Transient Stability Improvement of SMIB With Unified Power Flow Controller

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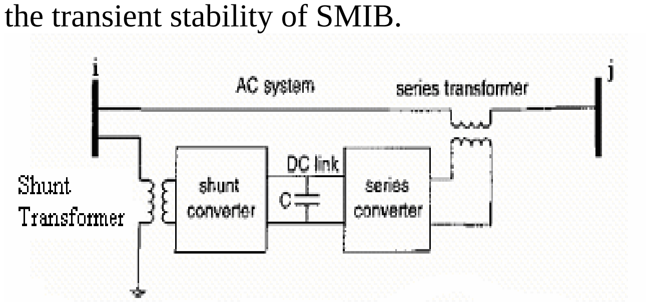
Abstract
The focus of this paper is on a FACTS device known as the Unified Power Flow Controller (UPFC), which can provide simultaneous control of basic power system parameters like voltage, impedance and phase angle. In this research work, two simulation models of single machine infinite bus (SMIB) system, i.e. with & without UPFC, have been developed. These simulation models have been incorporated into MATLAB based Power System Toolbox (PST) for their transient stability analysis. These models were analysed for three phase fault at different locations, i.e. at the middle and receiving end of the transmission line keeping the location of UPFC fixed at the receiving end of the line. Transient stability was studied with the help of curves of fault current, active & reactive power at receiving end, shunt injected voltage & its angle, series injected voltage & its angle and excitation voltage. With the addition of UPFC, the magnitude of fault current reduces and oscillations of excitation voltage also reduce. Series and Shunt parts of UPFC provide series and shunt injected voltage at certain different angles. Therefore, it can be concluded that transient stability of SMIB is improved with the addition of Unified Power Flow Controller.

1 Introduction

A number of Flexible Alternating Current Transmission System (FACTS) controllers are available today due to the rapid development in the field of power electronics. Generally, each of these controllers can act only on one of the three parameters (voltage, impedance and angle), that determine the power flow through a transmission line. But Unified Power Flow Controller (UPFC) is such a versatile FACTS device that has the capability of controlling all the three parameters simultaneously. [1] presented an approach to solve first-swing stability problem using UPFC, along with comprehensive analysis. [2] analysed that FACTS devices are used to control power flow through a line and damp out oscillations. Series controllers are more effective to control current/ power flow through a line and damp out oscillations. UPFC is a series-shunt controller that can be used to control active & reactive power through a line and line voltage control can be done simultaneously or individually. UPFC is also used to analyse transient stability of a single machine system or multi machine system. [3] proposed a versatile mathematical model of simplified Unified Power Flow Controller in a single machine infinite bus system. The model consists of a simple voltage source whose magnitude and angle depend on the UPFC control parameters.[4] investigated the mechanism of the three control methods of Unified Power Flow Controller, namely in-phase voltage control, quadrature voltage control and shunt compensation in improving the transient stability of power systems and examined the utilisation of the volt ampere ratings using the three control methods. [5] analysed that the stability problem is concerned with the behaviour of the synchronous machine after a disturbance. Transient stability deals with the effect of large, sudden disturbances such as the occurrence of a fault, the sudden outage of a line or the sudden application or removal of loads. [9] presented a power system simulation environment in MATLAB/ SIMULINK. The developed power analysis toolbox (PAT), is a very flexible and modular tool for load flow, transient and small-signal analysis of electric power systems.

2Modelling & Transient Stability Analysis

In this research work, simulation models of Single Machine Infinite System (with & without Unified Power Flow Controller) for three phase fault at different locations are developed, keeping UPFC fixed at the receiving end of SMIB. Simulation models have been prepared in MATLAB/SIMU-LINK to study the transient stability of SMIB. These models have been incorporated into the existing MATLAB based power system toolbox (PST).Curves of fault current, excitation voltage, active & reactive power, magnitude & angle of series injected voltage and magnitude & angle of shunt injected voltage versus time are presented to analyse the transient stability of SMIB.



