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Modelling and Analysis of Real Time Power System with Cascaded Multilevel STATCOM Using Fuzzy Controller

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Abstract

Electric Power is a major concern that has generated more importance in electrical utilities and consumers. To assure a reliable and quality power system, all the bus are expected to maintain steady acceptable voltage before and after being subjected to any disturbance. Among the FACTs devices a static synchronous compensator(STATCOM) is analyzed to provide a reliable and feasible solution. The STATCOM has been developed using cascaded multilevel converter. A FUZZY based controller for Cascaded Multilevel STATCOM is developed which produces improved performance.This paper presents a comprehensive analysis of CMC based STATCOM with fuzzy controller in real time power system concerning the problem of variable loading and losses. A real time substation with 20 bus are analyzed with power flow analysis with and without STATCOM. Without the connection of STATCOM, a observable changes in the system voltage, line flows and losses are in system behaviour. But this influences the quality of grid and hence the customers are affected badly, indicating the need of power flow analysis and location of STATCOM on the system to improve the voltage profile. It is demonstrated that the described model works to an excellent level in improving the substation performance.

Index Terms

Flexible AC Transmission System, Static Synchronous Compensator ,Power flow analysis, Voltage regulation, Fuzzy Logic control, Cascaded Multilevel Converter

1. INTRODUCTION

To attain the ever-increasing energy demand and power system problems, utilities are proposed number of next-generation projects to be constructed over the years. With the aim of remodelling our power systems**,** the performance of Cascaded Multilevel STATCOM on real power system is analyzed for varying load. The power flow studies are very common in power system analysis allowing us to know the present state of a system, given previous known parameters and values. The power that is flowing through the transmission line and its generated by the generators, the power that is being consumed by the loads, the losses occurring during the transfer of power from source to load and so on all are iteratively decided by the load flow solution or also known as power flow solution. The control of power system operation with FACTs devices are emerging with high efficiency [1],[2]. This study has been carried out with and without STATCOM. To achieve a greater control over the real time system, STATCOM is enforced with a better control. With this detailed investigation the real time has shown its feasibility in terms of reactive power compensation and voltage profile improvement.

2. CIRCUIT DESCRIPTION OF CMC BASED STATCOM

The STATCOM provides reactive power compensation and voltage regulation by acting as a controlled current source connected in parallel with the system bus. The controlled current source in the proposed system is realized using a current-controlled VSC and CMC. A typical configuration of a VSC/CMC based STATCOM is shown in Fig 1. The system consists of three bus grid which bus B2 is considered as source point for STATCOM. The VSC/CMC based STATCOM is connected through bus B2 with coupling transformer and harmonics elimination filter[3]-[5]. Three types of loads are connected through transformer in bus B3 for load variation purpose. The load and STATCOM currents are directed in the three bus system.The power circuit configuration is nothing but connection of VSC and a cascaded multilevel converter in the system. VSC bridge is formed by six IGBTs with associated anti- parallel diodes [6]. The capacitor is connected in parallel with VSC. Filter circuit is connected between the system bus and VSC. In reactive power compensation, seven level cascaded-multilevel converter with separated DC capacitors are constructed with a number of identical three H-bridge converters. The cascaded converter method is very simple and less components. The CMC based STATCOM improves the dynamic responses of the power system network. The proposed converter for the STATCOM is designed with the number of levels. The converters are designed based on the switching loss in the circuit. The Fig 2. shows the seven level cascaded multilevel converter.

