

Design and Implementation of Fuzzy Logic Controller cum Hysteresis Current Controlled STATCOM for Improving Power Quality

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Abstract

Objectives: In this paper, we propose a new hybrid controller, Fuzzy Logic Controller (FLC) cum Hysteresis Current Controlled (HCC) Static Compensator (STATCOM) for enhancing the power quality. **Methods/Statistical analysis:** The DC link capacitor voltage of VSI is manipulated by the FLC and the HCC is used to modify the shape the source current such that it is in-phase with the input voltage. **Findings:** The output results of THD across single phase and three phase power system without STATCOM are 71.75% and 18.06%. In this proposed work different control schemes and loads are considered e.g. FFT analysis output of Single phase with STATCOM (PI cum HCC, R-L load) = 6.49%, (PI cum HCC, R-C load) = 8.58%, (FLC cum HCC, R-L load) = 2.92%, (FLC cum HCC, R-C load) = 3.12%. Three phase with STATCOM (PI cum HCC, R-L-E load) = 14.65 %, (FLC cum HCC, R-L-E load) = 9.18%. **Application/Improvements:** In single phase system and three phase system, FLC cum HCC shows better performance compared to other methods and model is verified by using MATLAB/Simulink.

Keywords: Fuzzy Logic Control, Hysteresis Control, STATCOM

1. Introduction

One of the major power quality cries in power systems is harmonic distortion. The harmonics are engendered in the power source due to the non-linear loads for examples single phase/ three phase uncontrolled diode rectifier, controlled rectifier and storage elements capacitive loads. The continuation of the harmonics in power source that show the ways to heating of transformers, Electro-Magnetic-Interference (EMI) and electronics elements break. For this reason, it is necessary to abolish the harmonics less than 5% as specified in IEEE 519-1992 harmonic standard. In addition, the occurrence of harmonics and volt-ampere-reactive power in power source as results more power loss as well as malfunction. Several methods were introduced to rectify such cries in power systems. One of the most famous techniques is Passive

Filter (PF) arrangement^{1,2}. The structure of PF consisting of tuned L-C components has been extensively used to purge harmonics. It has benefits of the minimum initial cost and enhanced performance. On the other hand, this PF method has demerits of huge filter size components, un-stability, and resonance through load operating conditions. Another famous method is STATCOM. This method has become an option elucidation for regulating the current harmonics in the source. It is fit for low to medium voltage in distribution side as well as for controlling the Volt-Amp Reactance (VAR) power and voltage at high voltage distribution side. The structure of STATCOM is Voltage Source Inverter (VSI), which is used to compensate both harmonics currents and fundamental VAR^{3,4}.

There are various Current Control (CC) methodologies have been introduced in the literature such

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as Proportional-Integral (PI) controller, Average Current Mode Control (ACMC), Sliding Mode Control (SMC) and HCC^{5,6}. Among these CC methods, the HCC is the most popular one for STATCOM applications. The HCC is a method of controlling a current source inverter. Usually, PI controller is used to regulating the capacitor voltage of STATCOM. The PI controller based approach needs the precise linear mathematical equation, which is complex to evaluate. In addition, it is unsatisfactory to do the satisfactorily under parameter variations, non-linearity, and load disturbances etc.⁷ The implementation of FLC for STATCOM has been reported⁸. However, the reference current generation of this method has complex and enormous peak overshoots in DC link capacitor voltage of VSI. The above pointed-out cries are solved by designed FLC cum HCC for shunt STATCOM.

Hence, in this article, proposes a FLC cum HCC STATCOM for increasing power quality in power system at various load operating conditions. The STATCOM with their control schemes are implemented in Matrix Laboratory (MATLAB)/ Simulation link (Simulink) via. Computer simulation. The performance of the same model with their controllers is validated at different load operating condition over the traditional PI cum HCC. FACTS controllers increase the overall capacity of a large transmission network by 20% or more⁹⁻¹².

2. FLC cum HCC STATCOM

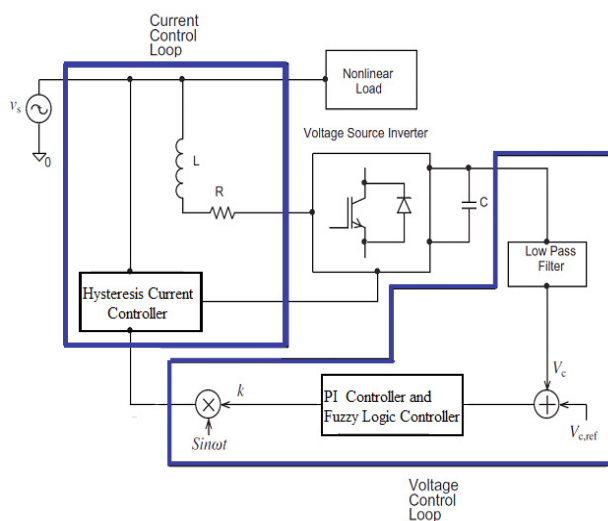


Figure 1. FLC cum HCC controlled STATCOM.

The structure of FLC cum HCC STATCOM is depicting in Figure 1. It consists of double loops such as outer loop acts as D.C link capacitor voltage loop and inner loop acts as current loop. The average value of the D.C link capacitor voltage V_c is control by the voltage loop and also, the sensed V_c is applied to Low Pass Filter (LPF) to eliminate the ripples appear in the V_c . Then, removed ripple of V_c is compared with suitable D.C link capacitor voltage reference $V_{c,ref}$ and its error is processed through the FLC/PI controller. Next, the output of the FLC/PI controller is produced the amplitude 'k' of the current that are used to generate the reference current. The generated reference current is compared with source current in the HCC loop for generating the PWM gate pulses for power switches of the VSI of the STATCOM. A HCC is utilized as current loop of the developed STATCOM and FLC/PI controller is applied as a voltage loop of the STATCOM.

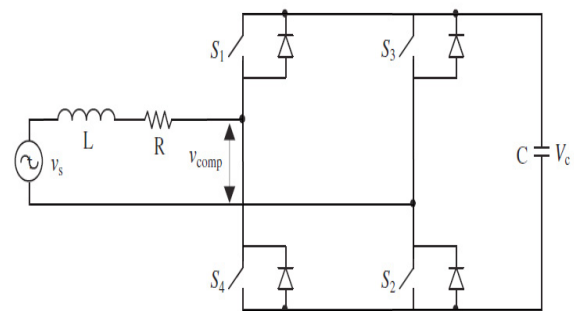


Figure 2. Typical diagram of VSI.

A FLC cum HCC for single phase VSI STATCOM is represents in Figure 2. While the fundamental VSI terminal voltage is higher than the effective value of system voltage V_s , an increasing current is drawn from the AC system, at the same time the VSI terminal voltage lower than the V_s , a lagging current drawn from the AC system. The amplitude of the VSI terminal voltage depends on the V_c . Though the controlling PWM gating pulses of the VSI power switches, the VSI terminal voltage can be made to lag/ lead the AC system voltage, in order that real power flows into (or) out of the VSI circuit. With proper working of power switches, a compensation voltage (V_{comp}) having a fundamental component V_{comp1} is derived at the output of VSI. When ($V_{comp1} > V_s$), leading current (with respect to V_s) can be drawn and the VSI supplies lagging volt ampere reactive (VARs) to the AC system. When ($V_{comp1} < V_s$), the VSI draws lagging current and the VSI

supplies leading volt ampere reactive (VARs) to the AC system. When ($V_{comp1} = V_s$), no current can flow into (or) out of the system. The VSI draws lagging current and the VSI supplies leading VARs to the AC system. The VAR supplied by the STATCOM is expressed as

$$Q = \frac{V_s |V_{comp1} - V_s|}{\sqrt{\omega^2 L^2 + R^2}} \quad (1)$$

Where, L is the inductor in series with the STATCOM, R is the resistance of inductor L and ω is the source frequency. By controlling V_{comp1} , the reactive power could be regulated.