Representation of UPFC as combination of Series & Shunt Converters

2.1Various Components of Simulation Diagram

- Alternator with Exciter & Prime-Mover Governor System
- Distributed Parameter Transmission Line
- Infinite Bus System
- Shunt Transformer (Two Winding)
- Series Transformer (Three Winding)
- Series & Shunt GTO Converter
- Synchronised Six Pulse Generator
- PI Controller
- Modulation Controller for V_{bp} & V_{bq}
- DC Capacitor

Time duration of fault in all simulations is considered between start of 0.2th second & upto the end of 0.4th second. The faults are cleared upto the end of 0.4th second.

3 Results and Discussion

Symmetrical Three Phase Fault on the Transmission Line

3.1 Fault at receiving end

a) Single Machine Infinite Bus (SMIB) System without UPFC

Resulting curves of the variation of excitation voltage, fault current and active & reactive power at receiving end are presented in fig.1 to 3.

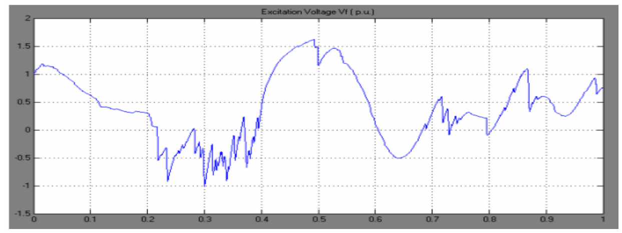


Fig.1 Variation of excitation voltage Vs time

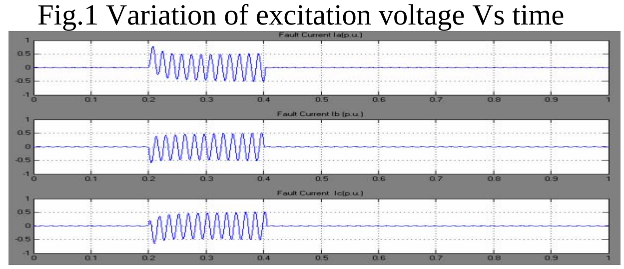


Fig.2 Variation of fault current Vs time

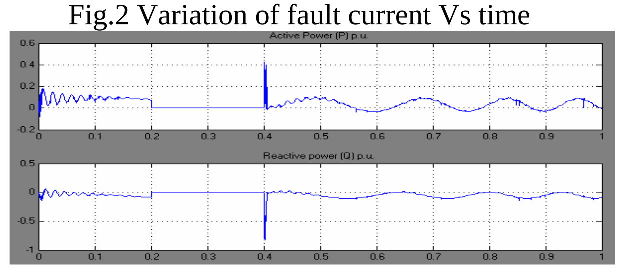


Fig.3 Variation of active & reactive power Vs time

b) Single Machine Infinite Bus (SMIB) System with UPFC at receiving end

Resulting curves of the variation of excitation voltage, fault current, active & reactive power at receiving end, magnitude & angle of series injected voltage and magnitude & angle of shunt injected voltage are shown in fig.4 to 8.

