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Multi-Pulse Voltage Source Converter Statcom For Voltage Flicker Mitigation

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Abstract:
Voltage flicker is a power quality problem caused by large rapid industrial load changes. This paper deals with voltage flicker compensation by means of STATCOM. For this purpose a two-bus system connected with STATCOM is used. Initially a 6-pulse voltage source converter STATCOM is used to compensate for the voltage flicker. In this case voltage flicker is not completely mitigated and harmonic content in the output load voltage is not within the maximum allowable THD. These drawbacks are later overcome by using 12-pulse voltage source converter STATCOM in combination with harmonic filter (passive filter). All the simulations have been performed on the MATLAB SIMULINK software. The obtained results show that STATCOM is very efficient and effective for the flicker compensation.

Key terms: voltage flicker, STATCOM, harmonic filter, programmable voltage source.

I. INTRODUCTION

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 [6-7], 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 [2], giving the impression of unsteadiness of visual perception.

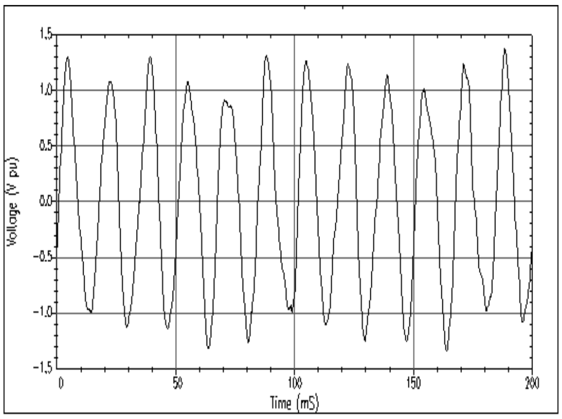

Fig.1 Voltage flicker

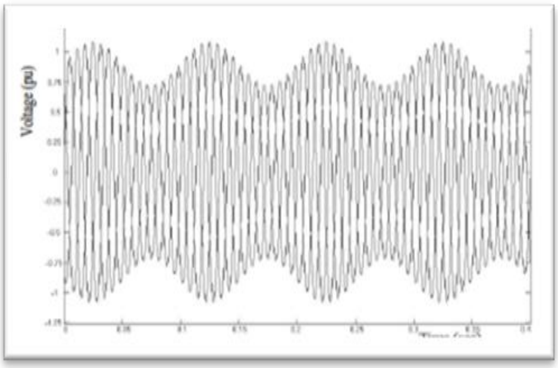

Fig.2 voltage flicker in 3Ø system.

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 modeled as a lumped reactance, a furnace reactance (included connection cables and busses) and a variable resistance [4,5] 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 [5] have usually to be connected. The most used shunt FACTS devices for compensation of voltage flicker are Static Var Compensator (SVC) and Static Synchronous Compensator (STATCOM). conventional SVC:s have disadvantages such as relatively long response time and the possibility to only compensate for the fundamental frequency reactive current of the load and introduces harmonics. These limits the possibilities to reduce flicker with an SVC [5,12]. These drawbacks can be overcome by switching converter based shunt FACTS controllers like STATCOM. This paper incorporates the STATCOM MATLAB SIMULINK model to solve the mitigation of voltage flicker.

II. SYSYTEM DESCRIPTION

In this paper, a two bus system is considered to investigate the voltage flicker compensation using STATCOM. This configuration block diagram is illustrated in fig.3 which consists of 3Ø programmable voltage source of 69kv and 3Φ Π-section power system line of 100km length and is connected to the step down 3Φ Transformer to serve the 3Φ parallel RL-load. For real time electric arc furnace load operation is the main source for voltage flicker/fluctuations into the system. In MATLAB SIMULINK a programmable voltage source block [10] is used as a flicker source to inject voltage flicker into the system (at PCC). The flicker/fluctuations are caused by amplitude modulation of the feeding alternating voltage (programmable voltage source). The disturbance of voltage flicker is transformed to other uses of electric energy via the point of common connection (PCC). So the voltage flicker appeared in the output load voltage [5]. STATCOM is connected at PCC (between the utility and load) to mitigate the voltage flicker in the output load voltage.