2.1 Control Principle

The power switches S_1 , S_2 , S_3 , and S_4 of VSI (see Figure 2. and refer **Table 1.**) are operated in such a way that the total current flows from the source is same shape as that of the source voltage V_s . The V_s can be expressed as

$$V_s = L \frac{di_{comp}}{dt} + Ri_{comp} + sV_c \quad (2)$$

Equation (2) becomes

$$\frac{di_{comp}}{dt} = \frac{V_s - Ri_{comp} - sV_c}{L} \quad (3)$$

Where, i_{comp} is the compensation current of the STATCOM.

Table 1. Switching status of the STATCOM

Conditions	Status of Power Switches
$s=1$	S_1 and S_4 conduct
$s=-1$	S_2 and S_3 conduct
$s=0$	S_1, S_3 or S_2, S_4 conduct

The V_c can be engraved as

$$\frac{dV_c}{dt} = \frac{si_{comp}}{C} \quad (4)$$

Using the equations (3) and (4), the state space average model of the STATCOM can be derived as equation (5)

$$\begin{bmatrix} \frac{di_{comp}}{dt} \\ \frac{dV_c}{dt} \end{bmatrix} = \begin{bmatrix} -\frac{R}{L} & -\frac{s}{L} \\ \frac{s}{C} & 0 \end{bmatrix} \begin{bmatrix} i_{comp} \\ V_c \end{bmatrix} + \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} V_s \quad (5)$$

The STATCOM compels the supply current to befall similar in shape as the V_s . the supply current i_s will be engraved in terms of i_{comp} and load current, i_{load} as

$$i_s = i_{comp} + i_{load} \quad (6)$$

Differentiating the equation (6) and it becomes

$$\frac{di_s}{dt} = \frac{V_s - Ri_{comp} - sV_c + L \frac{d_{load}}{dt}}{L} \quad (7)$$

The s is the switching function and then, equation (7) can be controlled. The V_c is retained at a voltage more than V_s . It is upon only with help of the outer voltage control loop. The dynamic stability of the FLC plus HCC for STATCOM depends on its capacity to maintain the V_c near to a $V_{c,ref}$. The V_c control loop presumes, which the active power supplied by the supply is the addition of the power flow by the load and the losses in the VSI. Whenever the rapid raise in load power demand, V_c falls as the energy stored in the capacitor supplies power to the load. This result into a raise in the capacitor voltage error that eventually boost the magnitude of the reference current. The raise in reference current revives the D.C link capacitor C voltage to the reference voltage value.

2.2 Design of DC Link Capacitor

The C has a function of supplies (or) absorbs energy, at any time there is an unexpected amend in the active power demand of the load. In such stipulations, the C sustains the load demand for the 50% period of the supply frequency. The value of C is computed with help of the energy balance principle. The stored energy in C is equal to the energy demand of the load in the transient period. This assumption after generalization provides the expression for estimating the value of C and it can be expressed as

$$C = \frac{2\pi V_s i_s}{\omega} \left(\frac{1}{V_c^2 - V_{c,min}^2} \right) \quad (8)$$

Where, $V_{c,min}$ is the preferred minimum C voltage. In real-time implementation, a faintly larger capacitance value is chosen to take care of the C losses.

2.3 Design of Filter Inductor

The value of filter inductor L can be low sufficient with the intention that the injected current d_{il}/dt is more than

that of the reference current $d_{i_{ref}}/dt$ for the injected current to follow the reference current. The reference current is expressed as

$$i_{ref} = k \sin \omega t \quad (9)$$

The highest $d_{i_{ref}}/dt$ of the reference current is engraved as

$$\max\left(\frac{d_{i_{ref}}}{dt}\right) = k\omega \quad (10)$$

The highest $d_{i_{ref}}/dt$ of the reference current is calculated for every harmonics component based on its amplitude and frequency. The L is calculated from the standard differential equation with negligible resistance as

$$\frac{di_L}{dt} = \frac{\Delta V_L}{L} \quad (11)$$

The optimal value of L is applied in the VSI to offer the smallest operating frequency. This results in trim downs the EMI and switching losses.

2.4 HCC

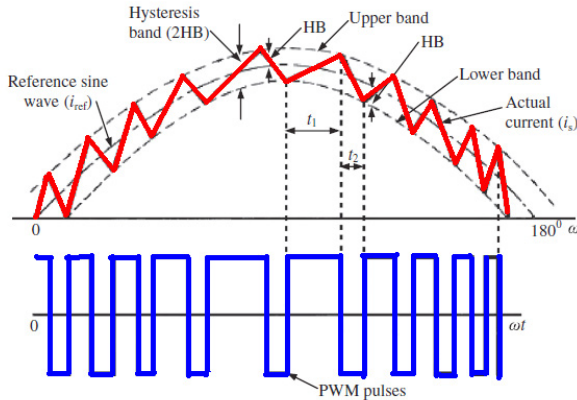


Figure 3. Structure of HCC.

The HCC (or) hysteresis band control method is illustrated in Figure 3. The HCC technique, the ON and

OFF instant transpire in such a way as to force the current to stay within a hysteresis band (HB)¹³. The ON/OFF occur when error go above a fixed magnitude HB. The control laws w.r.t the power switches of the VSI of the STATCOM are as follow;

- Minimum $HB \leq i_{ref} - i_s \leq$ Maximum HB, none of the power switches are closed.
- $i_{ref} - i_s >$ Maximum HB, S_1 and S_2 are closed.
- $i_{ref} - i_s <$ Minimum HB, S_3 and S_4 are closed.

- Consistent with the equation (7), the relevant equations for di_s^+/dt and di_s^-/dt will be expressed as

$$\begin{aligned} \frac{di_s^+}{dt} &= \frac{V_s - Ri_{comp} + V_c}{L} + \frac{di_{load}}{dt} \\ \frac{di_s^-}{dt} &= \frac{V_s - Ri_{comp} + V_c}{L} + \frac{di_{load}}{dt} \end{aligned} \quad (12)$$

The respective equations for ON and OFF intervals t_1 and t_2 (refer the Figure 3.) can be expressed as

$$\begin{aligned} \left(\frac{di_s^+}{dt} - \frac{di_{ref}}{dt} \right) t_1 &= 2HB \\ \left(\frac{di_s^-}{dt} - \frac{di_{ref}}{dt} \right) t_2 &= -2HB \end{aligned} \quad (13)$$