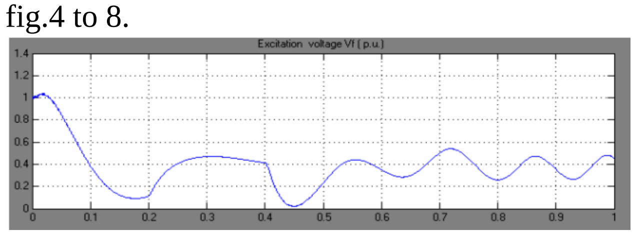


Figure 4 Variation of excitation voltage Vs time

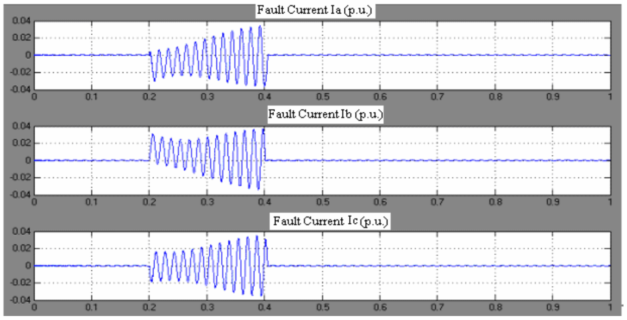


Figure 5 Variation of fault current Vs time

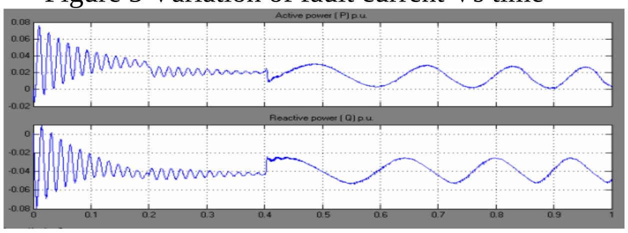


Figure 6 Variation of active & reactive power vs time

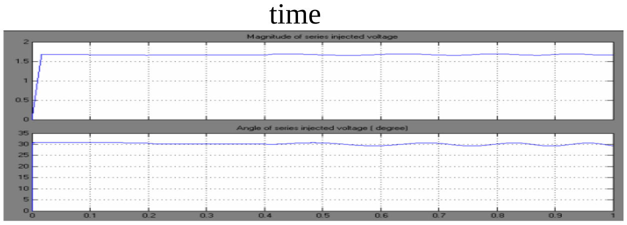


Figure 7 Variation of series injected voltage & its angle Vs time

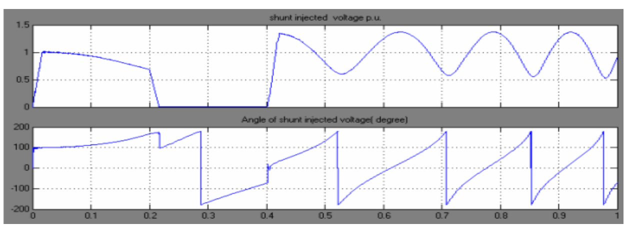


Figure 8 Variation of shunt injected voltage & its angle Vs time

Discussion of Results

- **Fault Current:** Without UPFC, during fault interval, fault current in phases a, b & c lies between 0.80 to -0.50 p.u., 0.50 to -0.50 p.u. & 0.50 to -0.50 p.u. respectively (fig.2). With UPFC, fault current is reduced to 0.04 to -0.04 p.u. in all the three phases (fig.5). So, using UPFC, the magnitude of fault current has reduced a lot in all the three phases.
- **Excitation Voltage:** Without UPFC, before occurrence of fault, excitation voltage lies between 1.2 to 0.3 p.u., during the fault, it lies between -1.0 to 0.5 p.u. with large oscillations and after the fault, it lies between 1.7 to -0.5 p.u. with oscillations (fig1). With UPFC, before occurrence of fault, excitation voltage lies between 1.0 to 0.1 p.u., during the fault, it lies between 0.1 to 0.5 p.u. and it lies between 0.0 to 0.55 p.u. with oscillations dieing out after the fault (fig.4). So, using UPFC, the number of oscillations of excitation voltage have decreased and die out more smoothly.
- **Series Injected Voltage:** Series part of UPFC injects a voltage of 1.7 p.u. at an angle of 30 degree (fig.7).
- **Shunt Injected Voltage:** Shunt part of UPFC injects a voltage of 1.0 to 0.7 p.u. with an angle of 100 to 180 degree before the fault, voltage of 0.0 p.u. with an angle of 180 to -180 during the fault and voltage of 1.3 to 0.7 p.u. with an angle of 180 to -180 degree after the fault (fig.8).
- **Active and Reactive Power:** Without UPFC, active & reactive power during the fault are 0.0 p.u. (fig.3).With UPFC, active & reactive during the fault are 0.02 p.u. & -0.04 p.u. respectively. So, using UPFC, some active & reactive power is available even during the fault (fig.6).

