Global Journal of Technology and Optimization

Research Article
Volume 11:5, 2021

ISSN: 2229-8711 Open Access

Mitigation of Voltage Fluctuations/Voltage Flicker and Power Quality Improvement in Power Systems Using Distributed Statcom

Abubakar Sufyanu*

Department of Electrical & Electronics Engineering, University of Science & Technology, Aliero, Nigeria

Abstract

This paper deals with power quality and more specifically, voltage flicker in power systems. Voltage flicker is one of the disturbances in power systems. This flicker mainly occurs due to nonlinear loads. The magnitude of the voltage flicker solely depends on the type of electrical load that is producing the disturbance. Voltage flicker can also occur due to voltage sag and/or voltage swell in the system. This voltage sag can generate inrush current and this current passes into the sensitive loads in the distribution system.

Keywords: Voltage flicker • Facts • D STATCOM power quality

Introduction

Recently, power systems are facing numerous power quality problems across the globe. This is because of the increase in power demand which is caused by the surge in global population and also the increase in industrial plants. Voltage flicker is one of these problems. Voltage flicker also occurs due to frequent switching on and off of loads on a weak distribution system. While starting of large motors, voltage decreases due to the requirement of inrush current. This decrease in voltage causes flicker on other loads that are connected to the same distribution system. Voltage flicker is extremely dangerous to sensitive loads connected to the same network.

There are many ways of power quality improvements suing power electronics devices such as FACTS (flexible AC transmission system) devices. Flexible AC Transmission System (FACTS) devices are controllers based on power electronics. It has been demonstrated that they can improve transient stability and help to damp electromechanical oscillations in distribution power systems [1].

The proposed FACTS device used in this paper is the Distribution Static Compensator D STATCOM. The D STATCOM will be configured and then designed to reduce the voltage flicker in the system.

Power quality in power system means how the supplier supplies a quality of power. Due to voltage fluctuations there is a disturbance of lightning which is known as voltage flicker. This voltage flickering occurs mainly due to the rolling mills, nonlinear loads, welding machines etc. Due to the above loads there is a reduced voltage in power system which is a major problem of power quality [2].

Furthermore, flickering lights can have adverse effects on health. They also cause fatigue, lack of concentration, migraines and some instances; epileptic shock. The severity of reaction and effects varies from person to person. Some people can see higher rate of flickering than others. Fluorescent lamps in particular can develop a fault that can cause them to have a noticeable flicker.

Theory and Methodology

Voltage flicker is mainly generated by the nonlinear industrial loads like electric arc furnace. Electric arc furnace behaves as variable resistance and constant reactance. If this type of load is connected in the network, this produces a variation in voltage at point of common coupling (PCC) [3]. This models the arc. Connecting this type of load to the network produces voltage variation at the common point of supply to other consumers. The equation for voltage drop is given by

$$\frac{\nabla V}{V_n} = \frac{R\nabla P + X\nabla Q}{V_n^2}$$

Where; Vn is the source voltage, $\Delta Q \, and \, \Delta P$ are the variation in reactive and active power, X & R are short circuit reactance and resistance respectively Since R is very small when compared with $X, \Delta V$ is directly proportional to reactive power Q. Therefore, by controlling the reactive power we can compensate the voltage flicker [4]. Fluctuations results in voltage drop and it can be compensated by the application of following structures

(a) Series Structure: In series type structure the dissipation of the reactive power is maintained constant by controlling the line reactance when there is a load fluctuation.

(b) Shunt tructue: In shunt type structure the compensator is kept constant at a particular value at which it consumes the constant reactive power.

