

THREE LEVEL CONVERTER BASED GUPFC FOR ENHANCEMENT OF POWER QUALITY IN MULTI-LINE TRANSMISSION LINE SYSTEM

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Abstract: In this paper it presents a new unified power flow controller (GUPFC), capable of simultaneous compensation for voltage and current in multilane transmission systems. In this configuration, shunt compensator injects current to achieve purely balanced sinusoidal source currents in phase with the supply voltages at rated magnitude and frequency. On the other hand series compensation is used to inject voltage to maintain terminal voltage at rated magnitude and frequency. One shunt voltage-source converter (shunt VSC) and two or more series VSCs exist. The system can be applied to adjacent feeders to compensate for supply-voltage and load current imperfections on the main feeder and full compensation of supply voltage imperfections on the other feeders. In the proposed configuration, all converters are connected back to back on the dc side and share a common dc-link capacitor. Therefore, power can be transferred from one feeder to adjacent feeders to compensate for sag/swell and interruption. The performance of the GUPFC as well as the adopted control algorithm is illustrated by simulation. The results obtained in MATLAB/SIMULINK on a three-bus/two-feeder system show the effectiveness of the proposed configuration.

Keywords: FACTS, UPFC, GUPFC, PQ, VSC, PI, Fuzzy, THD.

1. Introduction

The continual increase in demand for electricity has caused so problems for utility companies, such as inadequate transmission capacity, stability problems and so on. The Flexible AC Transmission system (FACTS) devices have been created to handle such these problems. However, because of high cost of these devices, the best possible benefits from their use should be extracted, so it is necessary to consider three main issues: the type of FACTS devices, their location and their settings.

The simultaneous solution of the three issues mentioned above represents a very complex and

difficult optimization problem. For solving this problem, there are four groups of methods, classical, technical, heuristic and mixed methods. Classical methods such as linear programming (LP), nonlinear programming (NLP) have been used in literature for solving FACTS optimization problem [1], [2]. But despite all the advancement in these methods, they do not expose desirable computational behaviour, especially because when the size of problem increases, search space in these methods increases exponentially, so, they suffer from convergence problems and have high computational time. Another group of methods used for FACTS optimization problem are those based on pure technical criteria, particularly sensitivity analysis for steady state [3] and modal analysis [4] for transient and dynamic optimization have been used. The main advantages of these methods are their simplicity and their main disadvantage is that they can not reach a global optimum. Third group of methods are heuristics. Heuristics are techniques such as genetic algorithm, evolutionary programming, differential evolution, evolution strategies, particle swarm optimization which seek optimal or near optimal solutions at a reasonable computational cost, also are usually population-based, stochastic-based and inspired of biological or human intelligence phenomena. Heuristics have been used much to solve FACTS optimization problem in literature, such as in [5]-[8]. They have so advantages over other methods, such as

- They are population-based, so are not sensitive to initial condition, and have better convergence behaviour.
- They do not require much knowledge about objective function.
- They have not requirements such as continuity and differentiability of objective function, so they are more flexible than other methods.

Forth group of methods that address FACTS optimization problem are those which are a combination of technical methods and technical or heuristic methods [9], [10]. In these methods, usually, first, the locations of FACTS devices are found using technical criteria, and next, their settings are

determined using classical or heuristic methods. By such strategy, computational burden reduces, but resultant solutions have less quality in comparison to other methods. There are several possibilities or operating configurations by combining two or more converter block with flexibility. Among them there are two operating configurations, namely the interline power flow controller (IPFC) and the generalized unified power flow controller (GUPFC) [1, 2], which are significantly extended to control power flows of multi-lines or a sub-network, which the originality is the control power flows of single line, by a unified power flow controller (UPFC) or static synchronous series compensator (SSSC).

2. Generalized Unified Power Flow Controller (GUPFC)

2.1 Operating Principle of GUPFC

The GUPFC with combining three or more converters working together extends the concepts of voltage and power flow control beyond what is achievable with the known two-converter UPFC FACTS controller. The simplest GUPFC consists of three converters, one connected in shunt and the other two in series with two transmission lines in a substation. It can control total five power system quantities such as a bus voltage and independent active and reactive power flows of two lines. Such a GUPFC, which is used to show the basic operation principle for the sake of simplicity. However, the mathematical derivation is applicable to a GUPFC with an arbitrary number of series converters.

