power system. Voltage flickering can be extremely harmful to sensitive electronic equipment. Computerized equipment requires stable voltage to perform properly. For this reason, voltage flicker is a major power quality problem. The magnitude of the voltage flicker depends upon the size and type of the electrical load that is producing the disturbance. A sag in voltage can also cause a voltage flicker; sudden voltage drops in the electrical distribution system can generate inrush current which can travel to sensitive equipment.

II. POWER QUALITY AND ROLE OF FACTS DEVICES

Power quality is a term that means different things to different people. Institute of Electrical and Electronic Engineers (IEEE) Standard IEEE1100 defines power quality as "the concept of powering and grounding sensitive electronic equipment in a manner suitable for the equipment." As appropriate as this description might seem, the limitation of power quality to "sensitive electronic equipment" might be subject to disagreement. Electrical equipment susceptible to power quality or more appropriately to lack of power quality would fall within a seemingly boundless domain. All electrical devices are prone to failure or malfunction when exposed to one or more power quality problems. The electrical device might be an electric motor, a transformer, a generator, a computer, a printer, communication equipment, or a household appliance.

All of these devices and others react adversely to power quality issues, depending on the severity of problems. A simpler and perhaps more concise definition might state: "Power quality is a set of electrical boundaries that allows a piece of equipment to function in its intended manner without significant loss of performance or life expectancy." This definition embraces two things that we demand from an electrical device: performance and life expectancy. Any power-related problem that compromises either attribute is a power quality concern. In light of this definition of power quality, this chapter provides an introduction to the more common power quality terms. Along with definitions of the terms, explanations are included in parentheses where necessary. This chapter also attempts to explain how power quality factors interact in an electrical system.

The common concerns of power quality are long duration voltage variations (overvoltage, under voltage, and sustained interruptions), short duration voltage variations (interruption, sags (dips), and swells), voltage imbalance, waveform distortion (DC offset, harmonics, inter harmonics, notching and noise), voltage fluctuation (voltage flicker) and power frequency variations. Most reasons of these concerns stems from loads connected to electric supply systems.

III. STATIC COMPENSATOR (STATCOM)

Voltage stability is one of the biggest problems in power systems. Engineers and researchers have met with the purpose of discussing and trying to consolidate a definition regarding to voltage stability, besides proposing techniques and methodologies for their analysis, some of them reported in [1]. Most of these techniques are based on the search of the point in which the system's Jacobian becomes singular; this point is referred as the point of voltage collapse or maximum load ability point [8]. The series and shunt compensation are able to increase the maximum transfer capabilities of power network [8]. Concerning to voltage stability, such compensation has the purpose of injecting reactive power to maintain the voltage magnitude in the nodes close to the nominal values, besides, to reduce line currents and therefore the total system losses [4].

At the present time, thanks to the development in the power electronics devices, the voltage magnitude in some node of the system can be adjusted through sophisticated and versatile devices named FACTS, being the static synchronous compensator (STATCOM) one of them. There are diverse publications regarding to model the STATCOM, for example, steady state studies [6], or transient stability ones [9]. There are other ones applied to voltage control problem using novel technical [13]. The focus in the present work is the analysis of the STATCOM model in a three-phase reference frame applied to the improvement of voltage stability margin. The intention of this analysis is to prove the device in severe conditions of load, to observe its behaviour and range of its control parameters in such circumstances, besides, checking that it is able to increases voltage stability margin. Among the tools used for the power systems analysis, three-phase power flow is so important, in order to simulate realistic conditions. There are three-phase transmission lines unbalanced in high-voltage transmission network and, there are one-phase or two phase lines in some distribution network.

A static synchronous compensator (STATCOM) [4] as shown in figure.1 is a regulating device used on alternating current electricity transmission networks. It is based on power electronic voltage source converter and can act as either a source or sink of reactive AC power to an electricity network. If connected to a source of power it can also provide active AC power. The mathematical model of the differential equation and the reactive power to be injected at the STATCOM node are given, respectively as follows.

$$\boxed{\begin{array}{c} \dot{i}_{SH} = (K_r\,(V_{ref} + v_{POD} - V) - i_{SH})/T_r \\ Q = -i_{SH}\,V \end{array}} \qquad (1)$$

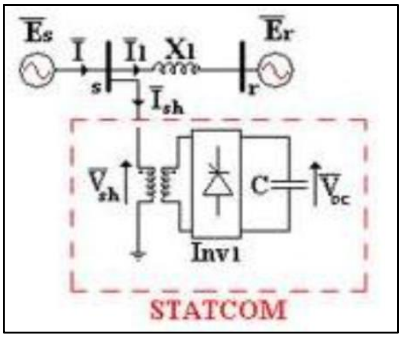


Fig. 1: Structure of STATCOM

IV. STATCOM MODELLING

A. Basic operation principles, (one-phase, STATCOM). A schematic representation of the one-phase STATCOM is shown in Figure-2. It is composed by a voltage source converter (VSC), and its associated shunt connected transformer [6]. The transformer is used as a link between the VSC and the system.

