ISSN: 2278 – 7798
International Journal of Science, Engineering and Technology Research (IJSETR)
Volume 5, Issue 7, July 2016

An Approach towards Power Quality Improvement by Reducing Voltage Flicker Using Ten-Pulse Converter

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***Abstract*— The suitability of electric power to consumers is determined by Power Quality. The emphasis on power system efficiency has led to growth in application of power electronic based devices. Dependency on renewable energy resources having converters for integration purposes have also contributed to power quality problems. Growing difference between the generated power and power demand has aggravated the problem. The main aim of improving power quality is basically to enhance the reliability of power supply. The consequence of power quality problem may cause the device or system to misoperate or fail. There are both internal and external factors affecting the quality of power. An attempt has been made to improve power quality using active and passive filters, hybrid filters and newly introduced custom power devices. In this paper most common power quality problem- Voltage flicker is discussed and is mitigated using a multi-pulse converter D-STATCOM due to its flexibility and fast response. The test model for the investigation has been simulated in MATLAB/SIMULINK.**

***Index Terms*— D-STATCOM, harmonics, point of common coupling, power quality, voltage source inverter.**

I. Introduction

Power quality affects all the electronic and electrical equipment connected in a power system and is a measure of deviation in voltage, current, frequency or temperature of a particular supply system. The increase in application of non-linear loads such as TV, monitor and lightning has given rise to harmonic currents. These harmonics causes communication interference, equipment overheating, loss of reliability, transformer failure, increase in equipment cost and inaccurate power metering. According to IEEE Standard 1100, power quality is characterized as "The idea of controlling and establishing the touchy supplies in a manner that is suitable for the operation of the gear." With modernization and automation of industry, use of computers, power electronic systems and microprocessors has increased. This is the major cause of power contamination. Power electronic based systems cause power quality problems by generating harmonics. In a deregulated market, the competition between electric utilities is increasing and customer's satisfaction has become the top priority. The power quality problems are a cause of concern among customers- industrial, commercial and even residential. Causes and effects of power quality issues and their analysis has become the important topic of research work now-a-days. Industrial and commercial consumers are becoming more sensitive to power quality problem [1]. Power quality problem is described as the deviation in voltage current or frequency from its nominal value in a power system [2]. Power quality is becoming important to consumers at all levels of consumption. With the end to the usage of static load, power quality problem has increased. Dynamic and non-sinusoidal type of loads increases the harmonics and unbalance in power system. The subject of power quality and its problem have been dealt in depth by the cited publications [3-6]. Power quality is defined as per IEEE standards IEEE 1100 as "The concept of powering and grounding sensitive electronic equipment in a manner suitable for equipment." One of the most common power quality problems is voltage fluctuations. The foremost effect of voltage distortion is flicker.

Manuscript received July 2016.
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II. Voltage Flicker

Voltage flicker is one of the most serious power quality problem found in loads like electric arc furnace operating in a weak distribution system. Manufacturing of steel causes load current to change extremely. If the system short circuit capacity is not sufficient, voltage fluctuations at the frequency range from 0.5 to 30 Hz would occur at the point of common coupling [7-8]. Even the small voltage fluctuations from 0.3% to 0.5% in the frequency range of 6-10 Hz will cause enough flickering [9-10]. This flickering is visible and harsh or uncomfortable to observer's eye. The main cause of voltage flicker is periodic switching on and off of heavy non-linear loads on a power system. Voltage flicker can cause damage to the extremely sensitive loads; hence its mitigation is necessary. Voltage fluctuations generate the inrush current which can affect the sensitive equipment. Fundamentally, voltage flicker is the disturbance in the form of annoying lightning intensity as a result of voltage fluctuation. High power loads like arc furnace or large motor drives draw fluctuating currents which result in low frequency cyclic voltage fluctuations causing light sources like incandescent and fluorescent lamps to flicker. This flickering can cause irritation or discomfort to human beings. The voltage flicker can affect the normal operation of electrical as well as electronic devices like motors and CRT (Cathode ray tube) devices. The voltage flicker lies in the range of 1 Hz to 30 Hz in the frequency spectrum. As the voltage flickers, luminous flux of the lamp fluctuates. At a power frequency, voltage is assumed to be sinusoidal and the magnitude is varying as periodic square wave of a specified frequency [11]. International Electrotechnical Commission (IEC) has bought out standard IEC 1000-4-15 for flicker measurement developed by Union of Electroheat (UIE) [12]. Fig. 1 shows the details of a flicker meter.