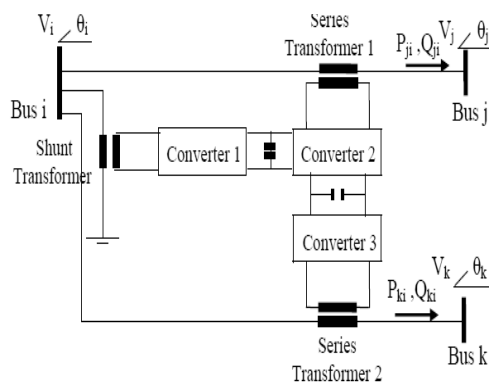


Figure 1. Basic circuit arrangement of GUPFC

In the steady state operation, the main objective of the GUPFC is to control voltage and power flow. The equivalent circuit of the GUPFC consisting of one controllable shunt injected voltage source and two controllable series injected voltage sources. Real power can be exchanged among these shunt and series converters via the common DC link. The sum of the

real power exchange should be zero if we neglect the losses of the converter circuits.

It has total 5 degrees of control freedom, which means it can control five power system quantities such as one bus voltage, and 4 active and reactive power flows of two lines. It can be seen that with more series converters included within the GUPFC, more degrees of control freedom can be introduced and hence more control objectives can be achieved. The simplest GUPFC consists of three switching converters. These converters are operated from two common dc link provided by two dc storage capacitors.

3. PI Controller

A PI-Lead controller is a proportional gain in parallel with an integrator; both in series with a lead controller. The proportional gain provides fast error response. The integrator drives the system to a 0 steady-state error. Proportional + Integral (PI) controllers were developed because of the desirable property that systems with open loop transfer functions of type 1 or above have zero steady state error with respect to a step input.

Proportional action: responds quickly to changes in error deviation.

Integral action: is slower but removes offsets between the plants output and the reference. Proportional-integral (PI) control is typically used to control the voltage response of the STATCOM. The block diagram of the control system is shown in Fig. 2.

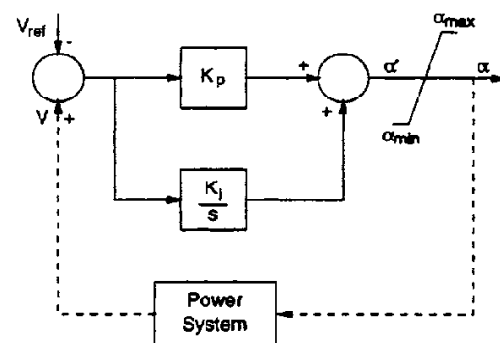


Figure 2. PI control scheme

The gains and are the proportional and integral parts of the controller respectively. The angles and are limits imposed on the value of the control angle by consideration of the maximum reactive power generation capability of the STATCOM as well as the maximum value of capacitor voltage allowable.

The PI- controller produces an output signal consist of two terms one proportional to error signal and the other proportional to the integral of error signal.

-Proportional gain,
-Integral gain.

- The proportional action increases the loop gain and makes the system less sensitive to variations of system parameters.
- The integral action eliminates (or) reduces the steady state error.

4. Fuzzy Logic Controller

In the conventional control, the amount of control is determined in relation to a number of data inputs using a set of equations to express the entire control process. Expressing human experience in the form of a mathematical formula is a very difficult task, if not an impossible one. Fuzzy logic provides a simple tool to interpret this experience into reality [7].

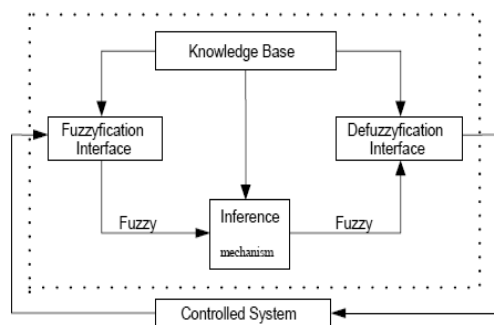


Figure 3. Schematic diagram of FLC system

Fuzzy logic controllers are rule-based controllers. The structure of the FLC resembles that of a knowledge based controller except that the FLC utilizes the principles of the fuzzy set theory in its data representation and its logic. The basic configuration of the FLC can be simply represented in four parts, as shown in figure 3.

