

Five Levels Flying Capacitor Converter based UPFC Using Fuzzy Logic Controller to Reduces Harmonic

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Abstract

In this paper, Fuzzy Logic controller (FLC) is proposed to overcome the problems of the existing five level unified power flow controller (UPFC) and to provide the dynamic power flow control through transmission lines. The basic control for the five levels UPFC is such that the series converter of the five levels UPFC controls the transmission line real/reactive power flow and the shunt converter of the five levels UPFC controls the bus voltage/shunt reactive power and the DC link capacitor voltage. In steady state, the real power demand of the series converter is supplied by the shunt converter of the five levels UPFC. To reduced reactive power and total harmonic distortion (THD) by using FLC for a five levels UPFC. The SPWM using for five levels UPFC the reactive power demand is 10MVAR and total harmonic distortion (THD) is 9.01% occurred and SVPWM is to reduce reactive power demand 9.5MVAR and total harmonic distortion (THD) 4.85%. The above two controller's technique having more THD value this reason the FLC based five levels UPFC is proposed. The FLC based five levels UPFC is to reduced reactive power demand on 9MVAR and 1.77% of THD. PSCAD-EMTDC simulation results have been presented to shows the improvement in the performance of the five levels UPFC control with the proposed reactive power and total harmonic distortion.

Index Terms: Unified power flow controller (UPFC), Shunt converter, Series converter, Space vector PWM, Fuzzy Logic Controller (FLC), DC link capacitor, PI controller.

I. INTRODUCTION

The unified power flow controller (UPFC) is the most effective device due to its capability of providing support concurrently or selectively for voltage regulation, series compensation, phase angle regulation, and control of the active or reactive power separately. Yet, UPFC is seldom used for power flow control owing

to the high cost and size of the bulky zigzag transformers. This high-voltage, high-power inverters have to use bulky and complicated zigzag transformers to reach their required VA ratings and desired voltage waveforms.

The zigzag transformers are: 1) very expensive (30-40% of total system cost); 2) losses (50% of the total power losses); 3) bulky (40% of system real estate area and 90% of the system weight); and 4) prone to

failure [1]. To release the problems of the zigzag transformers and isolation transformers, multilevel structure has drawn attention of academy and industry. Among which, the multilevel inverter (VSC) technology to reach high-voltage levels without the use of transformers and a large number of semiconductor devices (diodes).

To address this problem, a UPFC with two face-to-face connected (cascaded multilevel inverter) CMIs was developed in [2] to eliminate the zigzag transformers that are needed in the conventional multi-pulse inverter-based UPFC. However, it still required an isolation transformer. To eliminate the transformer completely, a new transformer-less UPFC based on an innovative configuration of two multilevel inverters (VSCs) has been proposed in [3], which is a modular transformer-less UPFC. UPFC which consists of a series and a shunt converter connected by a common dc link capacitor can simultaneously perform the function of transmission line real/reactive power flow control in addition to UPFC bus voltage/shunt reactive power control [4].

The shunt converter of the UPFC controls the UPFC bus voltage/shunt reactive power and the dc link capacitor voltage. The series converter of the UPFC controls the transmission line real/reactive power flows by injecting a series voltage of adjustable magnitude and phase angle. The interaction between the series injected voltage and the transmission line current leads to real and reactive power exchange between the series converter and the power system. Under steady state conditions, the real power demand of the series converter is supplied by the shunt converter. But during

transient conditions, the series converter real power demand is supplied by the dc link capacitor [5].

If the information regarding the series converter real demand is not conveyed to the shunt converter control system, it could lead to collapse of the dc link capacitor voltage and subsequent removal of UPFC from operation. Very little or no attention has been given to the important aspect of coordination control between the series and the shunt converter control systems [6]–[15]. The real power coordination discussed in [16] is based on the known fact that the shunt converter should provide the real power demand of the series converter. In this case, the series converter provides the shunt converter control system an equivalent shunt converter real power reference that includes the error due to change in dc link capacitor voltage and the series converter real power demand.

The control system designed for the shunt converter in [17] causes excessive delay in relaying the series converter real power demand information to the shunt converter. This could lead to improper coordination of the overall UPFC control system and subsequent collapse of dc link capacitor voltage under transient conditions. This is due to the fact that any change in transmission line reactive power flow achieved by adjusting the magnitude/phase angle of the series injected voltage of the UPFC is actually supplied by the shunt converter. This aspect of UPFC control has also not been investigated [18]–[25].