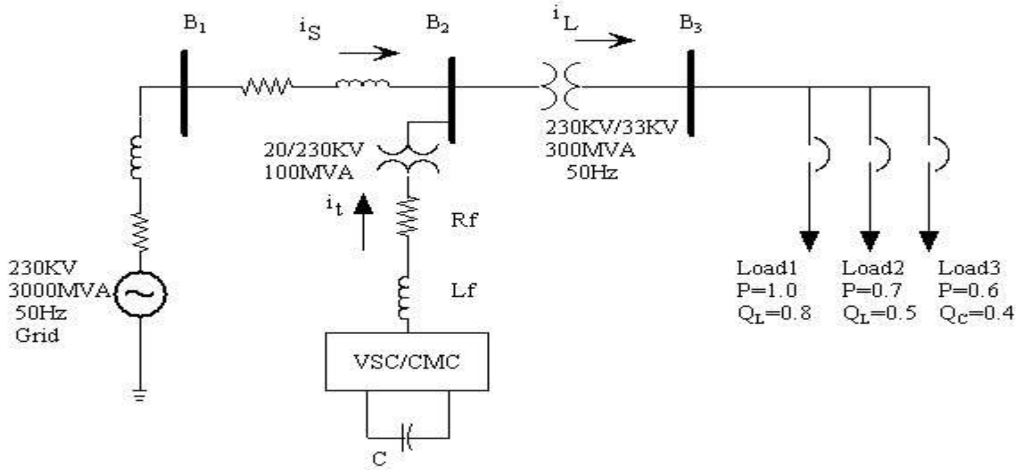

Fig 1.STATCOM network connection

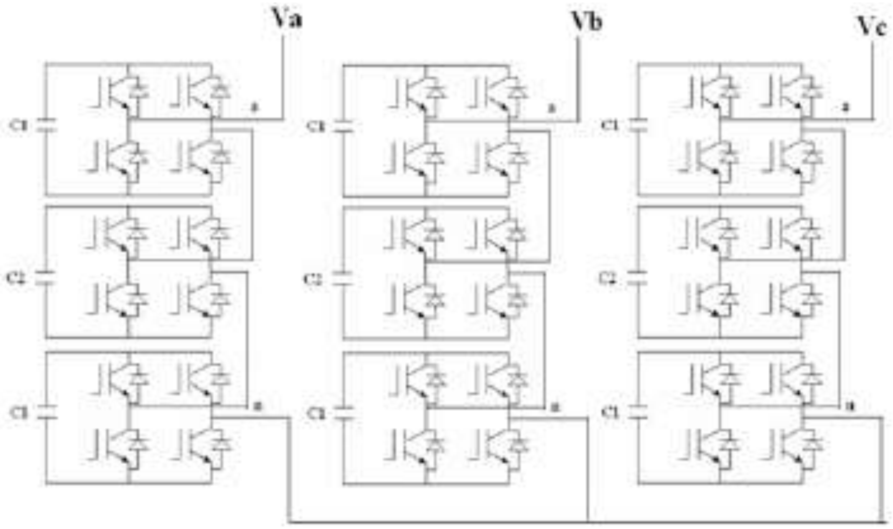

Fig 2. Seven Level Cascaded Multilevel Converter (CMC)

3. CONTROL METHODS

The successful operation of a STATCOM depends on the effective control methods. A comparative analysis is made here, providing a enhanced control technique.

1. PI control
2. Fuzzy based control

3.1 Internal control of STATCOM

The STATCOM considered in this study is a voltage source converter (VSC) type. It is essentially a voltage source inverter that is connected to the power system through a step-up transformer [7]. It consists of two PI controllers for regulating the line voltage at the PCC and the dc link voltage inside the STATCOM. An error signal is generated with line voltage and the dc link voltage, which is passed through these separate PI controllers in order to determine the inverter modulation index and the phase shift are estimated. These controlled signals are passed through the PWM controller that in turn generates the firing pulses applied to the STATCOM switches.

The outer regulation loop comprising the ac voltage regulator provides the reference current (Iqf) for the current regulator that is always in quadrature with the terminal voltage to control the reactive power. The voltage regulator is a PI controller.[8]. This control scheme can be applied to small scale as well as large scale disturbances in the power system by providing a effective performance of the STATCOM. The control circuit is capable of independently controlling the direct axis component itd and the quadrature axis component itq of the VSC current with minimal coupling between them. Cascaded PI controller is designed as shown in Fig 3. The RMS value of system voltage is compared with reference value and minimizes the error through one of the PI controllers. Similarly capacitor voltage is taken and compared with its reference value and its error is minimized through PI controller. Finally these outputs are given as references of q and d axis currents of controller. Actual values of d and q currents of converters compare with reference values and get error minimized through PI controller

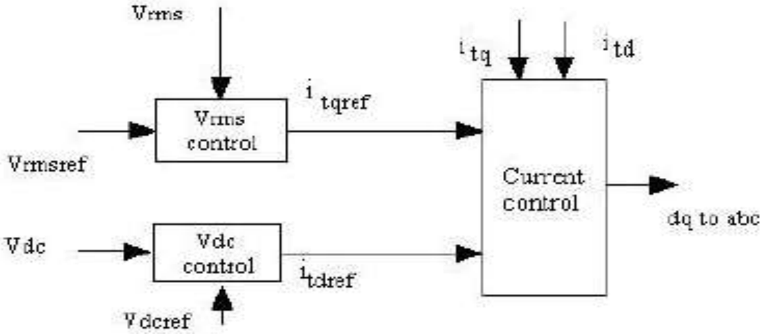

Fig 3: .Cascaded control with PI controller

The output predicted voltage signals of Vtd and Vtq are taken for conversion of three phase signals. These signals are used to generate gating signals for the converter [9].