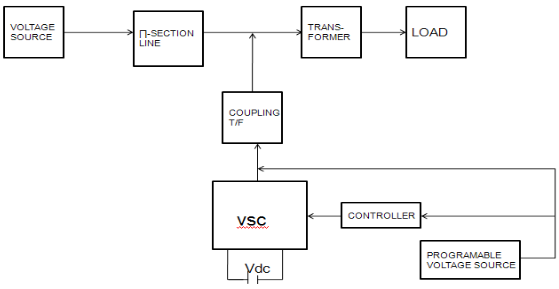

Fig.3 Block diagram of the studied power system

Parameter specifications of the studied system are as follows:
Generator: 3Ø AC, 69kv
Power system line**:** 3Ø Π- section, 100 km length

Parameter	value
Zero-sequence impedance	R=0.3864[Ohm/km], L=4.12[mH/km] C=751nF
Positive-sequence impedance	R=0.01273[Ohm/km], L=0.93[mH/km] C=12nF

Load: 3Ø parallel RL load, 30 MVA
Programmable voltage source (Flicker source):
Amplitude of the modulation= 0.3 p.u
Frequency of the modulation= 10 Hz
Variation time= 0 to 0.4 sec.
3Ø Transformer (load side): 30 MVA, 69KV/ 440 Volts.
Shunt connected 3Ø coupling Transformer: 30 MVA, 69 KV/ 11 kV.

III. 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 [11,5]. 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 [8,10]. 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: v_d on the d-axis (real or direct axis), v_q on the q-axis (imaginary or quadrature axis) and v_0 from 3Ø flicker voltage of v_a, v_b and v_c. The related equations of this transformation, expressed in the MATLAB Simulink software [10], are as follows:

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

$$V_q = \frac{2}{3}\left(v_a \cos(wt) + V_b \cos\left(wt - \frac{2\pi}{3}\right) + V_c \cos\left(wt + \frac{2\pi}{3}\right)\right) \qquad (3.1)$$

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

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 $V_{d,}$ V_q and V_0.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 (V_q), so to decrease the voltage flicker controlling system uses only V_q to control the STATCOM, the obtained V_q is entered as an input to the sum block and other input to the sum block is constant value zero, it indicates the V_q per unit reference value[5].

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 $\frac{180}{\pi}$ 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 (GTO's) of the STATCOM, to produce required magnitude of voltage and injection or absorption of reactive power[8,10].

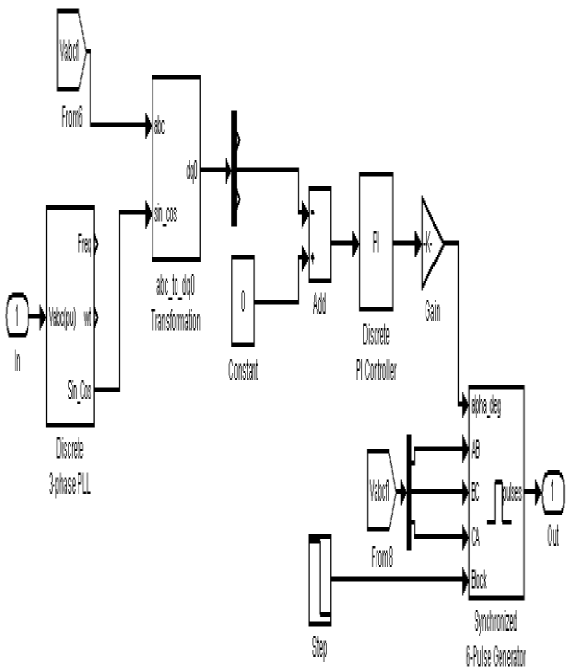

Fig. 4 Control circuit

IV. MITIGATION USING STATCOM SYSTEM AND SIMULATION RESULTS

In order to investigate the influence of the STATCOM as an effective mitigating device for voltage flicker, first a 6 pulse VSC STATCOM then a 12pulse VSC STATCOM and 12 pulses VSC STATCOM with 3Ø harmonic filter are simulated in MATLAB SIMULINK. The compensation technique and their results are as follows:

1) Compensation using 6-pulse voltage source converter STATCOM:

Fig 6 shows SIMULINK diagram of 6 pulse voltage source converter STATCOM connected to the power system. Six valves compose the converter and each valve is made up of a GTO with a diode connected in anti-parallel [8,9]. 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.

