

Reactive Power Compensation of Mutli-Machine System Using UPFC

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Abstract— A number of Flexible AC Transmission System (FACTS) controllers based on the rapid development of high power electronics technology have been proposed in recent years for better utilization of existing transmission facilities. FACTS devices have shown very encouraging results for improvement of power system steady state performance. Unified Power Flow Controller (UPFC) is a versatile FACTS device which has the ability to adjust the three control parameters, i.e. the bus voltage, the transmission line reactance, and the phase-angle between two buses. During transients, it can be used to improve the damping rate of low frequency oscillations. Multi-Machine (3-machines 9-Bus) electrical power system incorporated with UPFC has been simulated in the present work with the aim of analyzing the response of the device for enhancing transient stability of the electrical power system. MATLAB tool has been used for the simulation purposes. MATLAB is a new research tool which is capable of representing dynamic systems in block diagram form, along with a provision of simulation of system behavior in total. Results obtained are encouraging and indicate that the proposed simulation model is very near to the physical simulation.

Keywords— UPFC, FACT, VSC.

I. INTRODUCTION

The Electrical power lines are used to distribute electricity from power plants to the end consumers. The process is broken down into two main parts, transmission and distribution. The electrical power is generated at the generating station as per the requirement it can be stepped up and power is transmitted through transmission lines. That electrical power is then stepped down and carried through distribution lines and delivered to consumers. Transmission lines are responsible for getting electricity from the power plants to substations near load areas. Power plants helps in generating three-phase alternating current (AC) therefore three lines, known as conductors, are required to carry this electric power. They have extreme high voltage lines.

A power system is an interconnected network with components converting mechanical energy continuously into electrical form and transporting the electrical energy from generating sources to loads. Most if not all of the world's electric power supply systems are widely interconnected, which involves various connections inside utilities of their own territories which extend to inter utility interconnections and then to inter-regional and international connections.

Electric power systems mainly have three separate components namely:

- Generation
- Transmission and
- Distribution.

Electric power is generated at the power generating stations by synchronous alternators that are usually driven either by steam or hydro turbines. Almost the power generation takes place at generating stations that may contain more than one such turbine-alternator combinations known as turbo-alternators. Depending upon the type of fuel used, the generating stations are classified as thermal, hydro, nuclear etc. Many of these

stations are located from load centre away. Hence the electric power generated at any of these station has to be transmitted over a long distance to the load centers that are usually situated in cities and towns. This process is called power transmission. Modern day power systems are complicated networks with hundreds of generating stations and load centers being interconnected through power transmission lines. The purpose of the transmission network is to pool power plants and load centers in order to minimize the total power generation capacity and fuel cost.

In an early attempt at economic operation, it was decided that the power supply from the most efficient plant at light load conditions. As the load increased, the power was supplied by this most efficient plant till the point of maximum efficiency of this particular plant . With further when the load is increased, the next most good plant would supply power till its maximum efficiency is attained. The power in this way would be supplied by the most efficient to the least efficient plant to reach the peak demand.

The purpose of the transmission network is to pool power plants and load centers in order to minimize the total power generation capacity and fuel cost. Transmission interconnections enables us in taking advantages of diversity of loads, availability of sources, and fuel price in order to supply electricity to the loads at minimum cost along with the required reliability. Less transmission capability means more generation resources would be required regardless of whether the system is made up of large or small power plants. In fact small-distributed generation becomes more economically viable if there is a backbone of a transmission grid.

Demand of electrical power is continuously rising at a very high rate due to rapid industrial development. It is thus essential to raise the transmitted power in order to meet this demand along with the existing transmission facilities. The need for the power flow control in electrical power systems is thus evident.