3.2 Fuzzy Based Controller

The fuzzy controller does not respond to the system topology, parameters and operation condition changes. So it is a nonlinear controller which improves the transient stability of the system. This feature makes the fuzzy controller very useful for power system applications.

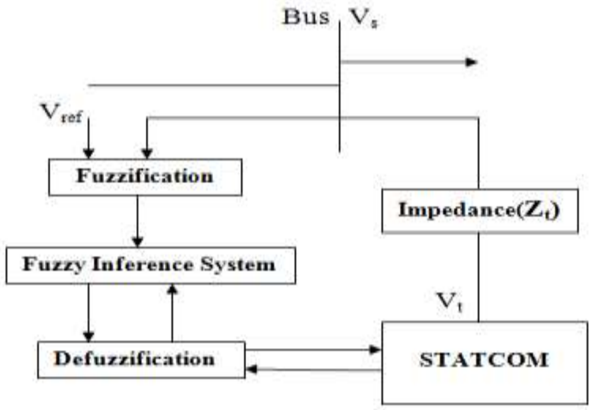

Fig 4: Fuzzy Control System

The fuzzy control system consist of Fuzzifier, Fuzzy Inference System(FIS), Defuzzifier. The main component of fuzzy control system is FIS, Which have the knowledge base system and fuzzy rule based system together to perform the control actions. The Fig 4. shows the control system based on the fuzzy logic. The control system which acts based on the rule based system, where the utilities provide certain control operation for STATCOM in the form of rules using FIS, which also classified as the main controller and supplementary controller. The rules for the STATCOM operation are shown in Table 1. Main controller controls the output voltage magnitude of STATCOM by adjusting modulation index in order to regulate the AC bus voltage. The other control loop is named supplementary controller controls DC link capacitor voltage by adjusting the phase angle of STATCOM output voltage[10],[11].

Table 1: Fuzzy Logic Rules

Shunt Voltage	Shunt Angle	Output Voltage
Small	Small	Medium
Small	Medium	Small
Small	High	Small
Medium	Small	High
Medium	Medium	Medium
Medium	High	Small
High	Small	High
High	Medium	Medium
High	High	Small

4. NEED OF COMPUTATIONAL ALGORITHM

The mathematical algorithms are used to compute the unknown quantities from the known ones through a process of successive trial and error methods and consequently produce a result. The initial values of the system are assumed and the program computes the successive quantities. The load flow solution is needed to determine the overloading of particular elements in the system. It is also used to make sure that the generators run at the ideal operating point, which ensures that the demand will be met without overloading the facilities and either maintains them without compromising the security of the system or the demand[12],[13]. The objectives of any load flow analysis is to produce the following information

- Voltage magnitude and phase angle at each bus.
- Real and reactive power flowing in each element.
- Reactive power loading on each generator.

4.1 Power Flow Equations of N Bus System with STATCOM

The STATCOM is connected in parallel with bus 'S' in the power system. The bus 'S' is heavily affected by voltage regulation. The controllable voltage source of STATCOM is denoted as V_t in series with Z_t impedance. The power flow equations of the system with STATCOM connected to bus 'S' are the same as power flow equations of the system without STATCOM for all buses except STATCOM connected bus 'S'. The load flow equation with FACTs devices modified using the following equations [14].

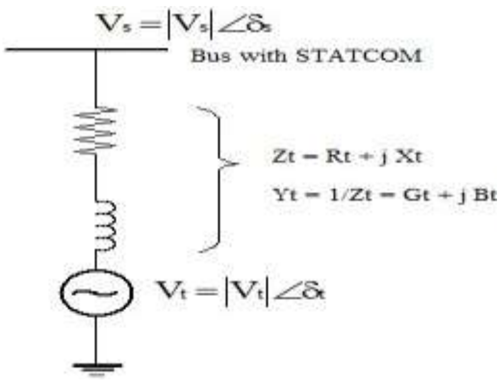

Fig 5: STATCOM connection in a bus

$$P_s = P_t + \sum_{j=1}^{n} |V_s||Y_{sj}||V_j| \cos(\delta_s - \delta_j - \theta_{sj}) \qquad (1)$$

$$Q_s = Q_t + \sum_{j=1}^{n} |V_s||Y_{sj}||V_j| \cos(\delta_s - \delta_j - \theta_{sj}) \qquad (2)$$

The summation terms of the injected active and reactive power for the system,

$$P_t = +G_t|V_s|^2 - |V_s||Y_t||V_t|\cos(\delta_s - \delta_t - \theta_t) \quad (3)$$

$$Q_t = -B_t|V_s|^2 - |V_s||Y_t||V_t|\sin(\delta_s - \delta_t - \theta_t) \quad (4)$$