The ON and OFF intervals t_1 and t_2 with operating frequency of HB, ω_s as

$$t_1 + t_2 = \frac{2\pi}{\omega_s} \quad (14)$$

Solving equations (12) to (14) to get the HB expressions as

$$HB = \left(\frac{0.5\pi V_c}{\omega_s L} \right) \left[1 - \left(\frac{V_s - Ri_{comp} + L \frac{di_{load}}{dt} - L \frac{di_{ref}}{dt}}{V_c} \right)^2 \right] \quad (15)$$

$$i_{ref} = k \sin \omega t$$

Where, $\frac{di_{ref}}{dt} = k\omega \cos \omega t$

The optimal operating frequency with desired HB can be written as

$$\omega_{s,max} = \frac{0.5\pi V_c}{HB * L} \quad (16)$$

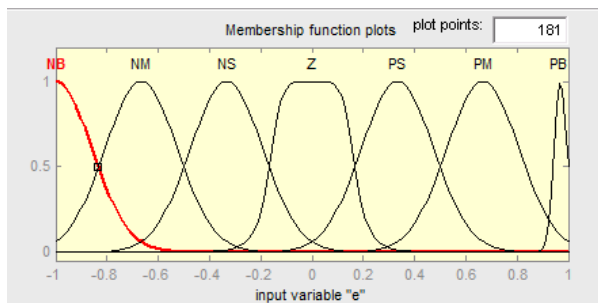
2.5 Design of PI Controller

A PI controller is utilized for afford the good V_c regulation and minimized steady state error for STATCOM. The V_c is sensed and compared with reference output voltage, which gives the V_c error signal (refer Figure. 1). This error signal is processed by the PI controller to keep the V_c fixed and decreases the steady state error. The PI controller parameters such as proportional gain (K_p) and integral times (T_i), are calculated with help of the Zeigler

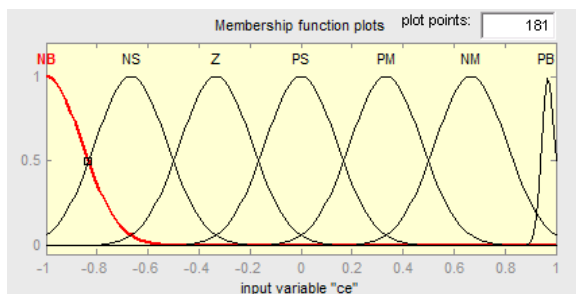
– Nichols tuning method. From this method, the system equation (5) is offering a sustained oscillation with ultimate gain ($K_{cr} = 0.04$) and ultimate period ($P_{cr} = 0.012$ s). Using this method the values of $K_p = K_{cr}/2 = 0.02$ and $T_i = P_{cr}/1.2 = 0.01$ s are evaluated.

2.6 Design of FLC

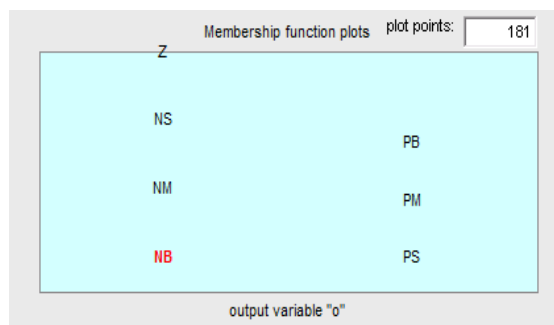
The FLC is adopted as a voltage loop of STATCOM to control the power switches of it¹⁴. The output and the inputs of the FLC is interpretation in Figures 4. (a) to (c). The D.C link capacitor voltage error (e) and its change in error (ce) of STATCOM are applied as input of the FLC and the output is o (scratch the reference current for the measured source current).



(a)

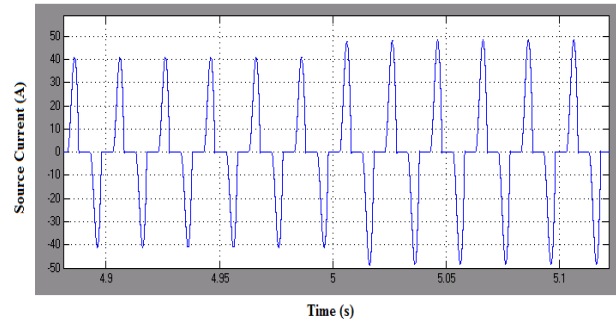


(b)

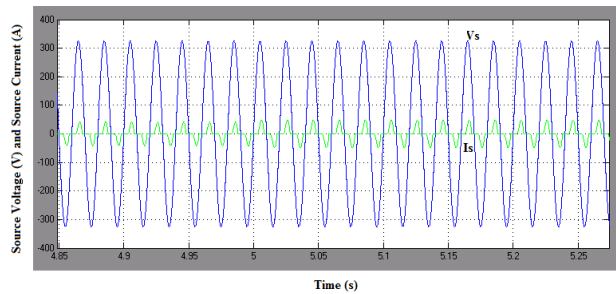


(c)

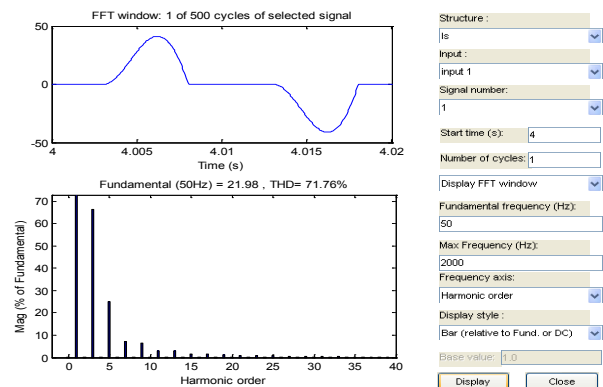
Figure 4. Membership's functions of FLC, (a) error (e), (b) change in error (ce), and (c) output (o).



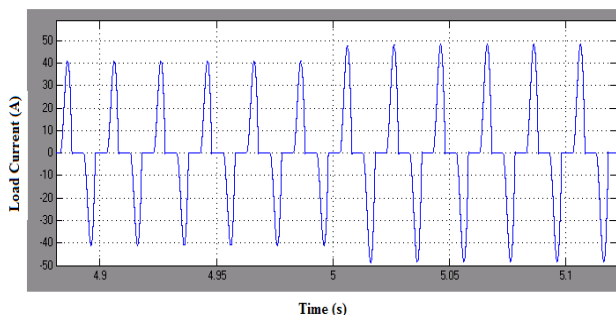
(a)



(b)



(c)



(d)

Figure 5. Simulated responses of 1- phase power system without STATCOM for non-linear diode rectifier R-L load, (a). Source current, (b). Source voltage and current, (c). THD analysis, and (d). Load current.

For correctness, the statistical ranges of the inputs and output of the FLC can be homogeneous and carved as tracks: $e = [-1.1 \ -1.08 \ -1.06 \ -1.04 \ -1.02 \ 0 \ 1.02 \ 1.04 \ 1.06 \ 1.08 \ 1.1]$, $ce = [-0.22 \ -0.14 \ -0.11 \ -0.056 \ 0 \ 0.056 \ 0.11 \ 0.156 \ 0.23]$ and $o = [-1 \ -0.067 \ -0.0433 \ 0 \ 0.0433 \ 0.0767 \ 1]$ and its subsequent fuzzy sets are [NB, NM, NS, Z, PS, PM, PB], where, NB (negative big),

NS (negative small), Z (zero), PS (positive small), PM (positive medium), PB (positive big), correspondingly. The membership functions of the e , ce , and o are shown in Figure. 4. The medley of FLC rules is utterly based on the performance tricks of the STATCOM. In this study, 49 rules are structured that are listed in the Table 2. Subsequently, the weighted average method (defuzzification-method) is used to complete the FLC design.

