

Cascaded Fuzzy Controller based Multilevel STATCOM for High-Power Applications

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Abstract: Voltage unbalance is one of the main limitations of cascaded based multilevel STATCOM. In this paper, a simple static var compensating scheme using a cascaded two-level inverter-based multilevel inverter is proposed. The topology consists of two standard two-level inverters connected in cascade through open-end windings of a three-phase transformer. A fuzzy logic control scheme is proposed for the controlling operation of STATCOM. By using the Fuzzy controller in this circuit THD can be reduced. The simulation study is carried out in MATLAB/SIMULINK to predict the performance of the proposed scheme under balanced and unbalanced supply voltage conditions. The presence of Fuzzy controller the disturbances normalized which enhances system performances.

Keywords: Voltage balance, multilevel inverter, power quality (PQ), static compensator (STATCOM), Fuzzy Logic Controller.

1. INTRODUCTION

The utilization of flexible air conditioning transmission frameworks (FACTS) controllers, as an example, static compensator (STATCOM) and static synchronous arrangement compensator (SSSC), is expanding effective frameworks. This is often due to their capability to settle the transmission frameworks and to enhance power quality (PQ) in conveyance frameworks. STATCOM is magnificently acknowledged as a dependable receptive force controller replacing ordinary var compensators, as an example, the thyristor-exchanged capacitor (TSC) and the thyristor controlled reactor (TCR). This device provides reactive force pay, dynamic force swaying damping, gleam construction, voltage regulation, so on [1]. By and large, in high-control applications, var pay is accomplished utilizing multilevel inverters [2]. These inverters comprise of an expansive number of dc sources that are usually acknowledged by capacitors. Henceforth, the converters draw a bit measure of dynamic energy to keep up dc voltage of capacitors and to repay the misfortunes within the device. Then again, because of confound in conductivity and exchanging

misfortunes of the exchanging gadgets, the capacitors voltages are lopsided. Adjusting these voltages may be a significant examination challenge in multilevel inverters. The topology consists of standard multilevel/two-level inverters connected in cascade through open-end windings of a three-phase transformer. Such topologies are standard in high-power drives. One among the advantages of this topology is that by maintaining asymmetric voltages at the dc links of the inverters, a number of levels within the output voltage wave form can be increased.

This improves PQ. Therefore, overall control is simple compared to conventional multilevel inverters various var compensation schemes based on this topology are reported during three-level inverter and two level inverter are connected to either aspect of the transformer low-voltage winding. The dc-link voltages are maintained by separate converters. In three-level operation, it is obtained by using standard two-level inverters. In this paper, a static var compensation arrange is proposed for a two-level inverter-based multilevel inverter. The topology utilizes standard two-level inverters to accomplish the multilevel operation. The dc-link voltages of the inverters are managed at every level to obtain four-level operation. To check the adequacy of the proposed control procedure, the modernization study is completed for adjusted and asymmetrical supply-voltage conditions.

This paper is organized as follows: The proposed control scheme is given in Section II. Stability analysis of the converter is discussed in Section III. Simulation and experimental results are conferred in Sections IV and V, respectively.

2. CASCADED TWO-LEVEL INVERTER-BASED MULTILEVEL STATCOM

Fig. 1 shows the power system model considered in this paper. Fig. 2 shows the circuit topology of the cascaded two-level inverter based multilevel STATCOM using two-level inverters. The inverters are connected to the low voltage (LV) side of the transformer and therefore the high-voltage (HV) side is connected to the grid. The dc-link

voltages of the inverters are maintained constant and modulation indices are controlled to achieve the specified objective. The proposed control scheme is derived from the AC side of the equivalent circuit that is shown in Fig. 3. in the figure, v'_a, v'_b, v'_c are supply voltages observed cardinal side of the transformer, r_a, r_b, r_c are the resistances that represent the losses within the transformer and two inverters, L_a, L_b, L_c are discharged inductances of transformer windings, e_{a1}, e_{b1}, e_{c1} and e_{a2}, e_{b2}, e_{c2} are the output voltages of inverters 1 and 2, respectively. r_1, r_2 are the discharge resistances of dc link capacitors C_1, C_2 respectively. Assuming $r_a = r_b = r_c = r$, $L_a = L_b = L_c = L$, and applying KVL on the AC side, the dynamic model can be derived using as

