Hybrid Control for Power System Based on STATCOM and UPFC with Two 3-level 48-pulse under Different Conditions

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Abstract: This research presents the proposed model, to control the power flow in the transmission power system by applying Unified Power Flow Controller (UPFC), STATCOM and two 3-level 48-puls converter. This hybrid has been used to improve performance and reduce the maximum over shoot which is obtained from proposed model when the fault is occurring or suddenly system changes. The behavior of the system is analyzed under different three cases. The first case, the model is applied to plus load at bus 3. The second case, the model is operating at normal work and the third case, the three phase fault is occurred at bus4. In this research, the performance of system is studied under applied all cases of the current, voltage and power for the system. The numerical results of the proposed model are introduced to show the maximum over shoot and RMS values after applied proposed control at three different cases to prove the suggested model gave a good performance especially, during three phases fault and after fault clearance.

Keywords: Power System, STATCOM, UPFC, SSSC, Fault Conditions

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1. Introduction

The active power filters which provide flexible current harmonic compensation and help in reactive power control are possible these days due to the development of power electronics. Hence by implementation of the power electronic based devices, such as Static Var Compensator and static synchronous compensator (STATCOM) [1], it is perfect for improving the quality of power given to the consumers [2]. Its principal function is to inject reactive power into the system which helps to support the system voltage profile, however, it has some other advantages; reduce the flicker that is found in fluctuating loads, moderate the power oscillations, reduce the hypo-synchronous oscillations, increase the power transfer and as consequences the power system performance has improved [3], [4].

The UPFC is the multi-functions FACTS device, which provides control of voltage magnitude (simultaneous and independent) and power flow (active and reactive) [5]. UPFC is consists of two FACTS a device: STATCOM is defined as Static Synchronous Compensator , also SSSC is defined as Static Series Synchronous Compensator and is linked across DC link [6], [7]. SSSC is applied to control the voltage which is connected in series with the line, while shunt converter (STATCOM) is applied to inject reactive power flow (VAR) into the line, voltage regulation at the connection point, and balancing the actual power flow passed between the series inverter and the transmission line [8], [9].

The series inverter is applied to control the magnitude and phase voltage also, control the active and reactive line power flow for the transmission line [10]. That way, the UPFC is ability to fulfill the functions of reactive shunt compensation, active and reactive series compensation and phase shifting. Also, the UPFC had another important function which is to supply stability control to repress power system oscillations for reducing the transient period of power system [11]. UPFC is flexible and fast controller for power flow controllers, which is a corresponding want for reliable and actual models of them to investigate the effect of these on the characteristics of the power system [12].

In this paper, the proposed model is presented, to control the power flow in the transmission power system by applying Unified Power Flow Controller (UPFC), STATCOM and two 3-level 48-puls converter. The performance of the system is studied under different the three cases. The first case, the system is applied to pulse load at bus 3. The second case, the system is operating at normal work and the third case, the system is subjected to three phase fault at bus4. In this paper, the performance of system is studied under applied all cases -of the current, voltage and power for the system.

2. Static Synchronous Compensator (STATCOM)

A STATCOM is a shunt tool that's applied to compensate the reactive power in electricity gadget and that way stabilizes the voltage. The STATCOM makes use of a voltage supply converter (VSC) linked in shunt to a transmission line. In maximum instances, the dc voltage help for the VSC is supplied by using the dc capacitor of exceptionally small power storage capability. In constant state operation, the power exchanged with the line is maintained to zero [13], [14].

STATCOM is defined as the static synchronous generator working as a static compensator related in parallel whose output modern inductive or capacitive can be managed independently of the voltage. This cutting-edge feeds an ac/dc energy converter, which produces a hard and fast of outputs with controllable 3-segment voltages [15]. Additionally, the frequency of those voltages is the ac gadget frequency. The ac/dc strength converter is Controlled by using PWM techniques, so the output voltages completed are nearly sinusoidal. Those controllers are possible by using the excessive switching frequency of the IGBT, GTo, IGCT or IEGT transistors of the power converter [16]. The basic structure of the STATCOM is consists of DC voltage result from inverter which is connected to shunt capacitor with PWM converter. This combination is connected to grid through transformer as shown in Fig. 1 which is represented a transformer, grid a inductor and resistor [17], [18].

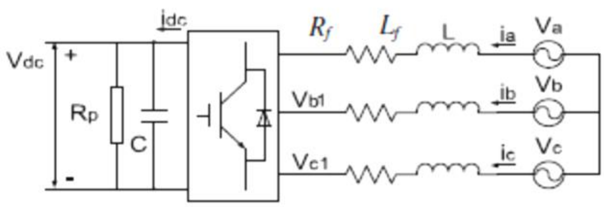

Figure 1. STATCOM Configuration

3. Unified Power Flow Controller (UPFC)

The UPFC is consists of two voltage source inverter (VSI) with common DC charge capacitor and linked to power system through transformers. First one of VSI is linked to shunt transmission line system through shunt transformer; second VSI is linked with series transformer as shown in Fig.2. [19]

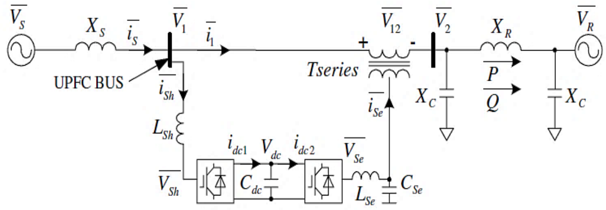

Figure 2. A basic UPFC Functional Schemes

The shunt converter of UPFC can be injected a current controller to transmission line system. The two components of current controller are real and reactive component. The real component is in phase or opposite phase with the transmission line voltage and it is controlled the real power of series inverter. The reactive component of the current controller is desired to inject or absorb reactive power from transmission line [20].

3.1. UPFC Static Model

In this section, it is represented modify estimation of state – state for UPFC by analyzing power equation (active and reactive) which are introduced the static analysis by determine the voltage nodes as illustrate in Fig. 3. [21], [22], [23].

An active and reactive power equation for static model can be analyses as follows:

$$P_{km} = V_k^2 G_{kk} + V_k V_m \left(G_{km} cos(\theta_k - \theta_m) + B_{km} sin((\theta_k - \theta_m)) + V_k V_{cR} \left(G_{km} cos(\theta_k - \theta_{CR}) + B_{km} sin\left((\theta_k - \theta_{cR})\right) + V_k V_{vR} \left(G_{km} cos(\theta_k - \theta_{vR}) + B_{km} sin((\theta_k - \theta_{vR})) \quad (1)$$

$$Q_{km} = V_k^2 B_{kk} + V_k V_m \left(G_{km} sin(\theta_k - \theta_m) + B_{km} cos((\theta_k - \theta_m)) + V_k V_{cR} \left(G_{km} sin(\theta_k - \theta_{CR}) - B_{km} cos\left((\theta_k - \theta_{cR})\right) + V_k V_{vR} \left(G_{km} sin(\theta_k - \theta_{vR}) - B_{km} cos((\theta_k - \theta_{vR})) \quad (2)$$

$$P_{mk} = V_m^2 G_{mm} + V_k V_m \left(G_{mk} cos(\theta_m - \theta_k) + B_{km} sin(\theta_m - \theta_k) + V_m V_{cR} \left(G_{mm} cos(\theta_m - \theta_{CR}) + B_{mm} sin\left((\theta_m - \theta_{cR})\right) \quad (3)$$

$$Q_{mk} = V_m^2 B_{mm} + V_k V_m \left(G_{mk} sin(\theta_m - \theta_k) + B_{km} cos(\theta_m - \theta_k) + V_m V_{cR} \left(G_{mm} sin(\theta_m - \theta_{CR}) - B_{mm} cos(\theta_m - \theta_{cR}) \quad (4)$$