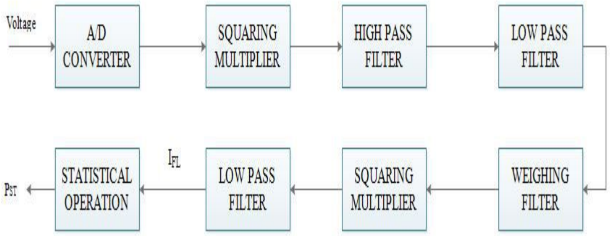

Fig. 1 Details of a basic flicker meter

The voltage signal either in analog or digital form serves as input. Squaring multiplier along with high pass and low pass filter are used for demodulating the signal. Demodulation is done to obtain fluctuating components of voltage. The high pass filter has a cut off frequency of 0.05 Hz and it filters out the constant component. The low pass filter has a cut off frequency of 35 Hz. Human reaction to fluctuation in the lamp luminosity is represented by weighing curve in frequency domain and is represented as a bode plot of a band pass filter with the transfer function as-

For a 60 W, 230 V incandescent lamp, k = 1.74802, $\lambda = 2\pi \times 4.05981$, $\omega 1 = 2\pi \times 9.15494$, $\omega 2 = 2\pi \times 2.7979$, $\omega 3 = 2\pi \times 1.22535$, $\omega 4 = 2\pi \times 21.9$

The weighing filter is designed based on research on the influence of luminous flux change on human being and is followed by a square multiplier and low pass smoothening filter of frequency 0.53 Hz modelling the fatigue effect of luminous flux changes [11]. The output of this filter is instantaneous flicker level (IFL) which is fed to evaluation block also called as statistical processing block. This block calculates cumulative probability function (CPF) based on IFL values collected over an observation time of 10 minutes. Instantaneous flicker level can be divided into two categories- short term flicker (P_{ST}) and long term flicker (P_{LT}). The short term flicker is defined by the formula-

Where, $P_{0.1}$ is the flicker level corresponding to 0.1%. Same can be said for P_1, P_3, P_{10} and P_{80}. Also,

Long term flicker severity can be calculated from short term flicker values using the following equation-

Where, N is the number of ten minute intervals within the observation time of P_{LT}.

III. TEN-PULSE CONVERTER

A DC to AC converter or voltage source inverter is designed in this paper. A traditional 3-phase, six-pulse voltage source inverter is used for low and medium range power operations. The conventional voltage source converter has harmonics associated with it. However, for high power applications where the voltage, magnitude and frequency should remain controllable and when no harmonics are desired, multi-pulse voltage source inverters can be used. Multi-pulse voltage source inverter also eliminates the need of harmonic filters. Fig. 2 shows the five-phase, ten-pulse inverter topology.

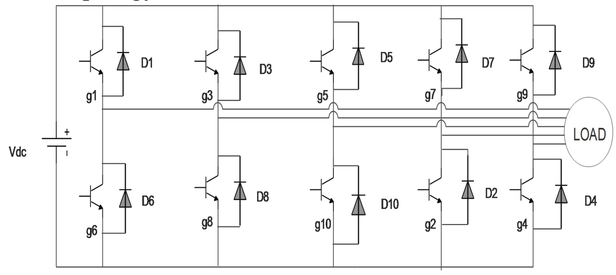

Fig. 2 Ten-pulse voltage source inverter

A single leg of voltage source inverter consists of two semi-conducting switches (S1 and S6, S3 and S8, S5 and S10, S7 and S2 or S9 and S4). Two switches in the same arm cannot be switched simultaneously as it would lead to short circuit across the DC link supply. Voltage source inverter is the building block of the D-STATCOM. Six-pulse voltage source inverter is used in basic design of D-STATCOM. However, for high power applications multi-pulse voltage source inverter (like ten-pulse voltage source inverter) is used for modelling the D-STATCOM.

IV. MODELING OF CONVERTER AND STUDIED TEST SYSTEM

The inverter is simulated in MATLAB/SIMULINK software [11]. The inbuilt IGBT/Diode blocks are used for simulation. The required gate pulse is applied by sinusoidal pulse width modulation as shown in Fig. 3. In this technique carrier signal is compared with the sine wave. The output of ten pulse inverter is shown in Fig.4. The designed inverter is then used along D-STATCOM for the purpose of voltage flicker mitigation. To achieve the desired purpose a two bus system is designed as shown in Figure 5. Flicker is generated using programmable voltage source. Digital flicker meter block set is used to investigate the voltage flicker. Fig 6 shows the output voltage waveform of uncompensated system.