Table 2. Fuzzy rules of STATCOM

E CE	NB	NM	NS	Z	PS	PM	PB
NB	NB	NM	NB	NB	NM	NS	Z
NM	NM	NM	NB	NM	NS	NM	PS
NS	NB	NB	NS	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PS	PM	PB
PM	NS	Z	PS	PB	PM	PM	PB
PB	Z	PS	PS	PS	PB	PB	PM

Output (o) : NB=-1; NM= -0.06; NS= -0.043; Z=0; PB=1; PM= 0.077; PS=0.042

3. Simulation Results and Discussions

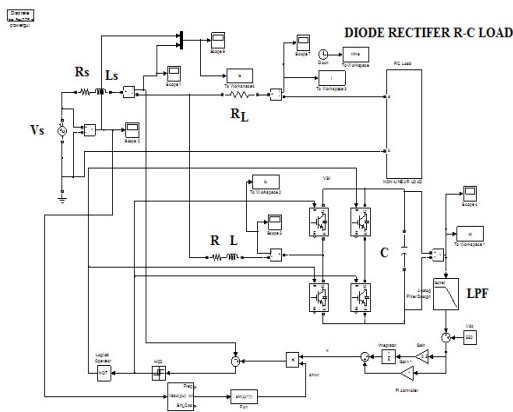
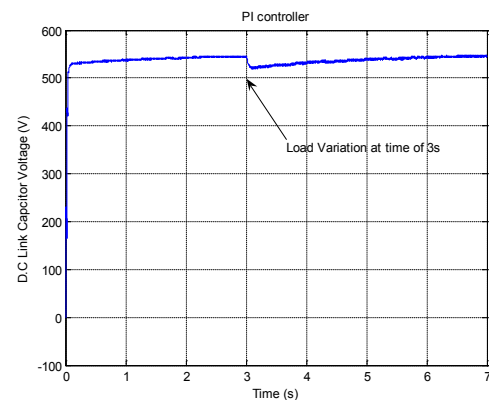
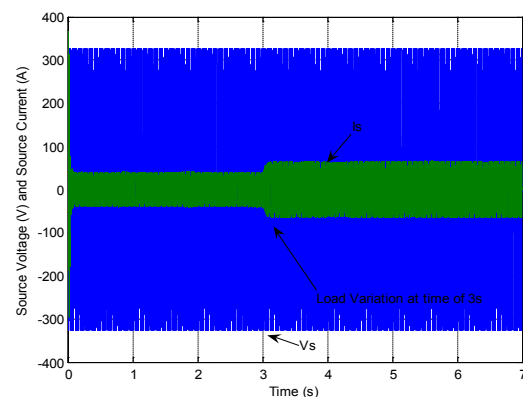


Figure 6. MATLAB/Simulink simulation model of 1-phase STATCOM using PI controller cum HCC.

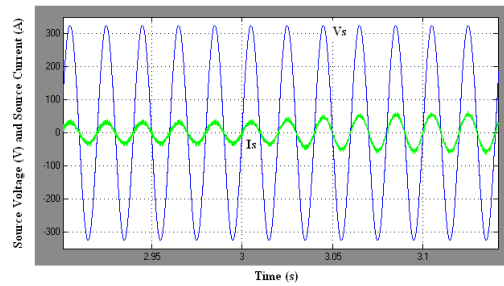
The main aim of this section is to deals about the simulation results of STATCOM using FLC cum HCC. Also, a PI controller cum HCC is designed for comparison with the designed controller. The validation of the system performance is done for different loads operating conditions. The MATLAB/Simulink model is performed on the STATCOM (both single phase and three phase) with specifications as follows (see Figure 5.); $V_s=230V$ (R.M.S Value), $L_s=2mH$, $R_s=0.1\Omega$, $R_L=0.01\Omega$, $L=2mH$, $R=0.01\Omega$, $C=3000\mu F$. **Diode rectifier R-L load:** $R=10\Omega$, $L=100mH$, **Diode rectifier R-C load:** $R=25\Omega$, $C=1000\mu F$. **Diode rectifier R-L-E load:** $R=10\Omega$, $L=100mH$, $E=50V$. Figure 6. shows the simulated responses of source current, source voltage, total harmonics distortion (THD), load current of single phase power system for non-linear diode rectifier R-L load without STATCOM. From Figure. 5 (a), it is found that the supply current surrounds harmonics. Figure 5. (c) indicates that THD analysis of source current for non linear load without STATCOM. It is measured that the THD is 71.76% for test power system without STATCOM.



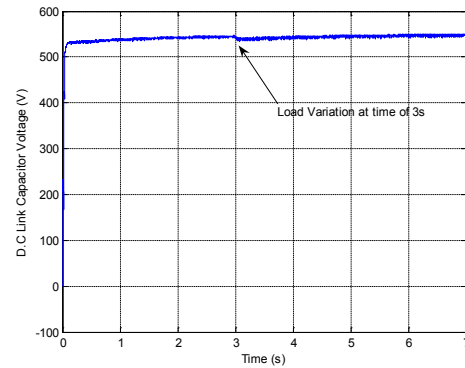
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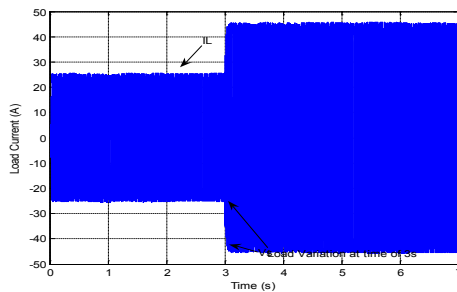
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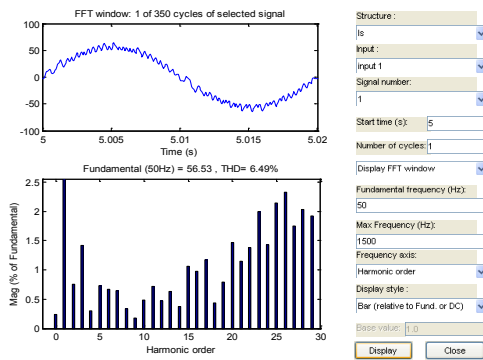
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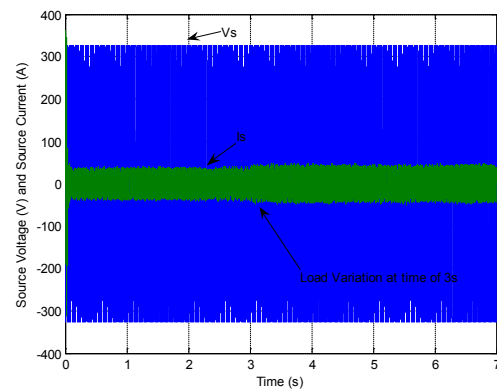
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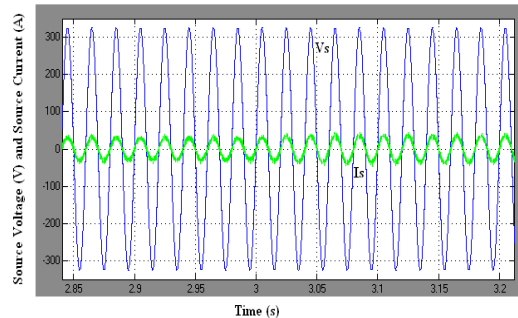
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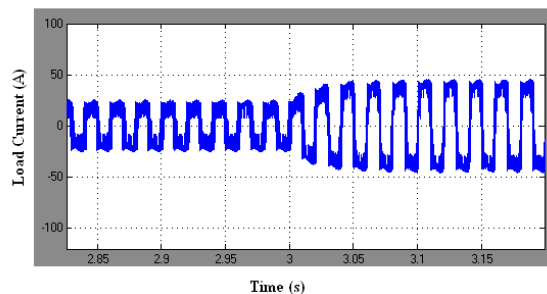
(e)