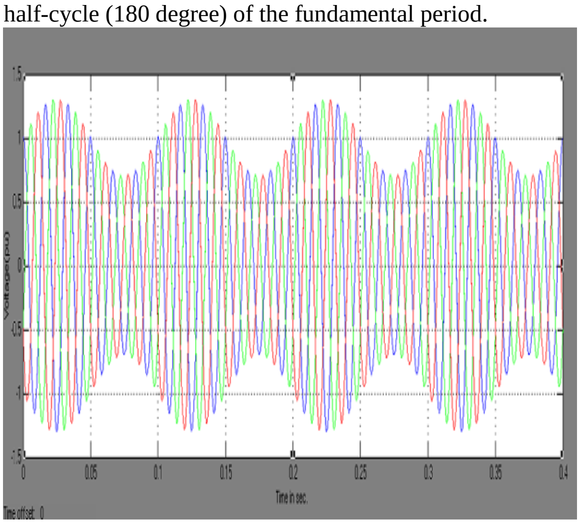

Fig.5 Output load voltage without STATCOM compensation.

The combined pulses of each leg have 120 degrees Phase difference to produce a balanced set of voltages. From the control circuit trigger pulses are given to the corresponding GTOs, by adjusting the conducting angle of the GTOs, the generated voltage and then the injected or absorbed power of the STATCOM are controlled [1,3].The six pulse bridge produces harmonics at 6N+/- 1.

Fig.7 and fig.8 shows the compensated output load voltage and harmonic spectrum respectively by 6 pulse voltage source converter STATCOM. It can be observed that the compensated output load voltage is 1.15pu (maximum value), the voltage flicker existing in the output load voltage is 0.15pu (15%), the considerable existing characteristic harmonics in the output load voltage wave form in addition to the fundamental component are 5^{th}, 7^{th}, 11^{th}, 13^{th} and higher. It can be observed from the harmonic spectrum that THD is 8.95%. 5^{th}, 7^{th}, 11^{th} and 13^{th} harmonic should be eliminated from the output load voltage.

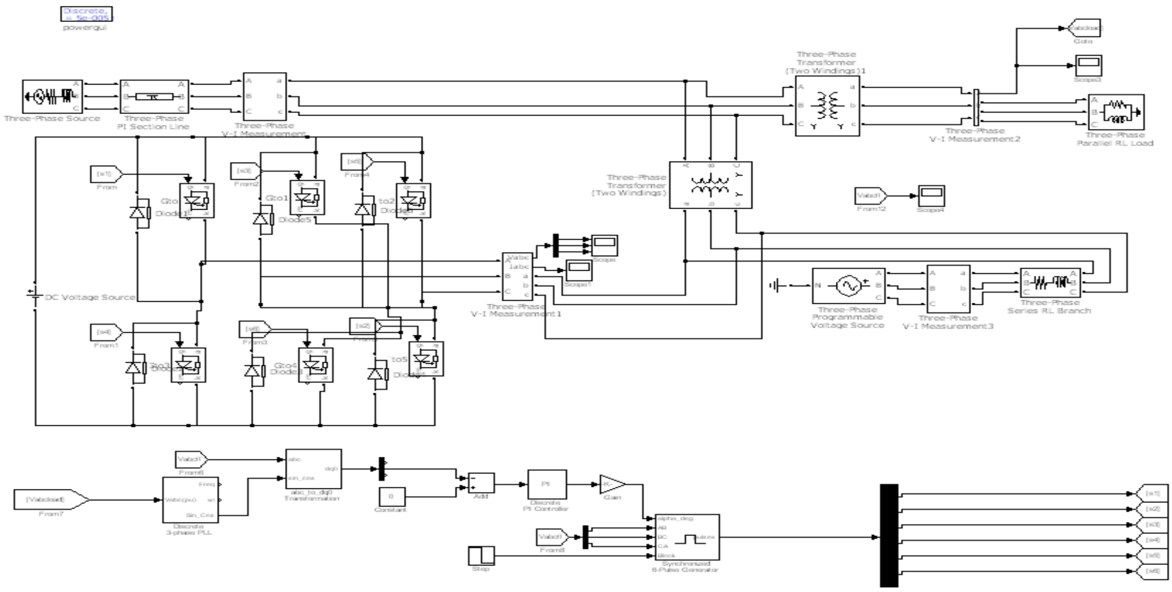

Fig.6 SIMULINK diagram of 6 pulse voltage source converter STATCOM connected to the power system.