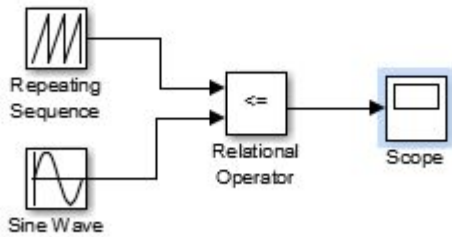

Fig. 3 Sinusoidal Pulse Width Modulation

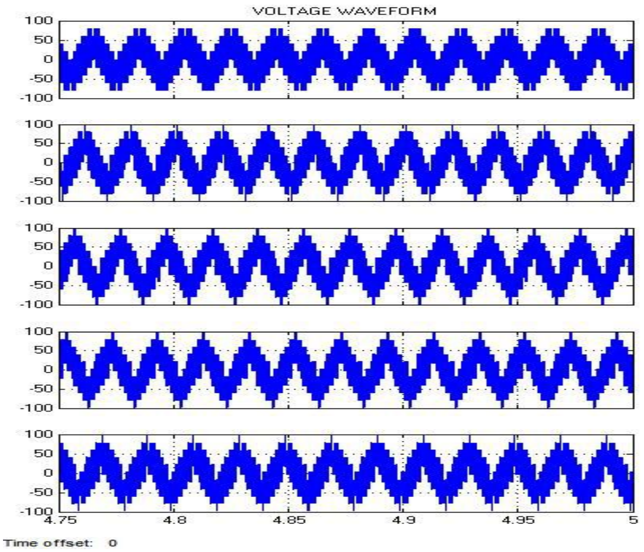

Fig. 4 Output waveform of ten-pulse VSI

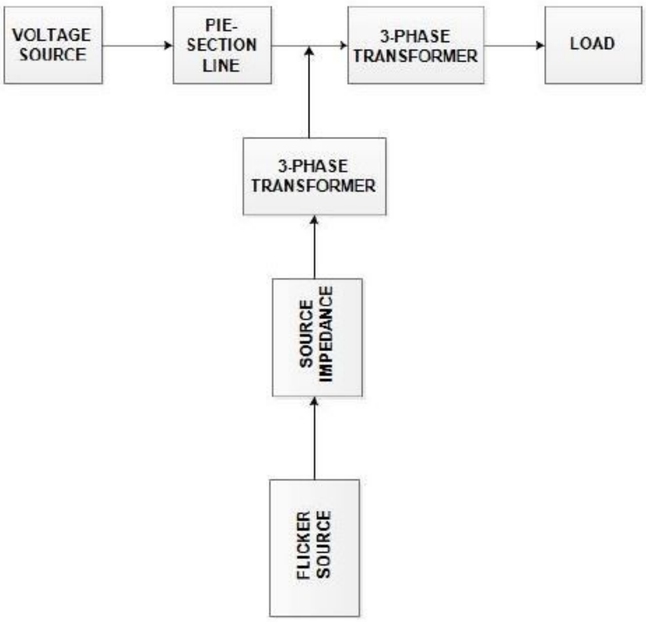

Fig. 5 Design of the test system

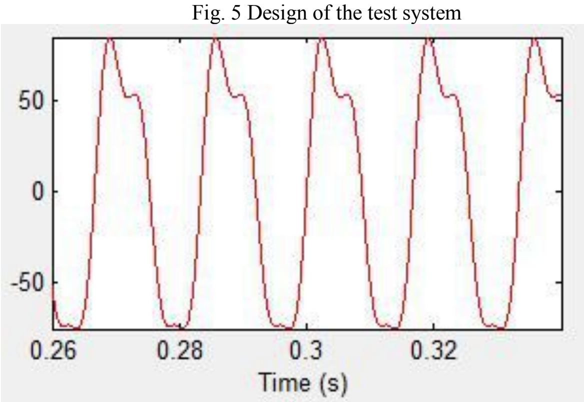

Fig. 6 Uncompensated output voltage waveform

Flicker meter receives polluted voltage and gives instantaneous flicker level as shown in Fig. 7 as output.

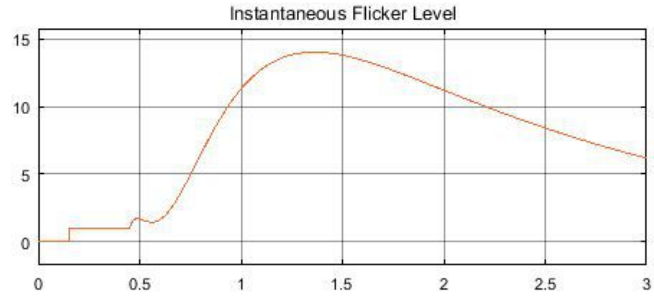

Fig. 7 Instantaneous flicker sensation (p.u)

V. RESULTS AND DISCUSSIONS

When the ten-pulse voltage source converter D-STATCOM is used for voltage flicker mitigation, the output voltage is shown in Fig. 8 and the instantaneous flicker sensation obtained from digital flicker meter is shown in Fig. 9.