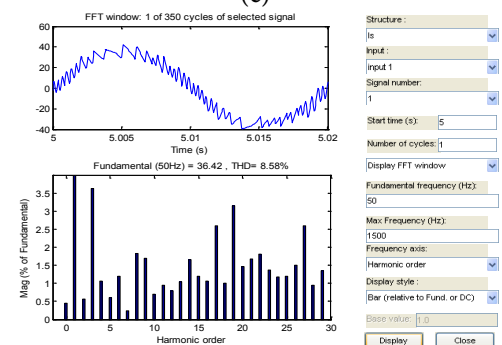
(b)



(c)



(f)



(d)

Figure 7. Simulated results of 1- phase STATCOM for load resistance change using PI controller cum HCC with R-L Load, (a). D.C link capacitor voltage, (b). Source current and voltage, (c). Zoomed source current and voltage, (d) Load current, (e) THD analysis, and (f). Zoomed load current.

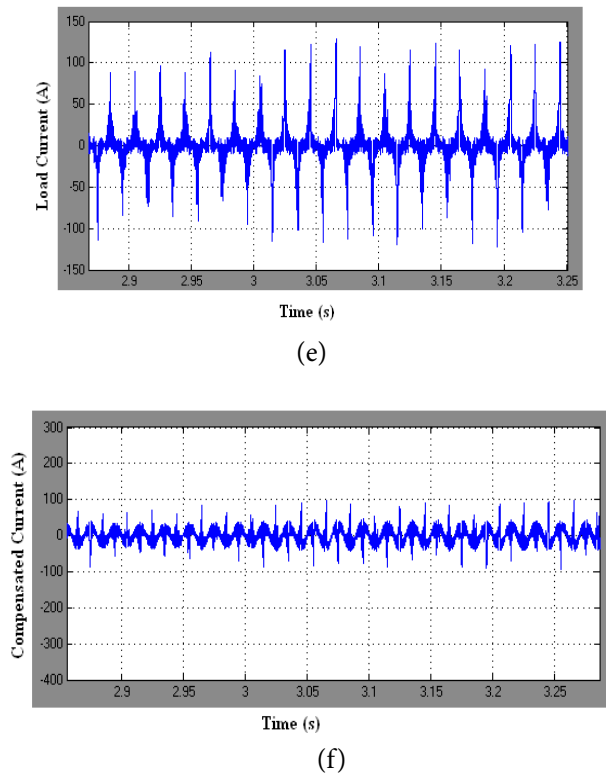


Figure 8. Simulated results of 1-phase STATCOM for load resistance change using PI controller cum HCC with R-C Load, (a). DC link capacitor voltage, (b). Source current and voltage, (c). Zoomed source current and voltage, (d) THD analysis, (e) Load current, and (f). Zoomed compensation current.

Figure 6. show the designed MATLAB/Simulink model of single phase STATCOM using PI controller cum HCC. Figure 7. shows the simulated responses of source current, source voltage, THD, D.C link capacitor voltage ($V_{c,ref} = 550V$), load current, and compensation current of single phase test power system for non-linear diode rectifier R-L load with STATCOM using PI controller cum HCC when step change load variations from 10Ω to 5Ω at time of 3s . From these results, it is found that the THD of source current, peak overshoots and settling time of D.C link capacitor voltage of designed STATCOM has produced 6.49%, 20V, and 2.5s. Figure 8. shows the simulated responses of source current, source voltage, D.C link capacitor voltage, THD, load current, and compensation current of single phase test power system for non-linear diode rectifier R-C load with STATCOM using PI controller cum HCC when step change load variations from 25Ω to 10Ω at time of 3s . From these results, it is visible that the THD of supply current, maximum overshoots and settling time of V_c of given model

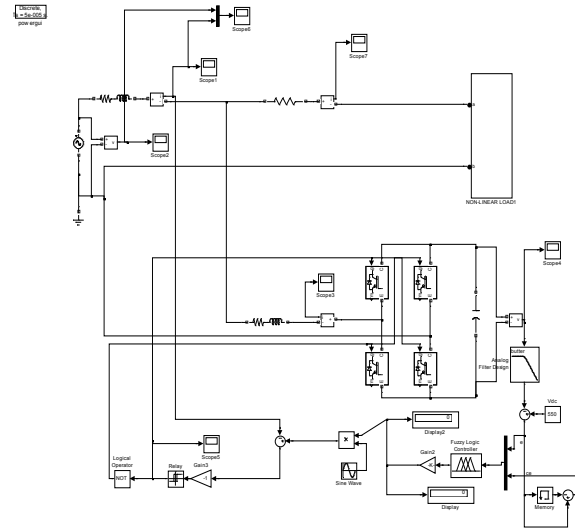
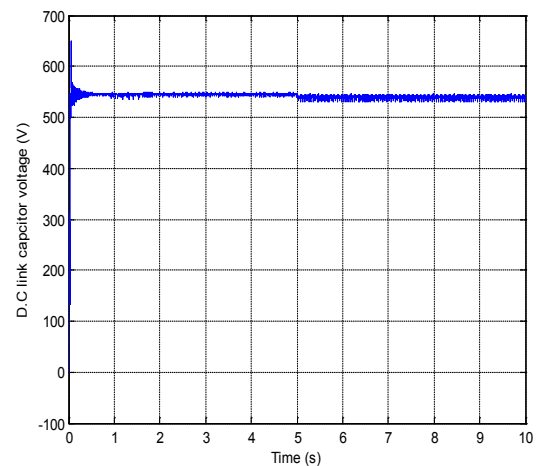
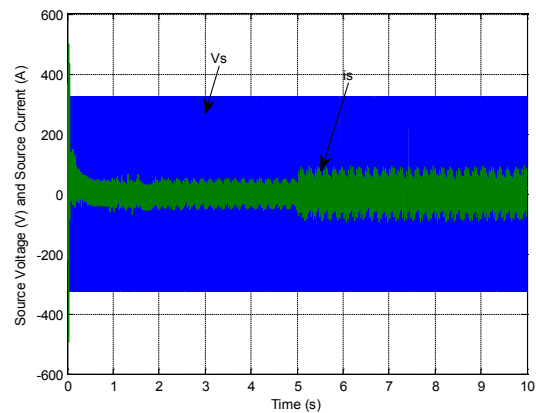


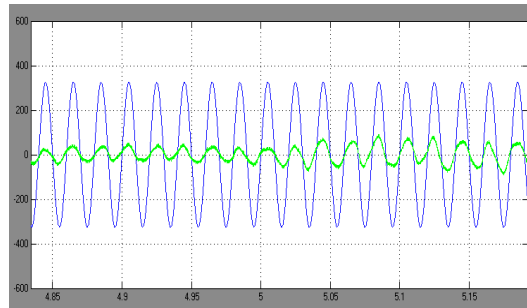
Figure 9. MATLAB/Simulink simulation model of 1-phase STATCOM using FLC cum HCC.



