Indonesian Journal of Electrical Engineering and Computer Science
Vol. 4, No. 2, November 2016, pp. 263 ~ 270
DOI: 10.11591/ijeecs.v4.i2.pp263-270

Voltage Flicker Reduction in Comparison with Using DSTATCOM and OLTC Transformer

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Abstract

Voltage Flicker is a major power quality problem as it has a significant impact on both the equipment and production environment. This work describes the voltage control techniques of mitigation of voltage fluctuations and clearing transient faults using Distribution Static Synchronous Compensator (DSTATCOM) and On Load Tap Changer (OLTC) Transformer and comparison between these two methods. The test system used is Egyptian native power distribution system. A simulation was done using MATLAB/Simulink software.

Keywords: *power quality, voltage flickering, DSTATCOM, OLTC transformer*

1. Introduction

Power quality has become one of the most focuses of attention in the power industry. Power quality is defined as any power problem detected in voltage, current, or frequency deviations that result in failure or misdirection of customer equipment [1]. Voltage flicker is the main power quality regard for both power utility and customers. Voltage Fluctuations or voltage flicker are defined as a series of random voltage changes, the magnitude of which does not normally exceed the voltage ranges specified by ANSI C84.1 of (0.9 to 1.1) per unit with frequencies less than 25 Hz and its typical duration is intermittent [2]. Voltage flicker at the load can be caused by events at many different points in the power system as distribution system from most consumers, power generation, and transmission lines because of different conditions [3]. Voltage flicker affect on impressible equipment such as light sources (flicker), electrical machines, electro-heat equipment and many other troubles [4].

In this paper, D-STATCOM and OLTC Transformer were utilized to mitigate voltage fluctuation and flicker in Egyptian native power distribution system. DSTATCOM is a fast response power quality device, which installed in the distribution system for reactive power compensation and mitigation of voltage fluctuation and many of other power quality troubles such as reducing Harmonics and power factor correction [5]. On Load Tap Changer (OLTC) is a device for changing the tapping connection of transformer winding while the transformer is on load [6]. It is a suitable component to mitigate voltage fluctuation, especially in power distribution network.

DSTATCOM is the best shunt connected FACTS devices [7]. The operation of the D-STATCOM is as follows, the Voltage Source Converter (VSC) voltage is compared with the AC bus voltage system, When the AC bus voltage magnitude is above that of the VSC magnitude voltage; the AC system sees the D-STATCOM as inductance connected to its terminals and it absorbs the increasing of nominal voltage. Also, if the VSC voltage magnitude is above that of the AC bus voltage magnitude, the AC system sees the D-STATCOM as a capacitance to its terminals and injecting require voltage. If the voltage magnitudes are equal, the reactive power exchange is zero [8]. OLTC changes the ratio of a transformer winding by adding or subtracting to/and turns from the primary or the secondary winding. The main function of OLTC is extinction a big arc in winding during the switching operation resulting from transition impedances and reducing the momentary loss of system load.

In this paper, the test and simulation of DSTATCOM and OLTC Transformer are using MATLAB/SIMULINK software in order to regulate and mitigate voltage flicker on Egyptian native

Received August 30, 2016; Revised October 15, 2016; Accepted October 29, 2016

power distribution system. In this paper, the system was tested with and without using DSTATCOM and OLTC Transformer in many cases such as fluctuated source, fluctuated load, fault occurrence and all of this case together in order to mitigate voltage flicker.