At static mode condition of UPFC, it is not supply or absorb active power. So, it can be calculated the active power of UPFC converter as follow:

$$P_{cR} = V_{cR}^2 G_{mm} + V_k V_{cR} \left(G_{km} cos(\theta_{cR} - \theta_k) + B_{km} sin(\theta_{cR} - \theta_k)\right) + V_m V_{cR} \left(G_{mm} cos(\theta_{cR} - \theta_m) \quad (5)$$

$$P_{vR} = -V_{vR}^2 G_{vR} + V_k V_{vR} \left(G_{vR} cos(\theta_{cR} - \theta_k) + B_{vR} sin(\theta_{vR} - \theta_k)\right) \quad (6)$$

$$P_{cR} + P_{vR} = 0 \quad (7)$$

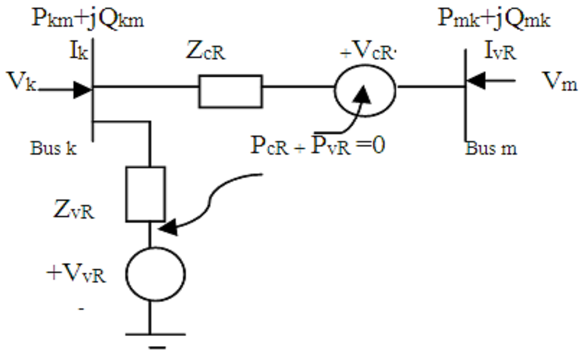

Figure 3. The Equivalent circuit of the UPFC

3.2. UPFC Control Model

The basic parameters are used to control of UPFC such as magnitude and phase shift of voltage, power (active & reactive). UPFC is consists of series and shunt converter with the transmission line through a series transformer and shunt transformer respectively as shown in Fig. 4.

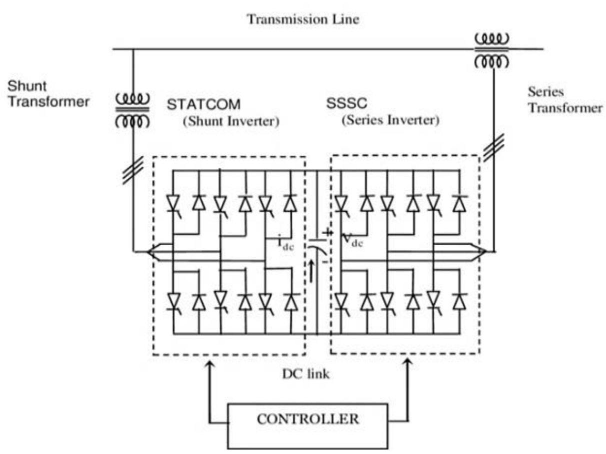

Figure 4. The basic diagram control of UPFC

Series converter is applied to control of power flow and voltage injection to the transmission line in this model, and it is can be controlled of power (active & reactive) errors and reduced its by using PI controller to compute references V_d, V_q [21].

Shunt converter (STATCOM) is used to control the line ac voltage and DC voltage by applied voltage regulation technique while SSSC is applied to control of reactive power and active power [22], [24].

3.3.2. Three level 48-pulse voltage

The three level 48-pulse converter working can be obtained by connecting two 24-pulse converter with phase shifted being 7.5 from each other. By applying symmetrical shift, To obtain the 7.5 phase shift can be applied by coupling two transformer with 3.75 phase shift to one of 24-pulse converter and +3.75 on the other two coupling transformer of the second 24-pulse converter. [21], [25]. The phase-shift model on each four 12-pulse converter cascade operates as follows:

The output voltage obtained from the first 12-pulse converter is:

$$V_{ab12}\,(t)_1 = 2[\,V_{ab1}\sin(\omega t + 30°) + V_{ab11} sin\,(11\omega t + 195°) + V_{ab13} sin\,(13\omega t + 225°) + V_{ab23} sin\,(23\omega t + 60°) + V_{ab25} sin\,(25\omega t + 120°) \ldots] \quad (8)$$

The output voltage obtained from the second 12-pulse converter is:

$$V_{ab12}\,(t)_2 = 2[\,V_{ab1} sin\,(\omega t + 30°) + V_{ab11} sin\,(11\omega t + 15°\,) + V_{ab13} sin\,(13\omega t + 75°) + V_{ab23} sin\,(23\omega t + 60°) + V_{ab25} sin\,(25\omega t + 120°) \ldots] \quad (9)$$

The output voltage Obtained from the third 12-pulse converter is:

$$V_{ab12}\,(t)_3 = 2[\,V_{ab1} sin\,(\omega t + 30°) + V_{ab11} sin\,(11\omega t + 285°) + V_{ab13} sin\,(13\omega t + 345°) + V_{ab23} sin\,(23\omega t + 240°) + V_{ab25} sin\,(25\omega t + 300°) \ldots] \quad (10)$$

The output voltage Obtained from the fourth 12-pulse converter is:

$$V_{ab12}\,(t)_4 = 2[\,V_{ab1} sin\,(\omega t + 30°) + V_{ab11} sin\,(11\omega t + 105°) + V_{ab13} sin\,(13\omega t + 165°) + V_{ab23} sin\,(23\omega t + 240°) + V_{ab25} sin\,(25\omega t + 300°) \ldots] \quad (11)$$

The four identical 12-pulse converters provide shifted ac output voltages, introduced by (34)–(37), which are added in series on the secondary windings of the transformers. The total output voltage 48-pulse is obtained by:

$$V_{ab48}\,(t) = V_{ab12}\,(t)_1 + V_{ab12}\,(t)_2 + V_{ab12}\,(t)_3 + V_{ab12}\,(t)_4 \ldots] \quad (12)$$

$$V_{ab48}\,(t)_4 = 8[\,V_{ab1} sin\,(\omega t + 30°) + V_{ab47} sin\,(47\omega t + 150°) + V_{ab49} sin\,(49\omega t + 210°) + V_{ab95} sin\,(95\omega t + 330°) + V_{ab97} sin\,(97\omega t + 30°) \ldots] \quad (13)$$

The output voltage 48-pulse ac from the STATCOM model is given by:

$$V_{ab48}\,(t)_4 = 8/\sqrt{3}\,\sum_{n=(48K\pm1)}^{\infty} V_{abn}\sin(n\omega t + 18.75°n - 18.75°i) \quad (14)$$

Voltages $\upsilon_{bn}48$ (t) and $\upsilon_{cn}48$ (t) have a same sinusoidal wave with a phase shifting of 120 and 240, respectively, from phase a $\upsilon_{an}48(t)$.

4. Proposed Control Model

4.1. Mathematical Control Model of STATCOM

The vector control (d-q) method is applied to control the STATCOM. This method can control active and reactive power by controlling the voltage and current id d-q reference frame, so it is introduced STATCOM control model in d-q reference[21]. The voltage equations across R-L are:

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = R_f \begin{bmatrix} i_d \\ i_q \end{bmatrix} + L_f \frac{d}{dt} \begin{bmatrix} i_d \\ i_q \end{bmatrix} + \omega_s L_f \begin{bmatrix} -i_q \\ i_d \end{bmatrix} + \begin{bmatrix} V_{d1} \\ V_{q1} \end{bmatrix} \quad (15)$$

Where:
ω_s: angular frequency for grid voltage
V_d, V_q: the grid voltage components of d-q
V_{d1},V_{q1}: the converter output voltage components of d-q
i_d , i_q : is the current flows between system and STATCOM components of d-q

From equation (1) it can be obtained the next equations of the line voltages for grid and output converter at steady state space at d-q reference frame:

$$V_{dq} = R_f i_{dq} + L_f \frac{d}{dt} i_{dq} + j\omega_s L_f . i_{dq} + V_{dq1} \quad (16)$$

$$V_{dq} = R_f I_{dq} + j\omega_s L_f . Ii_{dq} + V_{dq1} \quad (17)$$

And the instantaneous equations of power (active and reactive) at d-q for the ac system are:

$$P_{ac}(t) = V_d i_d + V_q i_q \cong V_d i_d \quad (18)$$

$$q_{ac}(t) = V_q i_d - V_d i_q \cong -V_d i_q \quad (19)$$

In equations (2),(3) after neglecting R_f, the current equations are calculated as follow:

$$I_{dq} = \frac{V_{dq1} - V_{dq}}{jX_f} = \frac{V_{d1} - V_d}{jX_f} + \frac{V_{q1}}{X_f} \quad (20)$$

Where:
X_f: is the combination reactance for the transformer and grid.

