Journal of Engineering and Sustainable Development
www.jeasd.org
Vol. 21, No.02, March 2017
ISSN 2520-0917

VOLTAGE STABILITY IMPROVEMENTS USING ADAPTIVE CONTROLLER FOR STATCOM

Dr. Abdelelah K. Mahmood [1], Dr. Inaam I. Ali [2], Ayad A. AL-Gailany [3]

1) Assist Prof., Electrical Engineering Department, Mosul University, Mosul, Iraq.
2) Lecturer., Electrical Engineering Department, University of Technology, Baghdad, Iraq.
3) M.s student., Electrical Engineering Department, Mosul University, Mosul, Iraq.

Abstract: In this work, A STATCOM of 12-pulse two levels is used to regulate the bus voltage at specific bus bar under many cases of abnormal conditions like load and source disturbances. The proposed system consists of a single machine, transmission line and load. The compensation process are performed and compared between the two suggested control methods, first, the conventional control by using PI controller only which is used to improve the voltage profile. Second, the adapting controller uses self-tuning fuzzy PI controller for improving the voltage profile. At the time of disturbance gets occurrence, the PI controller must change its parameters to recover the voltage profile into the stable state at the disturbance moment. The simulation results show the improvements of voltage profile for both two types and then compare them. The improvement of voltage profile using adaptation method is less over shoot and attains a steady state faster than the conventional PI when the system is subjected under many disturbances. The results of the harmonic effect show low values of total harmonic distortion (THD) of supply voltage and current. Moreover, it is acceptable with IEEE standards because a new technique of Sinusoidal Pulse Width Modulation (SPWM) is used.

Keywords: *FACTS, STATCOM, Fuzzy self-tuning PI, Voltage profile*

تعزيز أستقرارية الفولتية باستخدام المسيطر التكيفي للمعوض التزامني الساكن

الخلاصة: تم في هذا البحث استخدام معوض تزامني ساكن (STATCOM) ذو 12 نبضة ثنائي المستوى وذلك لتنظيم الفولتية عند احد القضبان العمومية في الحالات الغير طبيعية كما في اضطراب الحمل واضطراب المصدر. يتكون نظام القدرة المقترح من مولد واحد وخط نقل و حمل. تتم عملية التعويض والمقارنة بين طريقتين مقترحتين للسيطرة، الاولى، باستخدام السيطرة التقليدية عن طريق استخدام المسيطر (التناسبي- التكاملي) لتحسين الفولتية، الثانية، بأستخدام السيطرة التكيفية ذاتية التنغيم بواسطة المنطق المضبب لتحسين الفولتية. في لحظة حصول الاضطراب يحتاج المسيطر (التناسبي- التكاملي) الى تغيير في معاملاته وذلك لتحسين وتنظيم فولتية العمومي وارجاعها الى قيمتها المستقرة. بينت نتائج التمثيل تحسن في قيمة الفولتية لكلا الحالتين و بالمقارنة بينهم. تعزيز استقرارية الفولتية بأستخدام طريقة التكييف يكول اقل تجاوز للحد ويصل للحالة المستقرة اسرع من الطريقة التقليدية باستخدام المسيطر(التناسبي –التكاملي) . النتائج المستحصله من تأثير التوافقيات اظهرت قيم قليلة لنسبة تشوه التوافقيات الكلي (THD%) للفولتية والتيار بالاضافة الى مقبوليتها ضمن معايير IEEE وذلك بسبب استخدام تقنية تعديل عرض النبضة الجيبي (SPWM).

*Corresponding Author ayadaziz58@gmail.com

1. Introduction

Recently, engineers are looking for a solution to make an electrical power system more stable and efficient so in order to get these benefits, the flexible AC transmission system (FACTS) such as STATCOM is used and locating at weak bus of power system [1].

Power systems tend to be a widespread failure, because of their increasing power demand, environment condition and traditional planning leading to instabilities in power systems. Voltage instability is defined as a problem that leads to a greater power outage. The contest between direct contracts and utilities can lead to unplanned power exchange and hence, the control of voltage profile can be manage and improve voltage stability in power system as well it can be more reliable and efficient[2]. Flexible AC Transmission System (FACTS) is defined as a revolution of power electronics that should be within all parts of electrical power system.

FACTS devices are flexible AC transmission systems that combine both static controllers and power electronics to increase the capability of power transfer and improve the controllability. FACTS devices controller provide a suitable management for more than parameter of AC power system. The technology of FACTS devices is very essential to relieve some difficulties not all by ensure the power utilities to achieve the most countenance from the transmission facilities and improve the reliability of grid [2,3].

Voltage Source Converter (VSC) based on FACTS controllers are; Static synchronous Compensator (STATCOM) shunt connected. The main function of a STATCOM is to control and regulate the voltages at the weak bus in transmission system shown in Fig.1, which is the simple structure of suggested power system with STATCOM.

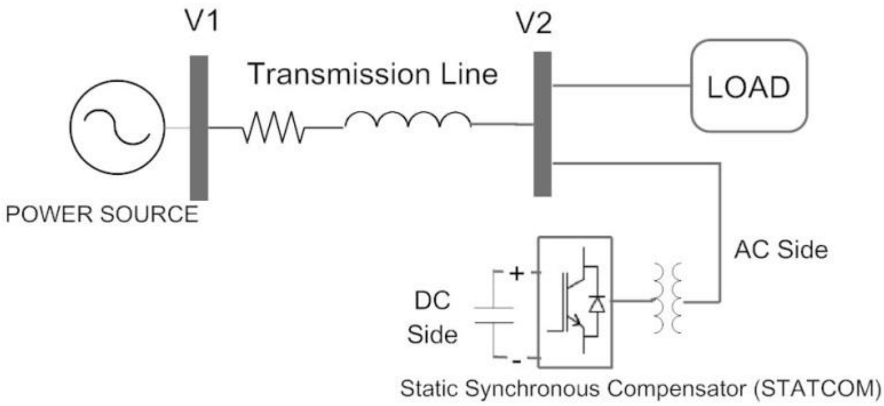


Figure 1. The Simple Structure of suggested Power System with STATCOM

In the past works, many control strategies have been suggested for STATCOM control. In [4] a multiple STATCOM using Particle Swarm Optimization (PSO) algorithm is proposed to improve the voltage stability. The optimization of different parameters is needed to acquire improved of voltage profile, minimum of total system losses, minimum transfer of reactive power and maximum stability limit. In [5] a

STATCOM with fuzzy logic controller is proposed for voltage regulation. It is performed in the MATLAB/SIMULINK using the power system blockset (PSB). The control strategy uses the method of bang-bang controller and a hysteresis current process, the results prove that fuzzy logic controller gives a better performance than conventional PI controller.

Obviously, PI controller is widely and popular used in control process and having simplicity and robustness. In this work, PI controller is kept to use but with an adaptation for locating the gains of Integral controller online through any disturbance take place by using fuzzy logic controller to enhance the process control and thereby the voltage stability.

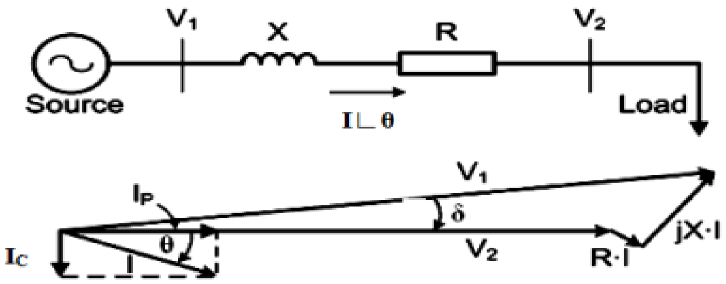
1. Compensation For Voltage Regulation

In any AC power utility, reactive power (Q) can be generated and stored from capacitor and reactor at quarter cycle, furthermore, it is transmitted from the power source during the next quarter cycle.