2. Methodology and Model Description

2.1. Distribution STATCOM

DSTATCOM is used to regulate voltage on a 22-KV real Egyptian native power distribution system. The structure of DSTATCOM and its equivalent circuit is shown in Figure 1. The D-STATCOM regulates voltage by absorbing or injecting reactive power. This reactive power transfers through the leakage reactance of the coupling transformer. The D-STATCOM consists of the following components as shown in Figure 1:

a) A 22 kV/1.25kV coupling transformer which ensures coupling between the PWM inverter and the network.
b) A voltage-sourced PWM converter consisting of two IGBT bridges. This twin inverter configuration produces fewer harmonics than a single bridge
c) LC damped filters connected at the inverter output. Resistances connected in series with capacitors.
d) A 10000-microfarad capacitor represents a DC voltage source for the converter
e) A PWM pulse generator.
f) Anti-aliasing filters used for voltage and current acquisition.
g) DSTATCOM control system

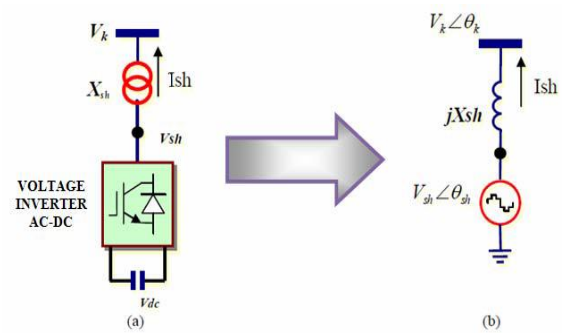

Figure 1. (a) Structure of DSTATCOM, (b) Equivalent Circuit

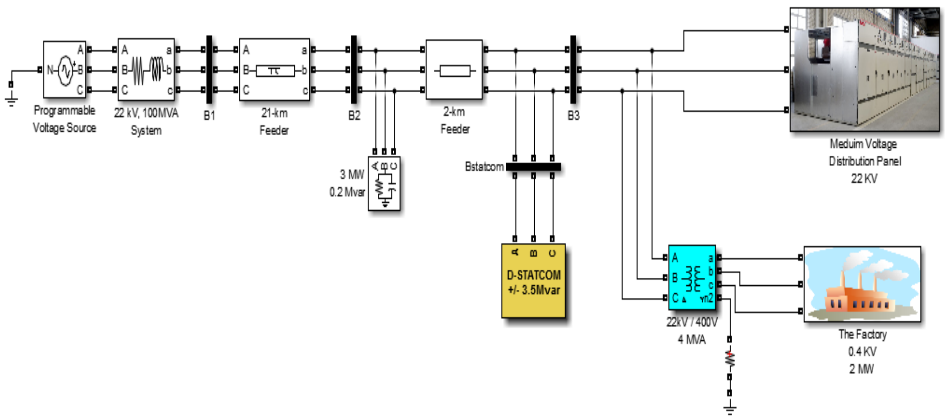

Figure 2. IEEE 9-bus Distribution System

In our work, part of real Egyptian native power distribution system was studied for utilizing DSTATCOM to regulate voltage on a 22-KV our distribution network as shown in Figure 2. Two feeders (21 km and 2 km) transmit power to loads at buses B2 and B3. A shunt capacitor is used for power factor correction at bus B2. The load is equivalent to a section of medium voltage distribution panel (22 KV) where the feeders come out as shown in Figure 3 and Figure 4. One of these feeders represents the (400-V and 2MW) load of the factory which it and its distribution panel connected to bus B3 through a 22kV/400V, 4 MVA transformer. The factory is producing voltage fluctuations and flicker. This factory connected to the distribution panel through a 22kV/400V, 4 MVA transformer (Table 1). This distribution panel connected to bus B3. The variable load current magnitude of the factory is modulated at a frequency of 5 Hz while keeping a 0.9 lagging power factor. The run time for the whole system is half second (0.5 s).

Then we test the system with and without DSTATCOM at many cases such as fluctuated source, fluctuated load, fault occurrence and all of this cases together in order to mitigate voltage and display a high response of DSTATCOM for mitigation voltage fluctuations.

Table 1. The Parameter Values of the System

Parameters	Values
Source voltage	22KV/ 50Hz
Source Power	100MVA
Line Length	23 Km
Coupling transformer	22 kV/1.25kV
DSTATCOM value	3.5 MVAR
Distribution Power Transformer	4 MVA
Reference Voltage of DSTATCOM	1 pu

2. 2. OLTC Transformer

The OLTC changes the ratio of a transformer winding by adding or subtracting to/and turns from the primary or the secondary winding on load. Principle winding arrangement of a regulating OLTC transformer in wye-delta connection shown in Figure 3 [6].