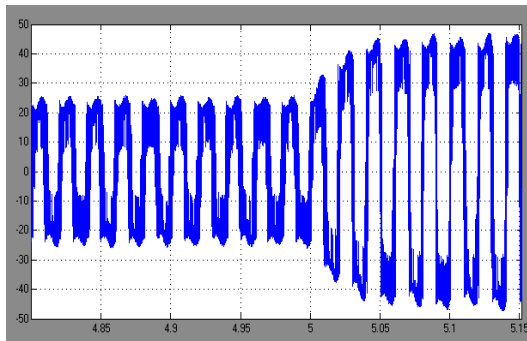
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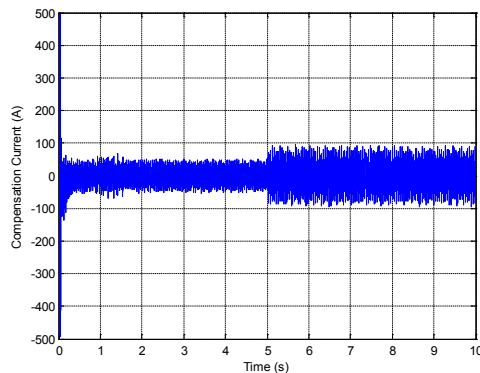
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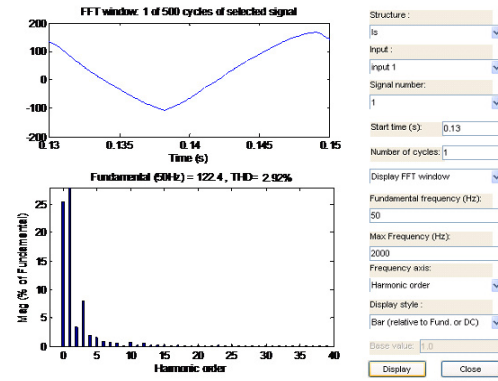


(d)



(e)

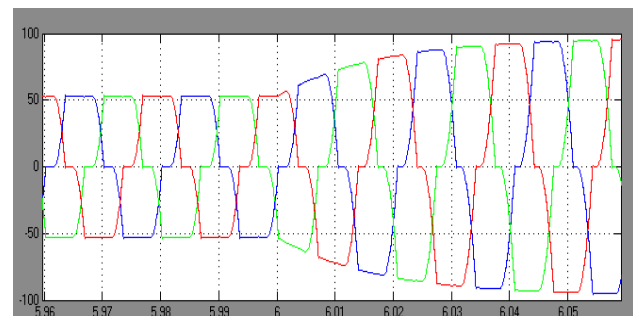
has generated 8.58%, 5V, and 0.5s respectively. Figure 9. depicts the designed MATLAB/Simulink model of single phase STATCOM using FLC cum HCC. Figure 10. shows the simulated responses of source current, source voltage, D.C link capacitor voltage, THD, load current, and compensation current of single phase test power system for non-linear diode rectifier R-L load with STATCOM using FLC controller cum HCC when step change load variations from 10Ω to 5Ω at time of 3s . From these figures, it is evident that the THD of supply current, maximum overshoots and settling time of V_c of given system has produced 2.92%, 1V, and 0.01s. Figure 11. shows



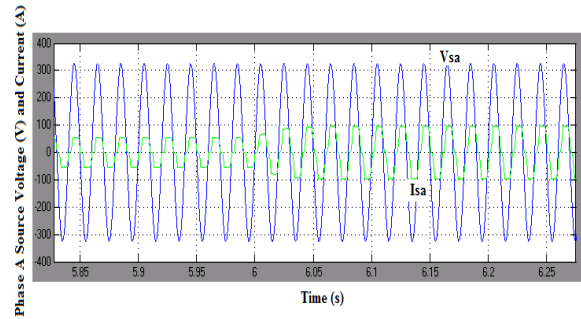
(f)

Figure 10. Simulated results of 1- phase STATCOM for load resistance change using FLC cum HCC with R-L Load, (a). D.C link capacitor voltage, (b). Source current and voltage, (c). Zoomed source current and voltage, (d) Zoomed Load current, (e) Compensation current, and (f). THD analysis.

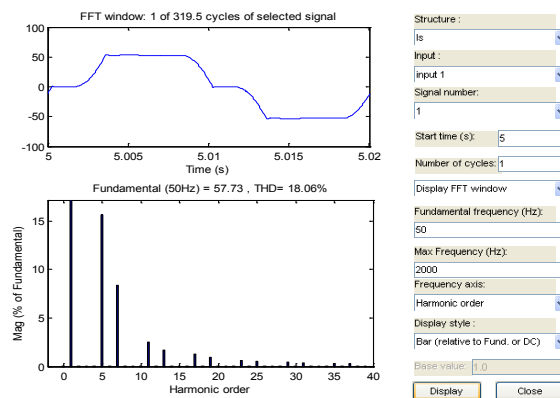
the simulated responses of source current, source voltage, THD, load current of three phase power system for non-linear diode rectifier R-L load without STATCOM. From Figure. 11 (a), it is found that the supply current contains harmonics. Figure. 11 (c) indicates that THD analysis of source current for non linear load without filter. It is obtained that the THD of source current has 18.06% for test power system without STATCOM. Figure 12. developed MATLAB/Simulink model of three phase STATCOM using FLC/PI controller cum HCC. Figures 13. and Figure 14. shows the simulated results of source current, source voltage, D.C link capacitor voltage ($V_{c,ref} = 720V$), compensation currents, THD, load current of three phase power system for non-linear diode rectifier R-L-E load with STATCOM using FLC/PI controller cum HCC, when step change load variations from 10Ω to 5Ω at time of 6s.



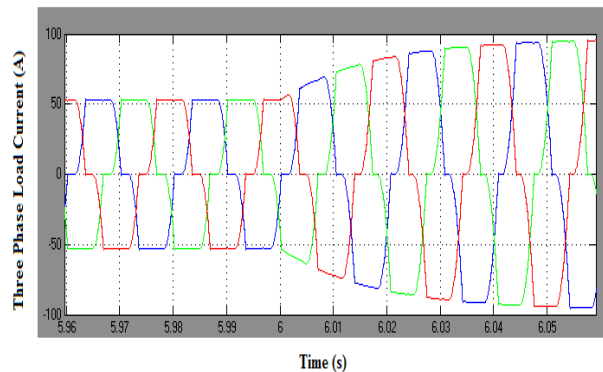
(a)



(b)



(c)



(d)

Figure 11. Simulated responses of 3-phase power system without STATCOM, (a). 3- phase source current, (b). Phase a source voltage and current, (c). THD analysis, and (d). Three phase load current.

From these results, it is found that the FLC cum HCC has best results in comparison with PI control.cum HCC. **Table 3** represents the THD analysis of STATCOM using controller at test power system various loads. Again, this table shows that the results of the designed model using FLC plus HCC has better over the PI controller cum HCC.