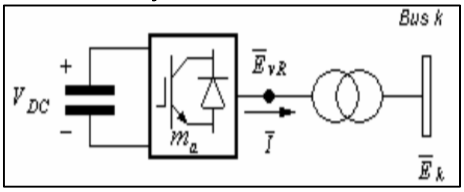


Fig. 2: STATCOM's schematic representation

To explain the basic STATCOM's operation principles, it is considered that the coupling transformer is lossless; this way, its equivalent one-phase circuit is depicted in Figure.3, where ***EvR*** represents the voltage in the STATCOM's terminals and ***Ek*** is the voltage in the power system bus.

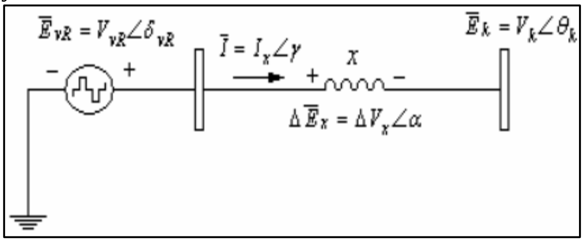


Fig. 3: Equivalent one-phase circuit of the STATCOM

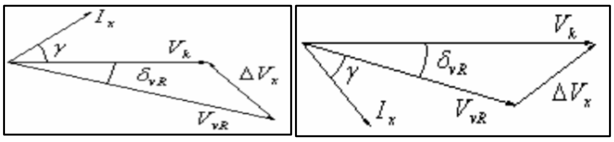
The basics of the STATCOM's operation is that the amplitude and phase angle of the voltage drop ***ΔEx,*** Figure-3, can be controlled, defining the amount and direction of active and reactive power flows through the reactance [6]. If we take *θk = 0* as the reference to simplify the formulation, the following equations (1)-(3), are the voltage and power equations applied to the circuit.

$$P = \frac{V_{vR}V_k}{x}\sin\delta_{vR} \qquad (2)$$

$$P = \frac{V_{vR}V_k}{x}\sin\delta_{vR} \qquad (3)$$

$$Q = \frac{V_{vR}^2}{x} - \frac{V_{vR}V_k}{x}\cos\delta_{vR} \qquad (4)$$

Under normal operation conditions, a small amount of active power must flows into the VSC to compensate for the power losses that exist in its interior, and in reference to Figure.3, *δvR* is kept slightly different that *θk*. In Figure.4(a) and (b) are drawn the space vector representation of the STATCOM.



(a) (b)

Fig. 4: Lagging and leading currents

Figure-4 (a) represents a operation condition where VvR > Vk, with a lagging power factor, in such circumstances, the STATCOM is absorbing active power from the system and giving reactive power to the same one. On the other hand, Figure.4 (b) represents a operation condition where (VvR < Vk), with leading power factor; now, the STATCOM absorbs active and reactive power from the system. In summary, in reference to the equations (1)-(3) and observing Figure-4, if Vk is assumed constant, we take the conclusion that through the variation of VvR, it can be achieved that the STATCOM absorbs or delivers reactive power to the system with compensation purposes. Therefore, a more flexible model of the STATCOM is represented as a variable voltage source EvR, for which the magnitude and phase angle can be adjusted with the object of satisfying a specific voltage magnitude at the point of connection. The voltage magnitude VvR is conditioned by some maximum and minimum limits, which are a function of the STATCOM's capacitor rating. In this paper, the simulations include the limits on STATCOM's voltage magnitude within (0.9–1.1) p.u. However, the phase angle δvR can vary between 0 and 2π radians [6].