3.2. Fault at Middle of Transmission line

a) Single Machine Infinite Bus (SMIB) System without UPFC

Resulting curves of the variation of excitation voltage, fault current and active & reactive power at receiving end are presented in fig. 9 to 11.

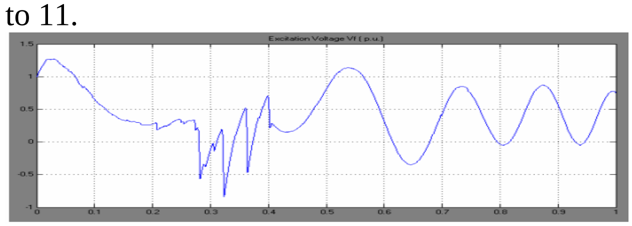


Figure 9 Variation of excitation voltage Vs time

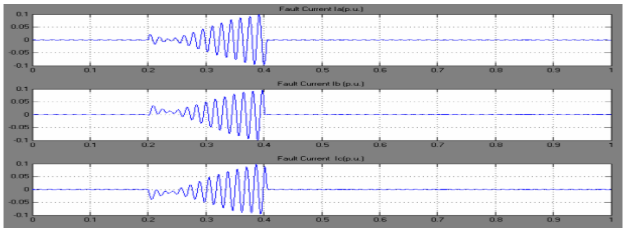


Fig. 10 Variation of fault current Vs time

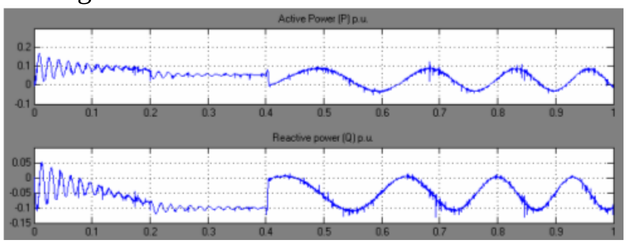


Fig.11 Variation of active & reactive power Vs time

b) Single Machine Infinite Bus (SMIB) System with UPFC at Receiving end

Resulting curves of the variation of excitation voltage, fault current, active & reactive power at receiving end, magnitude & angle of series injected voltage and magnitude & angle of shunt injected voltage are shown in fig.12 to 16.