One direction of large ac system development is the transmission of large amounts of power over long distances by high voltage transmission lines from remote power sources to the load centers. Due to growing public impact on environmental policy and enormous infrastructure cost, the building of new transmission facilities in general, lags behind the increased needs of power transmission. As a result, it is evident that some transmission lines are more loaded than was planned when they were built. With the increased loading of transmission lines, the problem of transient stability after occurrence of a major fault can become a transmission power-limiting factor. The power system thus, should adapt to momentary system conditions, or in other words, power system should be flexible in nature. The idea of the so-called Flexible AC Transmission System (FACTS) has been introduced in 1980s.

1.1 Power System Stability

Electric Stability of power system has been a major concern in system operation. This arises from the fact that in steady state, the angular speed of all the generators must remain the same anywhere in the system. This is known as the synchronous operation of a system. Any fault small or large, can affect the synchronous operation. The stability of a system determines whether the system can settle down to the original or close to the original steady state after the transients disappear. In general, power system stability is the ability of the system to respond to a disturbance from its normal operation by returning to a condition where the operation is again normal. Power system stability concept is defined as that property of a power system that enables it to remain in a state of operating equilibrium under normal operating conditions and to regain an acceptable state of equilibrium after being subjected to a disturbance.

Stability as per IEEE (USA) can be defined as:

“That attribute of a system or part of the system which enables it to develop restoring forces between elements there of equal or greater than distributing forces so as to restore a state of equilibrium between elements.”

The disturbances can be divided into two categories as explained below:

Small disturbance A small disturbance is one for which the system dynamics can be analyzed from linearizing the equations. The small changes in the load or generation can be termed as small disturbances. Initial power flow on that line may be considered as a small disturbance if the initial power flow on that line is not significant.

Large disturbance A large disturbance is one which results in a sudden dip in the bus voltages. They require remedial action in the form of clearance of the fault. The time period of the fault has a critical influence on system stability.

Stability of a power system is divided into three broad classes namely:

- Steady state stability
- Transient stability
- Dynamic stability

A power system is transiently stable for a particular steady state operating condition and for a large disturbance or sequence of disturbances if, following that disturbances it reaches an acceptable steady state operating condition. It refers to the maximum flow of power possible with sudden and large

changes such as sudden load changes. It is important to note that, while steady state is a function of only the operating condition, transient stability is a function of both the operating condition and the disturbances. Fig.1.1 shows the power system stability diagram.

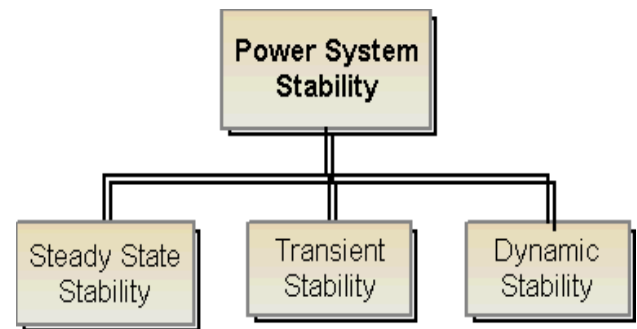


Fig.1.1 Power system Stability diagram

The ability of a power system to maintain stability under continuous small disturbances is termed as **Dynamic Stability** (also known as small-signal stability). These small disturbances occur due random fluctuations in loads and at various levels of generation. In an intertwined power system, these random variations can lead to catastrophic failure as this may force the rotor angle to increase steadily.

1.2 Concept of Transient Stability

Power Transient stability is the ability of the power system to maintain synchronism when subjected to a severe transient interruption which results in the response of large excursions of generator rotor angles and is influenced by the non-linear power-angle connection. Stability depends on both the incipient operating state of the system and the severity of the interruption. Usually, the system changes so that the post-disturbance steady-state operation differs from that prior to the disturbance.

In giant power systems, transient inequilibrium may not always occur as first swing instability, it could be the result of several modes of oscillations causing large excursions of rotor angle beyond the first swing.

Transient stability limits the available transfer capacity during the fault condition. Transient stability limit is the maximum power which can be transmitted during the transient state. Transient stability is important from the point of view of maintaining system security. In other words, incidence of a fault should not lead to tripping of generating unit due to loss of synchronism and the possibility of a cascaded outage leading to system black out.

