



# Reactive Power Compensation Using CPAT-UPFC

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## ABSTRACT

The stability of an interconnected power system is compare to normal or stable operation after having been subjected to some form of disturbance. With interconnected systems continually growing in size and extending over vast geographical regions, it is becoming increasingly more difficult to maintain synchronism between various parts of the power system. This paper investigates the Custom Power Active Transformer (CPAT)'s capability to provide UPFC services which includes power flow control, reactive power compensation, voltage regulation and harmonics elimination. Simulations of the Fuzzy-UPFC with a stiff grid and a 5-bus power system demonstrates its functionality as an inter-bus coupling transformer that provides the required grid services. Moreover, the impact of the Fuzzy-UPFC during load perturbations on the power system is investigated to further validate its transient and steady-state response.

**KEYWORDS:** CPAT, Transient Stability limit, UPFC, Fuzzy Logic Control.

## INTRODUCTION

An interconnected power system basically consists of several essential components. They are namely the generating units, the transmission lines, the loads, the transformer, static VAR compensators and lastly the HVDC lines. During the operation of the generators, there may be some disturbances such as sustained oscillations in the speed or periodic variations in the torque that is applied to the generator. These disturbances may result in voltage or frequency fluctuation that may affect the other parts of the interconnected power system. External factors, such as lightning, can also cause disturbances to the power system. All these disturbances are termed as faults. When a fault occurs, it causes the motor to lose synchronism if the natural frequency of oscillation coincides with the frequency of oscillation of the generators. With these factors in mind, the basic condition for a power system with stability is synchronism. Besides this condition, there are other

important condition such as steady-state stability, transient stability, harmonics and disturbance, collapse of voltage and the loss of reactive power. Recent progresses in power electronics and as a result in Flexible AC Transmission Systems (FACTS) technology, give the ability to have a real time control on power system parameters and improve the transient stability. UPFC is one of the most effective FACTS devices, which is the combination of series and the shunt converter, connected together by a common DC link and have abilities of two FACTS devices named Static Synchronous Series Compensator (SSSC) and Static Compensator (STATCOM) together. Studies reported in literatures like have shown that UPFCs can be used to enhance the transient stability of the power system. All mentioned papers use Single Machine Infinite Bus (SMIB) power system for simulations. Literature have shown that quadrature voltage injection have most effect on transient stability improvement. As mentioned above, not much attention has been

given to effects of UPFC on transient stability improvement of Multi-machine power system. In this paper a study is performed on transient stability comparison in multi-machine power systems using UPFC.

### MULTI-MACHINE STABILITY

The classical model of the power system including the synchronous machines shown in is used to study the stability of the system. This is the simplest model used in the study of the system dynamics and requires a minimum amount of data to be collected initially. Moreover using this model the analysis can be made at a short interval of time. The time is of the order 1 sec in most power systems, during which the system dynamic response is largely dependent on the stored kinetic energy in the rotating masses. This gives a multi-port representation of a power system where always  $m$  is less than 'n'.

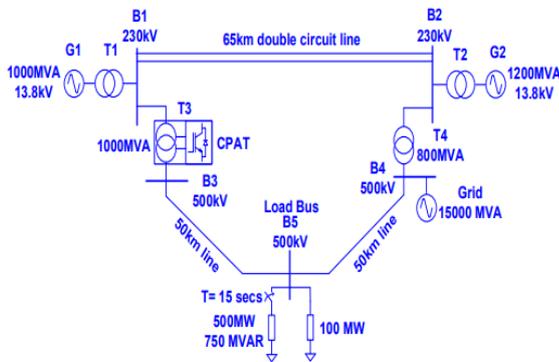


Figure 1: Multi-Machine System

Owing to interconnected systems, the loads cannot be ignored for transient stability analysis. Hence the loads are converted to equivalent admittances between the generators and ground. If the load bus has a voltage  $V_L$ , real power  $P_L$ , reactive power  $Q_L$  and a current  $I_L$  flowing into a load admittance

$$Y_L = G_L + jB_L \text{ then}$$

$$P_L + jQ_L = V_L I_L^* = V_L \{V_L^* (G_L - jB_L)\} = V_L^2 \{G_L - jB_L\}$$

$$Y_L^* = G_L - jB_L = \frac{(P_L + jQ_L)}{V_L^2}$$

Each generator is found to have an emf source behind the transient reactance of constant magnitude. This internal voltage is calculated from the load flow study on the system. The internal angle corresponding to this voltage is calculated from the pre-transient terminal voltage as follows:

Let the terminal voltage be considered as the reference for time being.  $V$  &  $I$  can be related by the expression as

$$V \cdot I^* = P + jQ$$

$$I = \{(P + jQ)/V\}^* = (P - jQ)/V$$

But the mathematical model we can write

$$E_i = V_i + jX_{di}I$$

$$E \angle \delta_i = V_i + jX_{di} \{P - jQ\}/V = V_i + \frac{X_{di}Q}{V} + j \frac{X_{di}P}{V}$$

The initial generator angle  $\delta_0$  is then obtained by adding the pre-transient voltage angle.

$$\delta_0 = \delta_i + \theta_i$$

### UNIFIED POWER FLOW CONTROLLER (UPFC)

The Unified Power Flow Controller (UPFC) is the most versatile member Flexible AC Transmission Systems (FACTS) family using power electronics to power flow on power grids. The UPFC uses a combination of a shunt controller (STATCOM) and a series controller (SSSC) interconnected through a common DC bus. The Unified Power Flow Controller (UPFC) is a power electronic co which can be used to control active and reactive power flows in a transmission injection of (variable) voltage in series and reactive current in shunt.

### UPFC MODEL:

The UPFC model that used in this paper is shown in figure 2. It consist of a series voltage source representing the UPFC series branch, the  $I_q$  parallel current source representing the UPFC parallel reactive compensating effect and the  $I_p$  parallel current source representing the UPFC parallel active current [5].

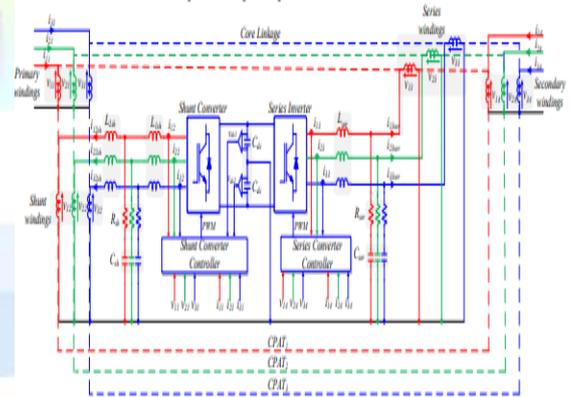


Figure 2: UPFC model connected between buses  $i$  and  $j$  in the power system

As described in the previous section, for transient stability calculations we need to model the UPFC with appropriate loads. Injection model of UPFC models series branch as loads that depend on related bus voltages. This model is shown in Figure 2 [5].

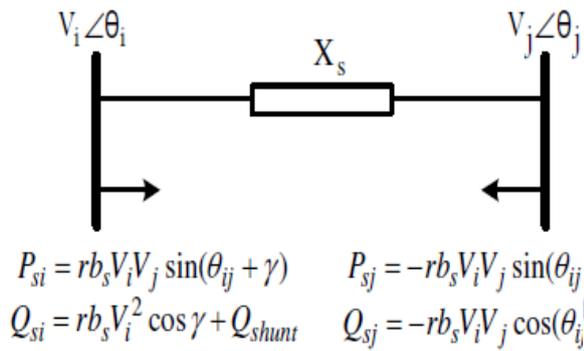


Figure 3: Injection model of UPFC

In this model  $V_s$  is the series injected voltage vector,  $V_s = rV_i$ ,  $X_s$  is series reactance of the series transformer,  $BS=1/ X_s$  and  $\gamma$  is the angle between the series injected voltage and the sending end bus voltage.

### UPFC CONTROL DIAGRAM

In the present scenario, the transmission systems mainly effects due to increasing of day by day demands in electrical utilization and usage of different loads such as non-linear and commercial appliances. These mainly causes the changes in system voltages (such as sag, swell, harmonics), harmonics in current. For compensating these problems a custom power device is proposed in this paper. The main components in this system is compensating element and a three phase converter for controlling the compensator.

A shunt converter is a one of the repaid hardware which is associated at the transmission framework. This shunt repaid framework has the capacity of either assimilate or produce dynamic power at the purpose of association subsequently controlling the voltage extent. Since the transport voltage extent must be fluctuated inside specific breaking points, controlling the power stream along these lines is constrained and shunt converter primarily fill different needs. A gadget that is associated in arrangement with the transmission line is alluded to as an 'arrangement gadget'. Arrangement gadgets impact the impedance of transmission lines. The guideline is to change (decrease or increment) the line impedance by embeddings a reactor or capacitor.