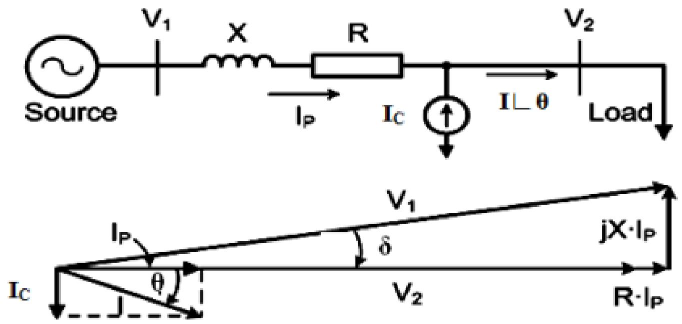
These processes can generate other losses and takes a part space enough from power lines so the reactive power generators can be introduced to prevent the circulation between source and loads as well as improving the voltage stability of AC power system [6]. Fig.2a shows AC power source connected at bus_1 (V1) and inductive load connected at bus_2 (V2) through a transmission line where typically without compensation. From phasor diagram presented in Fig.2, the angle (ɵ) belong to the current at load area so that the current (Ip) is coincided with Voltage (V2).

However, the inductive load consumes the reactive power from the source, thereby it can produces current through a power lines and increased of losses. When the reactive power being provide close the load, the currents through lines will reduce of losses in power circuit thereby enhancement of voltage stability. Fig.2b shows the device of current source that compensates the reactive current by injecting or absorbing a current (Ic) between the two nodes of system and compensated device. Finally, the voltage stability can be achieved to minimize the reactive current. STATCOM generates voltage support when the system is located under many disturbances.

The major advantage gained from using current source and voltage over using (capacitors or inductors) is attributed to the reactive power supply that can be independent from the voltage at PCC where the Q-V characteristics of the STATCOM shown in Fig.3 [7].



a) Without Reactive compensation



b) Compensation with a Current Source

Figure 2. Principles of Shunt Compensation in AC system

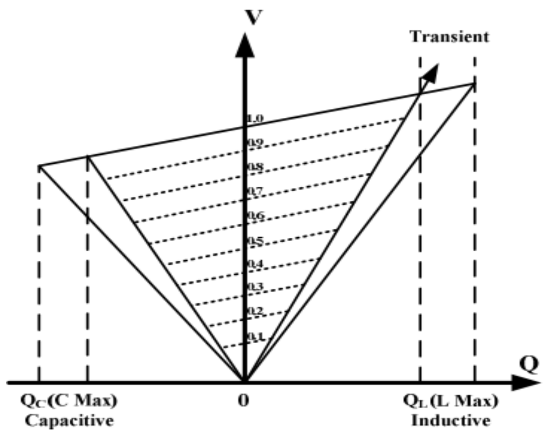


Figure 3. The Q-V Characteristics of the STATCOM

2. Equivalent Circuit Model of STATCOM

The voltage source converter (VSC) based on STATCOM (shunt connected) requires a suitable self-commutated device such as GTO, IGBT, IGCT, etc. Fig.4 shows the equivalent circuit model of STATCOM that is connected to the main system by a transformer. The symbols of va, vb and vc indicate the 3- phase system voltages at the point of common coupling (PCC), ea, eb, and ec can be represented a 3- phase voltage at AC side of STATCOM's converter. The transformer can be represented by; resistance (R) and reactance(X) while the resistance (Rp) can represent whole losses in VSC. The STATCOM draws a 3-phase current of ia, ib and ic. In DC side the capacitor (C) is used to provide a suitable energy into the switching device. The main objective of the controller is to meet the desired performance of the system according to the preset requirement [8].

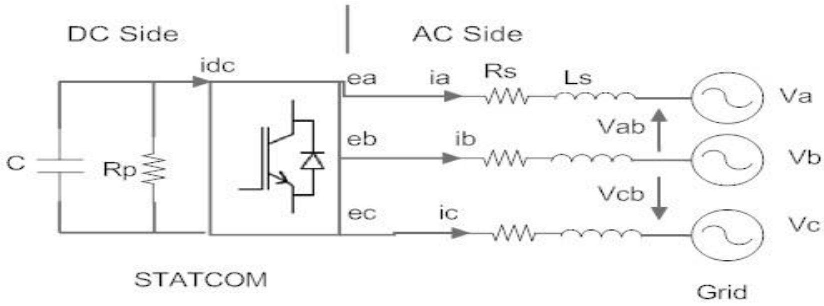


Figure 4. Equivalent Circuit Model of STATCOM [9]

By using KVL equations based on Fig.4.

$$Va - ea = R_s * ia + L_s * \frac{di_a}{dt} \tag{1}$$

$$Vb - eb = R_s * ib + L_s * \frac{di_b}{dt} \tag{2}$$

$$Vc - ec = R_s * ic + L_s * \frac{di_c}{dt} \tag{3}$$

The equations stated in (1), (2) and (3) can form as a matrix below.

$$p\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \begin{bmatrix} \frac{-R_s}{L_s} & 0 & 0 \\ 0 & \frac{-R_s}{L_s} & 0 \\ 0 & 0 & \frac{-R_s}{L_s} \end{bmatrix}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \frac{1}{L_s}\begin{bmatrix} V_a - e_a \\ V_b - e_b \\ V_c - e_c \end{bmatrix} \tag{4}$$

Where $p = \frac{d}{dt}$ operator

PerUnit system calculations:

$$L_s' = \frac{\omega_b L_s}{Z_{base}} \text{ , } C' = \frac{1\omega_b}{\omega_b C z_{base}} \text{ ,} R_s' = \frac{Rs}{Z_{base}} \text{, } R_p' = \frac{R_p}{Z_{base}} \text{ ,}$$

$$i_x' = \frac{i_x}{i_{base}} \text{ ,} v_x' = \frac{v_x}{v_{base}} \text{ , } Z_{base} = \frac{v_{base}}{i_{base}}$$

Parks transformation is utilized to convert the equation listed early from abc to dq values in (5).

$$p\begin{bmatrix} i_d' \\ i_q' \end{bmatrix} = \begin{bmatrix} \frac{-Rs\,\omega_b}{L_s'} & \omega \\ -\omega & \frac{-Rs\,\omega_b}{L_s'} \end{bmatrix}\begin{bmatrix} i_d' \\ i_q' \end{bmatrix} + \frac{\omega_b}{L_s'}\begin{bmatrix} e_d' - |v'| \\ e_q' \end{bmatrix} \tag{5}$$

The relation between ABC stationary axis and rotational axis of dq theory presented as shown in Fig.5.

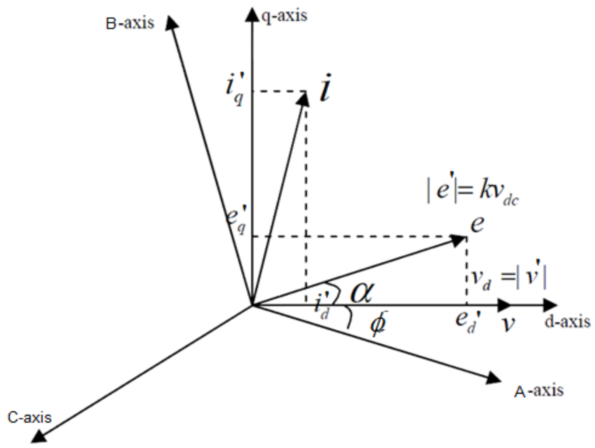


Figure 5. Vector Scheme of Voltage and Current among ABC/dq Transformation

Power transfer between AC and DC side must be equal as shown in (6) below.

$$P_{dc} = P_{ac} \quad ==\gg \quad v'_{dc}\, i'_{dc} = \frac{3}{2}\,(e'_d\, i'_d + e'_q\, i'_q\,) \tag{6}$$

The DC-side as shown in Fig.4 can be formed as (7).

$$\frac{dv'_{dc}}{dt} = -\,\omega_b\, C'\,(i'_{dc} + \frac{v'_{dc}}{R'_p}) \tag{7}$$

Where $|v'|$ is defined as the magnitude of system voltage, that supposes the d-axis close with vector of voltage where $Vd = |v'|$ and $Vq = 0$ by ignoring of harmonics out from converter as shown in Fig.5. The STATCOM state space equation can be achieved in (8).

$$p\begin{bmatrix} i'_d \\ i'_q \\ v'_{dc} \end{bmatrix} = [A]\begin{bmatrix} i'_d \\ i'_q \\ v'_{dc} \end{bmatrix} - \frac{\omega_b}{L'_s}\begin{bmatrix} |v'| \\ 0 \\ 0 \end{bmatrix} \tag{8}$$

Where "A" can be introduced in (9).