By substitution into the equations (4),(5) in terms of (6) , it is obtained the following equation:

$$P_{ac} = \frac{V_d V_{q1}}{X_L} \; , \; Q_{ac} = \frac{V_d}{X_L}(V_d - V_{d1}) \quad (21)$$

Fig. 5 is represented simulation STATCOM model according to analysis the previous equations.

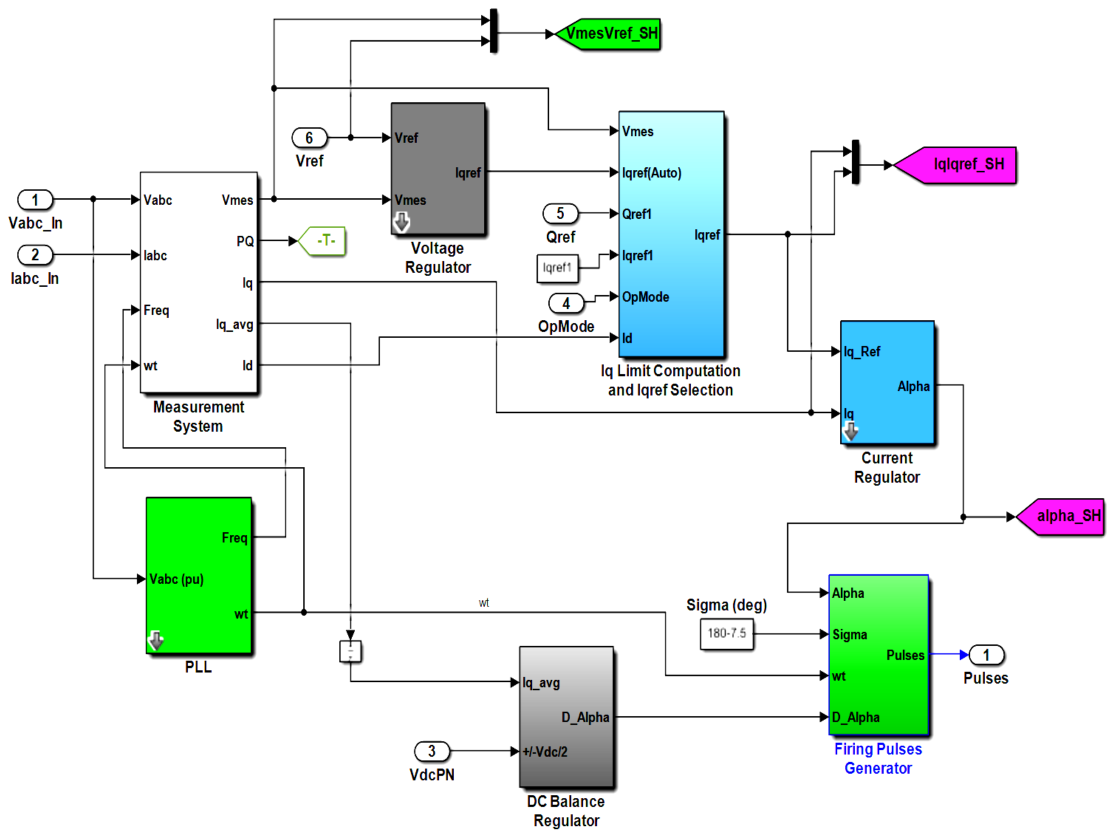

Figure 5. Matlab/simulation of STATCOM

4.2. Dynamic Model of UPFC

In Fig. 6, it can be applied Kirchhoff law on the equivalent circuit to analyze the dynamic model of the UPFC [23], [24]. So, the following three equations are obtained:

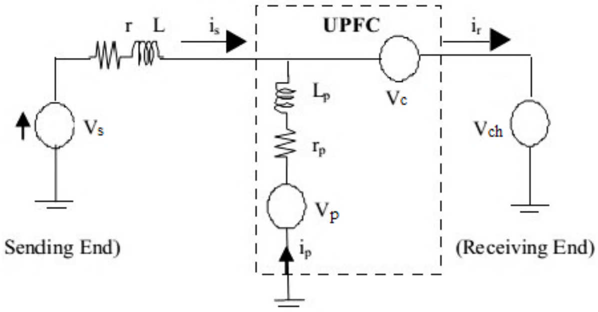

Figure 6. The equivalent circuit for dynamic of the UPFC

$$L\frac{di_{s1}}{dt}+ri_{s1} = V_{s1} - V_{c1} - V_{ch1} \quad (22)$$

$$L\frac{di_{s2}}{dt}+ri_{s2} = V_{s2} - V_{c2} - V_{ch2} \quad (23)$$

$$L\frac{di_{s3}}{dt}+ri_{s3} = V_{s3} - V_{c3} - V_{ch3} \quad (24)$$

The equations of the shunt circuit are:

$$L\frac{di_{p1}}{dt}+r_p i_{p1} = V_{p1} - V_{c1} - V_{ch1} \quad (25)$$

$$L\frac{di_{s2}}{dt}+r_p i_{p2} = V_{p2} - V_{c2} - V_{ch2} \quad (26)$$

$$L\frac{di_{s3}}{dt}+r_p i_{p3} = V_{p3} - V_{c3} - V_{ch3} \quad (27)$$

The DC circuit equations of are:

$$\frac{1}{2}c\frac{dV_{dc}^2}{dt} = P_e - P_{ep} \quad (28)$$

$$P_e = V_{c1}i_{ch1} + V_{c2}i_{ch2} + V_{c3}i_{ch3} \quad (29)$$

$$P_{ep} = V_{p1}i_{p1} + V_{p2}i_{p2} + V_{p3}i_{p3} \quad (30)$$

Where, Vdc : is the DC voltage

For the dynamic equations of the shunt compensator, assuming the active power in the capacitor is zero. Also, no active power losses in converter so the equations of the series circuit are:

$$\frac{d}{dt}\begin{bmatrix} i_{s1} \\ i_{s2} \\ i_{s3} \end{bmatrix} = \begin{bmatrix} \frac{-r}{L} & 0 & 0 \\ 0 & \frac{-r}{L} & 0 \\ 0 & 0 & \frac{-r}{L} \end{bmatrix} \begin{bmatrix} i_{s1} \\ i_{s2} \\ i_{s3} \end{bmatrix} + \frac{1}{L}\begin{bmatrix} V_{s1} & -V_{c1} & -V_{ch1} \\ V_{s2} & -V_{c2} & -V_{ch2} \\ V_{s3} & -V_{c3} & -V_{ch3} \end{bmatrix} \quad (31)$$

The equations of the shunt circuit are:

$$\frac{d}{dt}\begin{bmatrix} i_{p1} \\ i_{p2} \\ i_{p3} \end{bmatrix} = \begin{bmatrix} i_{p1} \\ i_{p2} \\ i_{p3} \end{bmatrix} + \frac{1}{L_p}\begin{bmatrix} V_{p1} & -V_{c1} & -V_{ch1} \\ V_{p2} & -V_{c2} & -V_{ch2} \\ V_{p3} & -V_{c3} & -V_{ch3} \end{bmatrix} \quad (32)$$

By applying Park transformation, the two equations (23) and (24), will be written as:

$$\frac{d}{dt}\begin{bmatrix} i_{sd} \\ i_{sq} \end{bmatrix} = R_f \begin{bmatrix} \frac{-r}{L} & w \\ -w & \frac{-r}{L} \end{bmatrix} \begin{bmatrix} i_{sd} \\ i_{sq} \end{bmatrix} + \frac{1}{L}\begin{bmatrix} V_{sd} & -V_{cd} & -V_{chd} \\ V_{sq} & -V_{cq} & -V_{chq} \end{bmatrix} \quad (33)$$

$$\frac{d}{dt}\begin{bmatrix} i_{pd} \\ i_{pq} \end{bmatrix} = R_f \begin{bmatrix} \frac{-r_p}{L} & w \\ -w & \frac{-r_p}{L} \end{bmatrix} \begin{bmatrix} i_{pd} \\ i_{pq} \end{bmatrix} + \frac{1}{L}\begin{bmatrix} V_{pd} & -V_{cd} & -V_{chd} \\ V_{pq} & -V_{cq} & -V_{chq} \end{bmatrix} \quad (34)$$

The dynamic equations of the circuit are:

$$\frac{dV_{dc}}{dt} = \frac{3}{2cV_{dc}}\left(V_{cd}i_{chd} + V_{cq}i_{chq}\right) \quad (35)$$

$$i_{chd} = i_{sd} + i_{pd} \quad (36)$$

$$i_{chq} = i_{sq} + i_{pq} \quad (37)$$

The active and reactive powers (deliver & absorb) are calculated as follow:

The active and reactive powers deliver are:

$$P_s = \frac{3}{2}\left(V_{sd}i_{sd} + V_{sq}i_{sq}\right) \quad (38)$$

$$Q_s = \frac{3}{2}\left(V_{sq}i_{sd} - V_{sd}i_{sq}\right) \quad (39)$$

The active and reactive powers absorb are:

$$P_{ch} = \frac{3}{2}\left(V_{chd}i_{chd} + V_{chq}i_{chq}\right) \quad (40)$$

$$Q_{ch} = \frac{3}{2}\left(V_{chq}i_{chd} - V_{chq}i_{chq}\right) \quad (41)$$

Fig. 7 is represented simulation UPFC model according to previous analysis.