Introduction to facts devices

The FACTS devices and controllers offer a great opportunity to regulate the transmission of alternating current AC increasing or decreasing the power

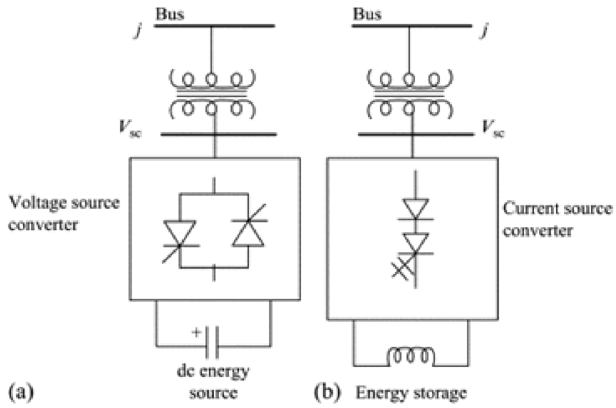

Figure 1. Schematic of a STATCOM.

***Address for Correspondence:** Abubakar Sufyanu, Department of Electrical & Electronics Engineering, University of Science & Technology, Aliero, Nigeria, E-mail: Sufeey190@gmail.com*

Received 15 March 2021; **Accepted** 29 March 2021; **Published** 05 April 2021

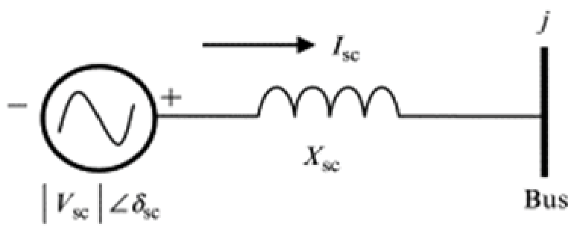

Figure 2. Voltage at the output of the STATCOM.

flow in specific lines and responding almost simultaneously to the stability issues. The future and potential of this technology is based on the possibility of controlling the direction of the power flow and the ability of the connecting networks that are not properly interconnected. FACTS are static equipment used for the transmission of electrical energy in AC [5]. It is meant to influence the controllability and increase power transfer capacity. They are generally a power electronics based devices. These FACTS devices can be divided into three groups depending on their switching mechanisms, these groups are

- Mechanically switched such as phase shifting transformers
- Thyristor switched and
- Fast switched using IGBTs.

Some type of FACTS devices such as phase shift transformer PST and static VAR compensator SVC are already well known in the power system world, new developments in power electronics and control have extended application range of FACTS.

Furthermore, intermittent renewable energy sources and increasing international power flows provide new applications for FACTS. The additional flexibility and controllability of FACTS allow mitigating the problems associated with the unreliable of supply issues of renewable. SVCs and STATCOM devices are well suited to provide ancillary services (such as voltage control) to the grid and fault rid through capabilities which standard wind farms cannot provide Furthermore, FACTS reduce oscillations in the grid, which is especially interesting when dealing with the stochastic behavior of renewable [4].

Examples of Facts Controllers for Enhancing Power Quality and Control

- Static Synchronous Compensator (STATCOM) -Controls voltage
- Static VAR Compensator (SVC) -Controls voltage
- Unified Power Flow Controller (UPFC) – controls voltage, impedance, power and phase
- Convertible Series Compensator (CSC) - controls voltage, impedance, power and phase
- Inter-phase Power Flow Controller (IPFC)- controls voltage, impedance, power and phase
- Static Synchronous Series Controller (SSSC)- controls voltage, impedance, power and phase
- Thyristor Controlled Series Compensator (TCSC) - Controls impedance
- Thyristor Controlled Phase Shifting Transformer (TCPST) - Controls angle
- Super Conducting Magnetic Energy Storage (SMES) - Controls voltage and power

Static Synchronous Compensator (STATCOM)

Static Synchronous compensator STATCOM is a shunt connected FACTS device. It behaves like the static counterpart of the rotating synchronous condenser, but it generates and absorbs reactive power at a higher rate because all the parts are static. It is also operated as a static VAR compensator (SVC) who's inductive and capacitive output currents are controlled to steady the bus voltage with which it is connected. Ideally, it performs the same voltage regulation as the static VAR compensator (SVC) but in a much more robust manner. Unlike the SVC, it's operation is not weakened by the presence of low voltages [6]. STATCOM goes extremely well and with advanced energy storage facility which in turn, opens the door for the number of new applications, such as energy deregulations and network security [4].