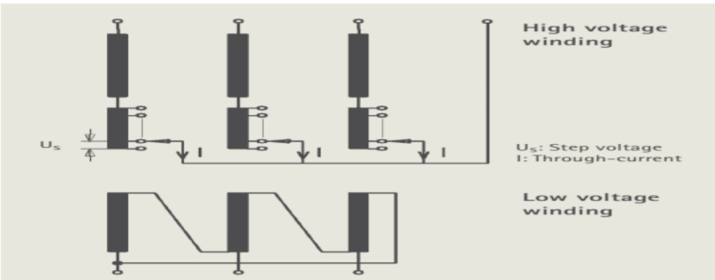

Figure 3. Arrangement winding of Regulating OLTC Transformer

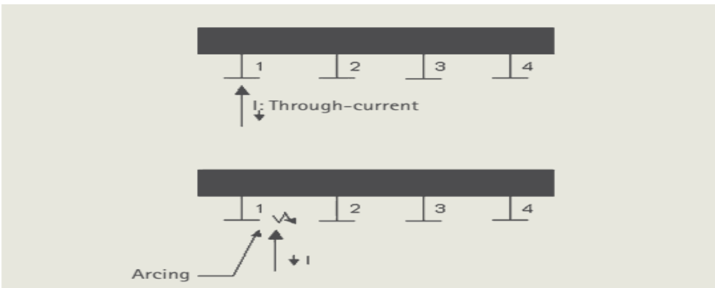

Figure 4. Loss and arc of System Load with Single Contact switching

Changing of taps during an energized status of a transformer without OLTC technique is unacceptable due to momentary loss of system load and a big arc in winding during the switching operation resulting from transition impedances as shown in Figure 4. The main function of OLTC is extinction a big arc in winding during the switching operation resulting from transition impedances and reducing the momentary loss of system load and switching phenomena. The main components of an OLTC are contacted systems for make and break the arc resulting from transition impedances, gearings, spring energy accumulators and a drive mechanism. The voltage between the taps normally lies between 0.8 % and 2.5 % of the rated voltage of the transformer.

Types of On-Load Tap Changer (OLTC) depend on the element using to extinguish the arc in winding during the switching operation resulting from transition impedances and switching principles have been used for load transfer operation such as a resistor, reactor and vacuum types.

The main circuit of the distribution system using OLTC shown in Figure 5. OLTC Transformer is used to regulate voltage on a 22-KV real part of Egyptian native power distribution network using and frequency 50-Hz (Table 2). A 22 kV distribution network consisting of three 23-km distribution feeders connected to a 66 kV/ 22 kV OLTC regulating transformer In order to supply the power to the load from a 66 kV and 1000 MVA system. The load is equivalent to a section of distribution panel where the feeders come out. One of these feeders represents the (400-V and 2MW) load is one of the factories there which producing voltage flicker. This factory connected to the distribution panel through a 22kV/400V, 4 MVA transformer. This distribution panel connected to bus B2. The OLTC transformer model implements a three-phase regulating transformer rated 60 MVA, 66 kV/22 kV, Wye/ Delta, with the OLTC connected on the high voltage side 66 kV.

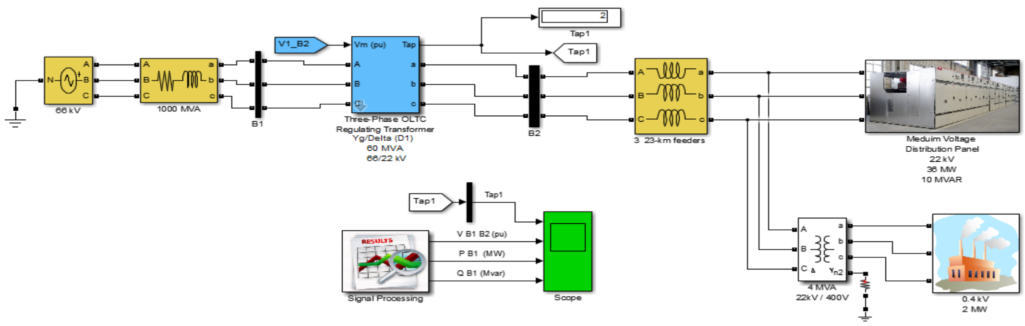

Figure 5. Part of 22 KV Real Egyptian Native Power Distribution System using OLTC Transformer