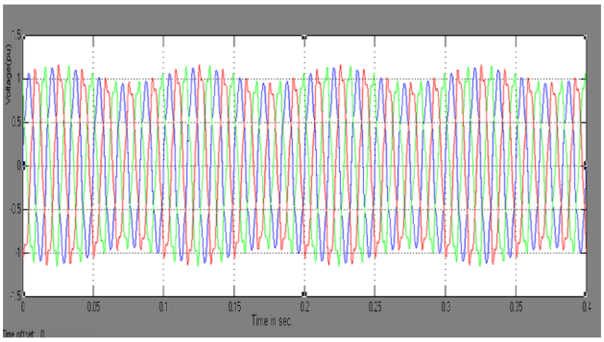

Fig.7 Compensated output load voltage by 6-pulse voltage source converter STATCOM.

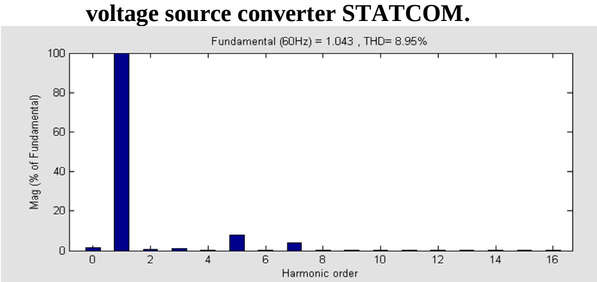

Fig.8 Harmonic spectrum of the compensated output load voltage by 6-pulse voltage-source converter STATCOM.

2) Compensation using 12-pulse voltage source converter STATCOM**:**

Fig.9 shows SIMULINK diagram of 12 pulse voltage source converters STATCOM connected to the power system.Two 6-pulse bridges are connected in parallel, forming a 12-pulse converter for a complete voltage flicker compensation design [1,3]. In this case, the first converter is connected with wye-winding (secondary) and the second one with a delta-winding of 3Φ-3winding Transformer. Moreover, the delta-connected secondary must have $\sqrt{3}$ 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 [3,8].

In this compensation, pulse generator outputs 1and 2 are two vectors of six pulses, are given to the two 6-pulse converters connected respectively to the Y winding and Δ connected windings of 3Ø transformer (three winding). The output load voltage mitigated by 12-pulse voltage-source converter STATCOM and its harmonic spectrum are shown in figure 10 and 11 respectively. In this respect, the voltage flicker is completely removed from the output load voltage. It can be observed from the harmonic spectrum that THD is 4.47%.

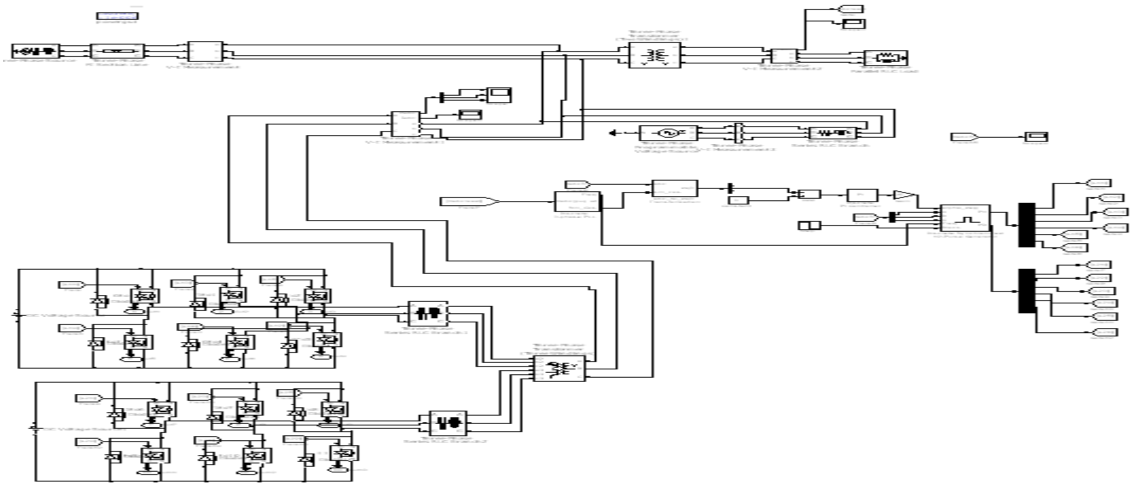

Fig.9 SIMULINK diagram of 12 pulse voltage source converter STATCOM connected to the power system.