$$A = \begin{bmatrix} \frac{-Rs\,\omega_b}{L'_s} & \omega & \frac{M\omega_b}{L'_s}\cos\alpha \\ -\omega & \frac{-Rs\,\omega_b}{L'_s} & \frac{M\omega_b}{L'_s}\sin\alpha \\ \frac{-2}{3}MC'\omega_b\cos\alpha & \frac{-2}{3}MC'\omega_b\sin\alpha & \frac{-\omega_b C'}{R'_p} \end{bmatrix} \tag{9}$$

Because of linearized form and certainty, the active power cannot be transferred at balance point so it is conceivable to achieve of a decoupled term for i'_q and i'_d.

$$p\begin{bmatrix}\Delta i'_d\\ \Delta i'_q\end{bmatrix}=\begin{bmatrix}\frac{-Rs\ \omega_b}{L'_s} & 0\\ 0 & \frac{-Rs\ \omega_b}{L'_s}\end{bmatrix}\begin{bmatrix}\Delta i'_d\\ \Delta i'_q\end{bmatrix}+\begin{bmatrix}C_1\\ C_2\end{bmatrix} \tag{10}$$

The symbols C_1 and C_2 are introduced in (11) express the real and reactive power vector of control technique. Therefore, by varying i'_d the active power flow is regulated too, as well varying of i'_q can lead to regulate of reactive power flow [10].

$$\begin{bmatrix}C_1\\ C_2\end{bmatrix}=\begin{bmatrix}(K_{p1}+\frac{K_{i1}}{s})(\,i'^*_d-\,i'_d)\\ (K_{p2}+\frac{K_{i2}}{s})(\,i'^*_q-\,i'_q)\end{bmatrix} \tag{11}$$

The relationship between line to neutral AC-side terminal voltage with DC-side voltage can be put through the following equations:

$$\mathrm{e'}_\mathrm{d}=\mathrm{M}\,.\,v'_{dc}\cos\alpha \tag{12}$$

$$\mathrm{e'}_\mathrm{q}=\mathrm{M}\,.\,v'_{dc}\sin\alpha \tag{13}$$

From (12) and (13), the symbol (M) is defined as the modulation index that related by a magnitude ratio between AC and DC side terminal voltage. The symbol (α) represents the angle of bus voltage that is lagging or leading of inverter voltage. Fig.6 shows a block diagram of suggested power system with STATCOM controller and decoupled vector control method.

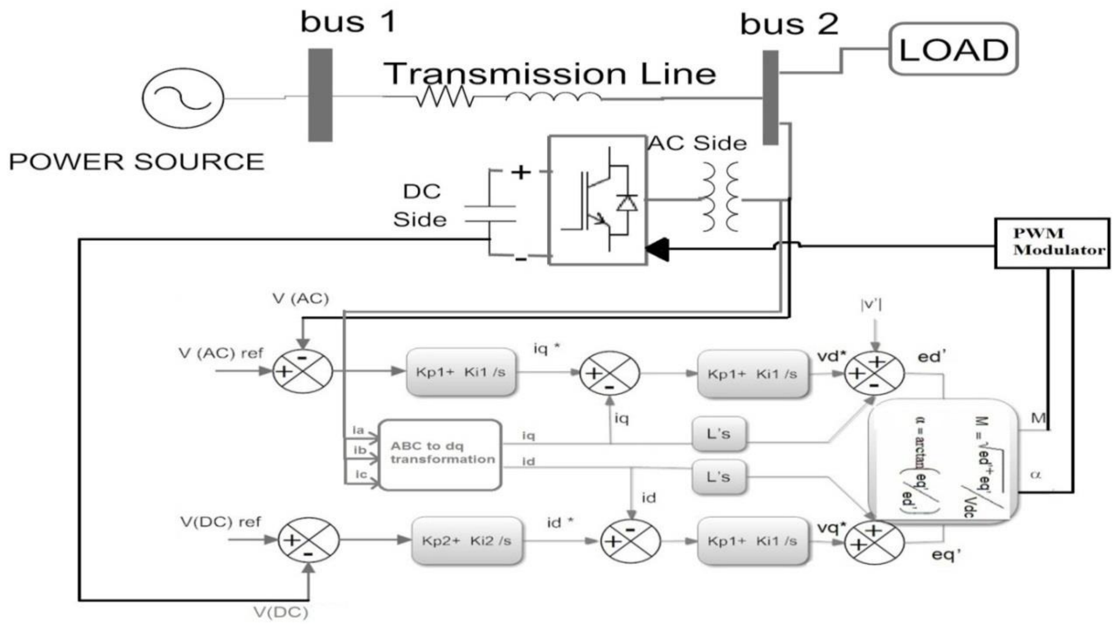


Figure 6. The Decoupled Vector Control Diagram of STATCOM [11]

3. Model Of Statcom Using Matlab/Simulink/Psb

The main parts of power system are located by three area ; generation area by using three phase AC voltage source of (11 KV, 100MVA) with step-up transformer (11KV/132KV, 100MVA), transmission area by using a power line extend about 21 km and finally the load area by using inductive load of (14MW, 7MVAR) as shown in Fig.7. The voltage source converter (VSC) is formed by using two bridges each one has 6-pulse two levels and the triggering pulses achieved by using Sinusoidal Pulse Width Modulation (SPWM).

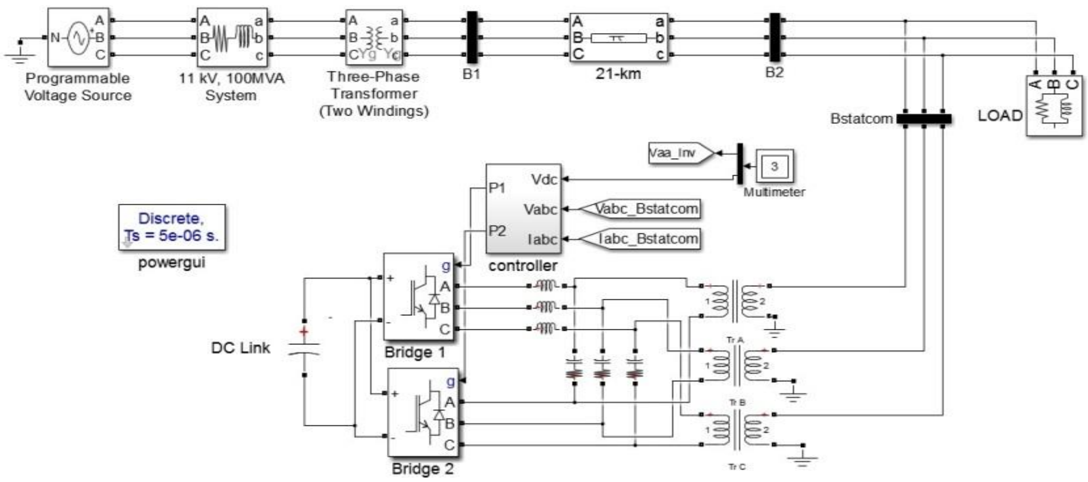


Figure 7. Model of Power System with STATCOM using MATLAB /SIMULINK/PSB

To enhance the voltage regulation, the vector control strategy can be utilized because it provides a fast response for controlling both of d-axis and q-axis currents. In the mode of voltage regulation, the STATCOM can absorb /injects reactive power to regulate the bus voltage under many disturbances. The q-axis current is responsible for controlling the reactive power flow while d-axis current is responsible to regulate the DC voltage at DC side of VSC [12]. The controller shown in Fig.8 consists of 3 regulators; AC voltage regulator, DC voltage regulator and current regulator in addition of phase locked loop (PLL) controller. The PLL is used to find the voltage vector angle for terminal bus bar.