Fuzzification module – The functions of which are first, to read, measure, and scale the control variable (speed, acceleration) and, second, to transform the measured numerical values to the corresponding linguistic (fuzzy variables with appropriate membership values);

Knowledge base - This includes the definitions of the fuzzy membership functions defined for each control variables and the necessary rules that specify the control goals using linguistic variables;

Inference mechanism – It should be capable of simulating human decision making and influencing the control actions based on fuzzy logic. The development of the fuzzy logic approach here is limited to the design and structure of the controller. The input constraints were terminal voltage error and its variations; the output constraint was the increment of the voltage exciter. FLC are defined as the voltage error and change of error.

The error and error rate are described as linguistic variables such as large negative (LN), medium negative (MN), small negative (SN), very small (VS), small positive (SP), medium positive (MP) and large positive (LP). The input values of the fuzzy.

Table 1. Fuzzy Control Rules

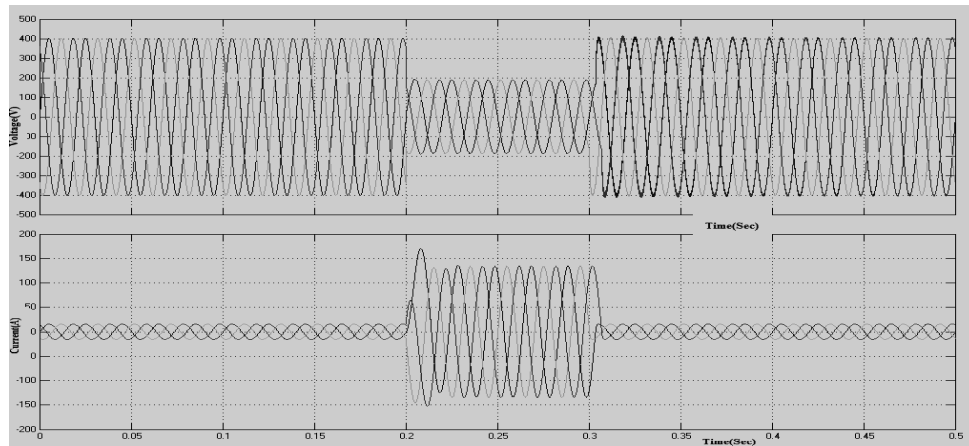
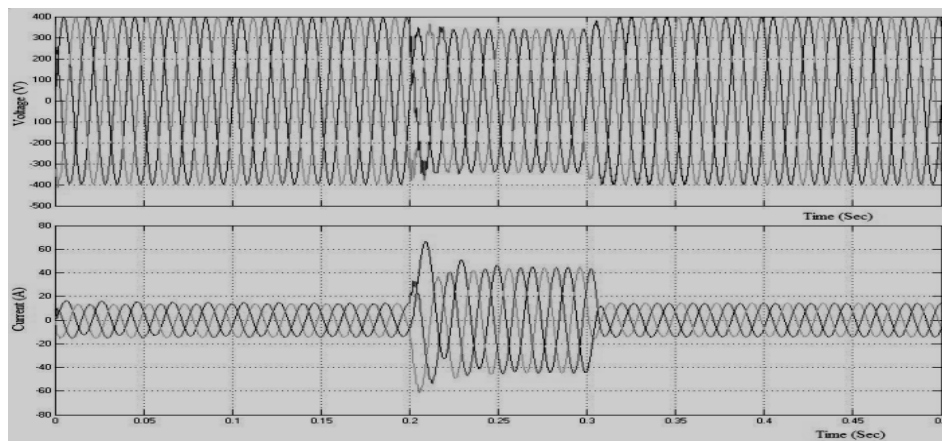
Error rate / error	NS	NM	NB	ZE	PS	PM	PB
NS	NM	NB	NB	NS	ZE	PS	PM
NM	NB	NB	NB	NM	NS	ZE	PS
NB	NB	NB	NB	NB	NM	NS	ZE
ZE	NS	NM	NB	ZE	PS	PM	PB
PS	ZE	NS	NM	PS	PM	PB	PB
PM	PS	ZE	NS	NM	PB	PB	PB
PB	PM	PS	ZE	PB	PB	PB	PB

controller are connected to the output values by the if-then rules. The relationship between the input and the output values can be achieved easily by using “Takagi-Sugeno inference” method. The output values are characterized by memberships and named as linguistic variables such as negative big (NB), variables such as negative big (NB), negative medium (NM), negative small (NS), zero (Z), positive small (PS), positive medium (PM) and positive big (PB). The membership functions of output variables and the decision tables for FLC rules are seen in Table 1.