The SPWM using for five levels UPFC the reactive power demand is 10MVAR and total harmonic distortion

(THD) is 9.01% occurred and SVPWM is to reduce reactive power demand 9.5MVAR and total harmonic distortion (THD) 4.85%. In this paper, Fuzzy Logic controller (FLC) is proposed to overcome the problems of the existing five level unified power flow controller (UPFC) and to provide the dynamic power flow control through transmission lines. This paper is to present an investigation of a UPFC based on the five levels flying capacitor multilevel VSCs.

The basic control for the five levels UPFC is such that the series converter of the five levels UPFC controls the transmission line real/reactive power flow and the shunt converter of the five levels UPFC controls the bus voltage/shunt reactive power and the DC link capacitor voltage. In steady state, the real power demand of the series converter is supplied by the shunt converter of the five levels UPFC. To reduced reactive power and total harmonic distortion (THD) by using FLC for a five levels UPFC.

The SPWM using for five levels UPFC the reactive power demand is 10MVAR and total harmonic distortion (THD) is 9.01% occurred and SVPWM is to reduce reactive power demand 9.5MVAR and total harmonic distortion (THD) 4.85%. The above two controller's technique having more THD value this reason the FLC based five levels UPFC is proposed. The FLC based five levels UPFC is to reduced reactive power demand on 9MVAR and 1.77% of THD. PSCAD-EMTDC simulation results have been presented to shows the improvement in the performance of the five levels UPFC control with the proposed reactive power and total harmonic distortion.

II. Configuration of system

Configuration of a typical UPFC is shown in Fig. 1. It consists of two VSCs of which one is connected in shunt and the other in series. They are operated from a common DC link. The series converter performs the main function of the UPFC by injecting an AC voltage with controllable magnitude and phase angle in series with the transmission line, via series connected transformers. This converter allows higher power handling, potentially lower power loss, lower harmonic distortion and hence less Filtering requirements when compared with the three-level converter.

The basic function of the shunt converter is to supply/absorb the active power demanded by series one at the common DC link, and thus maintain a constant DC link voltage. Furthermore, it can also be used to generate/absorb controllable reactive power and provide independent shunt reactive compensation for the transmission line. The series converter supplies/absorbs the reactive power locally and exchanges active power with the shunt converter via the common DC bus bar.

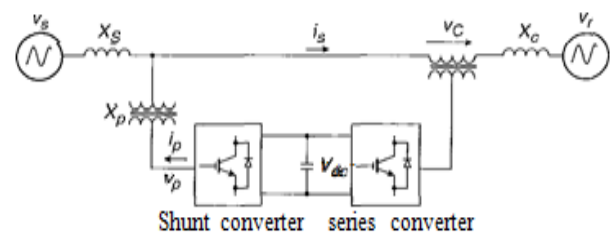


Fig: 1 System configuration of a based on UPFC VSCs

Basic Principle: UPFC works on the principle of injecting a voltage vector in the line in series which results into active and reactive power change in system according to the load change. Figure 1 shows basic

structure of UPFC in transmission line through single line diagram [26]. Here, V_s corresponds to sending end voltage, V_2 corresponds to UPFC bus voltage, and V_r is the receiving end voltage. Here VSC1 is the shunt active converter and VSC2 is the series active converter.

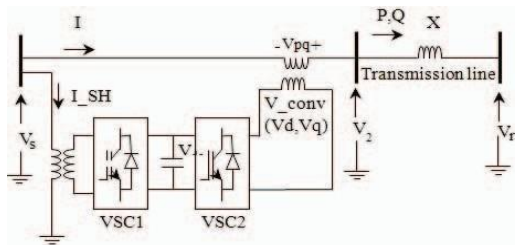


Fig.2 General Structure of UPFC

Apart from compensation for power in the system, UPFC basically performs these functions also: -

- 1) Voltage Regulation.
- 2) Phase Angle Regulation.
- 3) Multi-Function Power Flow Control.
- 4) Individual control of active and reactive power.