A. Three-Phase STATCOM's Equivalent Circuit and Steady-State Equations

With the help of the previous one-phase STATCOM formulation, it is easy to deduce the three-phase model. The shunt voltage source of the three-phase STATCOM may be represented by:

$$\boxed{E_{vR}^{\rho} = V_{vR}^{\rho}(\cos\delta_{vR}^{\rho} + jsen\delta_{vR}^{\rho})} \qquad (5)$$

Where ρ indicates phase quantities, *a*, *b* and *c*

The equivalent circuit of the three-phase STATCOM is shown in Figure-5 in a wye configuration. This model is used to derive the steady state equations included into the three-phase power flow formulation.

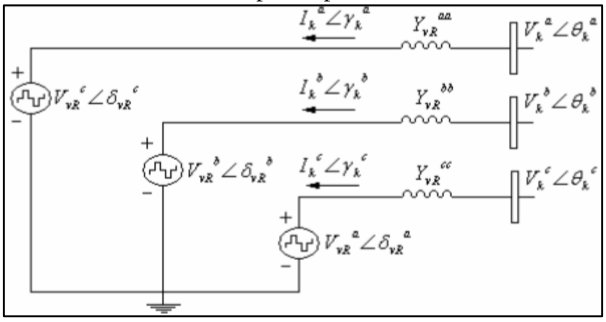


Fig. 5: Three-phase STATCOM´s equivalent circuit

To integrate the variables of the STATCOM into the three-phase power flow formulation, two variables are unknown by phase, *Vρ vR* y *δρ vR*, therefore, six additional equations are required. For the first equation, we will take account that the STATCOM can consume active power from the system or can be loss-less too, that is, it doesn't consume neither it generates active power. Thus, the three-phase STATCOM model is integrated into the steady state formulation. In the simulations, the STATCOM´s node where is connected, is represented as a PV type node. This node can change to PQ type when, during the process, one of the limits in the device's voltage magnitude is violated.

V. SIMULATIONS

For the development of this stage all points mentioned in this section are taken into account. Fig.6 depicts the flow chart representing the sequence of events for constructing the P-V curves by the aforementioned strategy.

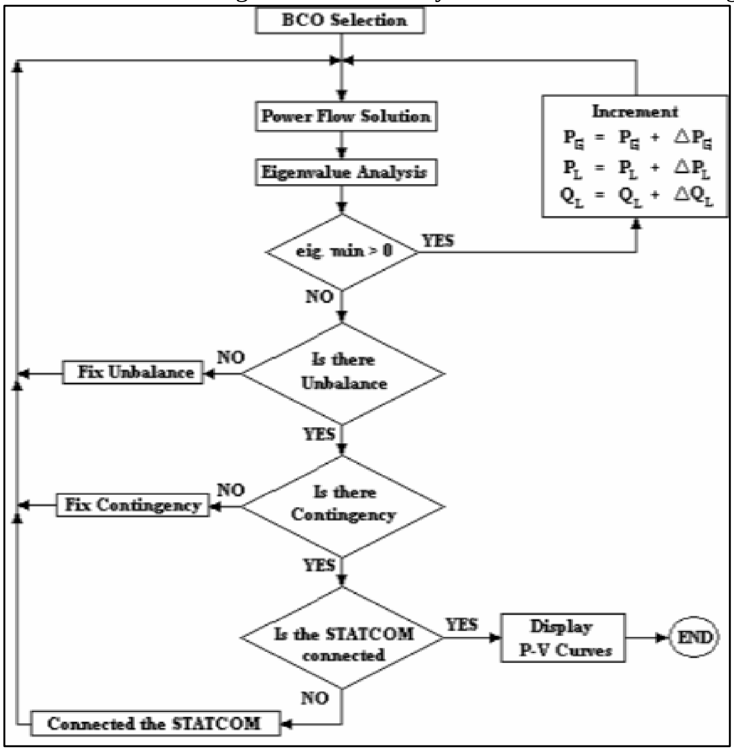


Fig. 6: Flow chart for the P-V curves calculation

VI. CONTROL TECHNIQUE

A new technique based on a novel control algorithm, which extracts the voltage disturbance to suppress the voltage flicker, is presented in this thesis. The concept of instantaneous reactive power is used for the controlling system. Following this 3Ø flicker voltage has been transformed to synchronous reference frame by the use of abc to dqo transformation (Park's transformation). To implement the synchronous reference frame some kind of synchronizing system (phased looked loop) should be used. STATCOM control system scheme implemented on MATLAB SIMULINK is shown in figure 4. 3Ø AC system load voltage is the input to the phase locked loop (PLL), this PLL can be used to synchronize on a set of variable frequency, 3Ø sinusoidal signals. From the output of PLL sinωt and cosωt value are given to abc to dqo transformation, this transformation leads to the appearances of three instantaneous space vectors: vd on the d-axis (real or direct axis), vq on the q-axis (imaginary or quadrature axis) and v0 from 3Ø flicker voltage of va, vb and vc. The related equations of this transformation, expressed in the MATLAB Simulink software are as follows:

$$V_d = \frac{2}{3}\left(V_a \sin(wt) + V_b \sin\left(wt - \frac{2\pi}{3}\right) + V_c \sin\left(wt + \frac{2\pi}{3}\right)\right)$$

$$V_q = \frac{2}{3}\left(v_a \cos(wt) + V_b \cos\left(wt - \frac{2\pi}{3}\right) + V_c \cos\left(wt + \frac{2\pi}{3}\right)\right)$$

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

Where ω= rotation speed (rad/s) of the rotating frame. Park's Transformation of 3-phase flicker voltage to the instantaneous vector's is given to demux block, it extract the component of an input signal and output's the components as separate signals Vd, Vq and V0.The active and reactive components of the system are represented by the direct and quadrature component, respectively, 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 (Vq), so to decrease the voltage flicker controlling system uses only Vq to control the STATCOM, the obtained Vq is entered as an input to the sum block and other input to the sum block is constant value zero, it indicates the Vq per unit reference value.

In sum block plus and minus signs indicate the subtraction or comparison operation to be performed on the inputs, resultant is the sum block output as the error signal is given to PI controller. PI controller output signal is firing angle component in radians, it is multiple by the gain of to get in degrees, and this firing signal is given to the input of pulse generator to control the pulses of the generator. The inputs AB, BC, CA are the phase – phase voltages these are given from the 3Ø flicker voltage. Step value is block (one of the input of pulse generator) reference value. Pulse generator output contains the pulse signal (pulse width 10 degree is specified) are to be sent to the voltage source converter to trigger the power switching devices of the SVC and STATCOM, to produce required magnitude of voltage and injection or absorption of reactive power.