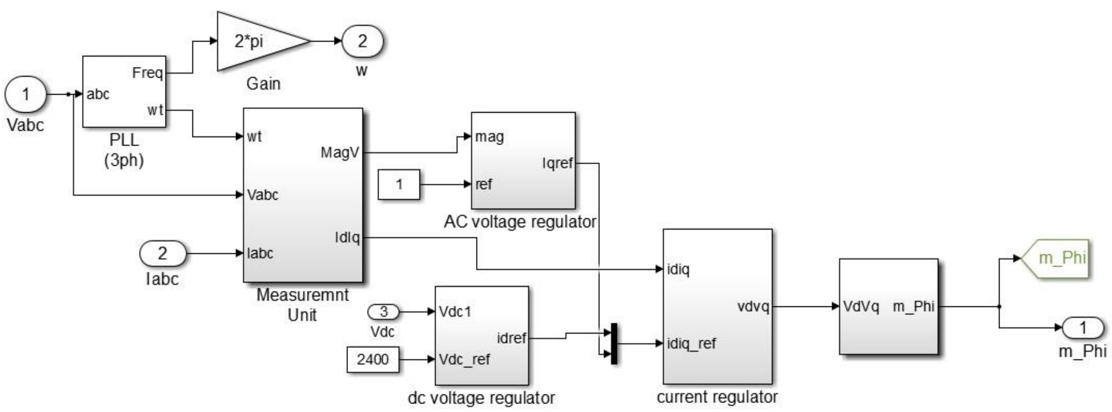


Figure 8. Model of STATCOM Controller using MATLAB/SIMULINK/PSB

4.1. Current Regulator

The reactive current (Iq) is regulated by using PI controller. The Iq regulator follows Iq reference value which is adjusted using AC voltage regulator between +1 pu (capacitive) and -1 pu (inductive). The output of the Iq regulator is the desired Vq voltage which is generated by the inverter as shown in Fig.9 that implies the control method of iq regulator by using PI controller.

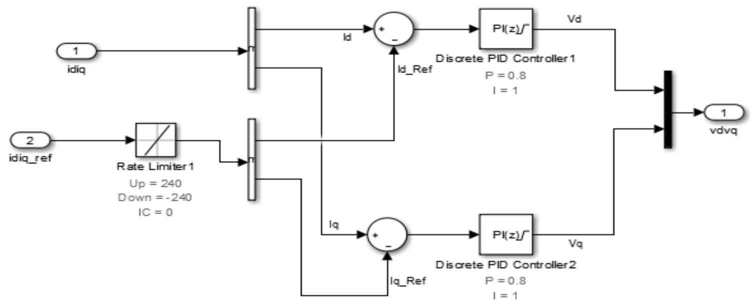


Figure 9. Model of Current Regulator (Idq) by using MATLAB/SIMULINK/PSB

The direct current (Id) is regulated by using PI controller. Therefore, (Id) can correspond to the small active power flowing into the STATCOM. The regulator follows a reference current (Idref) imposed by the DC bus voltage regulator. The output of Id regulator is the desired direct voltage (Vd) that is generated by the inverter as shown in Fig.9 that imply the control method of (id) regulator by using PI controller [13].

4.2. AC Voltage Regulator

The main purpose of using voltage regulator is to obtain the reference value of reactive current. After modeling the measurement unit, the voltage magnitude of STATCOM's bus bar is obtained by the formula state in (14). The value of voltage magnitude is compared with its reference value that is always 1 pu. Then, the error value is controlled by using a conventional PI controller where the gain parameters of PI controller can be estimated using a trial and error method. The output of the AC voltage regulator is the desired reference reactive current (Iqref).

$$|V| = \sqrt{v_d^2 + v_q^2} \tag{14}$$

The model of AC voltage regulator can be simulated using MATLAB /SIMULINK/PSB program as shown in Fig.10.

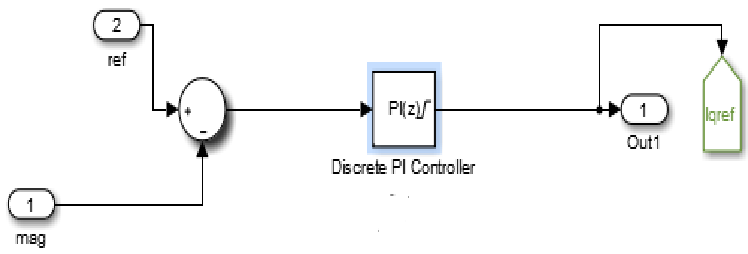


Figure 10. Model of AC Voltage Regulator using MATLAB/SIMULINK/PSB Program with Conventional PI Controller

4.3. Adaptive PI controller Design

Clearly, the conventional PI controllers used in industrial process are widely and popular because of its simplicity and reliability. In practical process, the conventional PI controller with fixed parameter may not be an efficient and robust in case of variation of system operating condition. Therefore, challenges urged to make a suitable technique to overcome these problems. Adaptive tuning of PI controller is one of these methods that are used to change the gain of integral controller online at any disturbances leading to a change in the system condition. Fuzzy logic control with PI controller is adopted to regulate the AC voltage in order to keep the voltage magnitude at the bus_2 near to 1 pu. Two inputs are presented in fuzzy logic; error (e) and change of error (Δe) as shown in Fig.11 and one output of Integral (I) controller with fixed value of proportional (P) gain.

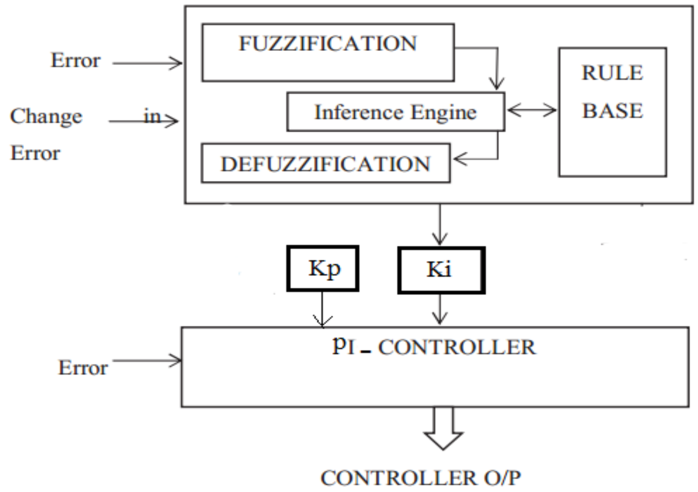


Figure 11. Fuzzy Logic based on Integral (I) Controller [14]

The model of AC voltage regulator with adaptive PI controller accomplished by using a fuzzy logic control and modeled in MATLAB/SIMULIK/PSB program is shown in Fig.12. In this work, the fuzzy logic used to adjust the value of Integral (I) based on error (e) and variation of error (Δe). The final value of Ki presented in (15) [15].

$$Ki = Ki^{*} + \Delta Ki \qquad (15)$$

The value of Ki^{*} is defined as a reference value of integral controller that can be calculated using trial and error method, while the value of ΔKi is achieved by using a Fuzzy logic with two inputs error (e) and variation of error (Δe).

According to the influence of system parameters, the principle of tuning the integral parameter changes in three cases:

a) At the moment of disturbance, when the voltage magnitude at bus_2 is far towards positive from reference value, the error value is increased also. If the error value is more than +0.025, the change of integral gain must be large to make a suitable damped in disturbance magnitude of voltage.
b) At the moment of disturbance, when the voltage magnitude at bus_2 is far towards negative from reference value, the error value is increased also. If the error value is less than -0.025, the change of integral gain must be large to make a suitable damped in disturbance magnitude of voltage.
c) The error value is limited between (+0.025 > e > -0.025) when disturbance are vanished. Moreover, the change of integral gain must be zero and the output of fuzzy-I controller is the fixed value of integral gain.

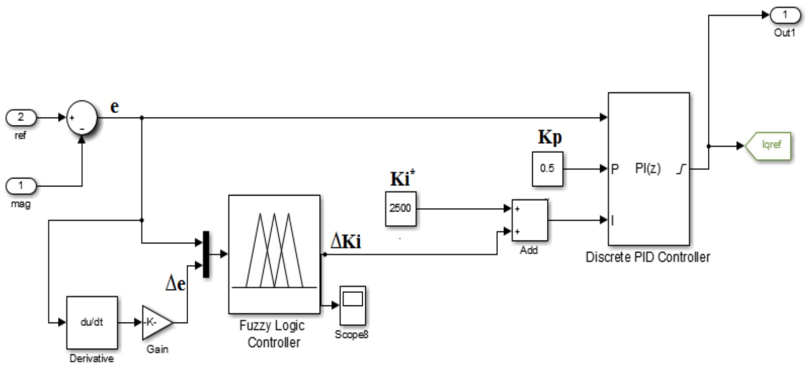


Figure 12. Model of AC Voltage Regulator by using Adaptive PI Controller

It is necessary for tuning the controller gets the fast settling and take over an algorithm to interact with error changing. Based on the control algorithm suggested in this work, the gain parameters are calculated for integral controller by presented the following steps [14]:

1- Sense the value of voltage magnitude and comparing it with reference value.
2- Estimate the error signal from comparison between voltage magnitude and its reference value.
3- Calculate the change of error.
4- Perform the error and change of error mapping by membership function.
5- Calculate the tuning value of integral gain (ΔKi) and combining it with fixed value of Ki^{*} to get the final value of Ki.