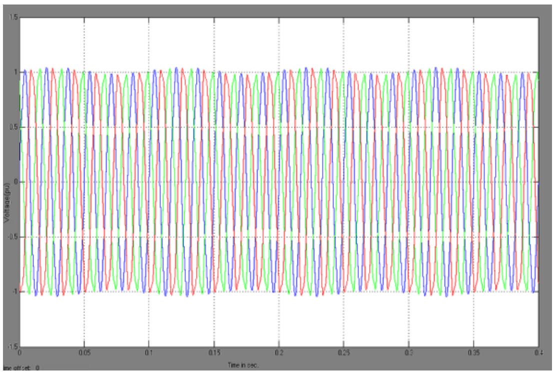

Fig.10 Output load voltage mitigated by 12-pulse voltage source converter STATCOM

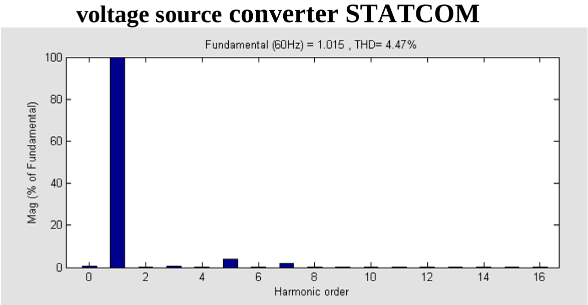

Fig.11 Harmonic spectrum of the output load voltage mitigated by 12-pulse voltage source converter STATCOM

3) Compensation using 12-pulse voltage source converter STATCOM with harmonic filter (passive filter):

Fig.12 shows SIMULINK diagram of 12 pulse voltage source converters STATCOM with 3Ø harmonic filter connected to the power system. To eliminate lowest order harmonics such as 11th and 13th harmonics, a passive filter (double tuned band pass filter) is connected across the 12-pulse voltage source converter output to divert the harmonic currents in low impedance path. The output load voltage mitigated by 12-pulse voltage-source converter STATCOM with 3Ø harmonic filter and its harmonic spectrum is shown in figures 13 and 14 respectively. In this respect, the voltage flicker is completely removed from the output load voltage and a sinusoidal waveform is obtained. It can be observed from the harmonic spectrum that THD is 2.30%.

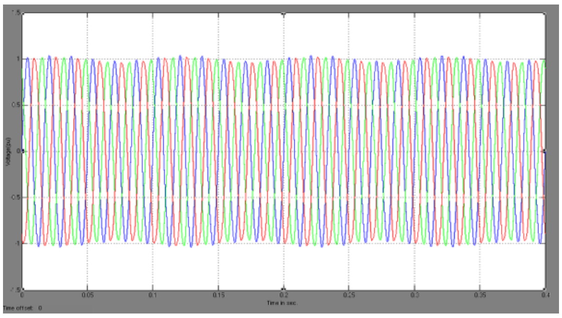

Fig.13 Output load voltage mitigated by 12-pulse voltage source converter STATCOM with 3Ø harmonic filters