STATCOM operation is based on the principle of current source converter or voltage source. The schematic of a typical STATCOM is shown in **Figure 1** .

When a STATCOM is used with voltage source converter, its AC output voltage is controlled in such a way that the required reactive power flow can be controlled at the load bus with which it is connected. The voltage source converter will then convert its voltage to ac voltage due to the presence of a dc voltage in the capacitor. The converter henceforth controls the bus voltage, the exchange of reactive power between the ac system and the converter can be managed by varying the amplitude of the three-phase output voltage of the converter as shown in the **Figure 2.**

If the magnitude or amplitude of the output voltage is increased above that of utility bus (j) voltage, then current will flow through the reactance of the converter to the AC system and the converter will generate a capacitive reactive power to the AC system. On the other hand, if the magnitude or the amplitude is decreased below the utility bus voltage, then current will flow from the AC system to the converter and the converter in turn, absorbs inductive reactive power from the system [7]. The STATCOM is said to be in floating state if the output voltage equals the AC system voltage because the reactive power exchange becomes zero [3].

Power flow model of a STATCOM

Reference to the Figure 2, let us assume $V_j < \theta_j$ be the utility voltage at bus $j, V_{sc} < \delta_{sc}$ be inverted AC voltage at the output of the STATCOM also known as Jth bus side. X_{sc} be the reactance of the line between the jth bus and the STATCOM. Q_{sc} Be the reactive power exchange for the STATCOM with the bus.

Thus

$$Q_{sc} = \frac{|V_j|^2}{X_{sc}} - \frac{|V_j||V_{sc}|}{X_{sc}} \cos(\theta_j - \delta_{sc}) \text{---} (1)$$

$$= \frac{|V_j|^2 - |V_j||V_{sc}|}{X_{sc}} if\, \theta_j = \delta_{sc} \, (for\ a\ lossless\ STATCOM)$$

Thus, if $|V_j| < |V_{sc}|, Q_{sc}$ becomes negative and the STATCOM generates reactive power. Also, if $|V_j| > |V_{sc}|, Q_{sc}$ becomes positive and the STATCOM absorbs reactive power.

Also, $V_{sc} = |V_{sc}|(\cos\delta_{sc} + j\sin\delta_{sc})$ --(2)

The minimum and maximum limits of the voltage source converter $|V_{sc}|$ will be observed by the STATCOM capacitor rating. δ_{sc} May have any value between $0° and 180°$. According to figure s above,

$$I_{sc} = Y_{sc}(V_{sc} - V_j) Where Y_{sc} = \frac{1}{Z_{sc}} = G_{sc} + jB_{sc}$$

$$S_{sc}(comple\,\mathrm{xp}\,owerflow) = V_{sc} I_{sc}^*$$

Therefore, $= V_{sc} Y_{sc}^* (V_{sc}^* - V_j^*)$

However, from equation 2 $V_{sc} = |V_{sc}|(\cos\delta_{sc} + j\sin\delta_{sc})$ substituting V_{sc} in the expression of S_{sc} leads to the following equations

$$P_{sc} = |V_{sc}^2| G_{sc} - |V_{sc}||V_j| \left[G_{sc}\cos(\delta_{sc} - \theta_j) + B_{sc}\sin(\delta_{sc} - \theta_j) \right] \text{----------------} (3)$$

$$Q_{sc} = -|V_{sc}^2| B_{sc} - |V_{sc}||V_j| \left[G_{sc}\sin(\delta_{sc} - \theta_j) - B_{sc}\cos(\delta_{sc} - \theta_j) \right] \text{---------} (4)$$

In order to simply these equations further, let us assume that the STATCOM is lossless that means $G_{sc} = 0$ and the STATCOM is not capable of active power flow, that means $P_{sc} = 0$ also, assume $\delta_{sc} = \theta_j$