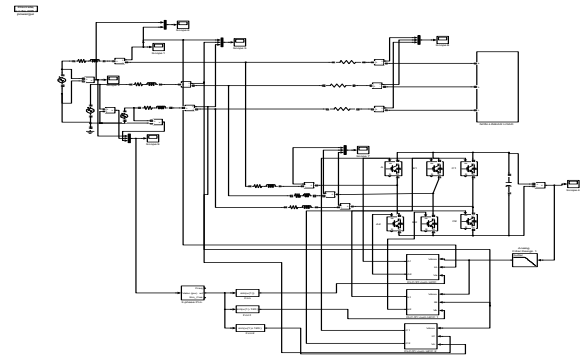
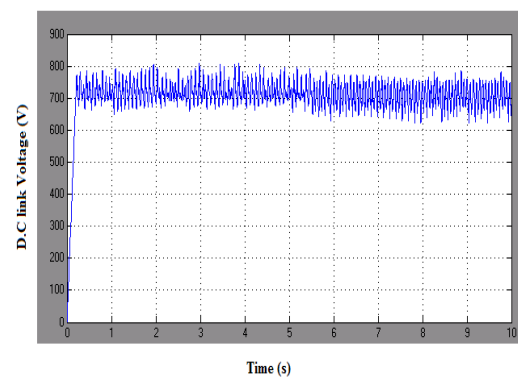
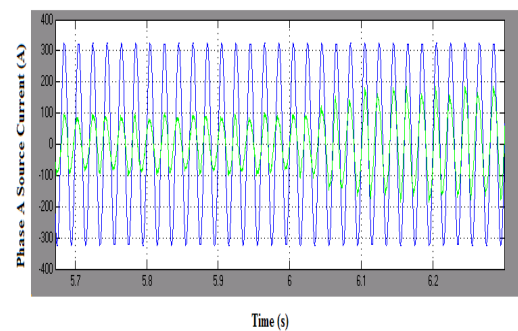


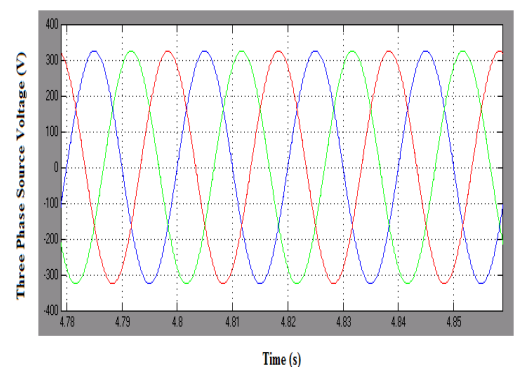
Figure 12. MATLAB/Simulink simulation model of 3- phase STATCOM using FLC/PI controller cum HCC.



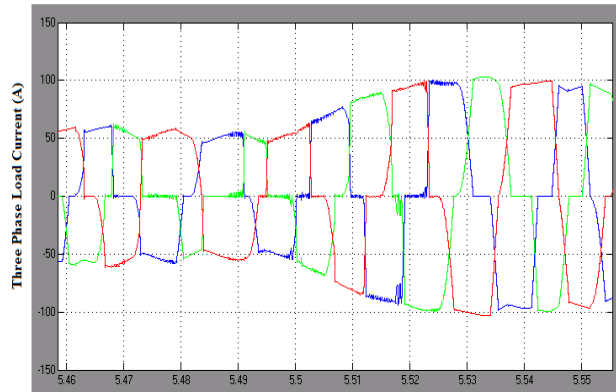
(a)



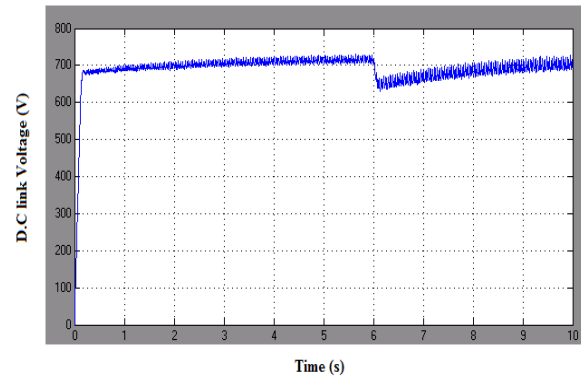
(b)



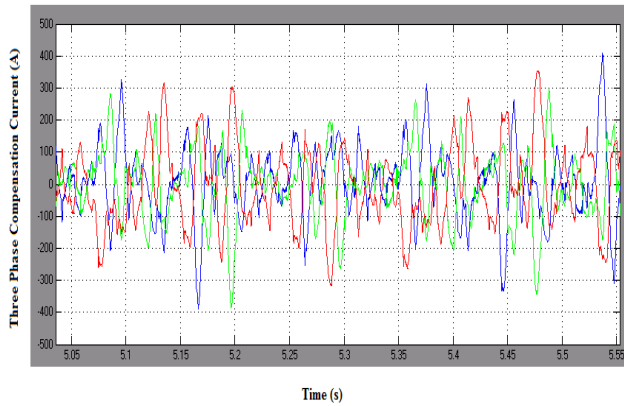
(c)



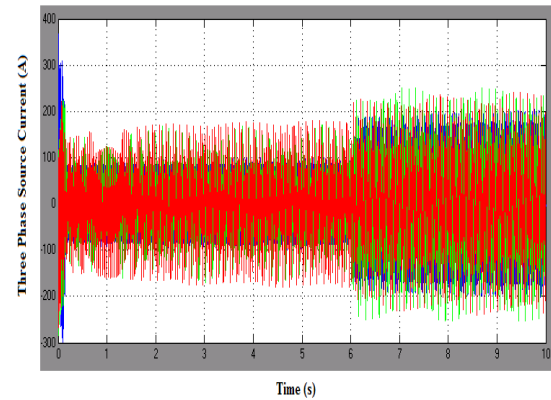
(d)



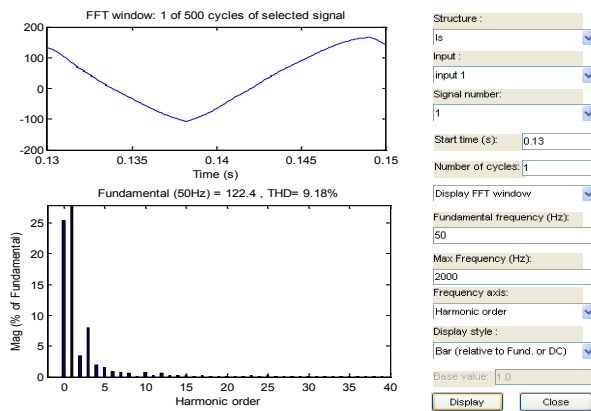
(a)



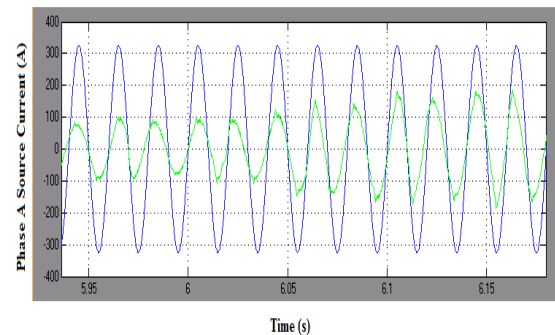
(e)



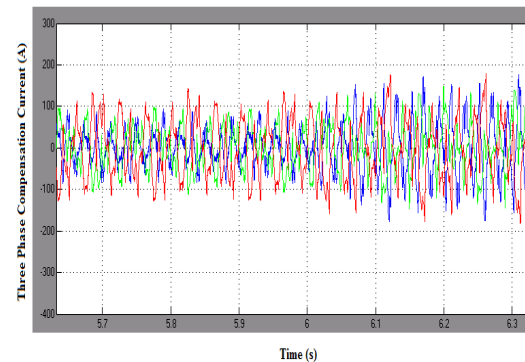
(b)



(f)



(c)



(d)

Figure 13. Simulated results of 3-phase STATCOM for load resistance change using FLC cum HCC with R-L-E Load, (a). D.C link capacitor voltage, (b). Source current and voltage, (c). Zoomed source current and voltage, (d) Load current, (e) Compensation current, and (f). THD analysis.

