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Simulation based Analysis and Mitigation of Voltage Flicker

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***Abstract*—**Trend of consumers of electrical energy being merely acceptors is changing. Earlier fluctuations and voltage disturbances that were the part of deal are no longer acceptable. Today electrical power is a product which can be predicted, measured, improved, and guaranteed. Utilities all over the world are concentrating over the improvement of the so called *Power Quality*. Voltage flicker being a power quality problem has gained interest of utilities as well as researchers. Voltage flicker is the disturbance in the form of lightning induced as a consequence to voltage fluctuations. The major source of voltage flicker is large non-linear loads like electric arc furnace. An approach towards the analysis of voltage flicker and its mitigation using DSTATCOM is discussed in this paper. DSTATCOM is considered to be an efficient technique for flicker mitigation owing to its fast response. The simulation tool MATLAB/ SIMULINK power system block set is applied.

***Keywords*—** Point of common coupling, Digital flicker meter, DSTATCOM, Programmable voltage source, THD and Harmonics

I. Introduction

The most common and undesirable consequence of voltage fluctuation is the variation in the illumination intensity of light source. Fundamentally speaking, flicker is quoted to account the behaviour of lightning and its effect perceived on the observer. Voltage flicker happens when heavy non-linear loads are turned on and off periodically, in a weak distribution network. Owing to the insufficient short circuit capacity of distribution system, voltage fluctuations occur. The major generator of voltage flicker, electric arc furnace (EAF), acts in the form of constant reactance and a variable resistance [1]. Large inrush current is required for starting the large motor, resulting in decrease in voltage causing a voltage flicker on lighting circuit connected to the same power system. Voltage flickering is extremely dangerous to sensitive electronic loads, as they require stable voltage to perform properly. As a result, voltage flicker proves to be major quality problem [2]. The magnitude of voltage flicker depends on type and size of electrical load causing disturbance. Voltage sag also initiates voltage flicker; inrush current is generated due to sudden voltage drops which can affect the sensitive equipment. Depending upon frequency of occurrence, flicker is sorted as- *Cyclic frequency*: - resulting from periodic voltage fluctuations, in the range of 10 per second to 2 per second. *Cyclic low frequency*: - fluctuation frequency varies from 2 per second to 12 per minute. *Non cyclic frequent*: - ranging from 12 per minute to 1 per minute. *Non cyclic infrequent*: - from 1 per minute to 3 per hour. Flicker irritations are more perceptible in incandescent lightning as compared to low-energy compact fluorescent lamps and can be used to reduce flicker.

International Union for Electro Heat (UIE) developed a flicker meter, objectifying flicker into two categories Pst and Plt [3]. According to IEC 61000-4-15 standards, Pst characterises, voltage fluctuations measured in 10 min would result in perceptible light flicker and is an indicator of flicker. IEC 61000-3-7 cites the acceptable annoyance level of flicker on power system network. Flicker acuteness is a function of both amplitude of fluctuation and the repetition rate; obtained using percentile values from a statistical classifier. A short term severity index Pst, reading of 1.0 indicates the level at which 50% of people would perceive flicker in 60-W incandescent lamp. the long term flicker severity index Plt is obtained out of 12 successive Pst values. Plt and Pst values are enumerated by utilities and standards. EN 50160 cites that the condition, Plt=1.0 should be fulfilled 95% of the time. Intensity of flicker severity can be measured with flicker meter (IEC 60868). A simple prediction formula for arc furnace flicker at point of common coupling (PCC) recommended by UIE is

$$Pst_{\_99\%} = Kst.\left(\frac{Sccf}{Sccn}\right) \quad (1)$$

Where Sccf is the short-circuit level of the arc furnace at the PCC. Sccn is the fault level of the network at the PCC, and Kst is the characteristic emission coefficient for Pst, ranging from 48 to 85 with a mean value of 60 [4]. EN 50160 gives flicker level at consumer terminals. In some Asian countries (Japan and Taiwan) another criteria for the flicker assessment is adopted by power companies- the voltage flicker index ΔV_{10} , characterizing the actual flicker with respect to an equivalent value of the voltage modulation component with the frequency of 10Hz [5]. It results that the same voltage fluctuations can be acceptable to one flicker criterion and non-acceptable according to another one, resulting in double cost of flicker level verification. A lot of endeavor has been put forward to find reliable and simple approach for the conversion of one index to another one by multiplying the indices with a factor, without any success of achieving a universal approach.