Where $|V_t|, \delta_t, |Y_t|$ and θ_t are noted in Fig 5. and other variables were given in equations (3) and (4). One more equation is needed to solve the power flow problem. This equation is needed to find the power consumed by the source V_t .The power must be zero in steady state condition.

$$P_{vt} = \mathrm{Real}\left[V_t I_t^*\right] = -G_t|V_t|^2 + |V_s||Y_t||V_t|\cos(\delta_t - \delta_s - \theta_t) = 0 \quad (5)$$

4.2 Jacobian Equation with STATCOM

As per the above equations, the new power flow problem with STATCOM has to be solved. The linearised Jacobian equation is extended and modified as per new Jacobian equation below.

$$\begin{pmatrix} \Delta P_i \\ \Delta Q_i \\ \Delta P_{vt} \\ \Delta F \end{pmatrix} = \begin{pmatrix} J_{11} & J_{12} & J_{13} & J_{14} \\ J_{21} & J_{22} & J_{23} & J_{24} \\ J_{31} & J_{32} & J_{33} & J_{34} \\ J_{41} & J_{42} & J_{43} & J_{44} \end{pmatrix} \begin{pmatrix} \Delta\delta_i \\ \Delta V_i \\ \Delta V_t \\ \Delta\delta_t \end{pmatrix} \quad (6)$$

Where control variable for jacobian matrix, $F=V_s$.

5. REAL TIME BUS SYSTEM

Real time power system is used to test and verify the performance of STATCOM. The Real Time bus system is shown in Fig 6. The real time system taken is 230/110kV Pugalur substation which is located in Karur, Tamilnadu. The line data of bus system are mentioned in Table 2 and the real and reactive power details are given in Table 3. Here, the STATCOM is connected randomly in different buses. The voltage of all buses is heavily affected for the increasing load. The power flow and losses for various buses are calculated. A profitable solution for voltage profile improvement and the reactive power compensation is provided with graphical results. Using the Newton Raphson method, the following analysis are made,

i) To find base load losses of all buses and also total losses of pugalur 20 bus system.

ii) To find load losses of all buses and also total losses for different load variation without STATCOM

iii) To find load losses of all buses and also total losses for different load variation with STATCOM

Initially the pugalur 20 bus system is tested without STATCOM. The real and reactive power flow is analyzed by using the Newton Raphson method.

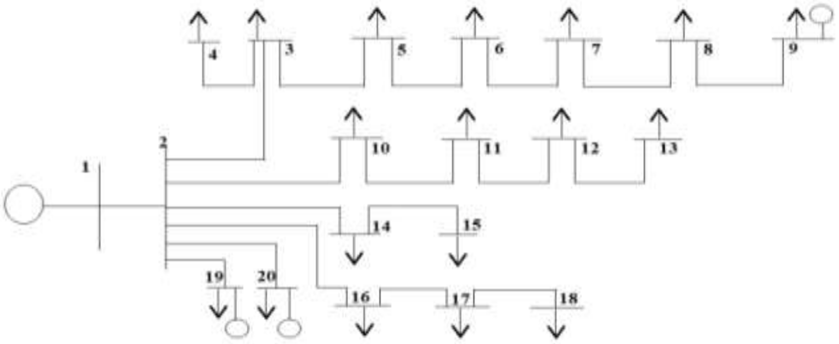

Fig 6: Real Time 20 bus System

Then all the buses are analyzed the same with the STATCOM. The power flow approach for voltage stability analysis of unbalanced power systems has been proposed. The approach can taken into account the unbalances of both network and load in pugalur 20 bus system . For this analysis, the STATCOM is connected randomly in different buses there by predicting the variation in the real and reactive power variation.

Table 2: 20 Bus System Line Data

Bus		Line impedance	
From	To	Resistance(p.u)	Reactance(p.u)
1	2	0.01843	0.0492
2	3	0.00827	0.0280
3	4	0.02140	0.0875
3	5	0.02200	0.0732
5	6	0.19230	0.7520
6	7	0.02700	0.0850
7	8	0.01730	0.0650
8	9	0.06526	0.1710
2	10	0.28270	0.6510
10	11	0.09580	0.1989
11	12	0.01033	0.0421
12	13	0.13440	0.2807
2	14	0.22810	0.6250
14	15	0.00464	0.0087
2	16	0.06701	0.1710
16	17	0.12710	0.2143
17	18	0.12290	0.2561
2	19	0.46000	0.9500
2	20	0.42300	0.9300

6. REACTIVE POWER SUPPORT FROM COMPENSATING DEVICE

The amount of reactive power supplied by any compensating device depends on the voltage drop at the bus and its capabilities.