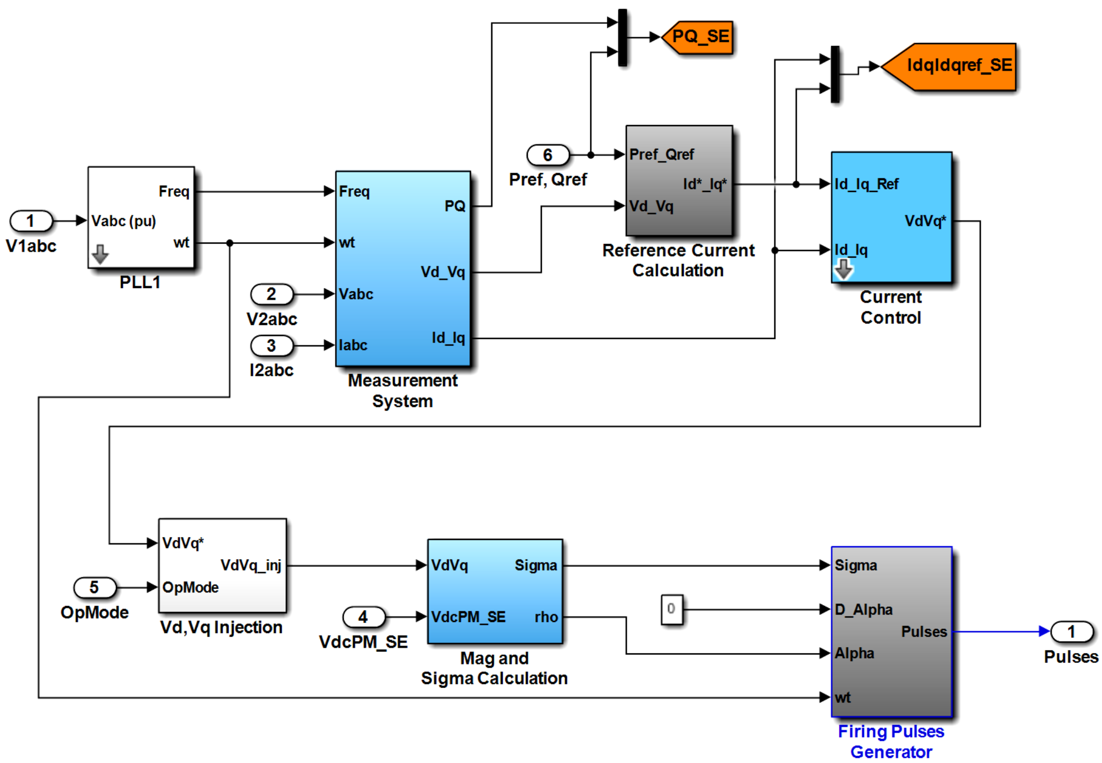

Figure 7. Matlab/simulation of UPFC

According to analysis for STATCOM and UPFC for the proposed model, it can be built Matlab/simulation as shown in Fig. 8.