The dc link capacitor also acts as compensation device which helps to control the transmission line parameters i.e impedance, voltage, power factor and load angle.

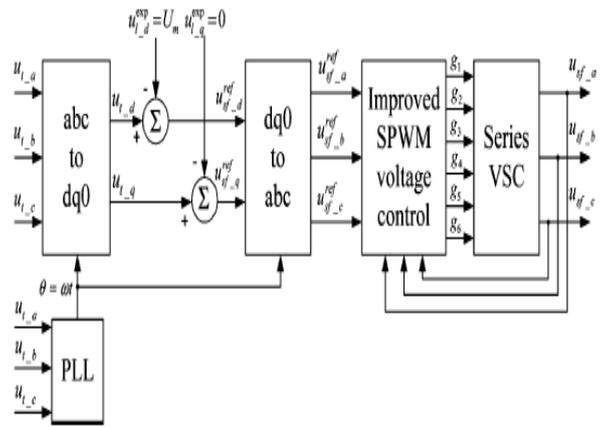


Figure 4: Control diagram for Series converter for UPFC

The series controller shown in above figure is used to compensate voltage interruptions like sag/swell or harmonics. In series converter the gate signals required for three phase VSC is obtained by using PWM technique. The PWM technique is operated by comparison of carrier and reference signal. In series controller, the reference signal is generated by using PCC and Dc link voltages. This controller consists of two loop namely, inner loop which acts as a DC link controller and the outer loop which control the pcc voltages which helps to compensates voltage distortions.

### UPFC Shunt converter control structure:

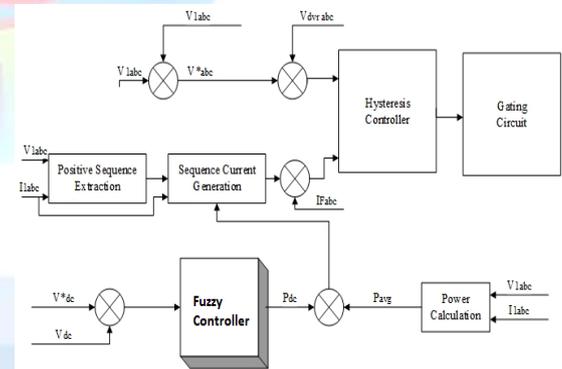


Figure 5: Closed loop control Diagram for shunt converter.

Shunt converter in DPF is used to compensate the harmonics in current and for controlling the load current. The three phase shunt converter is operated/controlled by a three phase hysteresis controller. The reference signals required for the shunt converter is generated by using PCC signals and dc link voltage. In the inner loop of shunt converter the reference current is generated by controlling DC link voltage and actual current is obtained from the PCC current signals in the outer loop. The closed loop control diagram of shunt converter is shown in figure 4 and figure 5.

### Fuzzy Logic Controller:

The major complexity in conventional PID controller is mathematical analysis with multiple variables and constant interfacing. The major three issues with conventional PID controller is (a) time delay, (b) step function response and (c) ramp or soak function response.

In order to overcome these issues, this paper is implemented with soft computing controller called as Fuzzy logic Controller. Fuzzy Logic is one type in artificial intelligence and it is based on the information which is either true or false. FLC is a function or group of flexible set of if-then rules.

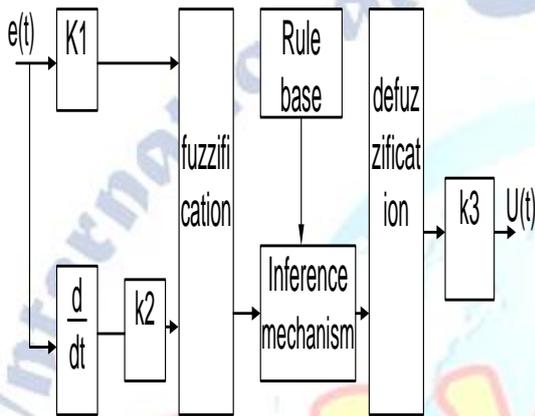


Figure 6: Architecture of FLC system

Figure 6, shows the basic structure of fuzzy logic controller with two inputs namely error of dc link voltage and change in error. Each input of FLC is a set of 5 memberships (i.e MS, S, Z, H, VH). The minimum of the two inputs of Medium small, small, zero, high and medium high are chosen which ultimately try to fire the set of IF-THEN rules. If error input is Z AND change in error input is H then the output is MH.

e/ ce	MS	S	Z	H	M
MS	MS	S	Z	H	M
S	M	H	Z	S	MS
Z	S	Z	H	M	MS
H	S	S	M	H	H
M	S	Z	H	H	M
H					H

Table 1 Rule-Base formation for 5\*5 input FLC

### 1. SIMULATION RESULTS

Investigations performed on the standard IEEE 6 bus system for determining the transient stability. Mat lab programming, has been done to test the systems for stability under various operating conditions. These results are based on performance index namely Transient Stability Index. This index is compare for certain predefined

outages on different operating conditions and tested upon the standard IEEE 6 bus system.