Table 3: Voltage Magnitude and Real Power Data

Bus Number	Voltage Magnitude	Generation		Load	
		MW	MVAr	MW	MVAr
1	1.060	0.0	0.0	0.0	0.0
2	1.058	0.0	0.0	1.0	0.5
3	1.013	0.0	0.0	8.0	3.0
4	1.041	0.0	0.0	7.0	4.0
5	1.055	0.0	35.0	10.0	4.0
6	1.032	0.0	6.0	4.0	2.0
7	1.026	0.0	0.0	5.0	2.0
8	1.042	0.0	0.0	7.0	3.0
9	1.050	14.0	5.0	22.0	9.0
10	1.059	0.0	0.0	14.0	5.0
11	1.030	0.0	20.0	9.0	3.0
12	1.032	0.0	0.0	10.0	6.0
13	1.021	0.0	0.0	10.0	4.0
14	1.030	0.0	5.0	8.0	3.0
15	1.028	0.0	0.0	3.0	1.0
16	1.022	0.0	0.0	9.0	3.0
17	1.060	0.0	5.0	8.0	3.0
18	1.012	0.0	0.0	6.0	2.0
19	1.050	3.0	1.0	3.0	2.0
20	1.030	2.0	0.7	7.0	3.0

For example, a STATCOM can supply its maximum rated compensating current even at lower voltages. The reactive power that can be supplied, but usually they have some extra capability called the transient capability which is available to the system for a short period of time. The reactive power supplied is also dependent on the immediate reactive power sources in the system.

7. SIMULATION AND TEST RESULTS

7.1 Voltage Variation

The real time power system has been analyzed and implemented with STATCOM using MATLAB m-file. The following results in Table 4 will show the variation in voltage magnitude of 20 bus system with and without STATCOM.

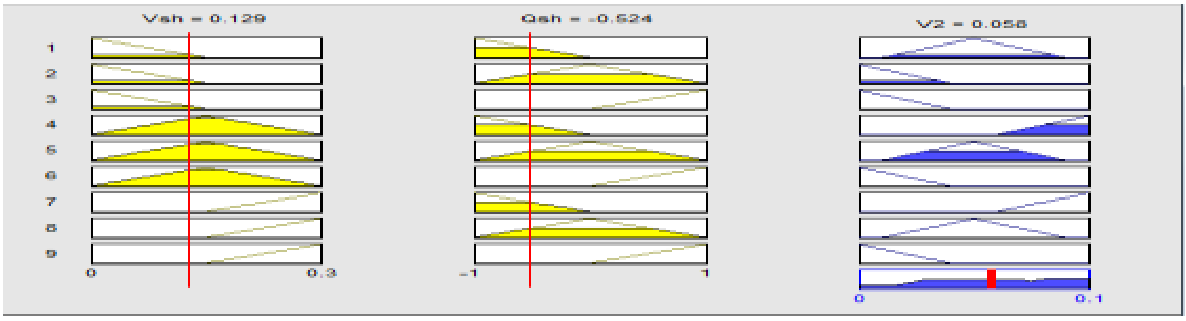

Fig 7: Fuzzy Ruler Output

The Fig 7. shows the fuzzy ruler output for the bus voltage, from which we can analyze the effective operation of STATCOM.

Table 4: Variation of Voltage Magnitude

Bus Number	V(p.u)at Steady State	V(p.u) after 50% load variation	V(p.u) with STATCOM	V(p.u) With fuzzy
1	1.0600	1.0600	1.0600	1.0600
2	1.0437	1.0309	1.0580	1.0580
3	1.0445	1.0351	1.0548	1.0550
4	1.0396	1.0302	1.0501	1.0511
5	1.0550	1.0550	1.0550	1.0550
6	1.0320	1.0320	1.0320	1.0320
7	1.0269	1.0269	1.0269	1.0273
8	1.0258	1.0258	1.0258	1.0258
9	1.0300	1.0300	1.0300	1.0310
10	0.9935	0.9740	1.0056	1.0660
11	1.0200	1.0000	1.0300	1.0300
12	1.0136	0.9935	1.0237	1.0237
13	0.9884	0.9677	0.9987	1.0010
14	1.0300	1.0300	1.0300	1.0300
15	1.0298	1.0298	1.0298	1.0298
16	1.0292	1.0175	1.0416	1.0426
17	1.0200	1.0100	1.0300	1.0300
18	1.0075	0.9974	1.0176	1.0176
19	1.0500	1.0500	1.0500	1.0500
20	1.0300	1.0300	1.0300	1.0300

7.2 Reactive Power Variation

The following tabulation show the real power and reactive power before and after compensation. The Table 5 justifies that the system behaves in a appreciable manner through a proper connection of STATCOM at the best location.