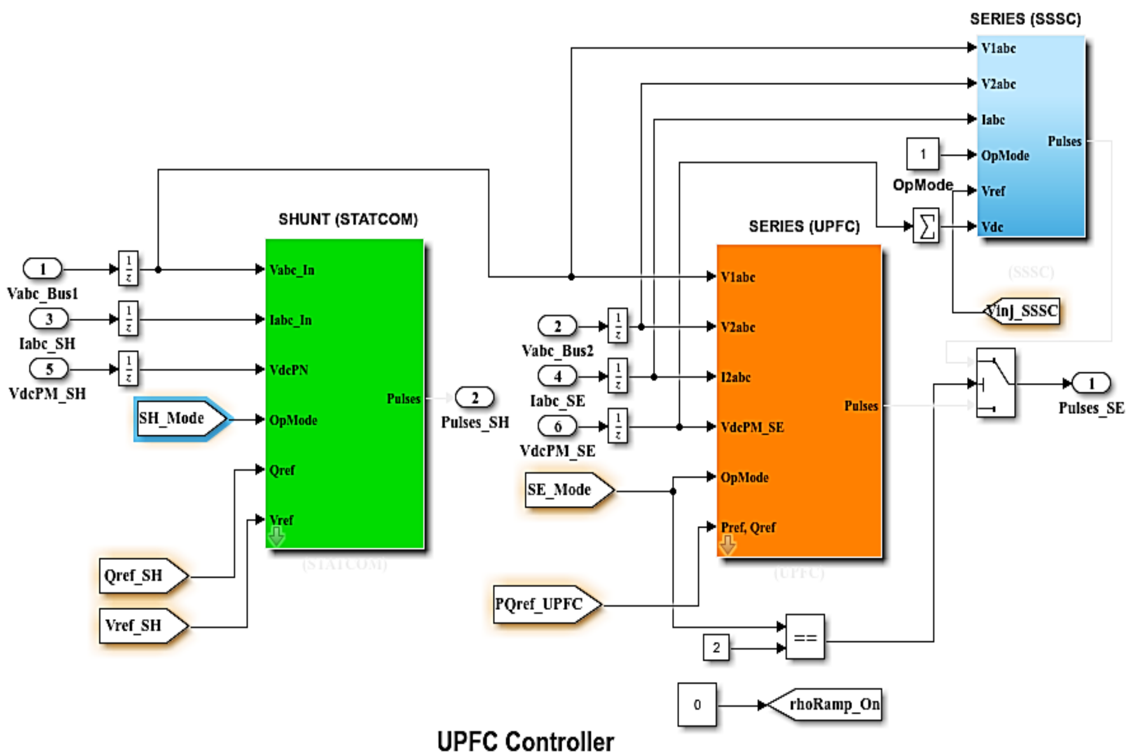

Figure 8. Matlab/simulation of UPFC Controller

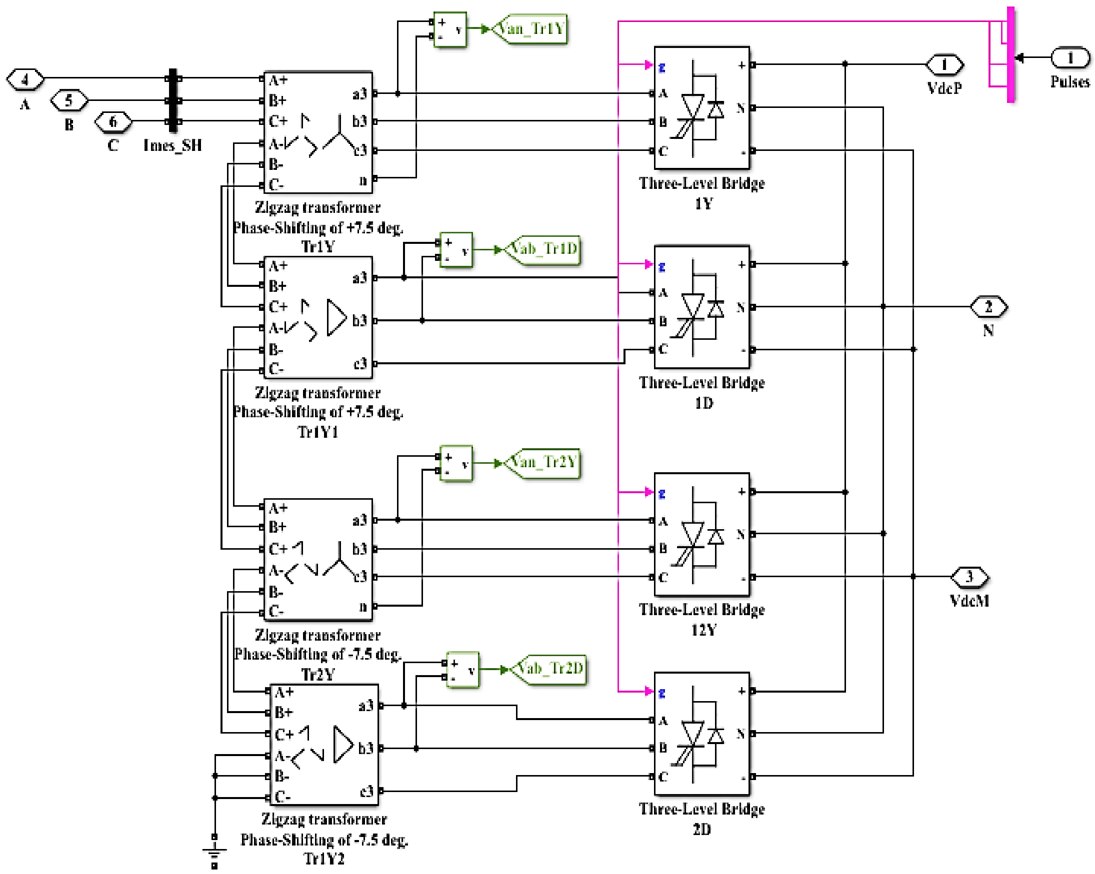

Figure 9. The 48-pulse converter

4.3. The Twice Three Level 48-pulse Converter

4.3.1. Converter principle

The 48-pulse voltage source converter (VSC) is designed from four 3-level inverter. It is obtained from converter that the output voltage is not a pure sinusoidal voltage but has a harmonics, which is not suitable for high power and high voltage applications [21].

To obtain the sinusoidal voltage with low harmonic content twice three level 48-pulse VSC model is designed in the proposed model as shown in Fig. 9.

The twice 3-level and 48-pulse converter are applied in high voltage and high power applications which have a very low harmonic without using any filter circuits as shown in Fig. 9.

5. Numerical Analysis

The proposed unified power flow controller (UPFC) is used to control the power flow in a 500 kV transmission system which is operated under different conditions. This system is subjected to three cases which are the normal operating condition, with different load conditions, and operates with three phase fault conditions. A Matlab/Simulink block of the proposed system is built as shown in fig. 10. The proposed system comprises a The UPFC located between the bus 1 and bus 2 at 500 kV, which is applied to control of power flow through bus 2 and control voltage at bus 1. UPFC consists of two 3-level 48-puls converter (500KV,100MW); the first circuit is shunt converter which is connected to bus 1 and the second circuit is the series converter connected between bus 1 and bus 2. The shunt converter is connected to the series converter through DC buses.48-pulse converter is connected to UPFC controller which is contained shunt STATCOM controller, series UPFC controller and SSSC to control injected voltage as shown in Fig.11. The variation load conditions is connected directly before bus 4 which is consists of inductive load at $0\leq t\leq 0.1$.Three phase fault is occurred between bus 4 and grid at $0.3\leq t\leq 0.4$. While the proposed system worked at normal conditions at $0.1\leq t\leq 0.2$, $0.4\leq t\leq 0.7$.

The system parameters For UPFC controller are taken as follows:

Shunt (STATCOM): rated voltage= 1 pu for base 500KV, parameters For voltage regulator are K_p=36 , K_i=9000,

Parameters For current regulator (Iq) are K_p=5 , Ki=40, Q_{ref}=0

Series (UPFC): rated DC voltage=20KV, parameters For current regulator are K_p=0.025, K_i=6, Q_{ref}=-0.5*10^8 VAR, P_{ref}=8*10^8 Watt.

Series (SSSC): parameters for DC voltage regulator are

K_p=0.000095, K_i=0.004, parameters For ac voltage regulator are K_p=3 , Ki=100.

UPFC rating: shunt transformer rating = 500kV/20kV, and rated power 100MVA, Series transformer rating = 20kV/500kV, and rated power 100MVA , Vdc = 20 kV, Capacitor rating = 2700 μF.

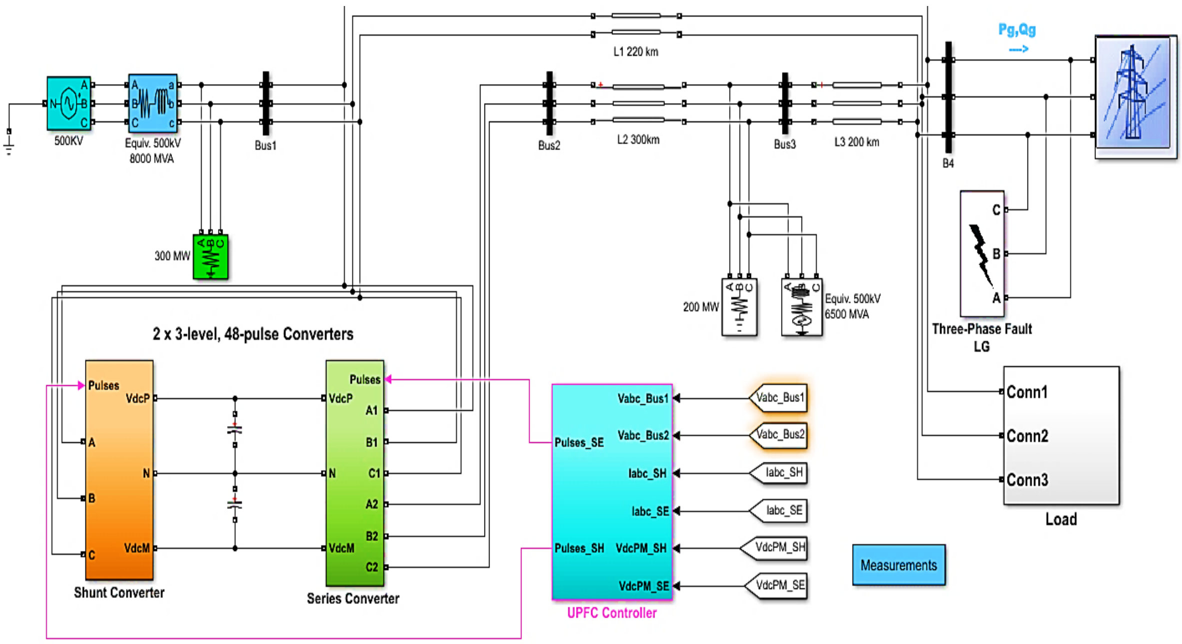

Figure 10. A Matlab/Simulink block of the proposed system.