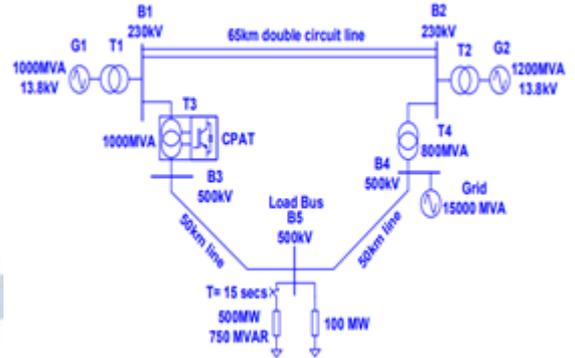


Figure 7: Typical IEEE 6 bus system

Whenever a fault occurs on a bus or on a transmission line various parameters like voltage, kinetic energy, potential energy, rotor swing angle etc., of the machines connected to the corresponding buses are also subjected to variations. These variations are mainly responsible for unstable and stable nature of the buses in the systems. The forthcoming graphs shows these comparisons experienced in the parameters of the machines in the standard buses explained above for the 3 phase short circuit at bus no.3s and bus no.5 respectively.

#### Case 1: Modelling with Conventional PI controller

In this case the proposed system is tested with PI controller and the experimental results are shown in below figures.