Table 5: Real and Reactive Power Variation

Increase in load	Before Compensation		After Compensation with fuzzy logic	
	P(MW)	Q(MVAr)	P(MW)	Q(MVAr)
Normal Load	15.396	39.089	15.103	38.395

40%	17.295	44.152	16.907	43.210
50%	18.954	48.607	18.373	47.123
60%	20.016	51.290	19.181	49.279

Here due to the reactive power compensation, the voltage of all buses are improved with rated valueby connection of STATCOM. The change in reactive power for load variation is shown in Fig 8. The STATCOM varied and adjusted slightly the real and reactive power and losses for the load variation.

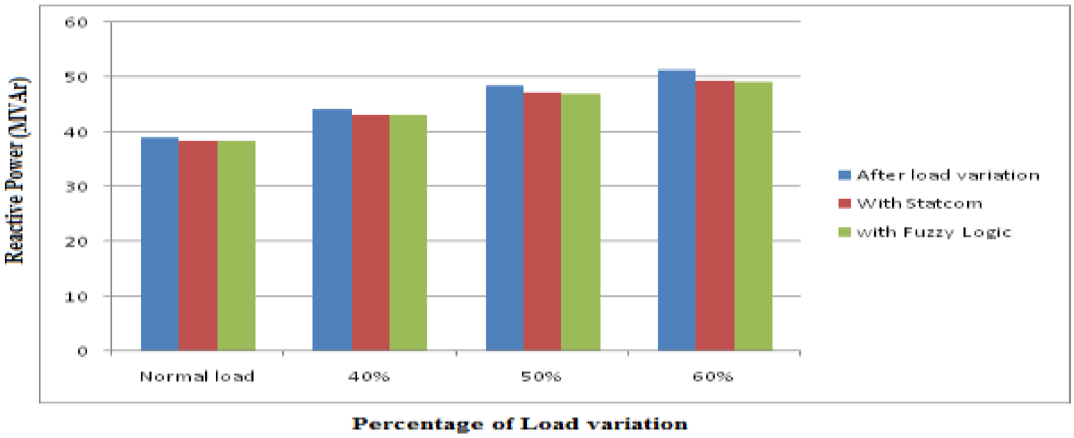

Fig 8: Reactive Power Variation

From the results which observed that the implementation of STATCOM in the real time 20 bus system will be give better performance during the unbalanced condition. Here the voltage magnitude and real and reactive power are enhanced by STATCOM.

7.3 Cascaded Multilevel converter

Cascaded and feed forwarded controller based STATCOM is designed for seven level cascaded multilevel converter (CMC)[11]-[15]. This proposed controller reduced the THD values which is compared with previous methods. This result is given clearly in fig 9. THD value of voltage is 16.24% and current is 0.76% as shown in fig 10. THD values are minimized in the converter output voltage and current.