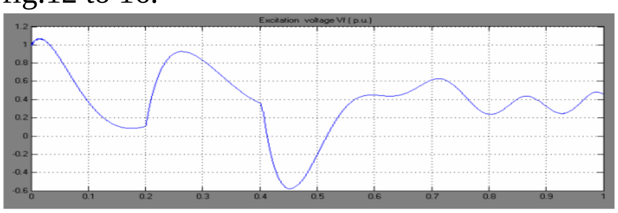


Figure 12 Variation of excitation voltage Vs time

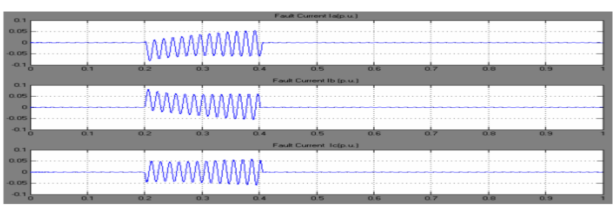


Figure 13 Variation of fault current Vs time

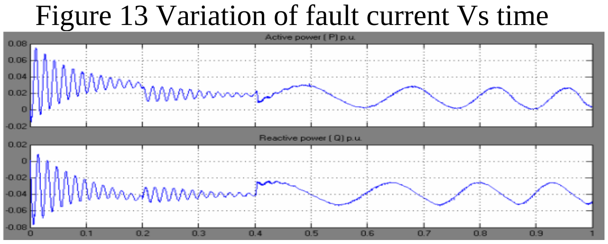


Fig.14 Variation of active & reactive power Vs time

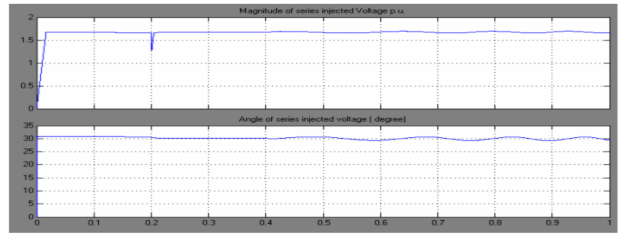


Fig.15 Variation of series injected voltage & its angle Vs time

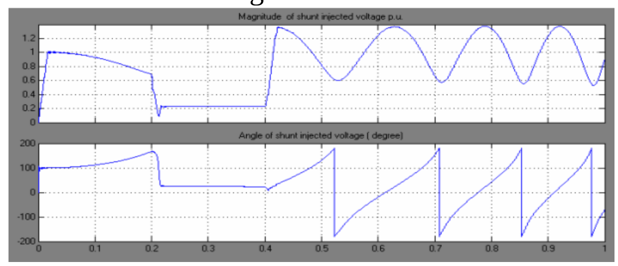


Fig.16 Variation of shunt injected voltage & its angle Vs time

Discussion of Results

- **Fault Current:** Without UPFC, during fault interval, fault current in all phases a, b & c lies between 0.10 to -0.10 p.u respectively (fig.10). With UPFC, fault current in phases a, b & c is reduced to (-0.075 to 0.05, 0.075 to -0.05 and -0.05 to 0.05 p.u) respectively (fig.13). So, using UPFC, the magnitude of fault current has reduced a lot in all the three phases.
- **Excitation Voltage:** Without UPFC, before occurrence of fault, excitation voltage lies between 1.25 to 0.3 p.u., during the fault, it lies between -0.8 to 0.7p.u. with large oscillations and it lies between 1.2 to -0.3 p.u. with oscillations after the fault (fig.9). With UPFC, before occurrence of fault, excitation voltage lies between 1.0 to 0.1 p.u., during the fault, it lies between 0.1 to 0.9 p.u. and after the fault, it lies between 0.4 to -0.6 p.u. with oscillations dieing out (fig.12). So, using UPFC the number of oscillations of excitation voltage have decreased and die out more smoothly.
- **Series Injected Voltage:** Series part of UPFC injects a voltage of 1.7 p.u. at an angle of 30 degree (fig.15).

- **Shunt Injected Voltage:** Shunt part of UPFC injects a voltage of 1.0 p.u. to 0.5 p.u. with an angle of 100 to 180 degree before the fault, voltage of 0.2 p.u. with an angle of 180 starting at the occurrence of fault & ultimately settling at 30 degree during the fault and voltage of 0.2 to 1.4 p.u. with an angle starting at 20 degree & then varying between 180 to -180 degree after the fault (fig.16).
- **Active and Reactive Power:** With addition of UPFC, there is no appreciable change in values of active and reactive power (fig.11 &14).

4 Conclusions

In this research paper, simulation models of single machine infinite bus system with and without unified power flow controller for three phase fault at different locations of fault were developed. The location of UPFC was kept fixed at the receiving end of the transmission line. Their transient responses like faults current, excitation voltage and active & reactive power at the receiving end of SMIB were discussed & compared. From the results & the curves presented above, the following conclusions are drawn if UPFC is added in SMIB system:

- Fault current is reduced when fault occurs at middle of the line or receiving end of the line.
- Excitation voltage is modified with damping out of oscillations when fault occurs at middle of the line or receiving end of the line.
- On the whole, the transient stability of SMIB is improved at middle of the line & receiving end of the transmission line if UPFC is included at receiving end of the line.

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