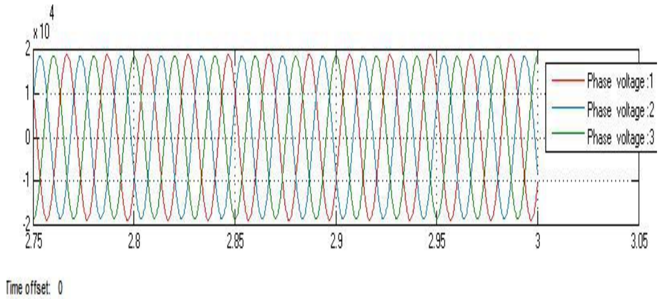

Fig. 8 Compensated output voltage by ten-pulse voltage source converter D-STATCOM

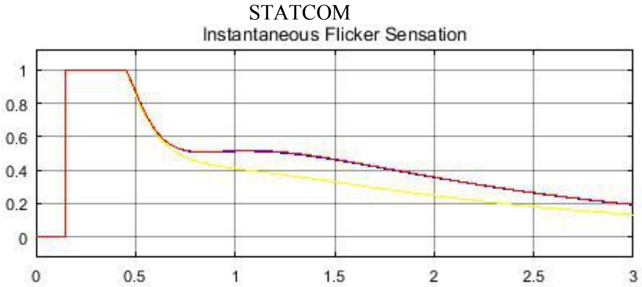

Fig. 9 Instantaneous flicker sensation with ten-pulse voltage source converter D- STATCOM

The instantaneous flicker sensation is measured for both uncompensated and compensated system at different time instances and is tabulated in Table 1 along with long term and short term flicker indices in Table 2.

TABLE I. INSTANTANEOUS FLICKER SENSATION VALUES FOR DIFFERENT SYSTEM CONDITIONS

TIME (S)	INSTANTANEOUS FLICKER SENSATION (pu)	
	Uncompensated System	D-STATCOM with Ten-Pulse Inverter
0.05	0	0
0.55	1.254	0.7259
1.05	11.47	0.3988
1.55	12.2	0.3169
2.05	9.661	0.2367

2.55	7.196	0.1733
3	5.449	0.1305

TABLE II. SHORT TERM AND LONG TERM FLICKER SEVERITY INDEX FOR SPAN OF TEN MINUTES

System	$P_{0.1S}$	P_{1S}	P_{3S}	P_{10S}	P_{50S}	P_{St}	P_{Lt}
Uncom pensate d	11.7 61	0.85 8617	0.02512 35	0.02 5123 5	0.02 5123 5	0.65 1971	0.651 971
Ten-pul se VSC	0.47 5725	0.02 3580 5	0.00195 312	0.00 1953 12	0.00 1953 12	0.13 0412	0.130 412

From the numerical vales it is quite evident that instantaneous flicker level falls to considerable proportion by ten-pulse converter thus, providing with better output wave shape and ensuring the power quality enhancement. Also a Table 3 is organized indicating the various harmonics present in uncompensated and compensated system.

TABLE III. HARMONIC ANALYSIS OF THE TEST SYSTEM

System Type	THD (%)	2nd Harmonics	3rd Harmonics	4th Harmonics	5th Harmonics	6th Harmonics	7th Harmonics	8th Harmonics	9th Harmonics
Uncompensated system	40.7	28.07 %	8.78%	21.81 %	9.45%	6.75%	5.39%	4.54%	3.95%
Ten-Pulse VSI D-STATCOM	8.01	0.02%	0.22%	0.02%	0.32%	0.03%	0.38%	0.13%	0.67%

From the table it can be seen that the harmonic level in the compensated system is also reduced thus improving the power quality and eliminating the need of filters.

Total harmonic distortion is also represented, indicated by Fig. 10 which also points to the same conclusion that ten-pulse converter based D-STATCOM is an efficient device for voltage flicker mitigation and improving the power quality.

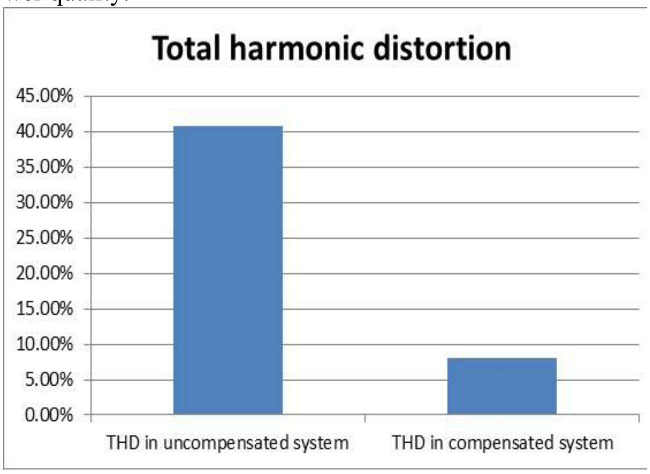

Fig. 10 Total harmonic distortion analysis

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