Defuzzification module: Defuzzification means the fuzzy to crisp conversions. The fuzzy results generated cannot be used as such to the applications, hence it is necessary to convert the fuzzy quantities into crisp quantities for further processing. This can be achieved by using defuzzification process. The defuzzification has the capability to reduce a fuzzy to a crisp single-valued quantity or as a set, or converting to the form in which fuzzy quantity is present. Defuzzification can also be called as “rounding off” method. Defuzzification reduces the collection of membership function values in to a single scalar quantity.

5. Case Study and Simulation Results

Standard IEEE 3 bus/2 feeder system network is tested with and without GUPFC to investigate its behaviour. In the analysis bus 1 is taken as slack bus and 3 is taken as load bus. To include a Generalised unified power flow controller an additional bus is attached in the network. When the three phase fault occurs, the output becomes zero making the need of a GUPFC essential to compensate the loss in power. The GUPFC is placed between bus 1 and bus 2.

A) Voltage Sag Mitigation**Figure 4.** Voltage sag and current at bus 2 during three phase to ground fault condition**Figure 5.** Voltage and current at bus 2 with GUPFC using PI**Figure 6.** Voltage and current at bus 2 with GUPFC using Fuzzy

BUS NO	Without GUPFC				With GUPFC-PI				With GUPFC-Fuzzy			
	V (V)	I (A)	P (MW)	Q (MVar)	V (V)	I (A)	P (MW)	Q (MVar)	V (V)	I (A)	P (MW)	Q (MVar)
1	188	114	17000	3400	341	44	3400	2200	332	40	3000	22000

At pre fault condition, each bus voltage and current value is to be maintained. A three-phase fault is applied at 0.2 to 0.3s duration and is simulated at Bus 2. The value of bus 2 voltage is reduced and current is also increased during fault condition as shown in fig 4. Table 2 shows value of increased real and reactive power due to oscillations. Hence GUPFC was connected between bus 1 and 2. Thus voltage is increased and current is also reduced by PI and Fuzzy controllers as shown in fig 5 and fig 6 respectively.

B) Voltage Swell Mitigation

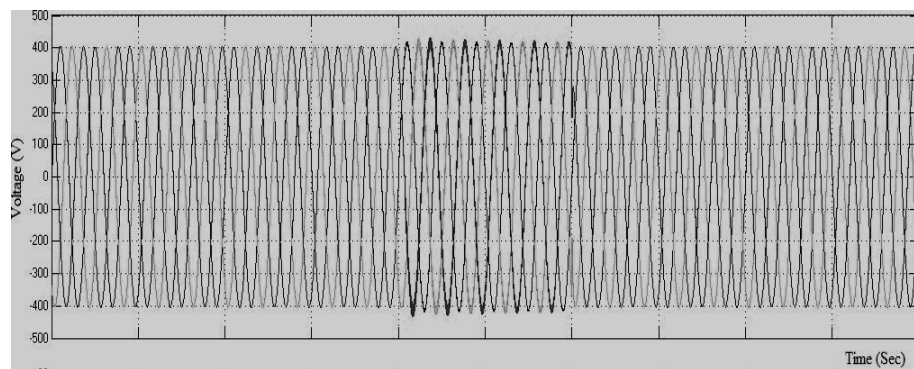


Figure 7. Voltage swell at bus 2(open loop)