$$\begin{bmatrix} \frac{di'_a}{dt} \\ \frac{di'_b}{dt} \\ \frac{di'_c}{dt} \end{bmatrix} = \begin{bmatrix} \frac{-r}{L} & 0 & 0 \\ 0 & \frac{-r}{L} & 0 \\ 0 & 0 & \frac{-r}{L} \end{bmatrix} \begin{bmatrix} i'_a \\ i'_b \\ i'_c \end{bmatrix} + \frac{1}{L} \begin{bmatrix} v'_a - (e_{a1} - e_{a2}) \\ v'_b - (e_{b1} - e_{b2}) \\ v'_c - (e_{c1} - e_{c2}) \end{bmatrix} \quad (1)$$

This equation represents the mathematical model of multilevel STATCOM in the stationary coordinate system. The control block for STATCOM is shown in the figure below. The control for STATCOM is achieved by using the unit signals \sin and \cos which are generated from phases fast loop that is provided by three phase supply voltages. using these unit signals the mathematical model represented in equation(1) is transformed into the synchronously rotating reference system .Therefore the d-q axes

reference voltage components of the converter are controlled as,

$$\begin{aligned} e_d^* &= -x_1 + \omega L i'_q + v'_d \\ e_q^* &= -x_2 - \omega L i'_d + v'_q \end{aligned} \quad (2)$$

$$(3)$$

Where v'_d is the d-axis voltage component of the AC source and i'_d, i'_q are d-q axes current components of the cascaded inverter, respectively. The synchronously

rotating frame is aligned with source voltage v'_q vector so that the q-component of the source voltage is made zero. The control parameters and are controlled as follows:

$$\begin{aligned} x_1 &= (k_{p1} + \frac{k_{i1}}{s})(i_d^* - i'_d) \\ x_2 &= (k_{p2} + \frac{k_{i2}}{s})(i_q^* - i'_q) \end{aligned} \quad (4)$$

$$(5)$$

The d-axis reference current i_d^* is obtained as

$$i_d^* = (k_{p3} + \frac{k_{i3}}{s})[(V_{dc1}^* + V_{dc2}^*) - (V_{dc1} + V_{dc2})] \quad (6)$$

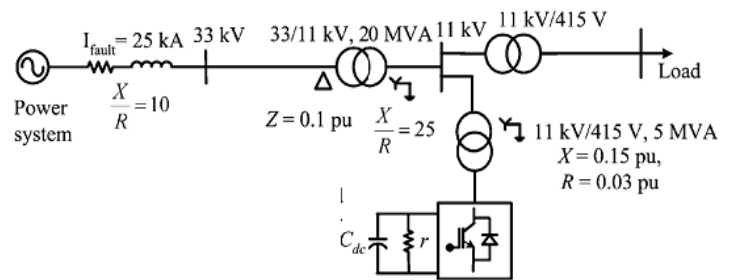


Fig-1: Power system and the STATCOM model

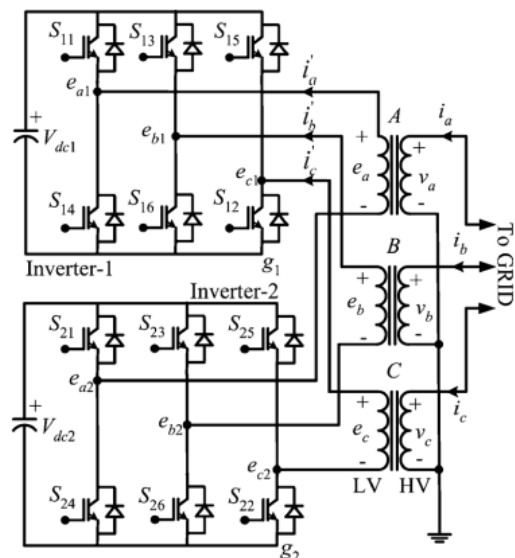


Fig- 2: Cascaded two-level inverter-based multilevel STATCOM.