Shunt Active Converter:

The main function performed by shunt converter is supplying or absorbing real power at the common dc link according to demand of series converter in order to support real power exchange. The shunt converter converts the dc power demand of the link back to ac and couples the ac power to the transmission line through a shunt connected transformer. Shunt converter can absorb or generate controllable reactive power, therefore also provides independent shunt compensation to the line, if desired.

Series Active Converter: Series Converter performs the main function of UPFC as it injects a controllable voltage of magnitude V_{pq} and phase angle ρ in the line series through a transformer in quadrature

with line current. This voltage behaves as a synchronous ac voltage source. The current flowing through the transmission line flows through this voltage source causing active and reactive power exchange between it and the ac system.

The converter generates the reactive power exchanged internally. This real power is converted to dc power and it appears across dc link capacitor as positive or negative real power demand. The basic operation mode of a UPFC can be identified as follows

Terminal voltage regulation only. V_c is injected in phase with V_s , to compensate voltage amplitude;

- (i) Shunt compensation only. The series element of the UPFC is disabled and it acts as a STATCOM;
- (ii) Terminal voltage regulation only. V_c is injected in phase with V_s , to compensate voltage amplitude;
- (iii) Terminal voltage regulation and series line compensation V_c is injected to compensate voltage amplitude and it also contains a voltage component which is in quadrature with the line current I_s .
- (iv) Terminal voltage and phase angle regulation V_c is injected to achieve the desirable voltage amplitude and phase angle with respect to the source voltage V_s .
- (v) Power flow control.

Basic Control Strategy

A. Shunt Converter Control Strategy
The shunt converter of the UPFC controls the UPFC bus voltage/shunt reactive power and the dc link capacitor voltage. In this case, the shunt converter voltage is decomposed into two components. One component is in-phase and the other in-

quadrature with the UPFC bus voltage. Decoupled control system has been employed to achieve simultaneous control of the UPFC bus voltage and the dc link capacitor voltage.

B. Series Converter Control Strategy
The series converter of the UPFC provides simultaneous control of real and reactive power flow in the transmission line. To do so, the series converter injected voltage is decomposed into two components. One component of the series injected voltage is in quadrature and the other in-phase with the UPFC bus voltage.

The quadrature injected component controls the transmission line real power flow. This strategy is similar to that of a phase shifter. The in-phase component controls the transmission line reactive power flow. This strategy is similar to that of a tap changer. The SPWM using for five levels UPFC the reactive power demand is 10MVAR and total harmonic distortion (THD) is 9.01% occurred and SVPWM is to reduce reactive power demand 9.5MVAR and total harmonic distortion (THD) 4.85%.

The above two controller's technique having more THD value this reason the FLC based five levels UPFC is proposed. **C. Fuzzy Logic Controller:** In this study, a UPFC control method based on FLC is proposed to overcome the problems of the existing UPFC controllers and to provide flexible power flow control through transmission lines. FLC has the advantage over conventional SPWM and SVPWM controllers. The FLC can provide fast response during dynamic operations of the power system and reduce reactive power, THD, and conduction losses. The fuzzy

logic controller (FLC) is used to applying the input and output of the converters. The inputs of the FLC are

$$\Delta P = P(k) - P(k - 1) \quad (1)$$

$$\Delta I = I(k) - I(k - 1) \quad (2)$$

And the output equation is

$$\Delta I_{ref} = I_{ref}(k) - I_{ref}(k - 1) \quad (3)$$

Where ΔP and ΔI are the output power and current change, ΔI_{ref} is the series converter current amplitude change reference, I_{ref} is the series converter current reference, and k is the sample instant[27]-[29]. The variable inputs and output are divided into four fuzzy sub-sets: PB (Positive Big), PS (Positive Small), NB (Negative Big), and NS (Negative Small). Therefore, the fuzzy algorithm requires 16 fuzzy control rules; these rules are based on the regulation of the hill climbing algorithm, where the fuzzy rules are shown in Table I. To operate the fuzzy combination, Mandeni's method with Max–Min is used.

