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Voltage Flicker Compensation Using Statcom

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ABSTRACT- 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. Huge non-linear industrial loads such as the electrical arc furnaces, pumps, welding machines, rolling mills and others are known as flicker generators. A new technique which extracts the voltage disturbance to suppress the voltage flicker, with usage of STATCOM for voltage flicker compensation to overcome the aforementioned problems related to other techniques with the concept of instantaneous reactive power components is used in the controlling system. The voltage flicker mitigation in three stages. In this stage a FCTCR one of the FACTS devices being controlled by a thyristor is used to mitigate the voltage flicking. The exerted voltage flicker into the system. A snubber circuit to eliminate voltage spikes caused by the huge TCR reactor switching, there are still distortions in the output waveform. In Compensation using 6-pulse voltage-source converter STATCOM adjusting the conducting angle of the GTOs, the generated voltage and then the injected or absorbed power of the STATCOM are controlled. The mitigation effects of this compensator are better than that of FCTCR and effectively mitigate the voltage flicker; but the output voltage waveform has some considerable harmonics. The output voltage mitigated by 12-pulse voltage-source converter STATCOM. 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.

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 [1]. 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 [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. The relative voltage drop is expressed by equation

$$\frac{\Delta U}{U_n} = \frac{R\Delta P + X\Delta Q}{U_n^{\,2}}$$

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 [5]. Two types of structures can be used for the compensation of the reactive power fluctuations that cause the voltage drop: A: shunt structure [1, 5-14]: in this type of compensation, the reactive power consumed by the compensator is kept constant at a sufficient value. B: series structure [15-16]: 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.

In addition to the aforesaid procedures for the compensators, the active filters are used for the voltage flickers mitigation as well [17]. Furthermore, the mitigating devices based on Static VAR Compensator (SVC) such as Thyristor Switched Capacitor TSC [18], Thyristor Controlled Reactor (TCR) [19], and FCTCR [20], 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 [5]. 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 [21-22] 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 [23]. 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.

VOLTAGE FLICKER

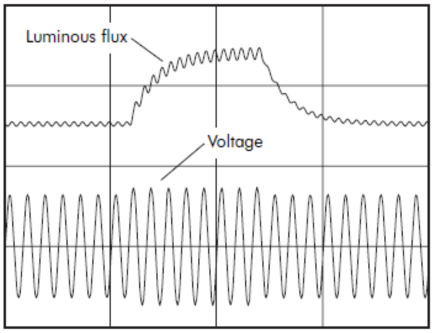
Flicker is a difficult problem to quantify and to solve. The untimely combination of the following factors is required for flicker to be a problem: 1) some deviation in voltage supplying lighting circuits and 2) a person being present to view the possible change in light intensity due to the voltage deviation. The human factor significantly complicates the issue and for this reason flicker has historically been deemed "a problem of perception." The voltage deviations involved are often much less than the thresholds of susceptibility for electrical equipment, so major operating problems are only experienced in rare cases. To office personnel, on the other hand, voltage deviations on the order of a few tenths of one percent could produce extremely annoying fluctuations in the output of lights, especially if the frequency of repetitive deviations is 5-15 Hz. Due to the clear relationship between voltage deviation and light response, the term "flicker" often means different things to different people with the interpretation primarily governed by the concerns of a particular discussion.

In each case, the deviation may or may not be strictly periodic and is usually expressed as a change (as indicated by the change in rms value) relative to the steady-state level (expressed as an rms value averaged over some time period). For voltage variations, the change is usually expressed as DV/V. A similar expression for light intensity variations also exists. From a utility application point of view, voltage fluctuations have usually been of interest, perhaps because voltage changes are easily measured with existing instrumentation. Historically, these voltage changes have been used in conjunction with "flicker curves". These curves, derived from controlled experiments, offer thresholds of perception and/or irritability when periodic rectangular voltage fluctuations occur continuously (only threshold of irritability curves are shown here). Even though the use of a simple curve leaves much to be desired (including an accepted industry-wide definition of the essential DV/V term), it is comforting to note that IEEE and UIE frequency weightings are very similar. The improvements that are now possible, based primarily on existing IEC standards, are the subject of this paper and will be presented in later sections. Standards-making bodies tend to focus on the changes in light intensity output in order to account for the human observability factor.