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II. VOLTAGE FLICKER

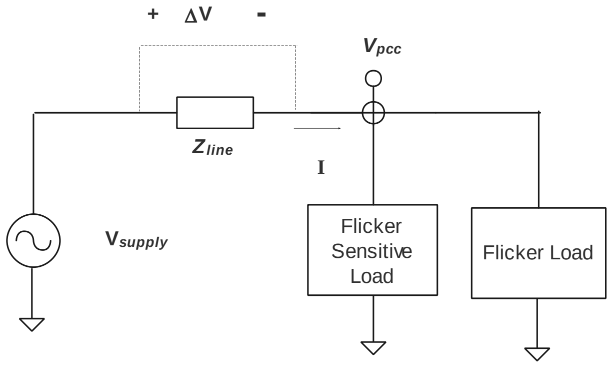

Fig. 1. Single Line Diagram of Load Causing Flicker

To investigate voltage flicker and its mitigation, a two bus system is considered. In real time application electric arc furnace (EAF) load operation is the main source of voltage flicker into the system as shown in Fig.1. In MATLAB Simulink [6], voltage flicker is injected externally into the system at the point of common coupling (PCC) using programmable voltage source block. Amplitude modulation of the alternating voltage (from programmable voltage source) causes flicker/fluctuations. The disturbance of voltage flicker is transformed to other uses of electric energy via point of common coupling (PCC), so the voltage flicker appeared in the output load voltage [7]. *Digital flicker meter* block is used to analyse the contaminated voltage. Flicker meter receives voltage, distorted by fluctuations in its input and gives instantaneous flicker level (IFL) as the output. To mitigate the effect of voltage flicker in the output load voltage, DSTATCOM is connected at the point of common coupling (between the utility and load).

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 [8] has been transformed to the synchronous reference frame (Park or dq0 transformation). Based on this 3-phase flicker voltage is transformed to synchronous reference frame by the use of abc to dqo transformation (Park's transformation). To implement Park's transformation a synchronizing system, essentially a phase lock looped block is used [9]. The input to the phase locked loop (PLL) is 3-phase AC system load voltage. This PLL can be used to synchronize on a set of variable frequency, 3-phase sinusoidal signals [10]. Output of PLL, Sinωt and cosωt serves as the input for abc to dqo transformation, leading to development of three instantaneous space vectors: Vd on the d-axis (direct or real axis), Vq on the q- axis (quadrature or imaginary axis) and V_0 . The required equations of this transformation are expressed in the MATLAB Simulink software is as follows:

$$Vd = \frac{2}{3}\left[Va\sin(\omega t) + Vb\sin\left(\omega t - \frac{2\pi}{3}\right) + Vc\sin\left(\omega t + \frac{2\pi}{3}\right)\right] \quad (2)$$

$$Vq = \frac{2}{3}\left[Va\cos(\omega t) + Vb\cos\left(\omega t - \frac{2\pi}{3}\right) + Vc\cos\left(\omega t + \frac{2\pi}{3}\right)\right] \quad (3)$$

$$V_0 = \frac{1}{3}\left[Va + Vb + Vc\right] \quad (4)$$

Where ω= rotation speed (rad/s) of the rotating frame. The output of Park's transformation is split into three components via demux. Out of the three components, to decrease voltage flicker, reactive component is required to be controlled. So, to decrease the voltage flicker controlling system uses only Vq to control the DSTATCOM, 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 [9]. Resultant of the sum block acts as an error signal for PI controller. PI controller output is firing angle component in radians, fed to pulse generator. Pulse signal from pulse generator are to be sent to the voltage source converter to trigger the power switching devices (GTO's) of the DSTATCOM, to produce required magnitude of voltage and injection or absorption of reactive power[6,10].