Table 2. The Parameter Values of OLTC Transformer System

Parameters	Values
Source voltage	66KV/ 50Hz
Source Power	100MVA
Line Length	23 Km
OLTC Transformer	66 kV/22 kV, 60 MVA
Distribution Power Transformer	4 MVA
Reference Voltage of OLTC	1 pu
Number of regulation taps	9

3. Results and Discussion

3.1. Distribution STATCOM

In this term, we test and simulate DSTATCOM using MATLAB/SIMULINK software in order to mitigate voltage fluctuations on 22-kV real Egyptian native power distribution system as shown in Figure 3. The simulation time is one second. In this simulation, the system was tested with and without DSTATCOM in many cases such as fluctuated source, fluctuated load, fault occurrence and all of this cases together. DSTATCOM used in this simulation +/- 3.5 MVAR.

3.1.1. Test System at Fluctuated Source Only

In this case, the system without and with installing DSTATCOM is displayed when voltage fluctuation comes from a supply (sources) and display the effect of inserting DSTATCOM on voltage quality of the distribution system as shown in Figure 6 and 7.

At t = 0.2 s, the source voltage is increased by 7%. The D-STATCOM compensates for this voltage increase by absorbing reactive power from the network (Q = +2.9 MVAR). At t = 0.3 s, the source voltage is decreased by 7%. The D-STATCOM must generate reactive power to maintain a (1 pu) voltage (Q changes from +2.9 MVAR to -3.4 MVAR). Note that when the D-STATCOM changes from inductive to the capacitive operation, the reversing of reactive power is very fast.

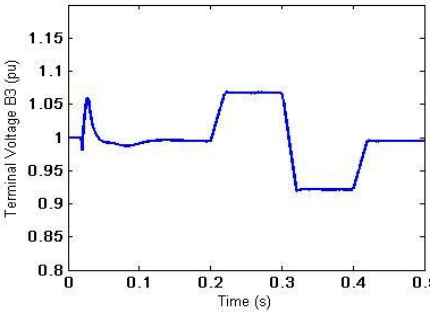

Figure 6. Terminal Voltage at Load Buses B3 without DSTATCOM

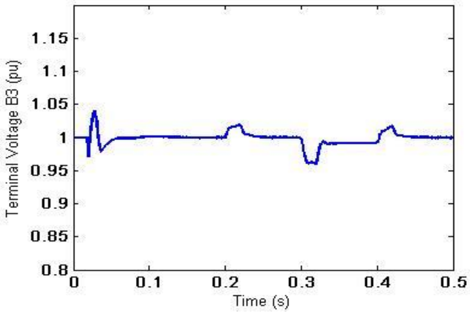

Figure 7. Terminal Voltage at Load Buses with DSTATCOM

3.1.2. Test System at Fluctuated Load Only

In this case, the system without and with installing DSTATCOM is displayed when voltage fluctuation comes from customer load only. And show the effect of inserting DSTATCOM to mitigate voltage flicker resulting from fluctuated load bus B3 as shown in Figure 8 and 9. In this case, the reactive power of DSTATCOM's compensation changed from +1.6 MVAR to -2.3 MVAR to mitigate voltage fluctuations by the high response.