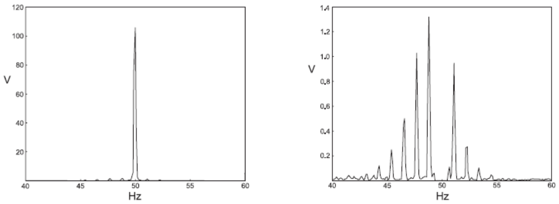
As standards have evolve, significant attempts have been made to include the years of experience obtained using the "flicker curve" method described previously. There are, however, a number of degrees of freedom that must be addressed in the development of a universally-accepted standard including lighting circuit voltage, type of lamp involved, randomness of voltage fluctuation, and human factors which affect perception. At this time, there are no widely-accepted flicker standards in the United States and Canada. In Europe and other countries, however, the International Electro technical Commission (IEC) has developed a group of standards which systematically account for many of the difficulties in the "flicker curve" methods. The IEEE Task Force on Light Flicker is presently considering modifications to these IEC standards that are required for them to be considered for adoption in the United States and Canada. The following sections describe the existing IEEE and IEC Standards.

Flicker Measurement Introduction

The power supply network voltage varies over time due to perturbations that occur in the processes of electricity generation, transmission and distribution. Interaction of electrical loads with the network causes further deterioration of the electrical power quality. High power loads that draw fluctuating current, such as large motor drives and arc furnaces, cause low frequency cyclic voltage variations that result in: flickering of light sources which can cause significant physiological discomfort, physical and psychological tiredness, and even pathological effects for human beings, problems with the stability of electrical devices and electronic circuits. Figure 1 illustrates the way in which a small voltage change produces a noticeable effect on the luminous flux of a bulb.



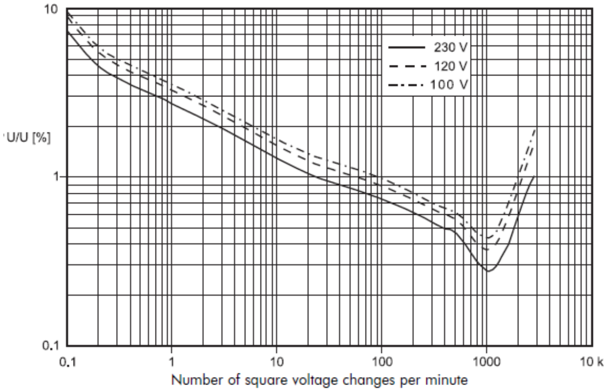
Recurrent small changes of network voltage amplitude cause flickering of light sources. The effect is popularly referred to as 'flicker' and is a significant power quality parameter. An example of a network voltage spectrum where flicker is apparent is shown in Figure 2. The spectrum shown is typical of the voltage of a network supplying a large non-stationary electrical drive. A bulb, supplied from the same node, will flicker with frequency about 1 Hz.



Power network voltage spectrum; in the diagram on the right the 50 Hz component is omitted

Estimation of voltage fluctuations

The phenomenon of flickering of light sources has been known since the introduction of power supply networks. However, it grew rapidly along with the increase in the number of loads and the increase in the power consumed. Considerable research has been conducted into the measurement and mitigation of flicker. In order to quantify the scale of light flickering phenomenon research has been conducted with the aims of developing measurement equipment, containment techniques and methods of mitigation. This Section discusses measurement principles and the generic design principles of measurement instruments. Initially, instrument designs were based on simple observation of luminous flux. The next step was to develop a model of the human reaction – in the form of discomfort or annoyance - to the fluctuation of luminous flux. The model was based on a 60 W, 230 V tungsten bulb, since that was the most commonly used light source in Europe at that time. Figure 3 shows the threshold of perception of flicker plotted against percentage voltage change (y axis) and frequency of change (x axis). Where the magnitude and frequency of the changes lie above the curve, the effect is likely to be disturbing to a human observer while below the curve it is likely to be imperceptible. The dashed lines represent tungsten bulbs designed for different nominal voltages. Early flicker measurement instruments included a typical 60 W, 230 V bulbs, a luminous flux sensor and an analogue model to simulate human reaction. Following research in the 1980s, activity in the area of flicker evaluation converged and is now centered on the UIE activities. The resulting normalized model instrument is completely electronic; it measures voltage fluctuation and simulates both the response of the light source and the human reaction. Two measurement results are derived; one for short term flicker effect, *PST*, measured over a ten minute period, and one for long term, *PLT*, which is a rolling average of *PST* values over a two hour time frame.



Measurement of short-term flicker severity

The block diagram of the instrument proposed by the UIE report is shown in Figure 4. The measured voltage fluctuations are processed using a model of the luminous flux versus voltage characteristic of the tungsten bulb and a model of the human reaction to fluctuations of luminous flux. This gives an instantaneous flicker measurement. However, individual people react differently to variations in luminous flux, so the *PST* value is derived using a statistical model based on experimental work with a large group of individuals.