There fore, $Q_{sc} = -|V_{sc}^2| B_{sc} - |V_{sc}||V_j| B_{sc}$ ----------------------------------- (5)

The power mismatch can now be written as

$$\begin{bmatrix} \Delta P_j \\ \Delta Q_{sc} \end{bmatrix} = \begin{bmatrix} \frac{\partial P_j}{\partial \delta_j} & \frac{\partial P_j}{\partial |V_{sc}|} \\ \frac{\partial Q_{sc}}{\partial \delta_j} & \frac{\partial Q_{sc}}{\partial |V_{sc}|} \end{bmatrix} \begin{bmatrix} \Delta \theta_j \\ \Delta |V_{sc}| \end{bmatrix} \quad (6)$$

At the end of the iteration p, the variable voltage V_{sc} can be corrected as

$$\left|V_{sc}^{(p+1)}\right| = \left|V_{sc}^{(p)}\right| = \Delta\left|V_{sc}^{(p)}\right| \quad (7)$$

Distributed STATCOM controller

The Distributed STATCOM or D STATCOM controller model can be used as a voltage controller and is shown in Figure 3. Amidst several shunt controllers, the STATCOM is much preferred than SVC because it has a better characteristics in the low voltage region. The primary function of the STATCOM and the conventional SVC is to regulate the transmission line voltage at the point of connection otherwise known as the point of common coupling PCC. According to the IEEE first benchmark system, the STATCOM that is equipped with a voltage controller only is not sufficient to damp all the oscillatory modes of the system. Hence, there's a need for an additional control signal together with the STATCOM voltage controller [8].

Results

The main strategy in controlling small signal oscillations using STATCOM damping controller is to use simple auxiliary stabilizing signals. The generator speed contains components of oscillatory modes; as such, if the generator speed is used to control the STATCOM, the entire oscillatory modes including swing modes and torsional modes will be affected. Hence, the auxiliary employed is the generator speed deviation.

Mathematically, the block diagram in Figure 3 can be represented by the following variable equations

$$\Delta X_{s1} = \left(\frac{K_w}{1+sT}\right)\Delta\omega \quad (8)$$

$$\Delta X_{s3} = \left(K_p + \frac{K_I}{s}\right)\Delta X_{s2} \quad (9)$$

$$\Delta V_{sc} = \left(\frac{1+sT_1}{1+sT_2}\right)\Delta X_{s3} \quad (10)$$

By equating equations 8 – 10 the linearized state space model obtained will be

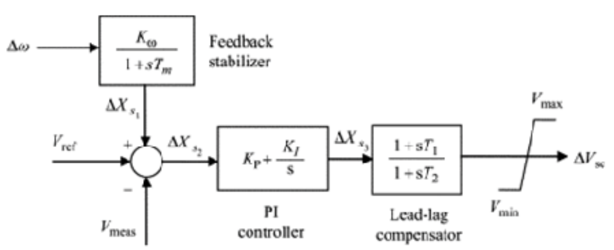

Figure 3. STATCOM voltage controllers for damping small signal oscillations.

$$\Delta \dot{X}_{s2} = -\frac{1}{T_m}\Delta X_{s2} + \frac{K_w}{T_m}\Delta\omega - \frac{1}{T_m}\Delta V_{meas}$$

$$\Delta \dot{X}_{s3} = \left(-\frac{K_p}{T_m} + K_I\right)\Delta X_{s2} +$$

$$\frac{K_p K_w}{T_m}\Delta\omega - T_m \Delta V_{meas}$$

$$\Delta \dot{V}_{sc} = -\frac{1}{T_2}\Delta V_{sc} + \Delta X_{s3}$$

$$+\frac{T_1}{T_2}\left(-\frac{K_p}{T_m} + K_I\right)\Delta X_{s2}$$

$$+\frac{T_1 K_p K_w}{T_2 T_m}\Delta\omega - \frac{T_1 K_p}{T_2 T_m}\Delta V_{meas}$$

The multi machine model with STATCOM controller can be formulated by adding state variables $\Delta X_{STATCOM} = \left[\Delta X_{s2}\Delta X_{s3}\Delta V_{sc}\right]^T$ With the differential algebraic equations and the STATCOM linearized power flow (equation 6) with the network equations of the multi machine system respectively.