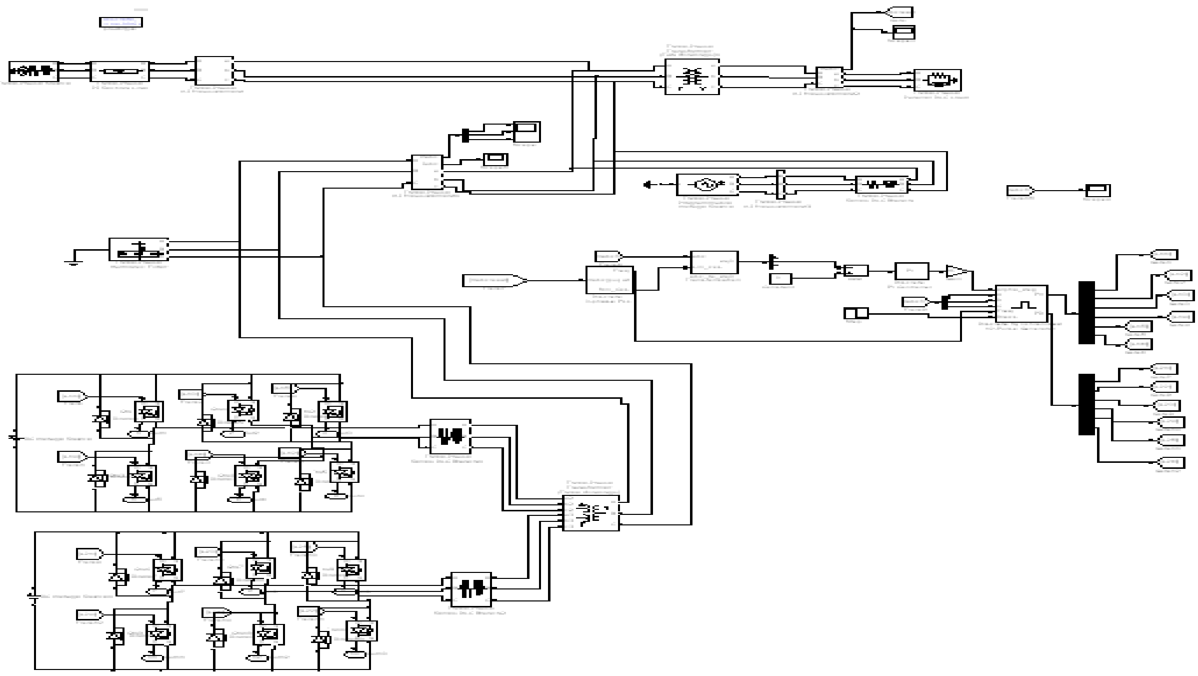

Fig.12 SIMULINK diagram of 12 pulse Voltage source converter STATCOM with 3Ø harmonic filter connected to the power system.

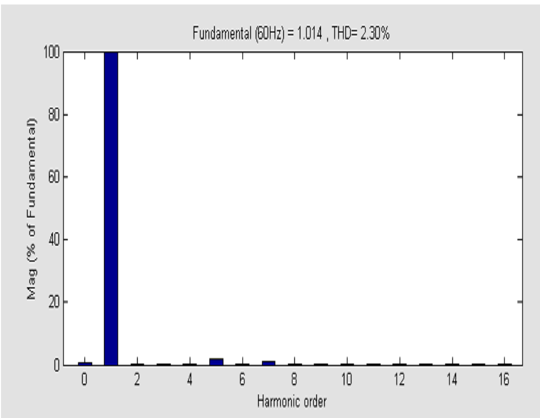

Fig.14 Harmonic spectrum of the output load voltage mitigated by 12-pulse voltage-source converter STATCOM equipped with a harmonic filter.

V. RESULTS ANALYSIS

The output load voltage without STATCOM and with STATCOM is obtained and compared as follows:

I. Without STATCOM:

The output load voltage is 1.3 p.u (maximum value).The voltage flicker existing in the output load voltage (exerted to the system) is 0.3 p.u (30%).

II. With STATCOM:

Table: Comparison of STATCOM compensator performance:

Compensator	Compensated output load voltage (maximum value)	Voltage Flicker	THD
6 pulse VSC STATCOM	1.15 pu	Existing is 0.15 pu (15%) (or) Mitigated by 50%	8.95 %
12 pulse VSC STATCOM	1.0 pu	Completely mitigated	4.47 %
12 pulse VSC STATCOM with 3Ø harmonic filter	1.0 pu	Completely mitigated	2.30 %

Above table shows the voltage flicker mitigation and THD value of STATCOM compensators in three stages. From these result, it can be understood that 12 pulse VSC STATCOM in combination with a harmonic filter is effective mitigating device for voltage flicker.

VI. CONCLUSION

Voltage flicker has emerged as a major concern in the area of power quality. Voltage flicker mitigation using voltage source converter STATCOM has been investigated in this paper. The MATLAB SIMULATION results show that a 6-pulse voltage source converter STATCOM is decreasing the voltage flicker by 50%. However the output load voltage waveform has some considerable harmonics which can be improved with the increase of the voltage source converters of STATCOM. Using a 12-pulse voltage source converter STATCOM in combination with a harmonic filter (passive filter), the voltage flicker is completely removed from the output load voltage and THD is reduced further.

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