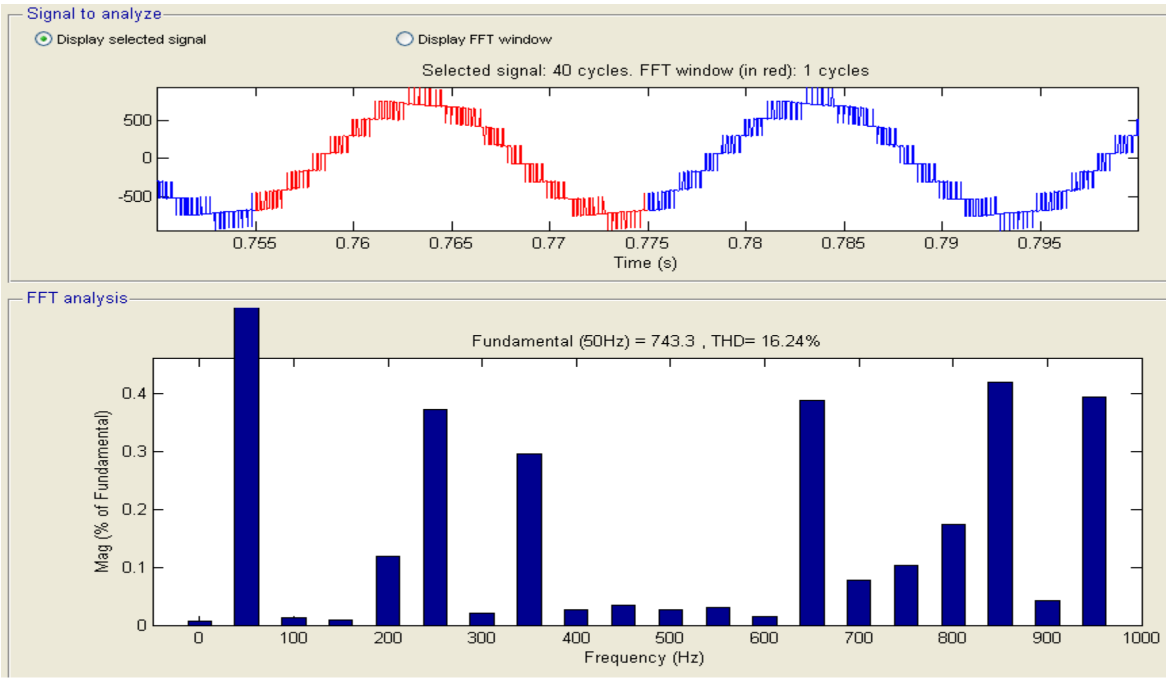

Fig 9: THD of output Voltage of Cascaded Multilevel converter

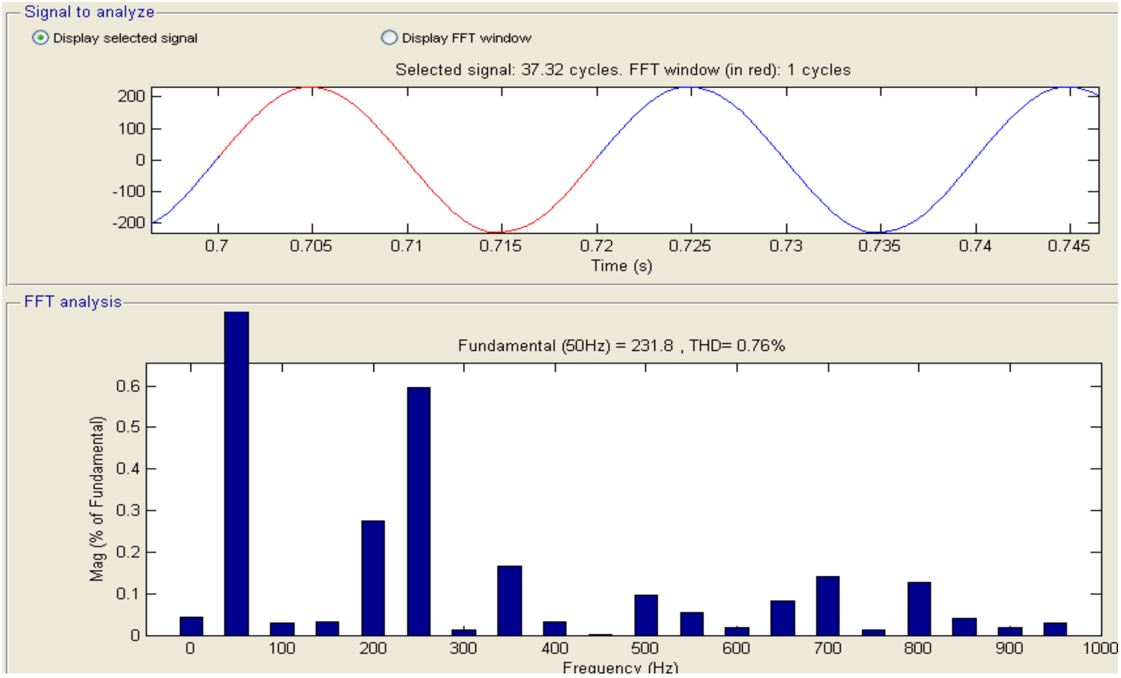

Fig 10: THD of output Current of Cascaded Multilevel Converter.

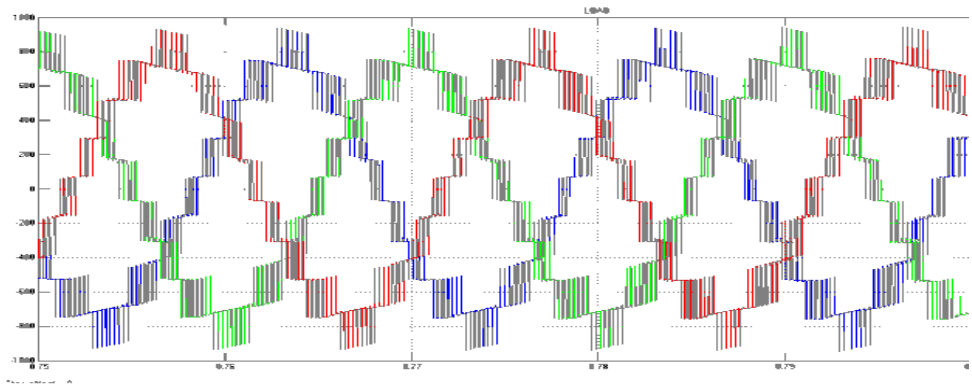

Fig 11: Three phase Supply Voltage of multilevel converter.