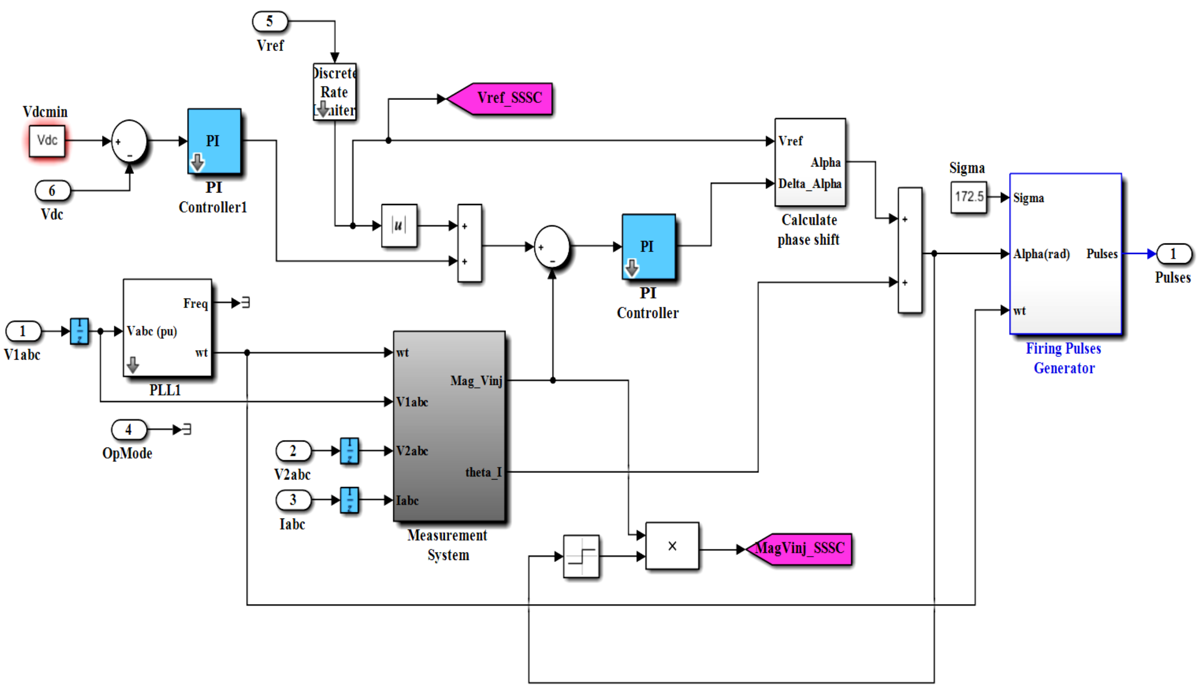

Figure 11. Matlab/simulation for Controlling injected voltage By using SSSC

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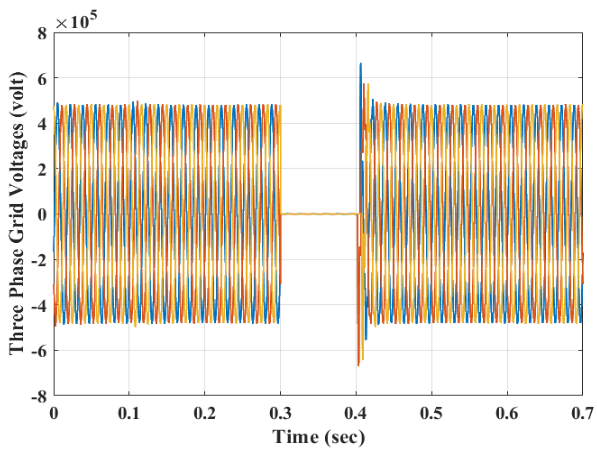
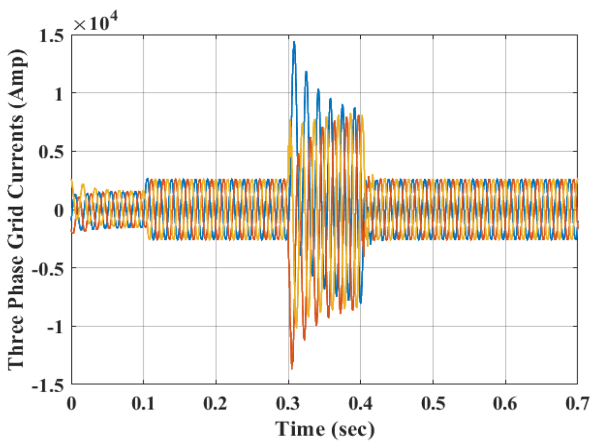
Fig.12 shows the time responses of the grid (voltages, currents and power) which are represented the performance of the proposed system at the three cases study, when applied load before bus 3 at 0≤t≤0.1, also under normal condition at 0.1≤t≤0.3, 0.4≤t≤0.7 and under applied three phase fault at 0.3≤t≤0.4 which are the results tabulated at table. It is clear in In Fig.12 (a) at 0≤t≤0.3, there are no disturbance or harmonic in the voltages waveform with constant maximum over shoot value but at 0.3≤t≤0.4, the voltages are equal zero at fault is occurred while the voltages waveform is returned to normal condition values after fault is clearance at 0.4≤t≤0.7 with the maximum over shoot being 1.35 times by normal voltage value.

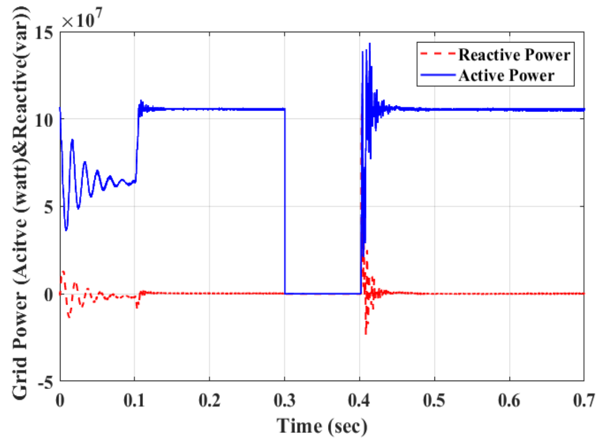
In Fig.12 (b) at 0≤t≤0.1, the current is reduced compared to rated grid current when the pulse load is connected to the system with the maximum over shoot being 1.34 times by rated current value, at 0.1≤t≤0.3, the current waveform is a pure wave with constant maximum over shoot, while at 0.3≤t≤0.4, the maximum over shoot is equal 1.732 times by rated rid current fault occurred. In Fig.12 (c) at normal conditions from 0.1≤t≤0.3 and from 0.4≤t≤0.7, the active power is equal 100 MW.



(a)



(b)



(c)

Figure 12. Time responses of the grid (a) the three phase voltages, (b) the three phase currents, (c) the three phase power.

Fig.13 shows the performances of the input shunt controller (voltages and currents). While Fig.14 shows the performances of the output series controller (voltages and currents) which are the results tabulated at table 1.

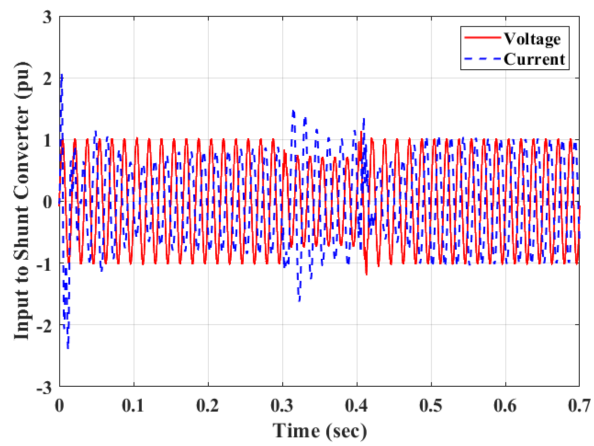


Figure 13. The performances of the output shunt controller

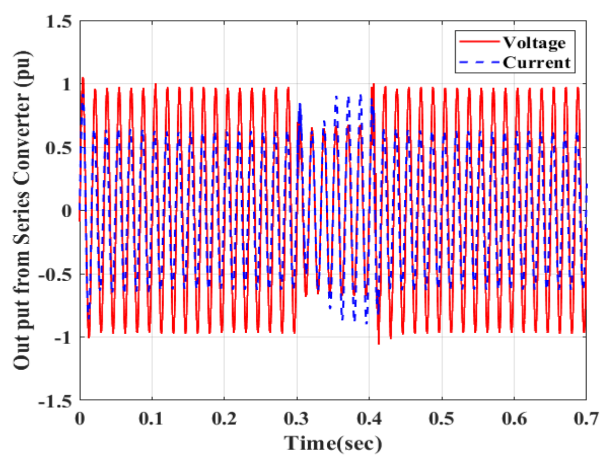


Figure 14. The performances of the output shunt controller

Fig. 15 represents the DC voltage of the output shunt controller which at normal conditions from 0.1≤t≤0.3 and from 0.4≤t≤0.7 is constant while it has a small variation at 0.3≤t≤0.4 when fault is occurred.