Measurement and assessment of flicker in the power supply network As mentioned in the introduction, the basic source of voltage fluctuations (and the consequential flickering of light sources) is large electrical loads. The mechanism is illustrated in Figure 9. The voltage at the point of the load connection is less than the source voltage because of the voltage drop

$$U_{Zn} = I_{Load} \cdot Z_{Zn}$$

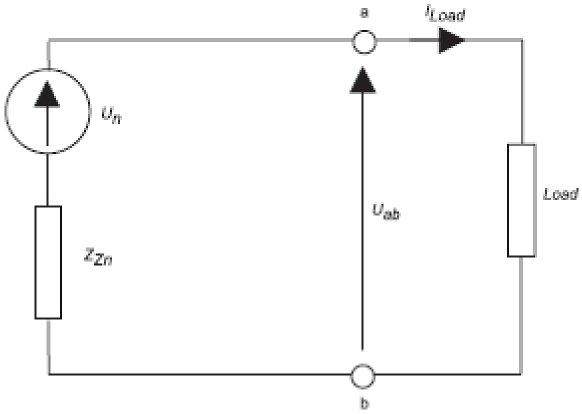
I_{Load} = load current, and

Z_{Zn} = network impedance,

as seen from the points of the load connection (a, b). Since the voltage at points (a, b) is

$$U_{ab} = U_n - U_{Zn}$$

it may be noticed that any *ILoad* current change, particularly in the reactive component, will cause an undesirable change in the voltage *Uab*. In a real power network this phenomenon is much more complex, but the principle is valid. Often, the question arises as to whether the planned connection of a load to the network would cause flicker or increase the level of flicker above the prescribed limit. The answer to this question depends on the parameters of the power network and any connected loads that may cause negative effects on it.



Since the effect cannot be measured in advance of connection, the effect must be estimated. Compatibility issues are dealt with in standardization document IEC 61000-3-3 [5], in which a reference source impedance *ZZn* equivalent to Re(*ZZn*) = 0.4Ω and Im(*ZZn*) = 0.25Ω at 50 Hz is assumed. Additionally, the standard provides a method of improving the assessment by taking account of the profile of the modulation of the supply voltage – i.e. the calculations assume the worst case square form modulation and will therefore require modification for other shapes.

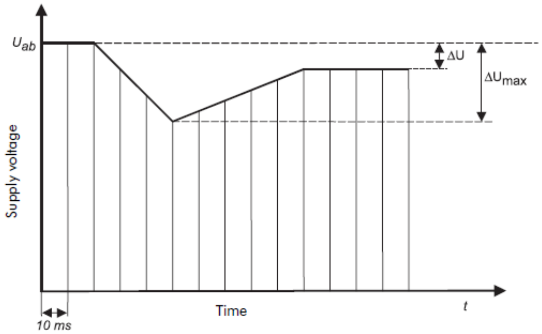


Figure 10 shows one profile, typical of a motor drive, from [5] showing how voltage changes Δ*U* are determined for the calculation of *d* = Δ*U*/*Uab* . Values of equivalent step parameters depend on t1, t2, t3 etc, as illustrated in the standard. The calculation of the effective value of voltage is performed every half cycle.

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 [24] has been transformed to the synchronous reference frame (Park or dq0 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 the 3-phase voltage of Va, Vb and Vc. The related equations of this transformation, expressed in the MATLAB software, are as follows:

$$V_d = \frac{2}{3}\left(V_a \sin(\omega t) + V_b \sin(\omega t - \frac{2\pi}{3}) + V_C \sin(\omega t + \frac{2\pi}{3})\right) \quad (2)$$

$$V_q = \frac{2}{3}\left(V_a \cos(\omega t) + \cos(\omega t - \frac{2\pi}{3}) + \cos(\omega t + \frac{2\pi}{3})\right) \quad (3)$$

$$V_0 = \frac{1}{3}(V_a + V_b + V_c) \quad (4)$$

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 (iq) and the derivative of the real current with respectto time ($(\frac{di_p}{dt})$). In general, for the complete voltage flicker compensation, the compensating current (ic) regarding the currents converted to the dq0 axis is given as [3]:

$$i_c = j(i_q + i_p \frac{R}{X} f + \frac{1}{\omega}\frac{di_p}{d\omega} f + k)$$

where R and X are the synchronous resistance and reactance of the line and *f* is the correcting coefficient. The constant *k* is also used to eliminate the average reactive power of the network [3]. If the compensation current of the above equation is injected to the network, the whole voltage flicker existing in the network will be eliminated. Regarding the equation, related to the dq-transformation of the 3-phase-voltages to the instantaneous vectors, it is obvious that under the conditions of accessing an average voltage flicker, Vd and V0, the obtained values are close to zero and Vq is a proper value adapting to the voltage oscillation of the network. This state of the 3-phase voltage flicker is presented in the following figures (simulated in the MATLAB Simulink package):