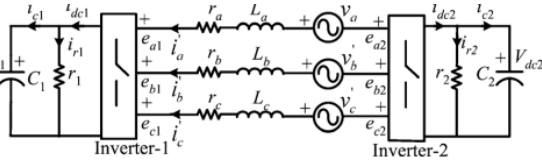


Fig-3:

Equivalent circuit of the cascaded two-level inverter based multilevel STATCOM

$$e_I = \sqrt{e_d^2 + e_q^2}$$

The active power transfer between the supply and electrical converter depends on and is usually small within the inverters supplying var to the grid [1]. Hence, may be assumed to be proportional to equivalent weight. Therefore, the -axis reference voltage component of inverter-2 eq2*is derived from controlling the dc-link voltage of inverter-2 as,

$$e_{q2}^* = (k_{p4} + \frac{k_{i4}}{s})(V_{dc2}^* - V_{dc2}) \quad (7)$$

3. PROPOSED CONTROL STRATEGY

The control block diagram is shown in Figure4. The unit signals Cos and sin are generated from the phase-locked loop (PLL) using three-phase supply voltages [14]. The converter currents are transformed to the synchronous rotating system using the unit signals. The switching frequency ripple within the converter current loops, i_q^* the controller generates d-q axes reference voltages, e_d^* and e_q^* for the cascaded inverter. With these reference voltages, the inverter provides the required reactive current draws required active current to regulate total dc-link voltage. However, this will not ensure that individual dc-link voltage is controlled at their respective reference values. Hence additional control is required control individual dc-link voltages of the inverters.

The q-axis reference voltage component of inverter-1 e_{q1}^* is obtained as

$$e_{q1}^* = e_q^* - e_{q2}^* \quad (8)$$

The power transfer in inverter-2 is directly controlled, whereas for the inverter-1, and it's controlled indirectly. Therefore, throughout the disturbances, the dc-link voltage of inverter-2 is improved to its reference quickly compared to the inverter-1. Using e_{d1}^* and e_{q1}^* , the reference voltages are generated in stationary reference system for inverter-1 and using e_{d2}^* and e_{q2}^* for inverter-2. The reference voltages generated for inverter-2 are in phase opposition to that of inverter-1. From the reference voltages, gate signals are generated using the sinusoidal pulse-width modulation (PWM) technique [15]. Since the two inverters' reference voltages are in phase opposition, the predominant harmonic appears at double the switching frequency.

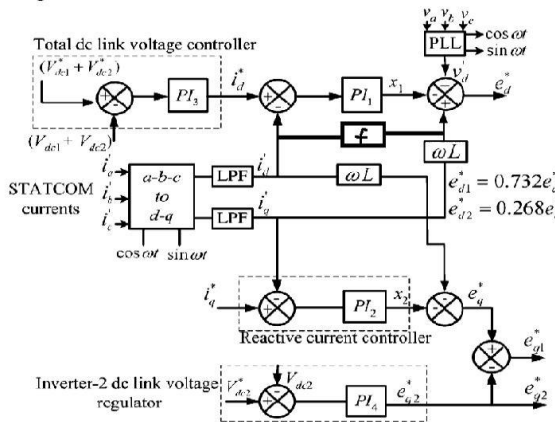


Fig-4: Proposed system controlled proposed strategy

3.1 DC-Link Balance Controller

The resulting voltage of the cascaded device is given as,

3.2 Fuzzy Logic Controller

The fuzzy logic toolbox is extremely impressive in all respects. It makes fuzzy logic an efficient tool for the conception and design of intelligent systems. The fuzzy logic toolbox is simple to master and convenient to use. it provides a reader-friendly and up-to-date introduction to the methodology of fuzzy logic and its wide go

applications. The fuzzy inference may be a technique that interprets the values in the input vector and, based on user-defined rules, assigns values to the output vector. using the interface editors and viewers within the fuzzy logic toolbox, you'll build the principles set, define the membership functions, and analyze the behavior of a fuzzy inference system (FIS). The subsequent editors and viewers are provided.