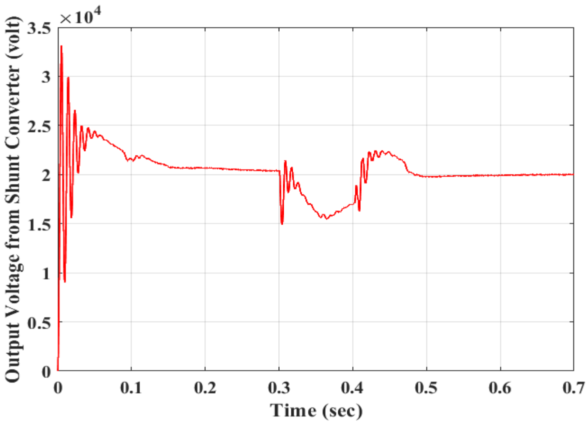
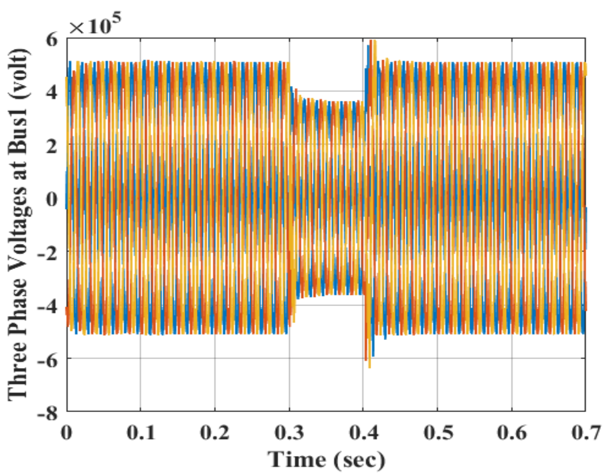


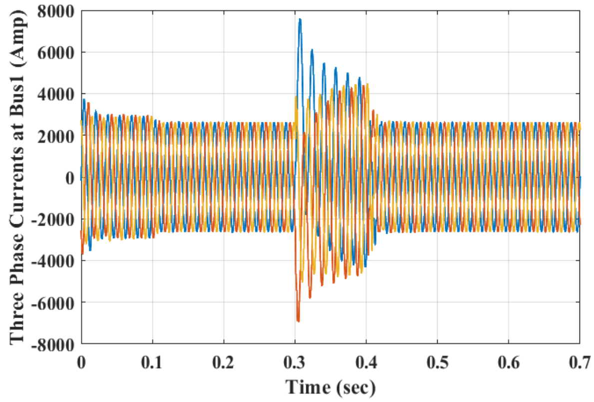
Figure 15. The DC voltage of the output shunt controller

Fig.16 shows the voltage and currents for bus 1. In Fig.16 (a) at 0≤t≤0.3 there are no disturbance or harmonic in the voltages waveform with almost constant maximum over shoot value but at 0.3≤t≤0.4, the voltages are reduced only by 22% when fault is occurred while the voltages waveform is returned to normal condition values after fault is clearance at 0.4≤t≤0.7 with the maximum over shoot being 1.1 times by normal voltage value.

In Fig.16 (b) at 0≤t≤0.1, the current waveform at bus1 is a pure wave with the maximum over shoot being only 1.25 times by rated current value, at 0.1≤t≤0.3, the current waveform is a pure wave with constant maximum over shoot, while at 0.3≤t≤0.4, the maximum over shoot is equal 2 times by rated grid current fault occurred. The results are tabulated at table 1.



(a)

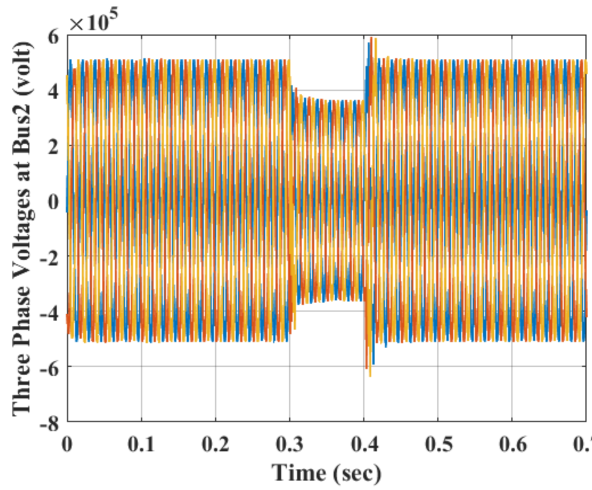


(b)

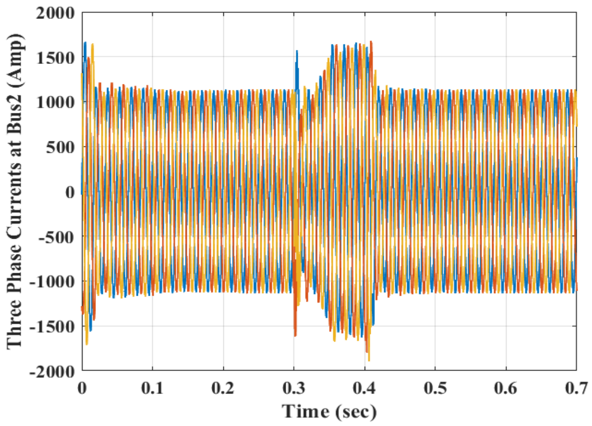
Figure 16. Time responses of the bus1 (a) the three phase voltages, (b) the three phase currents

Fig.17 illustrates the performances for bus 2. In Fig.17 (a) at 0≤t≤0.3, there are no disturbance or harmonic in the voltages waveform with almost constant maximum over shoot value, but at 0.3≤t≤0.4, the voltages are reduced only by 1.12% when fault is occurred while the voltages waveform is returned to normal condition values after fault is clearance at 0.4≤t≤0.7 with the maximum over shoot being 1.17 times by normal voltage value which are the results tabulated at table 1.

In Fig.17 (b) at 0≤t≤0.1, the current waveform is a pure wave with the maximum over shoot being only 1.4 times by rated current value, at 0.1≤t≤0.3, the current waveform is a pure wave with constant maximum over shoot, while at 0.3≤t≤0.4, the maximum over shoot is equal 1.49 times by rated grid current fault occurred. While Fig.18 shows an injection voltage for SSS.



(a)



(b)

Figure 17. Time responses of the bus2 (a) the three phase voltages, (b) the three phase currents

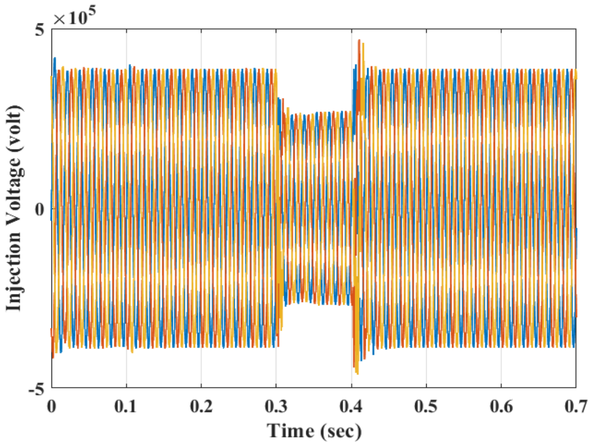


Figure 18. Injection voltage for SSS

6. Conclusion

The goal about this paper is improvement of the performance of system by using unified power flow controller (UPFC), STATCOM and two 3-level 48-puls converter for the power flow in a transmission power system. The proposed control model is analyzed under different the three cases. The first case, the model is applied to plus load at bus 3. The second case, the model is operating at normal work and the third case, the three phase fault is occurred at bus4. From observing the simulation results, it is clear that the suggested console gives a good transient and stable condition especially when the three phase fault is clearance. Also, it is found that the grid current is not significantly affected. Only the maximum value of the current increases when the fault is occurred by1.35 times from rating value and for a period of time not exceeding 0.02 sec. at normal conditions from $0.1 \leq t \leq 0.3$ and from $0.4 \leq t \leq 0.7$ the active power is equal a rated value.

During three phases fault is occurred, the voltage at bus1 is reduced only by 22% from nominal voltage while the maximum over shoot of the current is equal 2 times by rated grid current. After the fault is clearance and at normal conditions the voltage and current performance there are no harmonic.