VII. MODELLING & SIMULATION

A. Matlab Simulation for Flickering in the 3-phase System

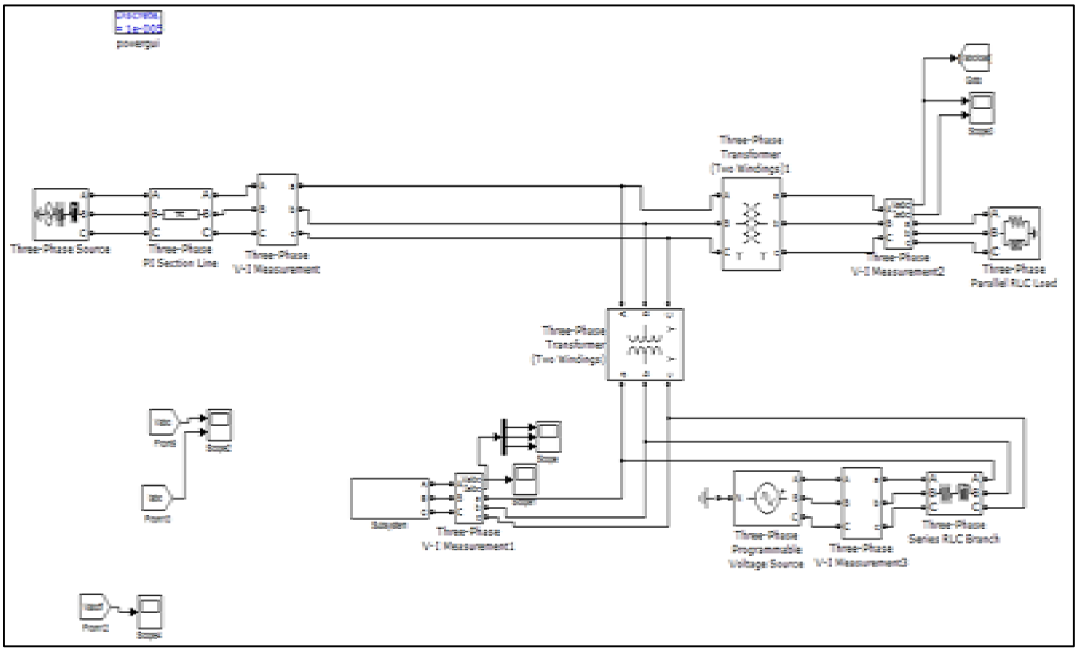


Fig. 7: 3-Phase system for voltage flickering in the system

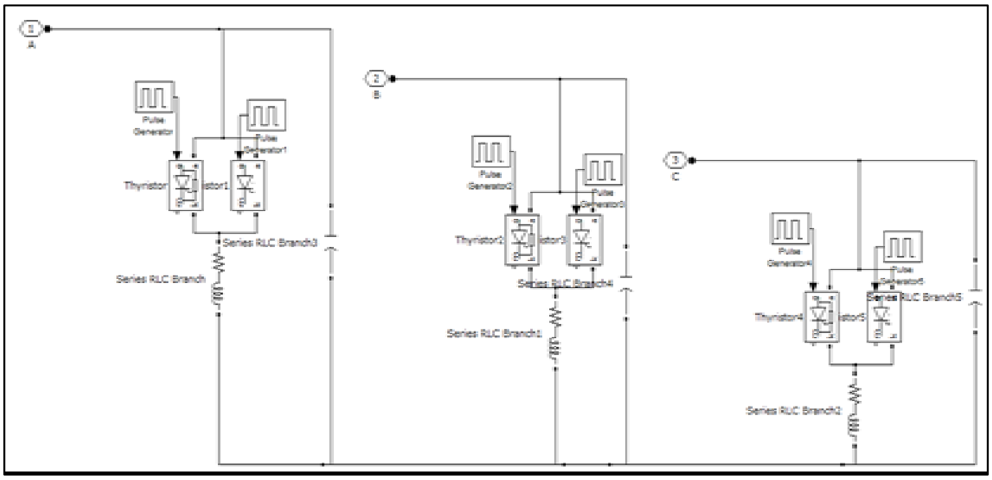


Fig. 8: FC-TCR Subsystem for the proposed work

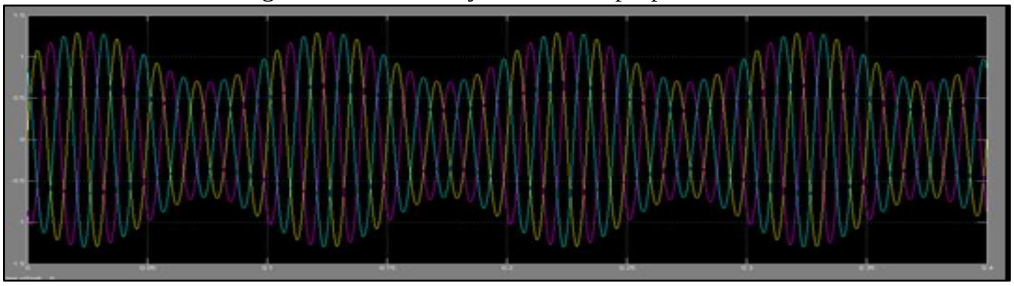


Fig. 9: Voltage flickering at load side

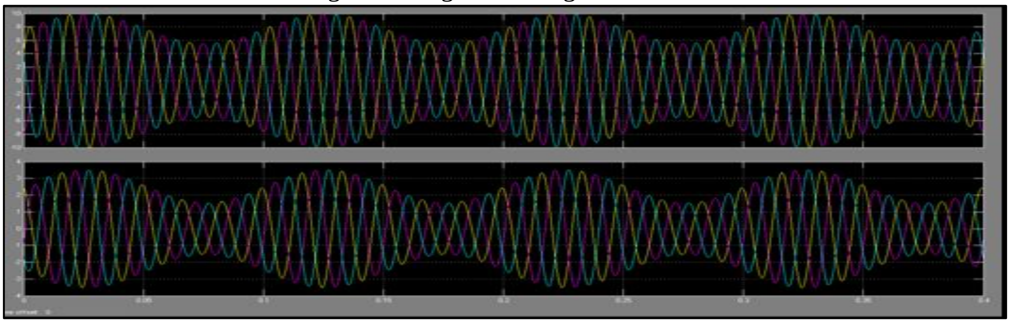


Fig. 10: Voltage flickering at voltage and current waveform

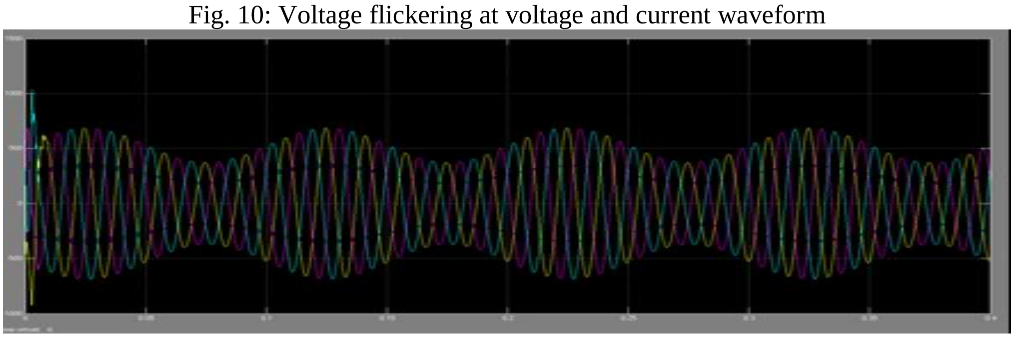


Fig. 11: Flickering and unbalancing condition