From the behavior of the controller inputs and output, the shapes and fuzzy subset partitions of the membership function in both the inputs and output are shown in Fig. 3. A center of area algorithm (COA) is used in the defuzzification stage to convert the fuzzy subset duty cycle changes into real numbers

TABLE I
FUZZY LOGIC RULES

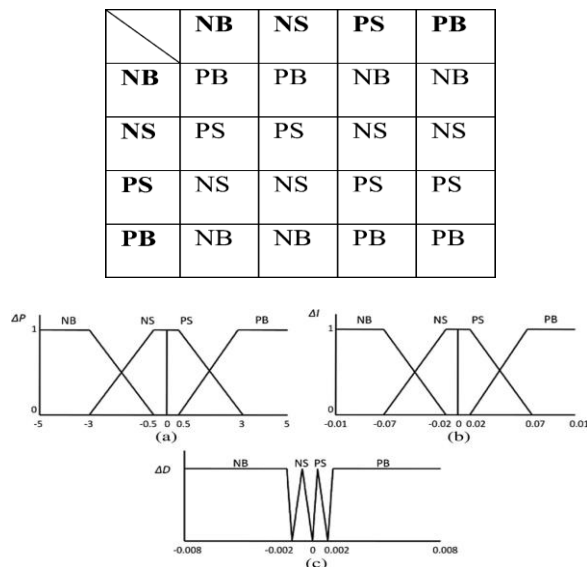


Fig.3 Membership function: (a) input ΔP , (b) input ΔI , and (c) output ΔD

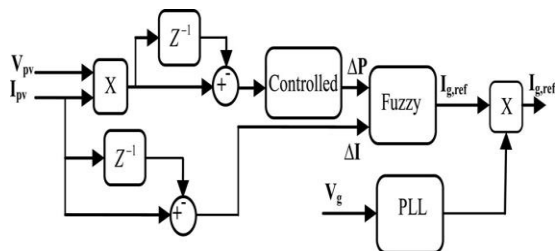


Fig.4. Block diagram of the FLC

Where ΔI_{ref} is the fuzzy controller output and I_{ref} is the center of max–min composition at the output membership function. To ensure synchronization between the series converter current and voltage, a sinusoidal signal generated by a phase-locked-loop (PLL) is multiplied by the output. Fig. 4 shows a block diagram of the FLC structure.

SIMULATION RESULTS

During the simulation, phase-shifted SPWM was used with the carrier and switching frequencies being equal to 1 kHz. The sending and receiving end bus bar

voltages are assumed to be constant, of the same amplitude of 10 kV (peak) and displaced by an angle of 15° . The output voltage of the shunt transformer is 3.75 kV (peak). The series inductance and resistance are 0.1p.u, and 0.01p.u, respectively (10 kV, 30 MVA, 50 Hz base).

For the shunt circuit, the inductance and resistance are 0.28p.u, and 0.03p.u, respectively [26]. A relatively large DC capacitor of $2000\mu F$ is used due to the large power demanded by the series converter at some operating conditions. However, the capacitances for the flying capacitors are set at $200\mu F$. This is due to the factor that, for the FC multilevel VSC, the voltage of each flying capacitor is balanced within each switching cycle; therefore, relatively small capacitors can be used. The DC voltage is well controlled with a small ripple. The fuzzy logic controller based five levels UPFC simulation diagram is shown in fig.5 and its controller design simulation is shown in fig.6.

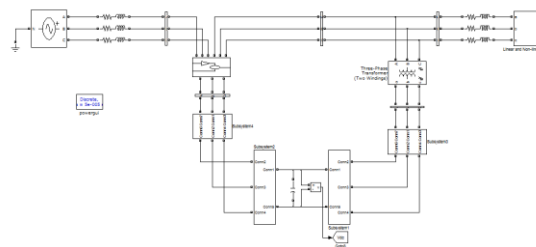


Fig 5 Simulation diagram of' UPFC operation by using FLC

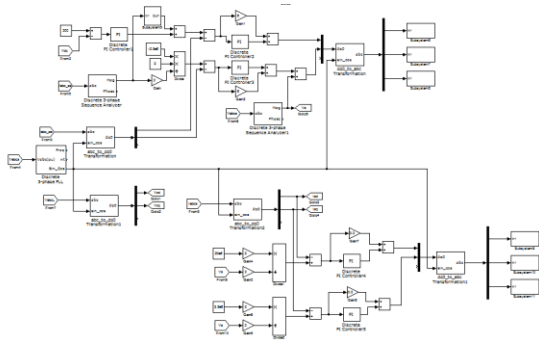


Fig 6 Simulation control circuit of UPFC operation by using FLC

In this paper to reduced reactive power and total harmonic distortion (THD) by using FLC for a five levels UPFC instead of SPWM and SVPWM. The SPWM using for five levels UPFC the reactive power demand is 10MVAR and total harmonic distortion (THD) is 9.01% occurred and SVPWM is to reduce reactive power demand 9.5MVAR and total harmonic distortion (THD) 4.85%.