At bus2 the voltage is reduced only by 1.12% from nominal voltage and during the maximum over shoot of the current is equal 1.49 times by rated grid current during the fault is occurred. After the fault is clearance, and at normal conditions the voltage and current performance, there are no harmonic.

Table 1. Results of the maximum over shoot and RMS obtained from proposed model.

Time interval (sec.)		$0 \leq t < 0.1$		$0.1 \leq t < 0.3$		$0.3 \leq t < 0.4$		$0.4 \leq t < 0.7$	
		V (KV)	I (A)	V (KV)	I (A)	V (KV)	I (A)	V (KV)	I (A)
Grid	Max. Over Shoot	491	2100	480	2590	0	14260	**658**	2971
	R.M.S	480	1561	480	2590	0	8232	**487**	2511
Shunt control	Max. Over Shoot	500	693	500	295	375	520	**520**	485
	R.M.S	500	243	500	277	350	349	**500**	347
Series control	Max. Over Shoot	510	317	486	228	385	312	500	299
	R.M.S	478	222	468	225	349	231	490	220
Bus 1	Max. Over Shoot	511	3717	508	2685	417	7477	582	2888
	R.M.S	506	2944	507	2652	362	3602	500	2600
Bus 2	Max. Over Shoot	536	1666	496	1134	395	1611	580	1653
	R.M.S	487	1185	498	1130	333	1079	495	1130

References

[1] Pranesh Rao, M. L. Crow, , Zhiping Yang, “STATCOM Control for Power System Voltage Control Applications”, IEEE Transactions on Power Delivery 2000-15(4):1311 – 1317.·

[2] Marta Molinas, Jon Are Suul and Tore Undeland, “Improved grid interface of induction generators for renewable energy by use of STATCOM”, International Conference on Clean Electrical Power June 2007, PP. 215-222.

[3] Haolin Zhang, Lingyun Wang, Jiaxing Sun, Xingyuan Hu, “Research on the Voltage Stability of Grid Connected Wind Farm Based on STATCOM Technology”, 2nd International Conference on Electrical, Automation and Mechanical Engineering (EAME 2017), 2017, pp:17-20.

[4] M.Alfaki Mohamed,Farouga Dasari,Narasimha Rao,Ravi Samikannu,Sampath KumarVenkatachary,Karthikrajan Senthilnathand, “Comparative analysis of controllers for stability enhancement for wind energy system with STATCOM in the grid connected environment”, Renewable Energy, Available online 5 July 2020

[5] Namra Joshi, Dr. Pragya Nema, “ Application Of Statcom In Voltage Stability Analysis Of Wind Based Distributed Generation System”, INTERNATIONAL JOURNAL OF SCIENTIFIC & TECHNOLOGY RESEARCH VOLUME 8, ISSUE 11, NOVEMBER 2019, PP. 2126-2129.

[6] Ahmed Nasser Alsammak, Hasan Adnan Mohammed, “ALiterature Review on the Unified Power Flow Controller UPFC”, International Journal of Computer Applications, 2018 Volume 182– No.12., pp 23-29.

[7] Fadi M.Albatsh,Shameem Ahmad, Saad Mekhilef, Ibrahim Alhamrouni1, Mohd Fairuz Abdul Hamid, “Power Flow Control using Fuzzy Based UPFC under different operating conditions”, J. Electrical Systems 13-2(2017), pp 398-414.

[8] Hamdan, I., Ibrahim, A.M.A. & Noureldeen, O., “Modified STATCOM control strategy for fault ride-through capability enhancement of grid-connected PV/wind hybrid power system during voltage sag”. SN Appl. Sci. 2, 364 (2020).

[9] Bouhadouza Boubekeur, Ahmed Gherbi, Hacene Mellah, “Application of STATCOM to increase transient stability of wind farm”. American Journal of Electrical Power and Energy Systems, 2013; 2(2): PP:50-56

[10] Bouhadouza Boubekeur, Ahmed Gherbi, Hacene Mellah, “Application of STATCOM to increase transient stability of wind farm”. American Journal of Electrical Power and Energy Systems, 2013; 2(2): PP:50-56

[11] V. M. Hrishikesan K. Venkatraman M.P. Selvan S. Moorthi, “Application of D-STATCOM in SCIG based Windfarms during Normal and Abnormal Grid Conditions”, IEEE Eighteenth National Power Systems Conference (NPSC). 2014.

[12] Bhim Singh, and Jitendra Solanki,“A comparison of control algorithms for DSTATCOM,” IEEE Transactions on Industrial Electronics, vol. 56, no. 7, 2009, pp.2738-2745.

[13] Movahedi A, Niasar AH, Gharehpetian G, “ Designing SSSC, TCSC, and STATCOM controllers using AVURPSO, GSA,and GA for transient stability improvement of a multi-machine power system with PV and wind farms”, Int J Electr Power Energy System, 2019(106), PP:455–466

[14] Hemeida M, Rezk H, Hamada MM., “A comprehensive comparison of STATCOM versus SVC-based fuzzy controller for stability improvement of wind farm connected to multi-machine power system”,. Electrical Engineering journal , issue 2,2018 , PP:935–951.

[15] Atma Ram Guptaa, Ashwani Kumarb “Impact of DG and D-STATCOM placement on improving the reactive loading

[16] Saman Babaei, Babak Parkhideh, and Subhashish Bhattacharya, “Analysis of 48-pulse Based STATCOM and UPFC Performance under Balanced and Fault Conditions”, 38th Annual Conference on IEEE Industrial Electronics Society- IECON 2012.

[17] Shuhui Li, Ling Xu, Timothy A. Haskew, “Control of VSC-based STATCOM using conventional and direct-current vector control strategies”, Electrical Power and Energy Systems 45 (2013), PP:175–186.

[18] Llus Trilla, Fernando Bianchi and Oriol Gomis-Bellmunt, “Optimal Control of VSC for STATCOM Applications”, IFAC Proceedings Volumes Volume 45, Issue 21, 2012, pp. 588-593.

[19] Promod Kumar Pandey, Baidyanath Bag “A Comparative study on UPFC and SVC towards Voltage Profile improvement of a Grid Connected Distributed Generation System”, International Conference on Energy, Power and Environment: Towards Sustainable Growth (ICEPE),2015.

[20] ABDELOUAHED Touhami1, ZIDI sid ahmed1, and HADDI ali2, “Enhancement of Active and Reactive Power Flow Control over the Transmission Line using UPFC”, International Journal of Computer Science, Communication & Information Technology (CSCIT),2018 Vol.6, pp.1-8.

[21] ABDELOUAHED TOUHAMI, ZIDI SID AHMED, FADI M. ALBATSHB and HADDI Ali, “ Analysis of 48-pulse Based UPFC Performance under Balanced and Fault Conditions” Conférence Internationale en Automatique & Traitement de Signal (ATS-2018) -Proceedings of Engineering and Technology – PET., 2018, Vol.35, pp.1- 8.

[22] Touhami Abdelouahed; Zidi Sid Ahmed, “Modeling and transient simulation of Unified Power Flow Controllers (UPFC) in power system”, 4th International Conference on Electrical Engineering (ICEE), 2015.

[23] A. Nabavi-Niaki M.R. lravani, “ STEADY-STATE AND DYNAMIC MODELS OF UNIFIED POWER FLOW CONTROLLER (UPFC) FOR POWERSYSTEM STUDIES” IEEE Transactions on Power Systems, Vol. 11, No. 4, November 1996, pp.1937-1943.

[24] Djilani Kobibi Y.I, Hadjeri Samir, Zidi Sid Ahmed, Djehaf Mohamed, “ Modelling a Unified Power Flow Controller for the Study of Power System Steady state and Dynamic Characteristics”, 5th International Conference on Modeling, Simulation and Applied Optimization (ICMSAO), 2013.

[25] Meera R Karamta and J G Jamnani, “ Dynamic Mathematical Modeling of Unified Power Flow Controller Integrated into Single Machine Power System for Dynamic State Estimation”, European Journal of Advances in Engineering and Technology, 2018, 5(2), pp. 122-127.