IV. SIMULATION RESULT ANALYSIS

To fulfill the investigation of stated procedure, a two bus system is probed. The test system used in this paper is 69kV, 3-phase, Π-section power system line are connected to 3-phase step-down transformer supplying a 3-phase parallel RL load. This configuration block diagram is illustrated in Fig.2. Voltage oscillations are result of 3-phase programmable voltage source.

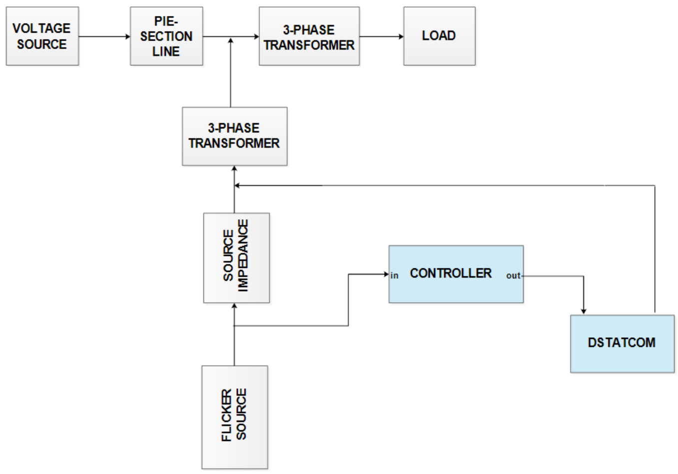

Fig. 2. Block Diagram of Studied Test System

In order to investigate the influence of the D-STATCOM as an effective mitigating device for voltage flicker, the voltage flicker compensation is adopted using a 6-pulse voltage-source converter D- STATCOM and the results were simulated as waveforms. Fig.3 and Fig.4 shows the output voltage of the system when external flicker source is added to the system. The contaminated voltage is analyzed by the aid of digital flicker block set as shown in Fig.5, giving the stepwise inspection of the studied wave.

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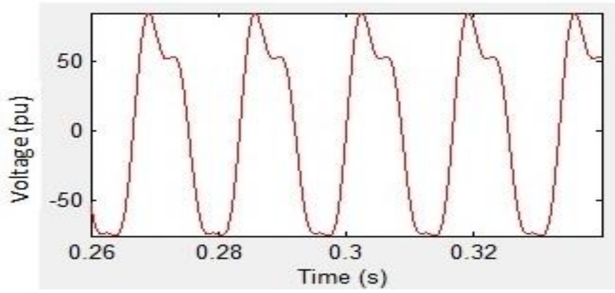