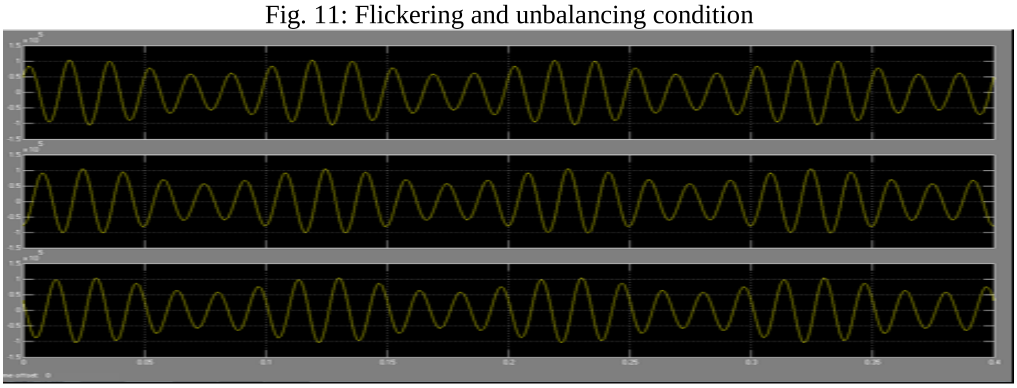


Fig. 12: Sag and swell condition and voltage unbalancing

B. Matlab Simulation for Flickering mitigation in the 3-phase System using 6-pulse Statcom

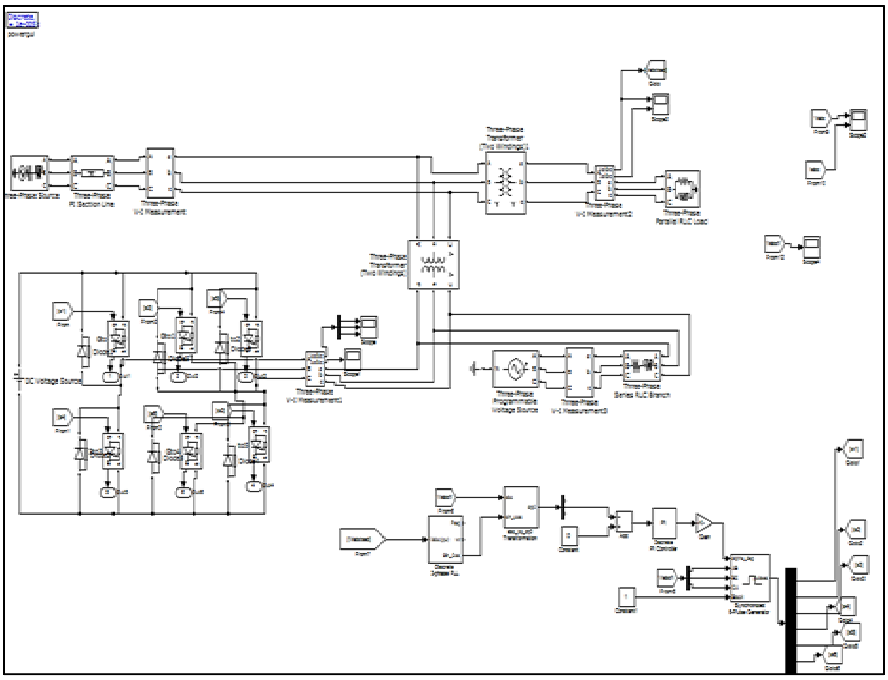


Fig. 13: Flicker compensation using 6-pulse Statcom Circuit

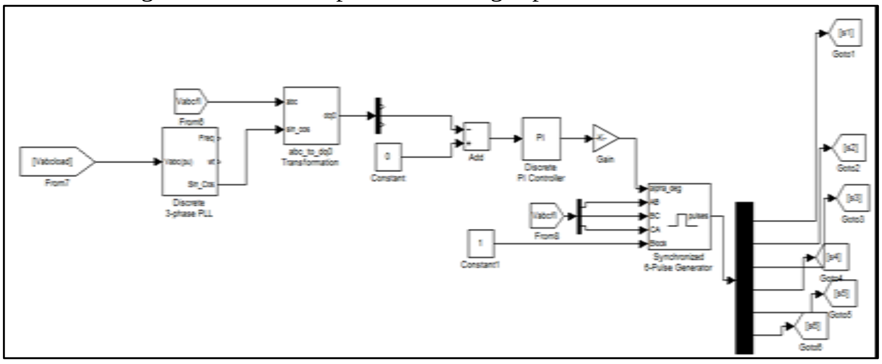


Fig. 14: Controlling circuit of STATCOM

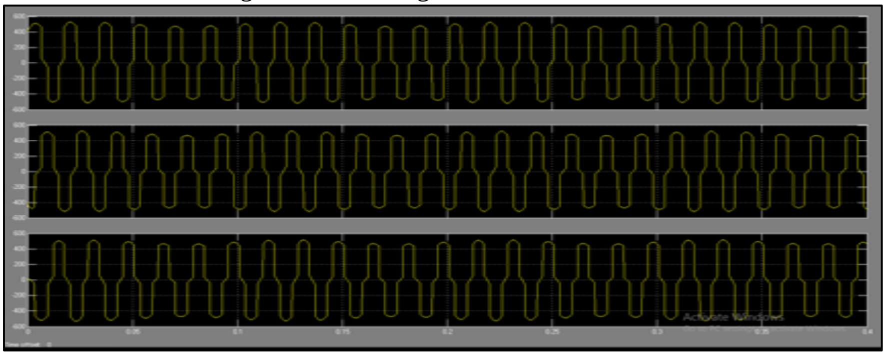


Fig. 15: Voltage improvement after the connection of 6-pulse Statcom

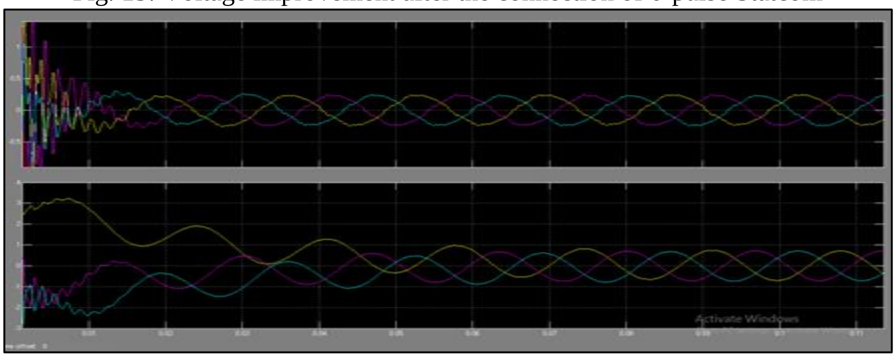