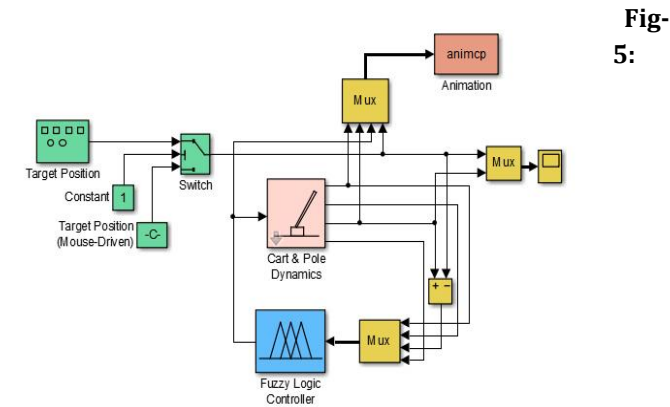


Fig-5:

Fuzzy inference system

This system consists of four main parts. First, by using the input membership functions, inputs are Fuzzified then based on rule bases and the interfacing system, outputs are produced and finally, the fuzzy outputs are Defuzzified and they are applied to the main control system. The error of inputs from their references and error deviations in any time interval are chosen as MATLAB. The output of the fuzzy controller is the value that should be added to the prior output to produce new reference output as shown in Figs.6 to 9.

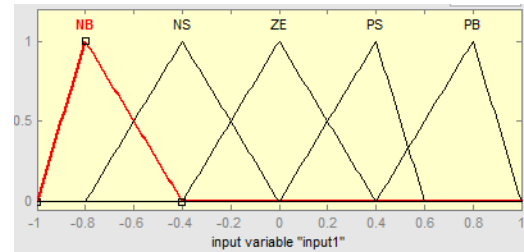


Fig-7: Input1 membership function

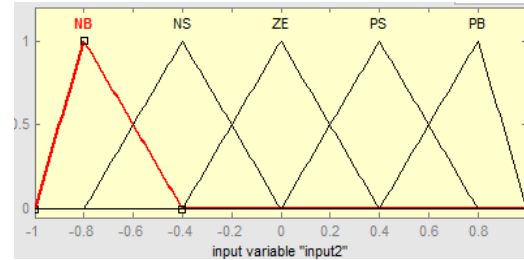


Fig-8: Input2 membership function.

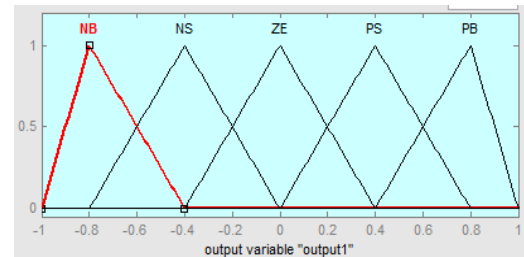


Fig-9: Output membership function

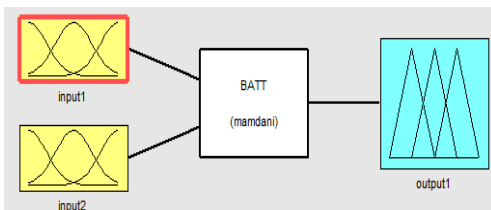


Fig-6:

Selection of input and output variables.

4. SIMULATION RESULTS AND DISCUSSION

The simulation study is carried out using MATLAB/SIMULINK. System parameters are given in Table 1. The system configuration is shown in fig10