Fig. 3. Uncompensated Output Voltage Waveform

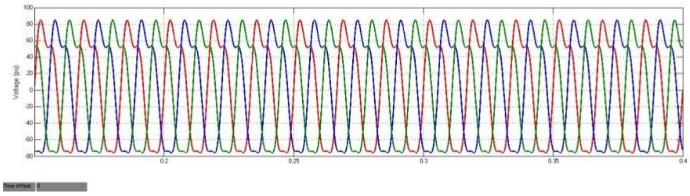

Fig. 4. Output Voltage Waveform of Test System

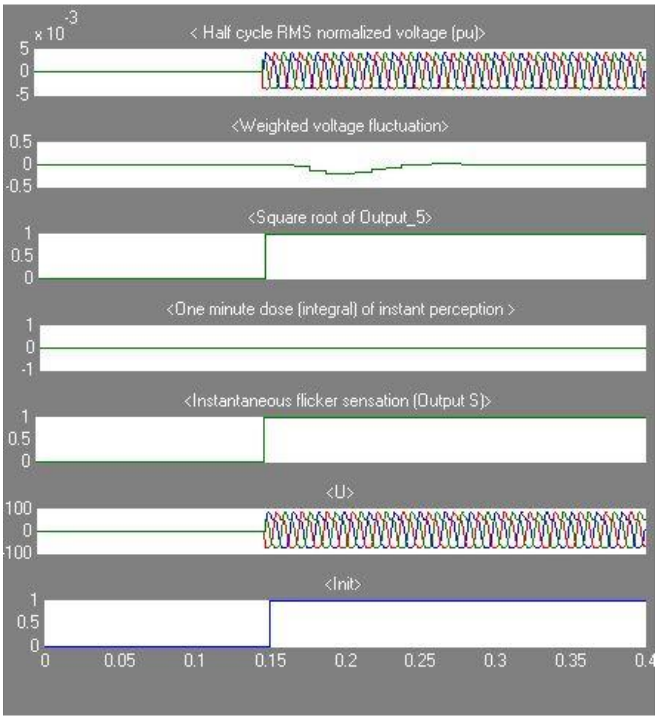

Fig. 5. Voltage Flicker analysis using Digital Flickermeter

From the FFT analysis of the load voltage, THD of 0.309 is evaluated at fundamental frequency of 50 Hz as shown in Fig.6.

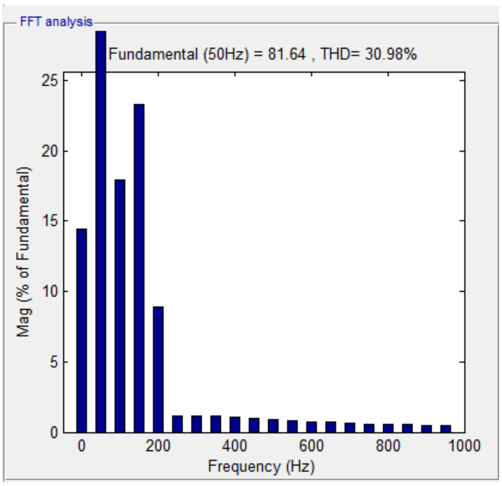

Fig. 6. Uncompensated Output Voltage Waveform

Fig.7 and Fig.8 shows the compensated output load voltage and harmonic spectrum respectively by 6 pulse voltage source converter DSTATCOM.

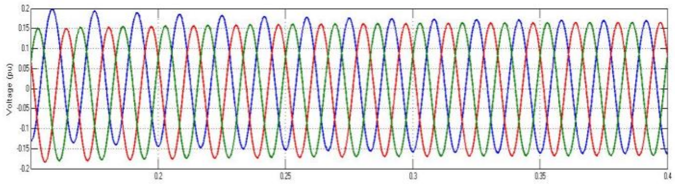

Fig. 7. Compensated Output Voltage by 6-Pulse Voltage Source Converter D- STATCOM

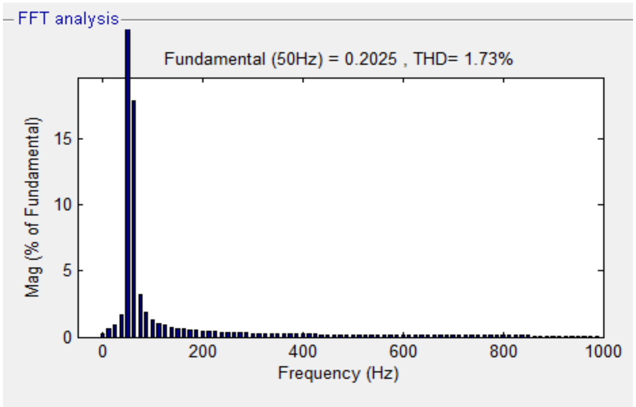

Fig. 8. **FFT Analysis of Compensated Load Voltage**

Harmonic content in the load voltage for compensated and uncompensated load voltage is tabulated in Table.1. Comparison of two cases deduced that harmonic content in compensated system is commendably low with respect to uncompensated system.

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TABLE 1. HARMONIC ANALYSIS OF LOAD VOLTAGE

Frequency(Hz)	Harmonic Level	
	Uncompensated System	*Compensated System*
0	14.42	1.96
50	100 (fundamental)	100
100	18.01	3.80
150	23.34	1.73
200	8.93	1.15
250	1.23	0.87
300	1.21	0.70

V. CONCLUSION

In this paper the voltage flicker problem in test system is examined using the digital flicker meter. The simulation of DSTATCOM for voltage flicker mitigation has been presented. The simulation result shows that owing to the fast response and flexible control, DSTATCOM is an efficient device for voltage flicker mitigation in distribution system.

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