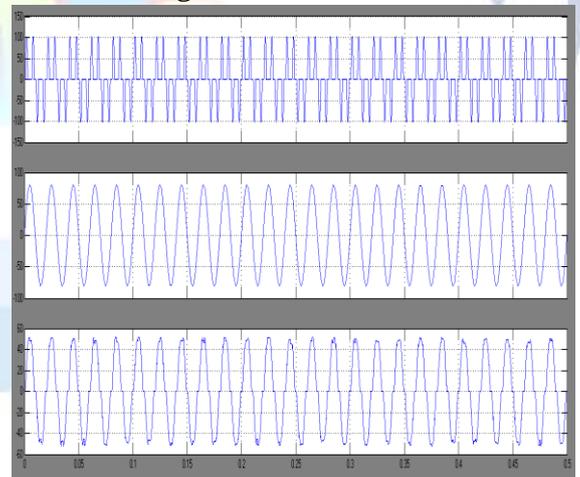


Figure 8: Output waveform for Bus currents

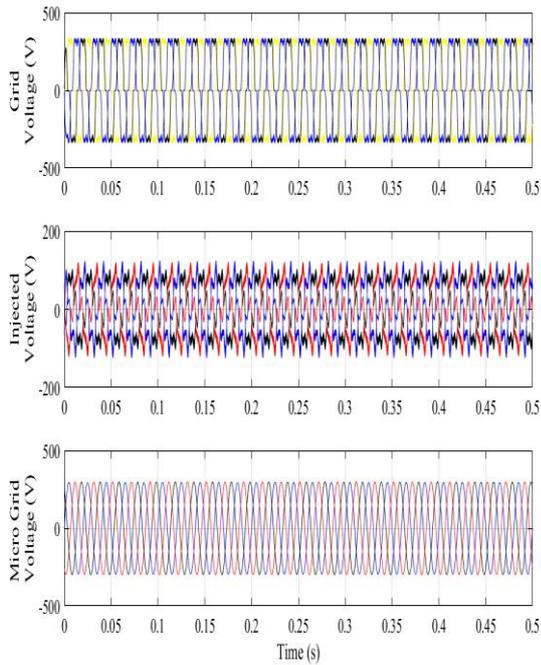


Figure 9: Output waveforms for Source Voltage, Injected Voltage and Load Voltage

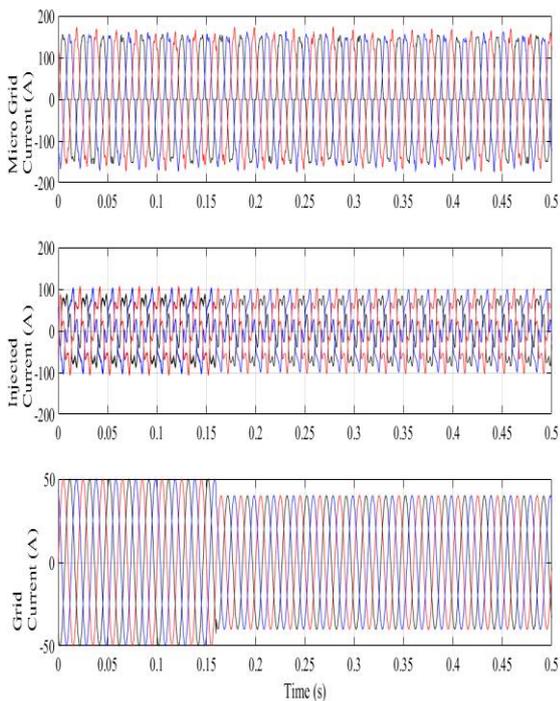


Figure 10: Output waveforms for Load Current, Injected Current, and Source Current

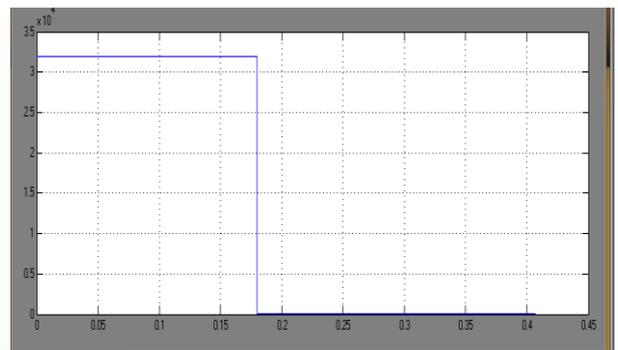


Figure 11: Output waveforms Active Power under Islanding Mode

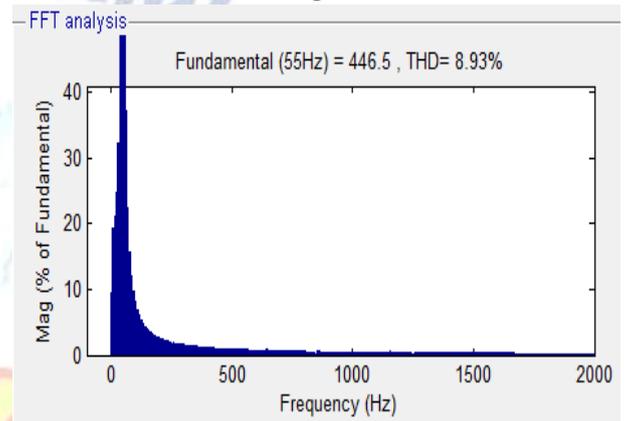


Figure 12: Total Harmonics Distortion for Grid Current

**Case 2: Modelling with Fuzzy Controller**

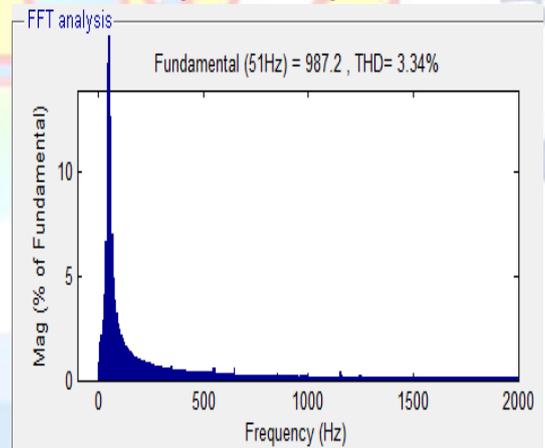


Figure 13: Grid Current THD with fuzzy controller

**CONCLUSION**

This paper has presented the Fuzzy based UPFC consisting of three single-phase CPATs equipped with a back-to-back converter. Through the available shunt and series windings in a CPAT, several services can be supplied to the grid such as grid harmonic currents elimination, reactive power compensation and power flow control. Linear and non-linear modeling approaches of a CPAT has been presented and investigated under stiff-grid operation and in a 5-bus power system model. The presented control architecture has been evaluated

through simulations and an experimental prototype demonstrating the ability of a Fuzzy to operate as a UPFC. The analysis, simulation results confirm the Fuzzy-UPFC ability to provide the required services.

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