Fig. 16: Voltage and current enhancement

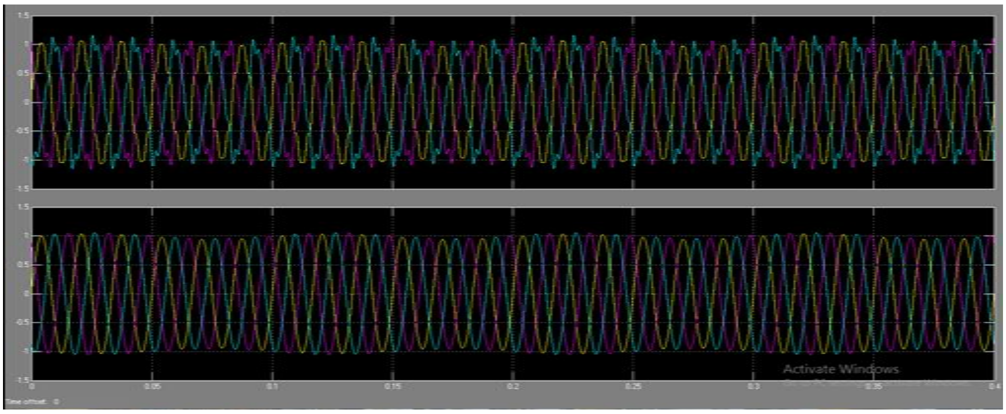


Fig. 17: load side voltage and current improvement

VIII. THD ANALYSIS

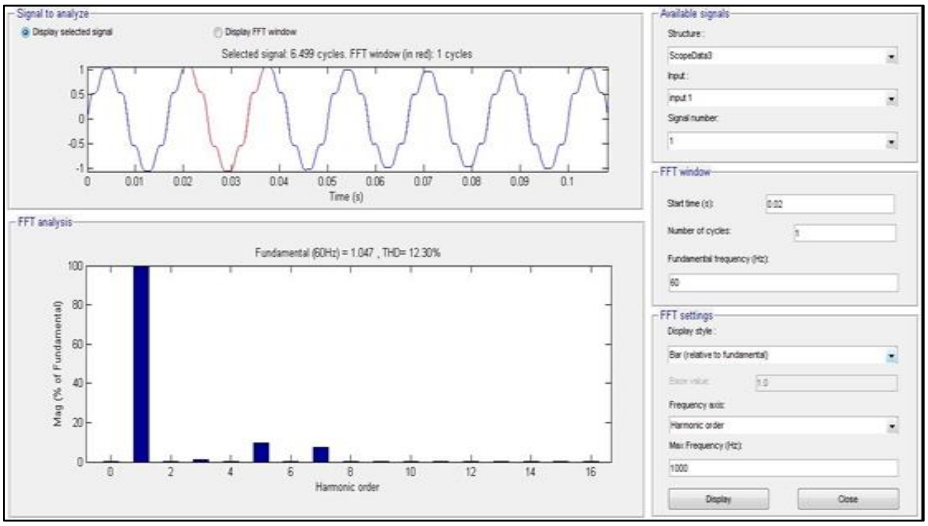


Fig. 18: THD before STATCOM connection

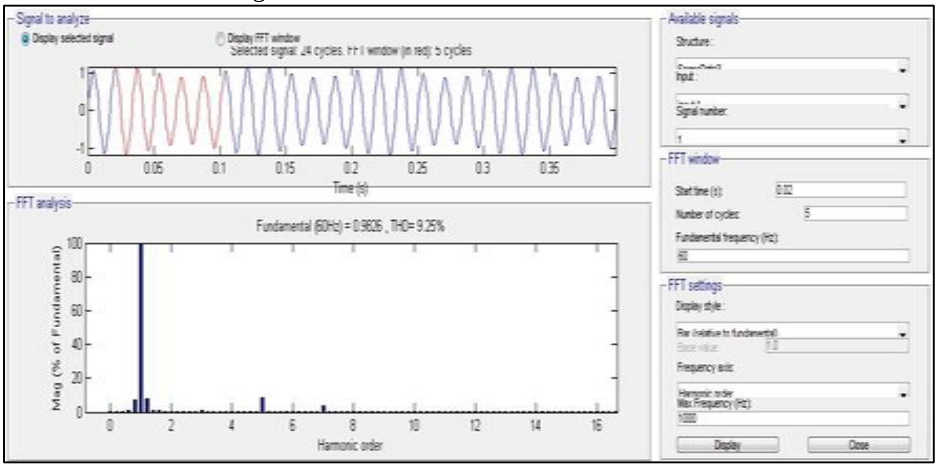


Fig. 19: THD after STATCOM connection

IX. CONCLUSION

This paper has compared the performance of STATCOM for compensation of flicker caused by Matlab. In this paper, the application of STATCOM technology based on voltage-source converters for voltage flicker mitigation has been investigated and simulation results emphasized its significant effect. A 6-pulse STATCOM is decreasing the voltage flicker by 50%. However, there is injection of the harmonic from 6-pulse 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 a harmonic filter. The obtained results clearly demonstrate that 12-pulse STATCOM equipped with a harmonic filter can reduce the voltage flicker completely and the output is obtained with minimum THD Value.

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