Fig.13 shows the control flow chart of adaptive PI controller, and observes the progress of tuning integral controller.

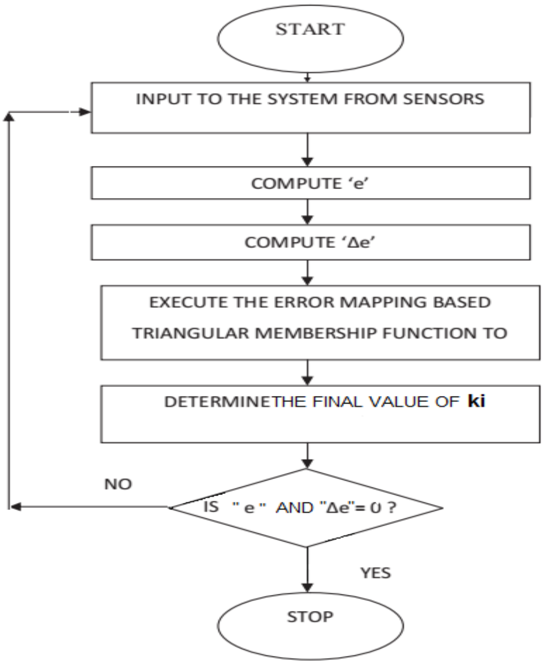
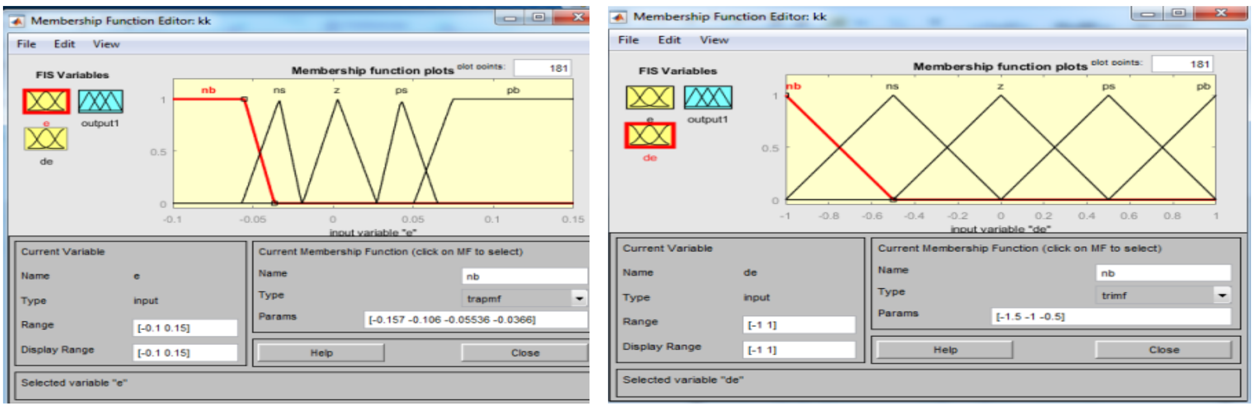


Figure 13. Flowchart for locating the Integral Parameter

The memberships function of error(e) and change of error(Δe) choose a five fuzzy sets defined as Positive Big (PB), Positive Small (PS), Zero (Z), Negative Small(NS) and Negative Big (NB) and two fuzzy sets for output named as Positive Big (PB) and Zero (Z) was used as shown in Fig.14 with rule base given in Table(1).

The region of error input variable can be ranged between a domain [-0.1, 0.15] and change of error input variable can be ranged between a domain [-1, 1].

The membership function has been choosing by fuzzy logic toolbox. For input variable of error (e), three triangle memberships are selected for (NS, Z, PS) and two trapezoidal memberships are selected for (NB, PB). For input variable of "change of error", all five memberships are trapezoidal.



(a) (b)

Figure 14. Membership Function of Input; (a) Error (e) , (b)Change of error(Δe)

Table 1. Adjusting Fuzzy Rules of (ΔKi)

E \ Δe	N B	N S	Z	P S	P B
N B	P B	PB	P B	P B	P B
N S	P B	PB	P B	P B	P B
Z	Z	Z	Z	Z	Z
P S	P B	P B	P B	P B	P B
P B	P B	P B	P B	P B	P B

Fig.15 shows the surface viewer for these rules

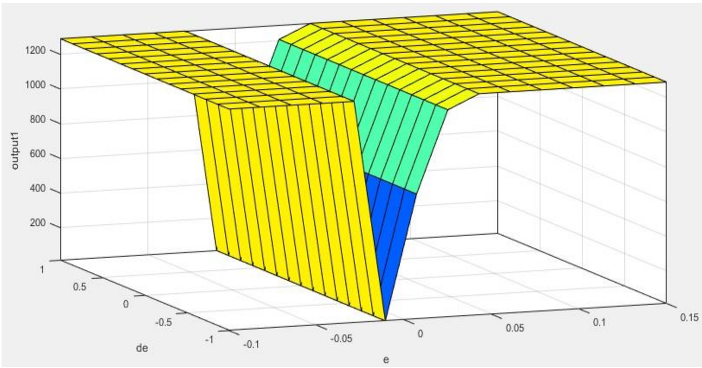


Figure 15. Surface Viewer for Rule Base.

5. Simulation Results

The STATCOM equipped at bus_ 2 should be maintaining the voltage near to 1 pu. The cases of voltage regulation presented and categorized into three cases below:

Case 1: The suggested power system overloaded by allowing additional inductive load of (9.8 MW, 4.9 MVAr) entered to bus 2 through a circuit breaker at time limited between 0.4 and 0.6 second as shown in Fig.16. The results show the magnitude of voltage at bus_2 with and without STATCOM as shown in Fig.17. It observed when the load entered at bus 2 between the intervals mentioned earlier lead to increase of total load between these intervals only, as well leads to decrease the voltage magnitude at bus 2 about 6% of terminal voltage for the same interval. In order to keep the voltage magnitude at bus 2 near to 1 pu, STATCOM must be used and leads to improve the voltage profile between the interval of disturbance. At the moment of disturbance occurred, the voltage takes about two cycle before return to the stable magnitude of 1 pu.

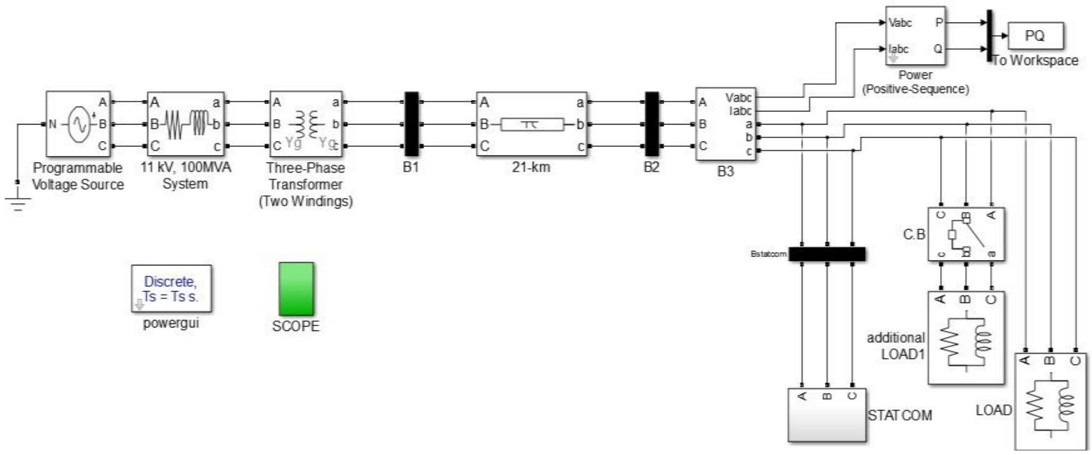


Figure 16. Model of STATCOM equipped to Power System proposed at Load Disturbance