The above two controller's technique having more THD value this reason the FLC based five levels UPFC is proposed. The FLC based five levels UPFC is to reduced reactive power demand on 9MVAR and 1.77% of THD. The simulated results of power flow control by the UPFC system are shown in Fig. 7 for $P^*=30$ MW, $Q^*=0$ MVAR, in Fig. 8 for $P^*=20$ MW, $Q^*=10$ MVAR, and Fore there $P^*=20$ MW, $Q^*=10$ MVAR, in fig. 9 for THD value is 9.01%, respectively. As shown, after the series element of the UPFC is started at the time of 0.15s.

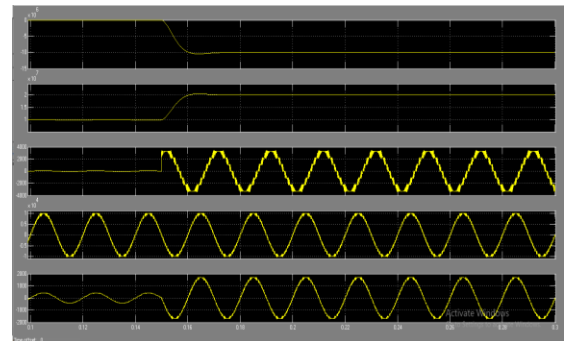


Fig.7 Simulated results of the SPWM based five levels UPFC series converter operation for $P^*=20$ MW; $Q^*=0$ MVAR.

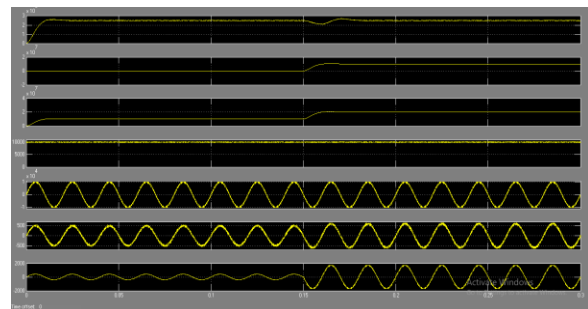


Fig.8 Simulated results of UPFC operation by using flying capacitor converter operation for $P^*=20$ MW; $Q^*=10$ MVAR.

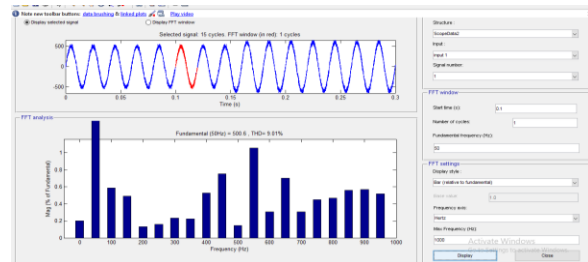


Fig 9 THD values of UPFC operation by using flying capacitor The SVPWM is to reduce reactive power demand 9.5MVAR and total harmonic distortion (THD) 4.85%. Shown in fig.10 and fig.11