The STATCOM controller model that was used as a voltage controller Figure 3 has three gains, the propotional gain K_p; the integral gain K_I and the speed deviation feedback gain $K\omega$. The objevtive is to damp all the swing nodes at the series compensation levels. Eigenvalue analysis is used to obtain the ranges of K_p, K_I and K_ω for which the system is stable [9].

Modelling of D STATCOM in order to mitigate voltage flicker

The D STATCOM modelled in this experiment includes representation in detail of power electronic IGBT converters. With the 1680Hz switching frequency used in this experiment, in order to get an acceptable accuracy, the model has to be discretized at a very small time step $(5\mu s)$. This model is very well suited for observing harmonics and control system dynamic performance over a relatively short period of time [10].

Discussion

A Distribution Static Synchronous Compensator (D-STATCOM) is used to to regulate voltage on a 25kV distribution network. There are 2 feeders in the network (21 km and 2 km). These feeders are used to transmit power to loads connected at buses B2 and B3. There is also a shunt capacitor used for power factor correction at bus B2 [11]. There is a 600V load connected at bus B3 through a 25k V/600 V transformer. This load represents a plant absorbing continuously changing currents, similar to an arc furnace, thus producing voltage flicker. The magnitude of the variable load current is modulated at a frequency of 5Hz so that its apparent power varies between 1 MVA and 5.2 MVA, while the power factor lags at 0.9. This variation in load will allow you to observe the ability of the D STATCOM to mitigate voltage flicker (Figure 4).

The D-STATCOM regulates bus B3 voltage by absorbing and/or generating reactive power. The reactive power transfer is done through the leakage reactance of the coupling transformer by generating a secondary voltage in phase with the primary voltage (network side) [12]. This voltage is provided by a voltage sourced PWM inverter. Whenever the bus voltage is higher than the secondary voltage, the D-STATCOM acts like an inductance absorbing reactive power. When the bus voltage is lower than the secondary voltage, the D-STATCOM acts like a capacitor generating reactive power (Figure 5).

The D-STATCOM model consists of the following components:

- A 25k v/1.25k V coupling transformer which ensures coupling between the

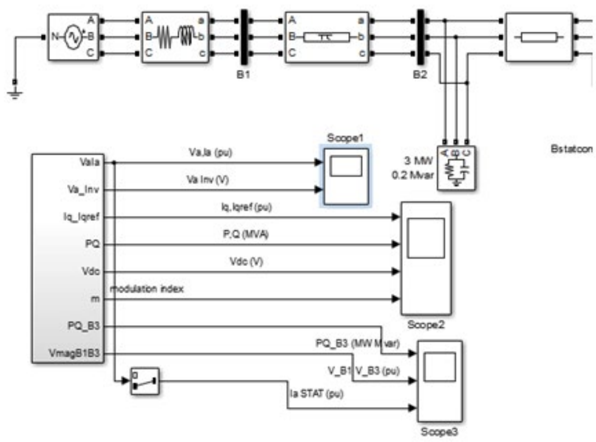

Figure 4. Modelled D STATCOM connnected to a power system.

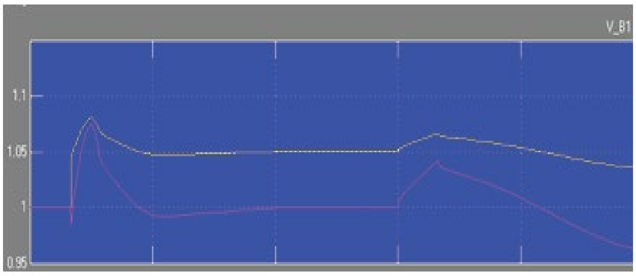

Figure 5. Output voltages with D STATCOM inactive.