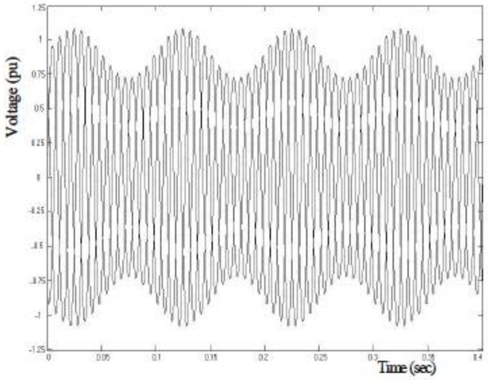


Figure 1: The voltage flicker exerted to the circuit

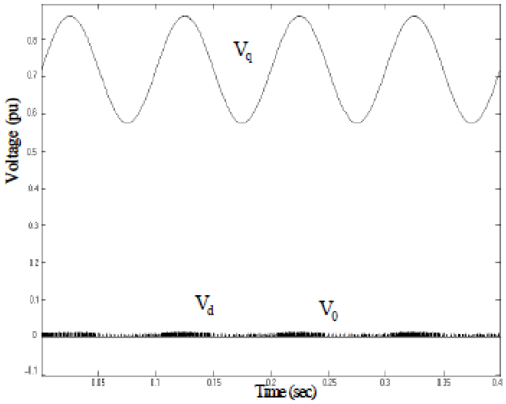


Figure 2: The instantaneous components of the 3-phase voltage flicker

Then, we may conclude that 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).

COMPENSATION SYSTEM

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. The complete STATCOM control system scheme implemented on MATLAB is shown in figure 4. First, using a 3-phase converter to dq0, the instantaneous vectors Vd, Vq and V0, 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 Vq to control the STATCOM, a de-multiplexer is used to extract Vq voltage from Vd and V0. The obtained Vq 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.

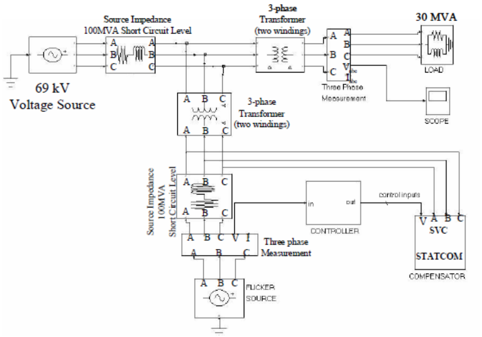


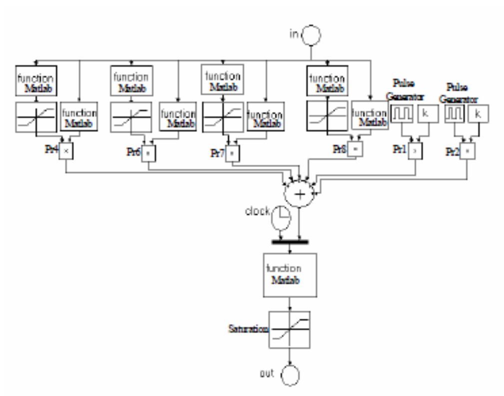
Figure 3. the studied power system

SIMULATION AND ANALYSIS OF THE RESULTS

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.

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 5 and 6 respectively.



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 [25] to eliminate voltage spikes caused by the huge TCR reactor switching, there are still distortions in the output waveform. 2) Compensation using 6-pulse voltage-source converter STATCOM *1)* The circuit diagram of a three-phase 6-pulse voltage source converter STATCOM is shown in figure 7. Six valves compose the converter and each valve is made up of a GTO with a diode connected in anti-parallel. 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. The combined pulses of each leg have a 120 degrees phase difference to produce a balanced set of voltages. By adjusting the conducting angle of the GTOs, the generated voltage and then the injected or absorbed power of the STATCOM are controlled. In this respect, the compensated output voltage by 6-pulse voltage-source converter STATCOM is presented in figure 8.