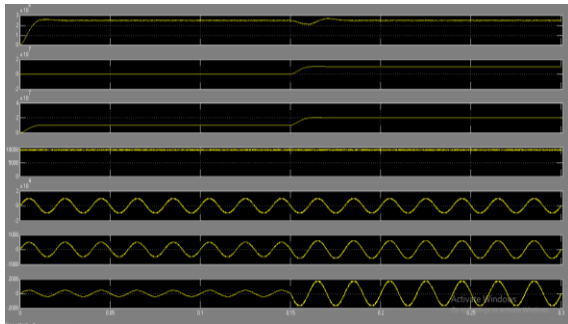


Fig.10 Simulated results of' UPFC operation by using SVPWM

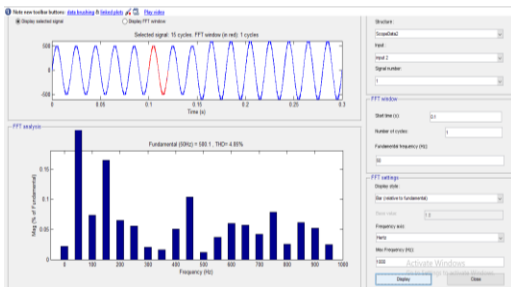


Fig. 11 THD values of' UPFC operation by using SVPWM In this paper proposes FLC for a five levels UPFC is controlled the reactive power and total harmonic distortion than the other controllers (SPWM and SVPWM). The simulation result and simulation harmonics are shown in fig.12 and fig.13.

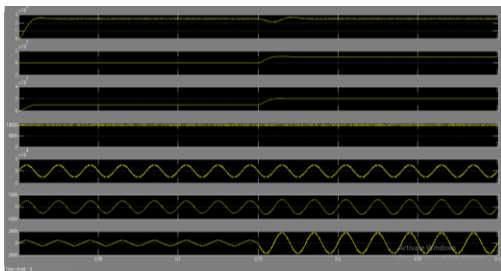


Fig.12 Simulated results of' UPFC operation by using FUZZY LOGIC CONTROLLER

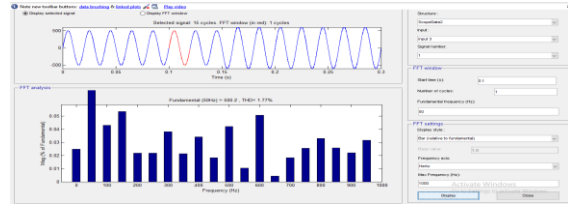
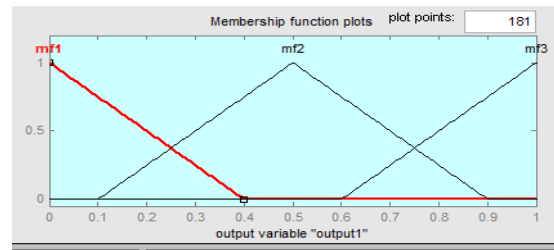
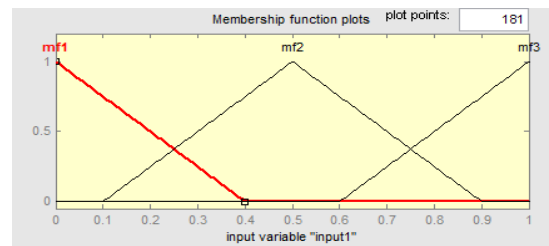


Fig 13 THD values of UPFC operation by using FUZZY LOGIC CONTROLLER The shapes and fuzzy subset partitions of the membership function in both the simulation inputs and output are shown in Fig. 14 and Fig.15.



The difference between SPWM, SVPWM and FLC controllers of the flying capacitor five levels UPFC are shown in table II

| CONTROLLER | SPWM | SVPWWM | FUZZY LOGIC |
|----------------------------|---------|----------|-------------|
| TOTAL HARMONICS DISTORTION | 9.01% | 4.85% | 1.77% |
| REACTIVE POWER | 10 MVAR | 9.5 MVAR | 9 MVA |

CONCLUSION

In this paper reduction of reactive power and total harmonic distortion (THD) using by FLC for a flying capacitor five levels UPFC application is discussed. The SPWM using for five levels UPFC the

reactive power demand is 10MVAR and total harmonic distortion (THD) is 9.01% occurred and SVPWM is to reduce reactive power demand 9.5MVAR and total harmonic distortion (THD) 4.85%. The above two controller's technique having more THD value this reason the FLC based five levels UPFC is proposed. The FLC based five levels UPFC is to reduced reactive power demand on 9MVAR and 1.77% of THD. A new FLC for a five level UPFC has been designed to limit excessive voltage excursions during reactive power transfers. PSCAD-EMTDC simulation results have been presented to shows the improvement in the performance of the five levels UPFC control with the proposed reactive power and total harmonic distortion. In this paper proposes FLC for a five levels UPFC is controlled the reactive power and total harmonic distortion than the other controllers (SPWM and SVPWM).

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