8. CONCLUSION

This investigation has been carried out the power flow analysis without and with CMC based STATCOM using fuzzy logic on real time pugalur bus system. The pugalur 20 bus system and CMC based STATCOM are modeled using MATLAB m-file. By injecting the current, the transmission losses are analyzed for various buses. The transmission losses are calculated and compared with other buses which are connected with STATCOM. The STATCOM using fuzzy logic will gives the better reactive power compensation and voltage regulation. So the implementation of CMC based STATCOM in utility side will supply power to customers with better power quality and by reducing the need of large capacitors banks and space on utility side.

REFERENCES

1. N.G. Hingorani, L. Gyugyi, “Understanding FACTS – Concepts and technology of Flexible AC Transmission Systems”, IEEE Press, 2000.
2. Y. H. Song, A. T. Johns. “Flexible AC Transmission Systems (FACTS)”, IEE Press, London, 1999
3. Mahesh K.Mishra and Arindam Ghosh, Jan 2003, ”Operation of a D-STATCOM in Voltage Control Mode”, IEEE Trans. Power Delivery, vol.18, pp.258-264.
4. Arindam Ghosh, Avinash Joshi, Jan 2000, ”A New Approach to Load Balancing and Power Factor Correction in Power Distribution System”, IEEE Trans. Power Delivery, vol.15, No.1, pp. 417-422.

5. Arindam Ghosh, Gerard Ledwich, Oct 2003,"Load Compensating DSTATCOM in Weak AC Systems", IEEE Trans. Power Delivery, vol.18, No.4, pp.1302-1309.

6. L.Dong, M.L.Crow,Z.Yang, C.Shen, L.Zhang, Feb 2004, "A Reconfigurable FACTS System for University Laboratories", IEEE Trans. Power Systems, vol.19, pp.120-128.

7. Salman Mohagheghi, Ganesh Kumar Venayagamoorthy. and Ronald G. Harley, "Optimal Neuro-Fuzzy External Controller for a STATCOM in the 12-Bus Benchmark Power System", IEEE Transactions on Power Delivery, Vol. 22, NO. 4, pp.2548-2558, 2007.

8. Dhall, P.K. and Asir Rajan, C.C. "Intelligence Controller for STATCOM Using Cascaded Multilevel Inverter", Journal of Engineering Science and Technology Review, Vol.3, No. 1, pp. 65-69, 2010.

9. K.Sundararaju and A.Nirmal Kumar, "Cascaded Control of Multilevel Converter based STATCOM for Power System Compensation of Load Variation",International Journal of Computer Applications, Vol.40,No.5,pp.30-35,2012.

10. L.J. Cai and I. Erlich, "Simultaneous Coordinated Tuning of PSS and FACTS Damping Controllers in Large Power Systems," IEEE Transactions on Power Systems,pp.1-6.

11. Stefan G Johansson, Gunnar Asplund, Erik Jansson & Roberto Rudervall, "Power System Stability Benefits with VSC DC-Transmission Systems", 21, rue d'Artois, F-75008 Paris, pp. 1-8, 2004.

12. G.W.Stagg and A.H.EL-abaid, "Computer methods in power systems" (New York hills, 1968).

13. P.K. Padiyar," Power system stability and control" EPRI Power system series 1994.

14. Radman, G and Raje, R.S, "Power Flow Model/Calculation for Power Systems and Multiple FACTS Controllers", Electric Power System Research, Vol. 77, No. 12, pp.1521-1531, 2007.

15. K.Sundararaju, A.Nirmal Kumar, S.Jeeva and A.Nandhakumar, "Performance Analysis and Location Identification of STATCOM on IEEE-14 Bus System using Power Flow Analysis", International of Theoretical and Applied Information Technology, vol.60, No.2, pp.365-371,Feb-2014.

16. K.Sundararaju and T.Rajesh, "Control Analysis of STATCOM under Power System Faults", International Journal of Communication and Computer Technologies(IJCCTS), vol.4, No.1, pp.4001-4006,Mar-2016.

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