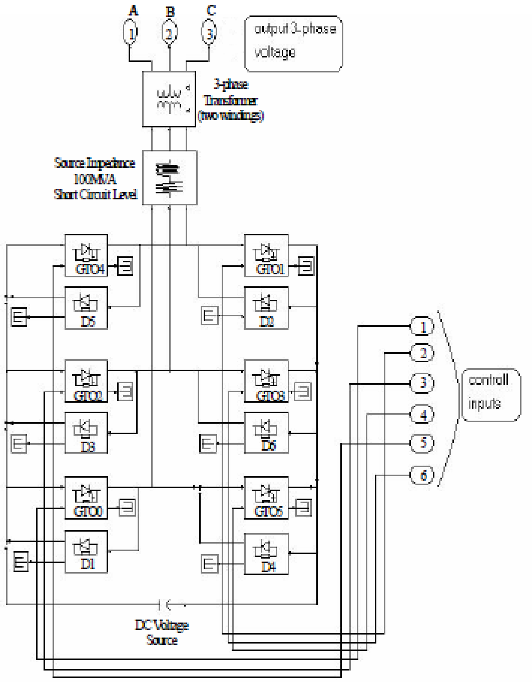


Figure 7. the circuit diagram of a 6-pulse voltage-source converter STATCOM

It can be seen that the mitigation effects of this compensator is better than that of FCTCR and effectively mitigate the voltage flicker; but the output voltage waveform has some considerable harmonics. The instantaneous output line-to-line voltage (Vab) of the 6- pulse voltage-source converter is as follows

$$V_{ab} = \sum_{n=1,3,5,\ldots}^{\infty} \frac{4V_S}{n\pi}\cos\frac{n\pi}{6}\sin n(wt+\frac{\pi}{6}) \qquad (6)$$

As we see it is clearly perceptible from the above equation that, the even harmonics in the instantaneous line-to-line voltage has zero value and does not enter the network voltage. Connecting the voltage-source converter with a wye-delta transformer to the network, multiple 3rd Harmonics (3, 9, 15 …) are eliminated from the line voltages.

Therefore, the considerable existing characteristic harmonics in the output voltage waveform in addition to the fundamental component are 5, 7, 11, 13 and higher whose values are shown in the harmonic spectrum of figure 9. It can be observed from the harmonic spectrum that 5th and 7th harmonics have considerable level comparing to the fundamental harmonics. Furthermore, 11th and 13th harmonics are considerable which should be eliminated from the network voltage waveforms. However, higher harmonics (namely 17th, 19th and above) have values very close to zero

Compensation using 12-pulse voltage-source converter STATCOM

In order to reduce the harmonic contents at the output voltage, the number of pulses can be increased, forming a multi-pulse configuration. Multi-pulse converters are composed by n (n=2, 4, 8 …), where n is the number of pulses. 6-pulse bridges connected in parallel on the same DC bus and interconnected in series through transformers on the AC side. Depending on the number of pulses, these transformers and their connections can become very complex.

Two 6-pulse bridges are connected, forming a 12-pulse converter for a complete voltage flicker compensation design. In this case, the first converter is connected with a wye-wye transformer and the second one with a wye-delta transformer. These are linked together using a three winding transformer. Moreover, the delta-connected secondary of the second transformer must have 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. The 12-pulse voltage-source converter STATCOM circuit diagram is shown in figure 10

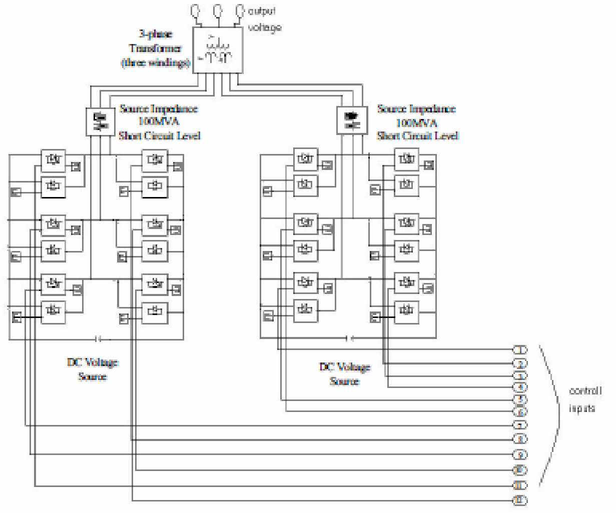


Figure 10. Circuit diagram of the 12-pulse voltage-source STATCOM configuration

The complete STATCOM control system scheme is implemented on the power system introduced in figure 3. The output voltage mitigated by 12-pulse voltage-source converter STATCOM and its harmonic spectrum are depicted in figures 11 and 12 respectively. In this respect, the voltage flicker is completely removed from the output voltage and a sinusoidal waveform is obtained. Furthermore, it is clearly obvious (from the harmonic spectrum) that almost all harmonics are removed from the output voltage. The only injected harmonics to the system are 11 and 13 that are deleted adding an RLC active filter to the designed compensator.

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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