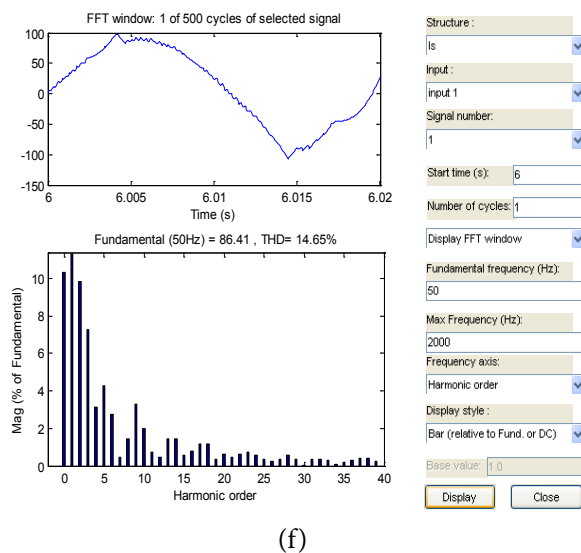
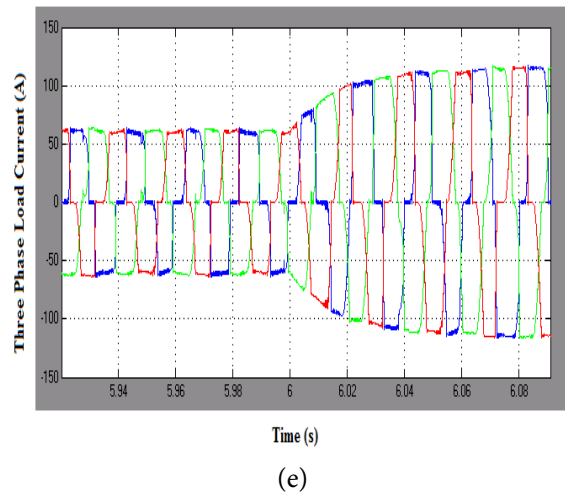


Figure 14. Simulated results of 3-phase STATCOM for load resistance change using PI controller cum HCC with R-L-E Load, (a). D.C link capacitor voltage, (b). Source current and voltage, (c). Zoomed source current and voltage, (d) Load current, (e) Compensation current, and (f). THD analysis.

Table 3. THD analysis of controllers for single/three phase STATCOM at different loads

Power System	THD (%)	
Single phase power system without STATCOM (Diode Rectifier R-L Load)	71.75	
Three phase power system without STATCOM (Diode Rectifier R-L-E Load)	18.06	
Control Schemes with single phase STATCOM	THD (%)	
	PI cum HCC	FLC cum HCC

Diode rectifier R-L load	6.49	2.92
Diode rectifier R-C load	8.58	3.12
Control Schemes with Three phase STATCOM	THD (%)	
	PI cum HCC	FLC cum HCC
Diode Rectifier R-L-E load	14.65	9.18

4. Conclusion

Thus, the FLC cum HCC for single phase/ three phases STATCOM at various operating loads for enhancing the power quality in power system has been verified through the computer simulation using MATLAB/Simulink software platform. The analytical design approaches of the inner loop and the outer loop controls for STATCOM has been clearly derived. A many of the simulation results are presented to show the superiority of the designed controllers for single/three phase STATCOM. One of the main merits of the designed STATCOM has its reference current is derived from the D.C link capacitor voltage without evaluating the reactive current drawn by the load. Also, its compensation procedure is direct and simple as compared to traditional STATCOM. The THD and time domain analysis of the designed model using FLC plus HCC has high-quality performance in comparison with PI controller cum HCC.

5. References

1. Singh B , Al-Haddad K ,Chandra A. A Review of active filter for power quality improvements IEEE *Transactions on Industrial Electronics*. 1999; 46(5):960–70 .
2. Mohanadasse K, Sharmela C , Sudhakar TD. Filters for power quality improvement – A survey Australian Journal of Basic and Applied Sciences. 2015; 9(2):81–93.
3. Gautam S, Yunqing P, Kashif M, Kafle Y, Yibo L. DC side voltage control consideration for single phase shunt active power filter for harmonic and reactive power compensation. *Journal of Electrical Engineering*. 2015; 15(4):290–7.
4. Chelli Z , Toufouti R , Omeiri A , Saad S. Hysteresis control for shunt active power filter under unbalanced three-phase load conditions. *Journal of Electrical and Computer Engineering*. 2015:1–9.
5. Anzari M, Chandran R , Kumar AR . Single-Phase shunt active power filters using indirect control method. *Advance in Electronic and Electric Engineering*. 2013; 3(1):81–90.
6. Ashraf A , Sherif HA, Ahmed ZA. ,Elkousyshokkry M , Saad S. Ensures DC voltage control with back stepping

- design scheme for shunt active power filter. *Journal of Electrical Engineering*. 2015; 15(1):294–303.
7. Belaidi R , Haddouche A , Guendouz H. FLC based three-phase shunt active power filter for compensating harmonics and reactive power under unbalanced mains voltages. *Energy Procedia*. 2012; 18:560–70.
 8. Mani PK, Naidu K. FLC based three phase shunt active filter for power quality improvement in distributions system. *ARPN Journal of Engineering and Applied Sciences*. 2016; 11(2):1127–32.
 9. Pal S, Ray SP, Dasgupta D, Chongdar L. Performance analysis of a three level twelve-pulse VSC based STATCOM under fault condition. *Indian Journal of Science and Technology*. 2013 Sep; 6(9):1–6.
 10. Karthikeyan K, Dhal PK. Small signal stability enhancement using STATCOM based on Eigen value analysis. *Indian Journal of Science and Technology*. 2015 Dec; 8(34):1–7.
 11. Thilagar PP, Harikrishnan R. Application of intelligent fire-fly algorithm to solve OPF with STATCOM. *Indian Journal of Science and Technology*. 2015 Sep; 8(22):1–5.
 12. Ravi M. Comparison of PV supported DVR and DSTATCOM with multiple feeders in standalone WECS by mitigating power quality problems. *Indian Journal of Science and Technology*. 2015 Jul; 8(15):1–5.
 13. Manjula HS, Sasikumar M. Current harmonics reduction using HCC for a wind driven self-excited induction generator drives. *Indian Journal of Science and Technology*. 2015 Jul; 8(13):1–6.
 14. Aminifar S, Marzuki AB. Voltage-mode FLC. *Indian Journal of Science and Technology*. 2012 Nov; 5(11):1–4.