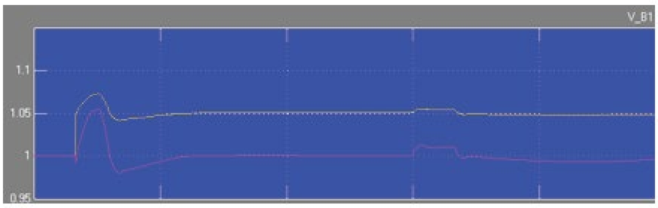

Figure 6. Output voltages with D STATCOM activated.

PWM inverter and the network

- A voltage-sourced PWM inverter consisting of 2 IGBT bridges. This twin inverter configuration produces fewer harmonic than a single bridge. This results in a smaller filters and improved dynamic response. In this model, the inverter modulation frequency is 1680 Hz so that the first harmonics will be around 3360 Hz
- LC damped filters connected at the inverter output. Resistances connected in series with the capacitors provide a quality factor of 40 at 60 Hz
- A $10000\mu F$ capacitor acting as a DC voltage source for the inverter
- A voltage regulator that regulates and control voltage at bus B3
- A PWM pulse generator using a modulation frequency of 1680Hz
- Anti-aliasing filters used for the acquisition of voltage and current.

The D-STATCOM controller consists of several functional blocks:

- A PLL (Phase locked loop). The PLL is synchronized to the fundamental of the transformer primary voltages
- Two measurement systems (Vmeas and Imeas) blocks compute the d axis and q axis components of the currents and voltages by executing an abc-dq transformation in the synchronous reference determined by $\sin(\omega t)$ *and* $\cos(\omega t$ provided by the PLL
- An inner current regulation loop. This loop consists of 2 propotional-integral (PI) controllers that control the d axis and q axis currents. The controller's outputs are Vd and Vq voltages that was generated by the PWM inverter. The Vd and Vq voltages are then converted into phase voltages (Va, Vb and Vc) which will be used to synthesize the PWM voltages. The Iq reference voltage comes from the outer voltage regulation loop (in automatic mode) or from the referenced that will be imposed by the Qref (in manual mode). The Id reference comes from the DC link voltage regulator.
- An outer voltage regulation loop. In automatic mode (regulated voltage), a PI controller maintains the primary voltage equal to the reference value defined in the control system dialog box
- A DC voltage controller which keeps the DC link voltage constant to its nominal value.

The electrical circuit is discretized using a sample time $T_s = 5\mu s$. The controller uses a larger sample time $32^* T_s = 160\mu s$

Simulation

Mitigation of voltage flicker : During this experiment, the voltage of the programmable voltage source was kept constant and hence, the modulation of the variable load became possible so that we can observe how the D-STATCOM can be used to mitigate voltage flicker or voltage fluctuations. In the programmable voltage source block, time variation parameter was changed to 'none' where as in the variable load block, the modulation timing was set to 0.15s (Ton) and 1s (Toff). Furthermore, in the D-STATCOM contro ller, mode of operation was changed to "Q regulation" and Qref set to zero [13]. Applying these settings means that the D-STATCOM is floating and performs no voltage correction (Figure 6).

After running the simulation, the variation of P and Q was observed at bus B3 through scope 3 as well as voltages and buses B1 and B3. When the D-STATCOM was disabled, voltages varies between 0.96 and 1.04 pu with a +/- 4% variation [14]. The D-STATCOM was enabled by changing the mode of operation to "Voltage Regulation" and running the simulation again. Voltage fluctuation at bus B3 was observed through scope 3 and the variation was reduced to +/- 0.7%. a perfect voltage without any flicker will be edging towards variation of 0% and since our D-STATCOM successfully reduced the variation from +/- 4% to +/- 0.7% we can say that it drastically reduced the fluctuations and hence, can be used to mitigate voltage flicker in power systems.