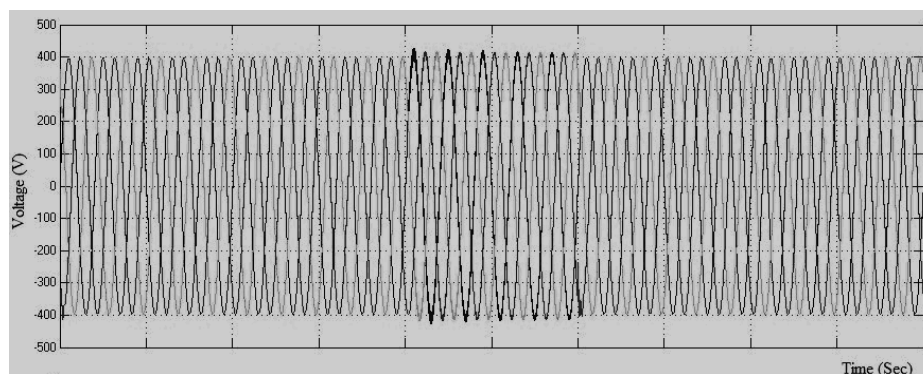


Figure 8. Voltage swell at bus 2 with GUPFC using PI

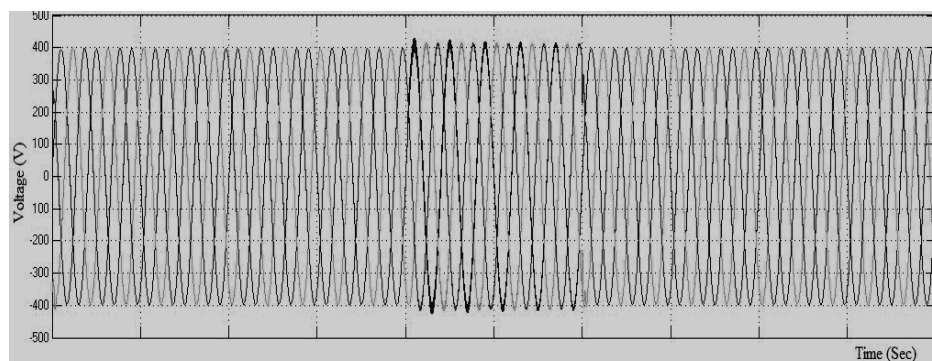


Figure 9. Voltage swell at bus 2 with GUPFC using Fuzzy

C) Voltage harmonics

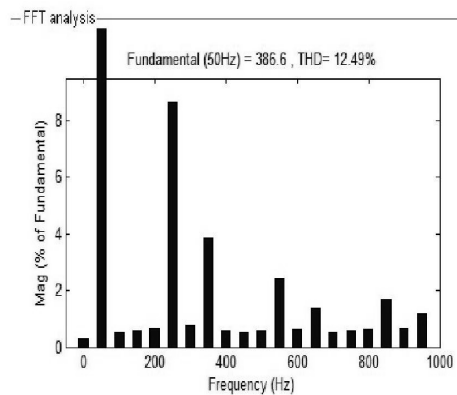


Figure 10. Voltage harmonics at during open loop

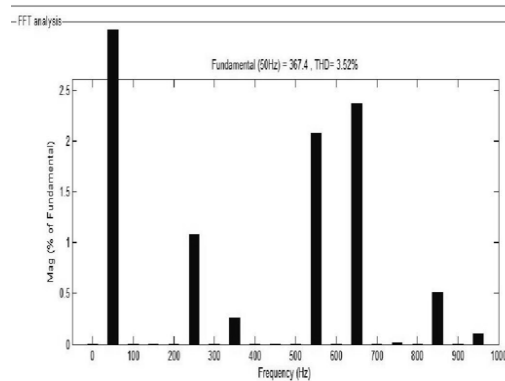


Figure 11. Voltage harmonics using GUPFC with PI

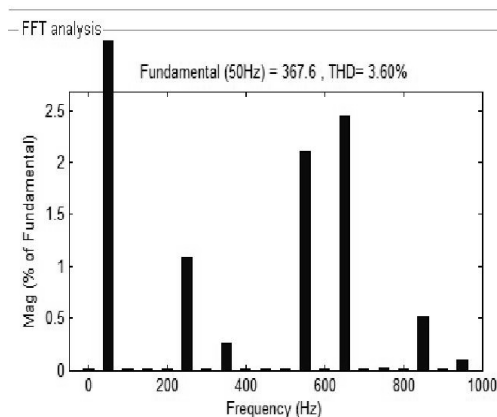


Figure 12. Voltage harmonics using GUPFC with Fuzzy

THD	Without GUPFC	With GUPFC-PI	With GUPFC-Fuzzy

V_{THD}	12.49%	3.52%	3.60%
I_{THD}	18.87%	2.83%	2.87%

6. Conclusion

An AI based GUPFC system has been modeled using matlab toolbox. The novelty of this paper lies in the application of PI and Fuzzy control to generate switching signals for the series and shunt compensator of the GUPFC system. The performance of the system for applications such as voltage interruption, control of zero and negative sequence components, harmonic elimination and reactive power compensation has been successfully examined and analyzed. The implementation of fuzzy is better than pi controllers for same output performance

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