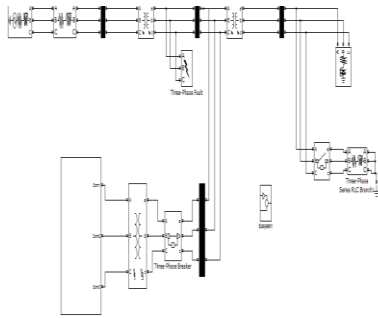
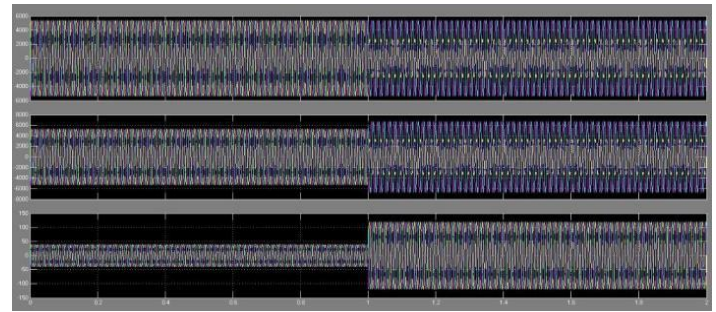


Fig-10: Simulation circuit diagram of a Proposed STATCOM fuzzy logic controller

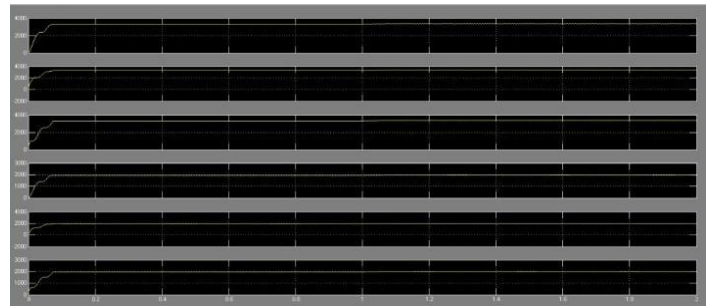
TABLE 1

Rated Power	5 MVA
Transformer voltage rating	11KV/400
AC supply frequency, f	50 Hz
Inverter-1 dc link voltage, V_{dc1}	659V
Inverter-2 dc link voltage, V_{dc2}	241V
Transformer leakage reactance, X_1	15%
Transformer resistance, R	3%
DC link capacitances, C_1, C_2	50mF
Switching frequency	1200 Hz

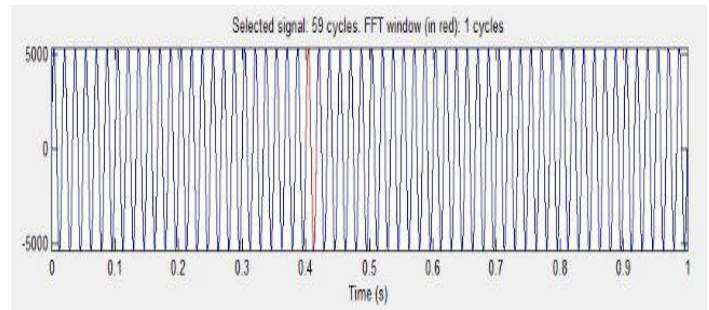
SIMULATION SYSTEM PARAMETERS



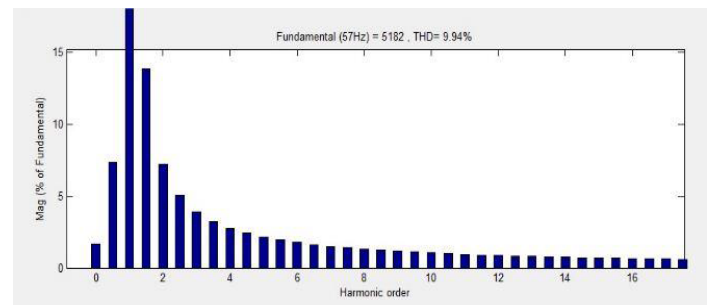
(a)



(b)

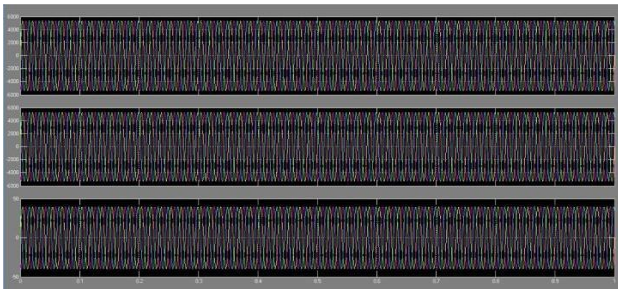


(c)