Conclusion

The design, modelling and application of Distributed STATCOM technology based on voltage source converters for voltage flicker mitigation is discussed in this paper. Mitigation was done with a 12-pulse DSTATCOM based on voltage source converter consisting of an RLC filter was designed for complete compensation without harmonics. Simulation was performed in MATLAB show that the DSTATCOM equipped with RLC filter can reduce voltage fluctuations caused by non linear loads such as electric arc furnaces.

Acknowledgement

Conflict of interest

None.

References

1. Mohanty, Alok Kumar, and Amar Kumar Barik. "Power System Stability Improvement using FACTS Devices." *Inte J Mod Eng Res* 1 (2011): 666-672.
2. Joorabian, Mahmood, Davar Mirabbasi, and Alireza Sina. "Voltage Flicker

Compensation using STATCOM." In *2009 4th IEEE Conference on Industrial Electronics and Applications*, pp. 2273-2278. IEEE. (2009).

3. Gibbard, Michael John, David J Vowles, and Pouyan Pourbeik. *Small-Signal Stability, Control and Dynamic Performance of Power Systems*. University of Adelaide press (2015).
4. Mondal, Debasish. "SVC Nonlinear Optimal Control with Comparison to GA Based Conventional Control in Power System Stability Improvement." In *International Conference on Electronics, Communication and Instrumentation (ICECI)*, pp. 1-4. IEEE. (2014).
5. Ohno, Hideo, NA Shen, Fumihiro Matsukura, and A Oiwa, et al. "(Ga, Mn) As: A New Diluted Magnetic Semiconductor Based on GaAs." *Appl Phys Lett* 69 (1996): 363-365.
6. Ohno, Hideo. "Making Nonmagnetic Semiconductors Ferromagnetic." *Sci* 281 (1998): 951-956.
7. Matsukura, F, H Ohno, A Shen, and Y Sugawara. "Transport Properties and Origin of Ferromagnetism in (Ga, Mn) As." *Phys Rev B* 57 (1998): R2037.
8. Dietl, T, O H Ohno, and F Matsukura. "Hole-Mediated Ferromagnetism in Tetrahedrally Coordinated Semiconductors." *Phys Rev B* 63 (2001): 195205.
9. Dietl, Tomasz, O H Ohno, A F Matsukura, and J Cibert, et al. "Zener Model Description of Ferromagnetism in Zinc-Blende Magnetic Semiconductors." *Sci* 287 (2000): 1019-1022.
10. Hayashi, Takashi, Yoshiaki Hashimoto, Shingo Katsumoto, and Yasuhiro Iye. "Effect of Low-Temperature Annealing on Transport and Magnetism of Diluted Magnetic Semiconductor (Ga, Mn) As." *Appl Phys Lett* 78 (2001): 1691-1693.
11. Van Schilfgaarde, Mark, and O N Mryasov. "Anomalous Exchange Interactions in III-V Dilute Magnetic Semiconductors." *Phys Rev B* 63 (2001): 233205.
12. Das, G P, B K Rao, and P Jena. "Ferromagnetism in Mn-Doped GaN: From Clusters to Crystals." *Phys Rev B* 68 (2003): 035207.
13. Nazmul, A M, T Amemiya, Y Shuto, and S Sugahara, et al. "High Temperature Ferromagnetism in GaAs-Based Heterostructures with Mn δ Doping." *Phys Rev Lett* 951 (2005): 017201.
14. Nakata, J. "Mechanism of Low-Temperature (≤ 300 C) Crystallization and Amorphization for the Amorphous Si Layer on the Crystalline Si Substrate by High-Energy Heavy-Ion Beam Irradiation." *Phys Rev B* 43 (1991): 14643.

How to cite this article: Sufyanu, Abubakar. "Mitigation of Voltage Fluctuations/ Voltage Flicker and Power Quality Improvement in Power Systems Using Distributed Statcoms". *Global J Technol Optim* 11 (2021): 554