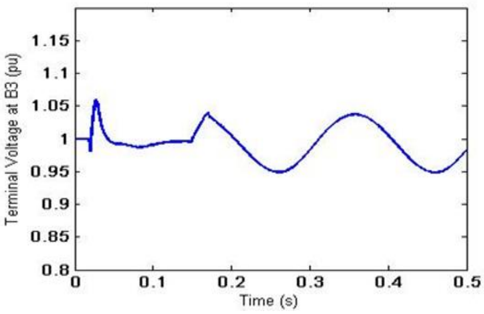

Figure 8. Terminal Voltage at Load Buses without DSTATCOM

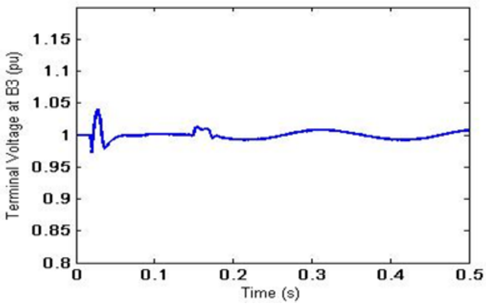

Figure 9. Terminal Voltage at Load Bus B3 with DSTATCOM

3.1.3. Clearing Transient Three Phase Fault to Ground

In this case, the transient fault occurs between 0.1 s to 0.2 s. The 3-ph to a ground fault by a fault resistance of 79 Ω which affects the load voltage stability at B3. DSTATCOM acts a capacitor which compensates this voltage decrease by injecting reactive power by (- 3.3 MVAR) at time 0.1 s to 0.2 s and clearing transient fault as shown in Figure 10 and 11.

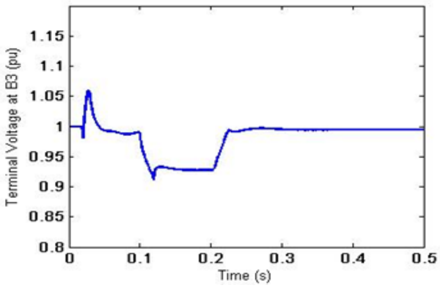

Figure 10. Terminal Voltage at Load Bus without DSTATCOM

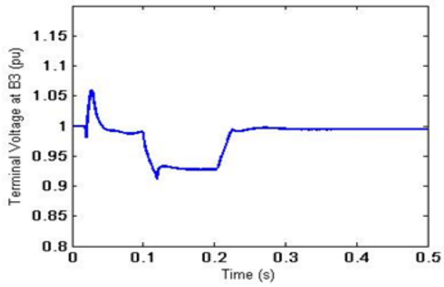

Figure 11. Terminal Voltage at Load Bus with DSTATCOM

3.1.4. Test Simulation System at Fluctuated Source and Fluctuated Load applying Three Phase Fault to Ground Together

This case considers a worst case. In this case, the voltage at load fluctuates between (1.06 to 0.92) pu. The system without and with installing DSTATCOM is displayed during the occurrence of all cases mentioned above together. Displaying the effect of installing DSTATCOM on voltage fluctuation mitigation of the distribution system as shown in Figure 12, and Figure 13. The compensated Reactive Power (MVAR) by DSTATCOM as follow, DSTATCOM acts a capacitor which compensates voltage decrease which it caused by a transient 3-ph fault to ground- by injecting reactive power (- 3.3 MVAR) at time 0.1 s to 0.2 s. At t = 0.2 s, the voltage is increased by 6%. The D-STATCOM compensates for this voltage increase by absorbing reactive power from the network (Q = +2.6 MVAR). At t = 0.3 s, the source voltage is decreased by 8%. The D-STATCOM must generate reactive power to maintain a (1 pu) voltage (Q changes from +2.6 MVAR to -3.3 MVAR). Note that when the D-STATCOM response is very fast where between (3-6) msec.