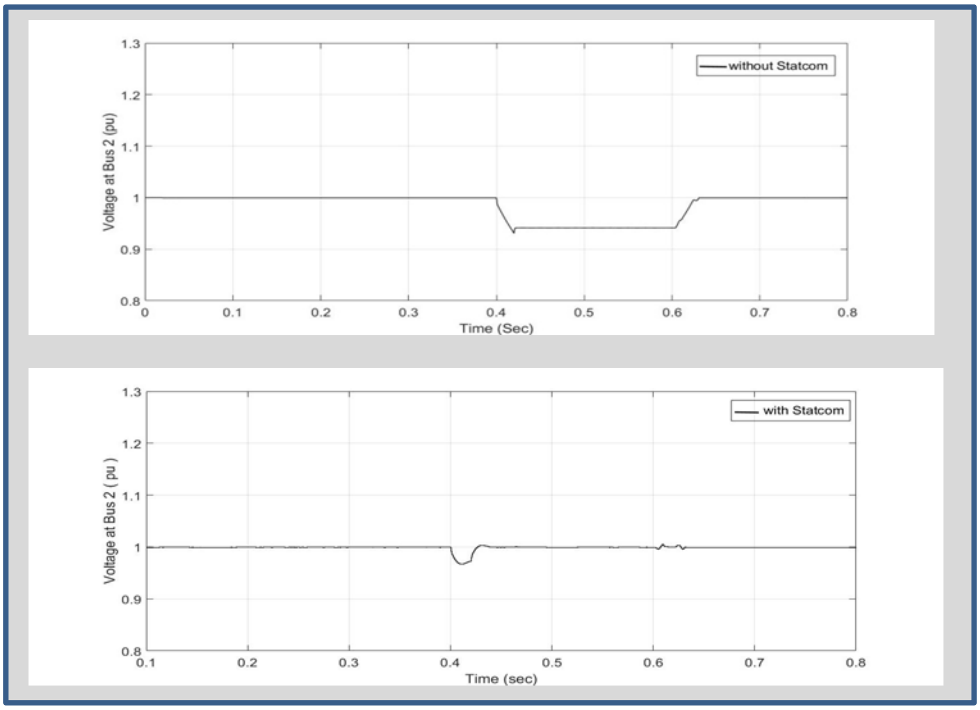


Figure 17. Voltage Magnitude at Bus 2 under Load Disturbance

The output of Active and reactive power from STATCOM can be calculated at STATCOM bus bar as shown in Fig.18. The STATCOM can inject reactive power only because an inductive load suddenly entered to the power system at bus_2. It was cleared that reactive power injected to the power system about 2 pu and needed to make a voltage magnitude near to 1 pu.

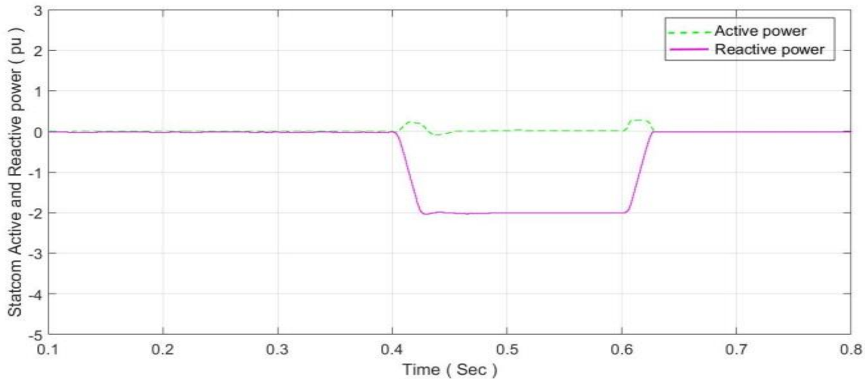


Figure 18. Active and Reactive Power produced form STATCOM.

The control variables like Modulation Index (MI) and firing angle (α) are needed to control the output voltage of VSC. Variation of MI between 0 and 1 leads to compensation of reactive power as well voltage profile. In this case and other cases, the firing angle couldnot shifting to control Active power because no energy storage used with STATCOM as shown in Fig.19. It observed that modulation index increased from 0.7 to 1 and that required to increase the voltage magnitude until reached to the stable state.

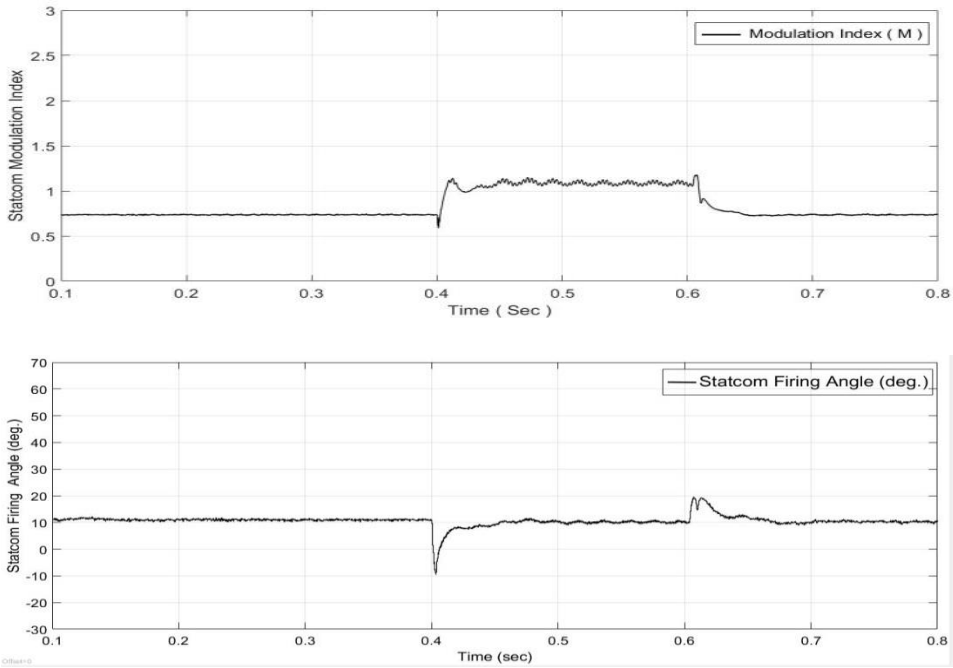
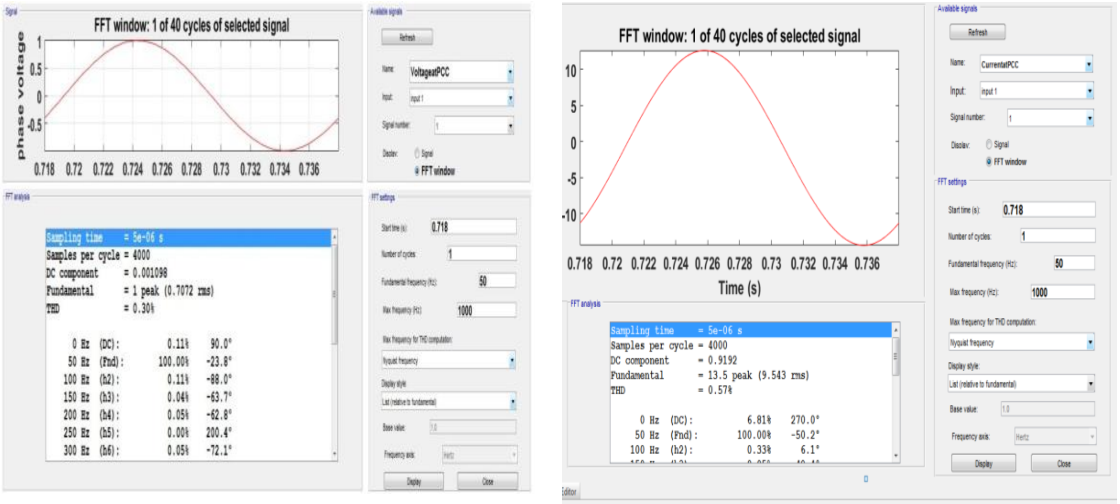


Figure 19. Control Variables of STATCOM Controller at Load Disturbance

Fig.20 shows the Fast Fourier Transform (FFT) of the phase voltage and current at bus 2. The results illustrate that harmonic content after STATCOM adding to the power system are small because a new technique of SPWM is used in the STATCOM. The value of total harmonic distortion (THD) for waveform started from 0.718 second is 0.3% for phase voltage and 0.57% for current. These values are acceptable for standards of IEEE [16].