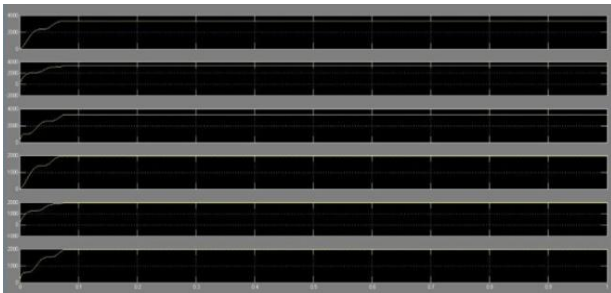


(d)

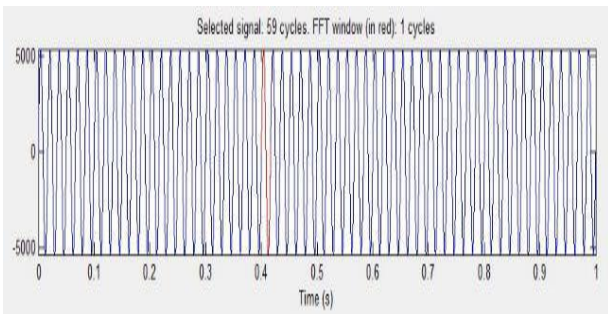
Results of Proportional and integral controller



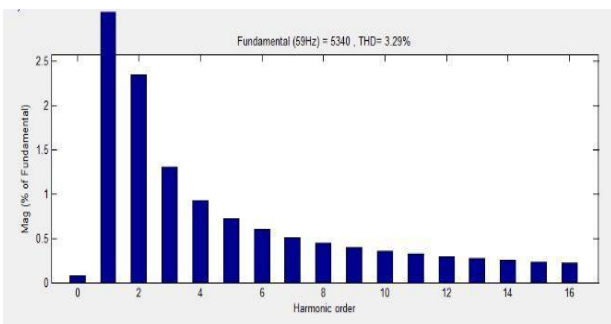
(e)



(f)



(g)



(h)

Results of fuzzy logic controller

DISCUSSION

Here the above figures (a) to (d) are the results of PI controller. Where in figure (a) the execution time taken in 0 to 1 are the fault. Before 0 to 1 it is pre-fault. After 0 to 1 it is post fault. Actually we create line fault, initially there is no fault. By using PI controller time gap after 0 to 1 STATCOM automatically ON and clears the fault. Coming to figure (b) V_{dc} values are represented. Instantaneously it increases and decreases and equivalently ON and OFF. In figure we represents V_{dc}, V_{abc} . Figures (c) and (d) represents FFT Analysis and Total Harmonic Distortion (THD). In PI controller THD value we got is 9.94% that showed in above figure.

Figures (e) to (h) are the results of Fuzzy Logic controller. Coming to fuzzy it is easy to write our own rules and also own membership functions. Fuzzy controller can instantaneously ON and OFF. So it is easy when compared with PI controller. Where in PI controller we occurs some faults. So in fuzzy it overcomes that faults and reduces fault and output comes smooth compares with PI. In fuzzy the THD value is 3.29% that shows in above figure. Comparatively when compared with PI Fuzzy logic can overcome errors and decreases THD value.

5. CONCLUSION

A simple STATCOM theme using a cascaded two-level inverter-based multilevel inverter is presented in this paper. The proposed topologies have two VSI based two level inverters are connected in cascade through open-end windings of a three-phase transformer and filter parts. Converter fed dc-link voltages is regulated at different levels to obtain four-level operation. The proposed STATCOM structure inverter has operated below MATLAB/SIMULINK settings and also the results are verified in balanced and unbalanced conditions. Further, stability behavior of the topology is investigated. The dynamic model is developed and transfer functions are derived. The system behavior is analyzed for various operating conditions.

6. REFERENCES

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