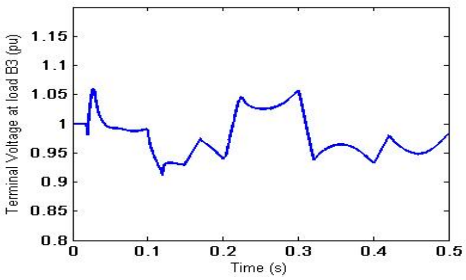

Figure 12. Terminal Voltage at Load Bus B3 without DSTATCOM

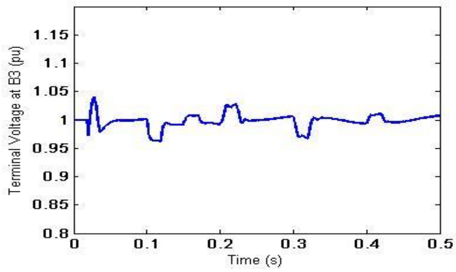

Figure 13. Terminal Voltage at Load Bus B3 with DSTATCOM

3.2. OLTC Transformer

In this term, OLTC was tested and simulated using MATLAB/SIMULINK software in order to mitigate voltage flicker on 22-kV real Egyptian native power distribution system as shown in Figure 5. The OLTC transformer is used to regulate system voltage and mitigate voltage flicker at 22 kV bus B2. Voltage flicker mitigation is performed by varying the transformer turn ratio. This is obtained by connecting on each phase. Nine OLTC switches allow selection of eight different taps which tap positions in our model from 2 to -6, plus tap 0. Each tap provides a voltage correction of +/-0.01875 pu of nominal 66 kV voltage. The simulation time is 120 s.

3.2.1. Test Simulation System at Voltage Fluctuation Case

Voltage fluctuations can happen because of fluctuated source or fluctuated load or together. All of the previous causes of voltage fluctuation make the same effect on the load bus.

In this test, we will use the OLTC transformer to regulate system voltage at 22 kV bus B2 by varying the transformer taps via On Load Tap Changer (OLTC) Control.

In this case, the system without and with installing OLTC is displayed when voltage flicker comes from supply or loads and display the effect of using OLTC Transformer on voltage quality of the distribution system as shown in Figure 14, 15, 16 and 17. The voltage decreases to 0.93 pu and increases to 1.07 pu. OLTC Transformer starts with (-2) tap and changes taps to obtain reference voltage (1) pu so as to mitigate voltage fluctuation.