(a) (b)

Figure 20. Fast Fourier Transform (FFT) of ; (a)Phase Voltage at Load Disturbance ,(b) of Line Current at Load Disturbance

Case 2: The proposed power system is located under source disturbance where the voltage magnitude is raised to 1.05 pu in duration between 0.3 and 0.5 second and reduced to 0.95 pu in duration between 0.6 and 0.8 second. Therefore, the results concluded from bus 2 show the voltage magnitude with and without STATCOM as clarified in Fig.21. It is observed that when the voltage source was exposed to a sudden increase in voltage generated about 5% (1.05 pu of nominal voltage), STATCOM can act and change its operating points into inductive by absorbing reactive Power from the load equipped at bus 2. Contradictorily, when the source voltage decreased about 5% (0.95 pu of nominal voltage), the STATCOM reacts to generate the reactive power to bus 2 and changing its operating point from inductive to capacitive.

Fig.22 indicates the output of active and reactive power produced from STATCOM located to source disturbance. It is observed that the voltage of power source increases about 0.05 pu, the STATCOM will absorbed about 5 MVAr from power system to recover the voltage at bus_2 to 1 pu. When the voltage of power source decreased about 0.05 pu, the STATCOM will injected about 5 MVAr to recover the voltage magnitude at bus_2 to 1 pu.

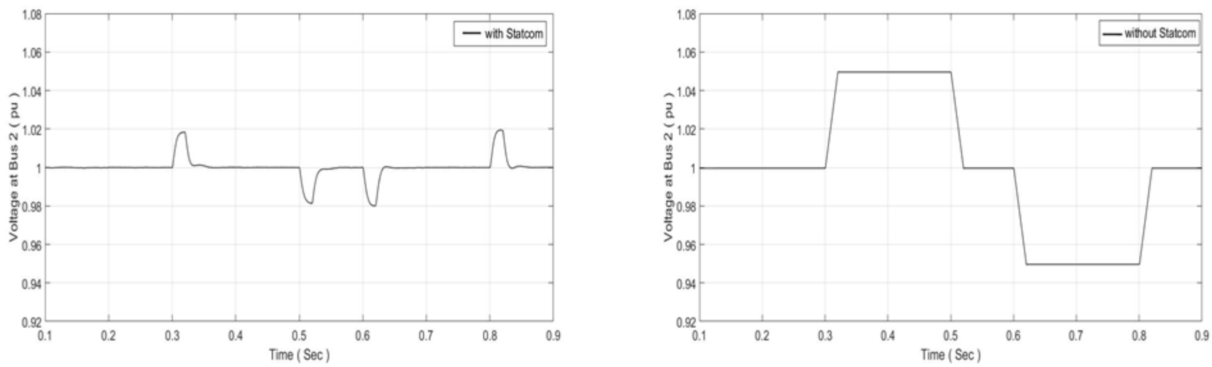


Figure 21. Voltage Magnitude at Bus 2 under Source Disturbance

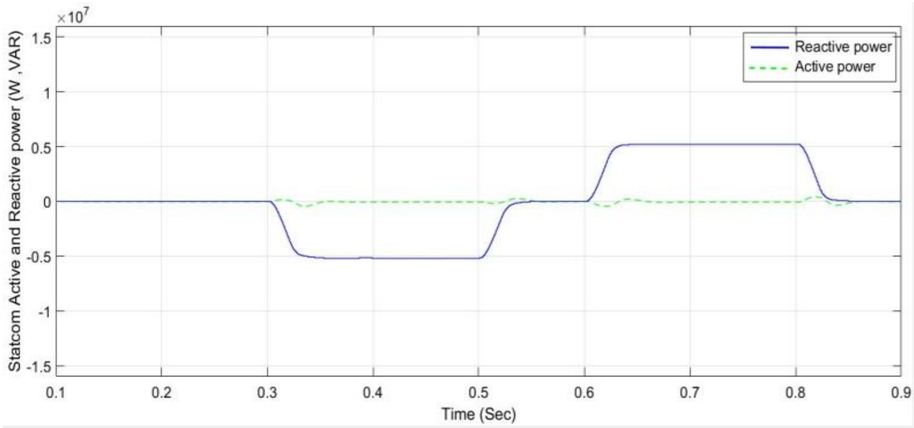


Figure 22. Active and Reactive Power produced from STATCOM

Case 3: In this case, the adaptive PI control method is applied to improve the voltage stability by locating the gain parameters of integral part (Ki) control using fuzzy logic control under any disturbances to the proposed power system and the type of disturbance are similar to the "Case 2".
In this case, the source disturbance (as case 2) is subjected to the proposed power system and hence, voltage level is raised to 1.05 pu in duration between 0.3 and 0.5 second, and is reduced to 0.95 pu in duration between 0.6 and 0.8 second. The voltage profile at bus_2 is compensated by using conventional PI and adaptive PI control respectively as shown in Fig.23. The results of adaptation method show an enhancement in a voltage profile. The voltage waveform after compensation by adaptation method is less over shoot and attains to steady state faster than conventional PI for the period from the beginning of simulation and when it is located under source disturbance in the moment of increased and decrease in voltage source.

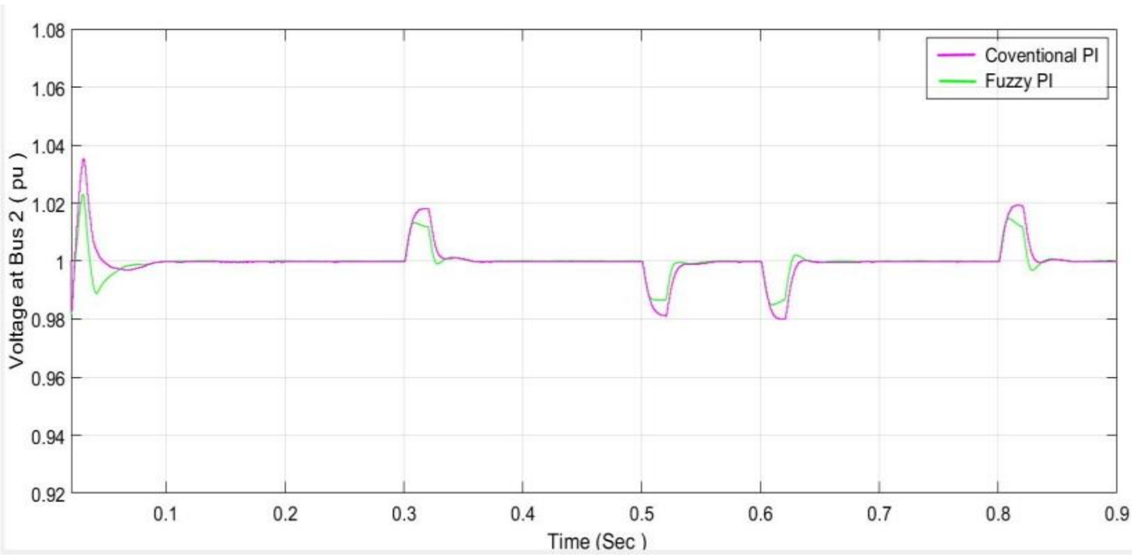


Figure 23. Voltage Magnitude at Bus 2

Fig.24 shows the zooming of disturbance magnitude started increasing at the moment of disturbance occure starting from 0.3 second and keep to rise until reaching

the maximum value and then back to normal of 1 pu. It is noted that fuzzy-PI controller gets an enhancment and a good response in voltage profile.In fuzzy-PI the disturbance magnitude occuring in voltage profile is about 0.013 pu while in conventional PI ,the disturbance magnitude is about 0.018 pu.
The variation of integral gain can be change at any disturbance as shown in Fig.25