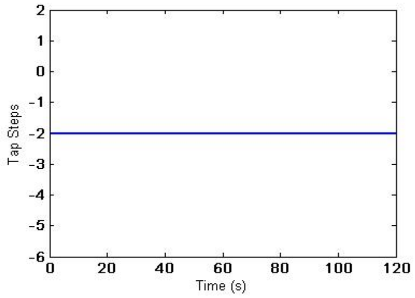

Figure 14. Tap Steps without OLTC

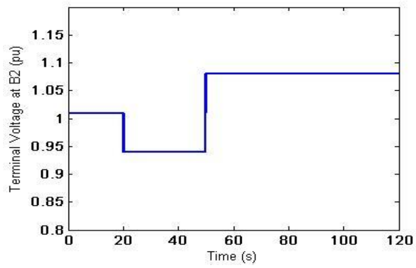

Figure 15. Terminal Voltage at B2 (pu) without OLTC

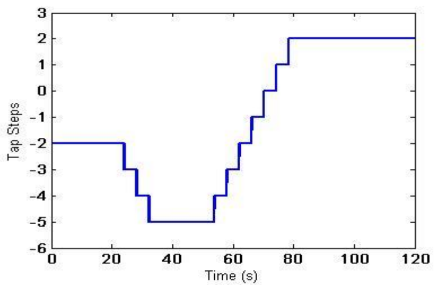

Figure 16. OLTC Transformer Steps

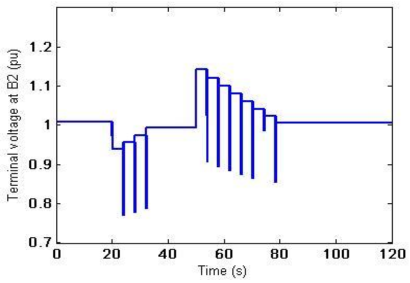

Figure 17. Voltage at B2 (pu) with OLTC

3.2.2. Test Simulation System at Voltage Fluctuation with 3-ph to Ground Fault

In this case, the system without and with installing OLTC control is displayed to regulate system voltage flicker at 22 kV bus B2 and mitigate transient 3-ph to ground fault by varying the transformer taps via OLTC Control as shown in Figure 18, 19, 20 and 21. The 3-ph to Ground Fault occur in this simulation between (90-100) s. The voltage decreases to 0.93 pu and increases to 1.07 pu and decreases again because of transient 3-ph-ground fault. OLTC Transformer starts with (-2) tap and changes taps to obtain reference voltage (1 pu) so as to regulate voltage.

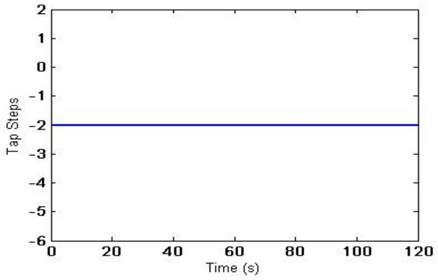

Figure 18. Tap Steps without OLTC

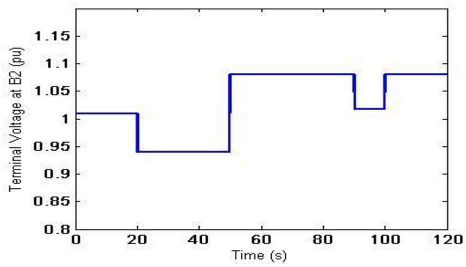

Figure 19. Terminal Voltage at B2 (pu) without OLTC

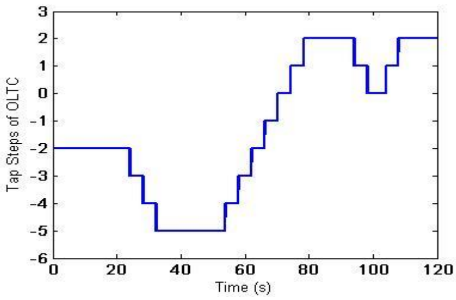

Figure 20. OLTC Tap Steps

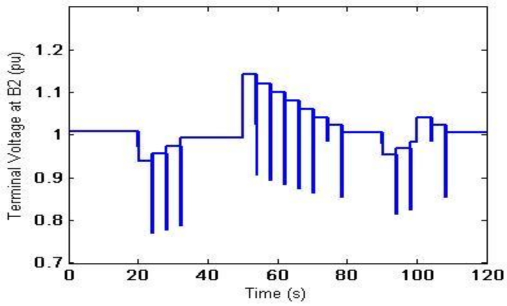

Figure 21. Voltage at B2 (pu) with OLTC

3.3. Comparison between DSTATCOM and OLTC Transformer

In this part, the comparison between DSTATCOM and OLTC Transformer would illustrate clearly from the previous testing. Clearly evident that DSTATCOM is a faster response and highest efficiency from OLTC Transformer but more expensive. So, OLTC is more presence because it is cheaper. Table 3 shows a comparison between DSTATCOM and OLTC Transformer.

Table 3. Comparison between DSTATCOM and OLTC Transformer.

	DSTATCOM	OLTC
System Voltage	380 V to 35 kV, 50 or 60 Hz	380 and above, 50 or 60 Hz
Time Response	2-4 msec.	3-10 sec per tap
Efficiency	near to 98%	near to 90%
Cost	about 70$ /KVAR	about 10$ /KVA

4. Conclusion

Voltage flicker is a major power quality problem as they have a significant impact on both the equipment and production environment. In this work the simulation done by MATLAB/Simulink software. In this paper, D-STATCOM and OLTC transformer are used to mitigate voltage flicker in Egyptian native power distribution system. Clearly evident that DSTATCOM is a faster response and highest efficiency from OLTC Transformer but more expensive. After reviewing this paper you have the ability to define voltage Fluctuation and overcome voltage flicker problems in your native power distribution network with latest and suitable techniques.

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