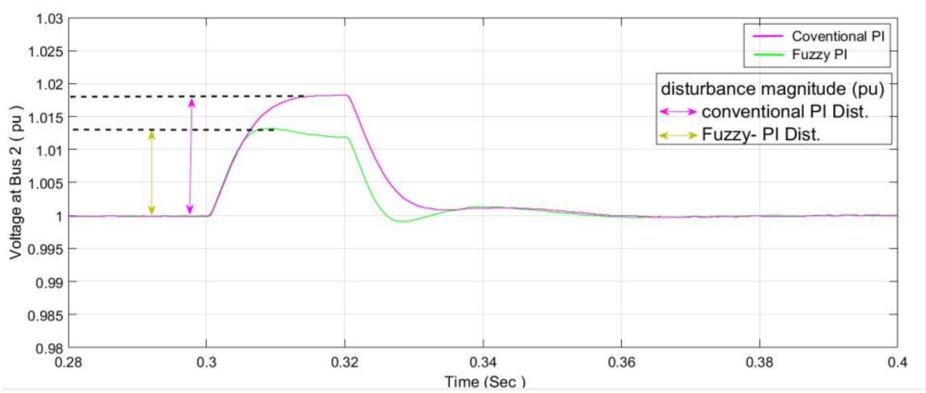


Figure 24. Disturbance Magnitude of Voltage Profile in two Control Technique

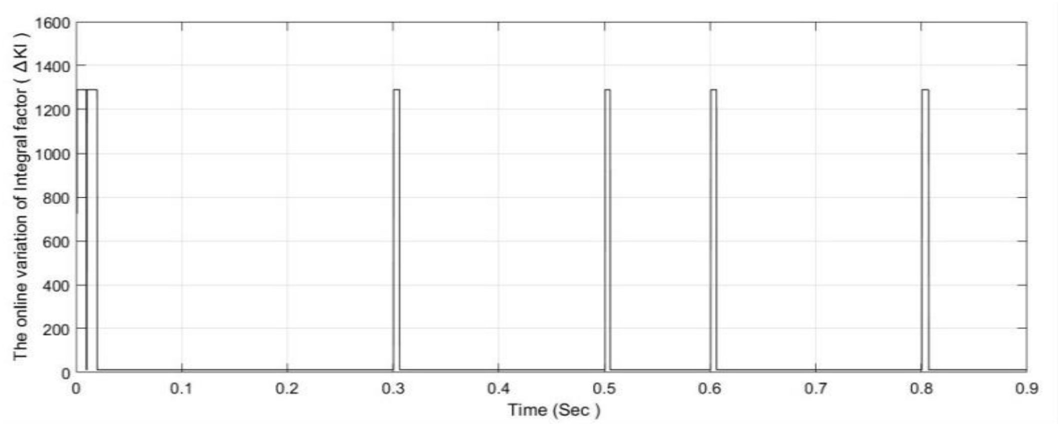


Figure 25. The Variation of Integral Gain under Source Disturbance.

6. Conclusions

A STATCOM of 12-pulse two levels is introduced to improve the voltage stability of the suggested power system that consists of three-phase voltage source, 21 km transmission line and loads. In this work, two methods are studied related with STATCOM's controller. First, the conventional PI controller introduced in AC voltage regulator. Second, an adaptive PI controller using self-tuning fuzzy-PI controller technique was used for locating gains parameters of integral (I) controller. The simulation results of STATCOM with adaptation method show that voltage waveform at bus_2 is less over shoot and attains a steady state faster than conventional PI when the system is subjected to many disturbances. Moreover, the addition of STATCOM at bus_2 gets a low value of total harmonic distortion (THD) for phase voltage and current and it is acceptable with IEEE-519 standards [16].

7. References

1. Padiyar, K.R. (2007).*"FACTS controllers in power transmission and distribution"*. New Age International Limited.
2. Baghaee, H.R. and Vahidi, B. (2008).*"Improvement of Voltage Stability and Reduce Power System Losses by Optimal GA-based Allocation of Multi-type FACTS Devices"*. 11th International Conference on Optimization of Electrical and Electronic Equipment, pp. 209-214.
3. Hingurani, N.G. and Gyugyi, L. (2000). "*Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems*". IEEE Press, New York.
4. Kumarasamy, K. and Raghavan, R. (2012). "*Particle Swarm Optimization Algorithm for Voltage Stability improvement using Multiple STATCOM*". International Conference on Emerging Trends in Electrical Engineering and Energy Management, India, pp. 235-242 .
5. Ponananthi,V. and Kumar, B.R. (2015). *"STATCOM with FLC and Pi Controller for a Three-Phase SEIG Feeding Single-Phase Loads"*. International Journal of Innovative Research in Science, Engineering and Technology,Vol.4,Iss.4, pp. 96-103.
6. Dixon, J., Moran, L., Rodriguez, J. and Domke, R. (2005). "*Reactive Power Compensation Technologies: State of the Art Review*". IEEE Proceedings, Vol. 93, No.12, pp. 2144–2164.
7. Suliman, M.Y. (2016). "*Voltage profile Improvement Using Static Synchronous Compensator STATCOM*", International Journal of Advanced Engineering, Management and Science, Vol.2, Iss.5, pp. 524-528.
8. Bina, M.T. and Hamill, D.C.(2005). "*Average Circuit Model for Angle-Controlled STATCOM*". IEE Proceedings on Electrical Power Applications, Vol. 152, No. 3, pp. 653-659.
9. Luo, A., Tang, C., Shuai, Z., Tang, J., Xu, X.Y. and Chen, D. (2009). "*Fuzzy-PI Based Direct Output Voltage Control Strategy for the STATCOM Used in Utility Distribution Systems"*. IEEE Transactions on Industrial Electronics, Vol. 56, No. 7, pp.2401-2411.
10. Banos , C., Aten , M., Cartwright , P. and Green , T.C. (2006). *"Benefits and Control of STATCOM with Energy Storage in Wind Power Generation"*.8th IEE International Conference on AC and DC Power Transmission, London, pp.230-235.
11. Singh , B. and Hussain , Z. (2010). *"Application of Battery Energy Storage System (BESS) in Voltage Control and Damping of Power Oscillations"*. 5th International Conference on Industrial and Information Systems, India, pp. 514-519.
12. Shah, C.B. (2014).*"Voltage Improvement Using SHUNT FACTs Devices: STATCOM"*. International Journal of Engineering Development and Research, Vol.2, Iss.2, pp. 2267-2272.
13. Schauder, C. and Mehta, H.(1993). "*Vector analysis and control of advanced static VAr compensators*". IEE Proceedings C - Generation, Transmission and Distribution, Vol. 140, Iss. 4, pp.299-306.

14. Ganeshkumar, D. (2014). *"Virtual instrument system based arrangement for monitoring analysis and control of vibrations in rotating machinery".* M.Sc. Thesis, Department of Electrical Engineering; Anna University, India.
15. Ofosu, R.A., Kamau, S.A., Nderu, J.N., Kaberere, K.K. and Muhia, A.M. (2016). *"Determination of Optimal PI Gains For Fuzzy-PI Controller Using Bacterial Foraging Algorithm (BFA)".* IOSR Journal of Electrical and Electronics Engineering, Vol.11, Iss.2, PP- 26-33.
16. IEEE Std 519.(1992). "*IEEE Recommended Practices and Requirements for Harmonic Control in Electric Power Systems".* Institute of Electrical and Electronics Engineers, New York, USA.

Appendix – A

Parameters: (Base – 5MVA) , 5 MVAR STATCOM.

Converter parameters : two brides of IGBT – 12-pulse two level ; nominal AC voltage =132 KV ; DC link voltage = 2.4 KV ; Capacitors (C) = 0.02 F .

Converter Transformer: Each one of 3-winding Transformer Rating : (5/3) MVA ,50Hz , 132 KV/1.25 KV , 3% (X)

PI-controller Gains : AC Voltage Controller: K_{P1} = 0.5, K_{I1} = 2500.DC Voltage Balancer: K_{P2} = 0.001, K_{I2} = 0.15. Decoupled Current Controller: D-axis controller: K_{P3} = 0.8, K_{I3} = 1; Q-axis controller: K_{P4} = 0.8, K_{I4} = 1.

Thevenin's Equivalent Voltage Source : Nominal Voltage: 11kV ; Source Resistance and inductance : R=0.121Ω , L=3.85mH , frequency: 50Hz; Short circuit level: 100 MVA

Step –up power transformer Rating **:** Nominal power :100MVA , 11KV/132KV ,50Hz, R_{pu}=0.002 pu , X_{pu}= 0.008 pu.