II. RELATED WORK

An adaptive neuro- fuzzy inference system (ANFIS) based supplementary Unified Power Flow Controller (UPFC) to superimpose the damping function on the control signal of UPFC is proposed. By using a hybrid learning procedure, the proposed ANFIS construct an input-output mapping based on stipulated input-output data pairs. The linguistic rules, considering the dependence of the plant output on the controlling signal are used to build the initial fuzzy inference structure. On the basis of linearized Philips-Hefron model of power system installed with UPFC, the damping function of the UPFC with various alternative UPFC control signals are

investigated. In the simulations under widely varying operating conditions and system parameters, ANFIS based controller yields improved performance when compared with constant gain controller, based on phase compensation technique. To validate the robustness of the proposed technique, the approach is integrated to a multi-machine power system and the nonlinear simulation results are presented

III. PROPOSED WORK

The proposed work includes simulation of multi-machine power system incorporated with UPFC controller using MATLAB/Simulink (7.5 version) and response analysis of the device. The simulated UPFC shows how the oscillations are damped out with UPFC controller. Optimum location of the UPFC in the system is also studied. I had gone through various literatures on FACTS controllers especially UPFC controller incorporated on Multi-machine system and revealed the following observations:

- Simulations of different controllers are carried out by using various software such as MATLAB/Simulink, Lab VIEW etc.
- Choice of hardware and software should necessarily be considered very carefully taking into consideration the cost effectiveness.
- This is very significant with the advent of rich technological advancements. It is quite obvious that the cost of designing new instrumentation can be decreased significantly if displays are modeled in software rather than using hardware components.
- A number of interactive computer delivered simulations, control, scientific visualizations software solutions are available which employ diverse software such as Lab VIEW, MATLAB/SIMULINK etc.
- This criterion may be contemplated for selecting application software to build instrumentation modularity, extendable libraries, advanced debugging features etc.

According to research study the model designed in MATLAB/Simulink appears to be same as a physical model. Since, the physical model is not possible practically, because of cost constraint, the model simulated in MATLAB/Simulink serves almost all the conditions of physical model. Various changes can be incorporated on the model and results can be analyzed..

3.1 Power system simulation using simulink

The Sim Power Systems Block set in Simulink is a tool for modeling and simulating generation, transmission, distribution and consumption of electrical power. It provides models of many components used in these systems including three-phase machines, electric drives and libraries of application specific models such as FACTS and wind power generation.

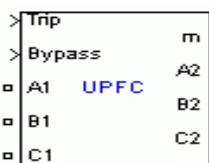


Fig.3.1.The UPFC block

3.2 Inputs And Outputs Of UPFC Block

Figure 3.3 shows **A1 B1 C1**:- The three input terminals of the UPFC.

A2 B2 C2:-The three output terminals of the UPFC.

Trip:-Apply a simulink logical signal (0 or 1) to this input. When this input is high the shunt converter is disconnected and the series converter is bypassed. In addition, when the trip signal is high the shunt and series control systems are disabled. Use this input to implement a simplified version of the protection system.

Bypass:-This input is visible only when the Bypass Breaker parameter is set to External Control. Apply a simulink logical signal (0 or 1) to this input. When this input is high the bypass breaker is closed.

Vdqref:-This input is visible only when the External control of injected voltage Vdref_ Vqref parameter is checked. Apply a simulink vectorized signal specifying the reference voltages Vdref and Vqref, in pu.

PQref:-This input is visible only when the External control of power references Pref_Qref parameter is checked. Apply a simulink vectorized signal specifying the reference powers Pref and Qref, in pu.

3.3 UPFC Dialog Box And Parameters

The dialog box opens up to two categories of:

- Power-data-parameters and
- Control parameters.

They are discussed below:

3.3.1 Power-Data-Parameters

These parameters are displayed by clicking 'Power-data' in the Display option of this dialog box, as shown in Fig. 2.2

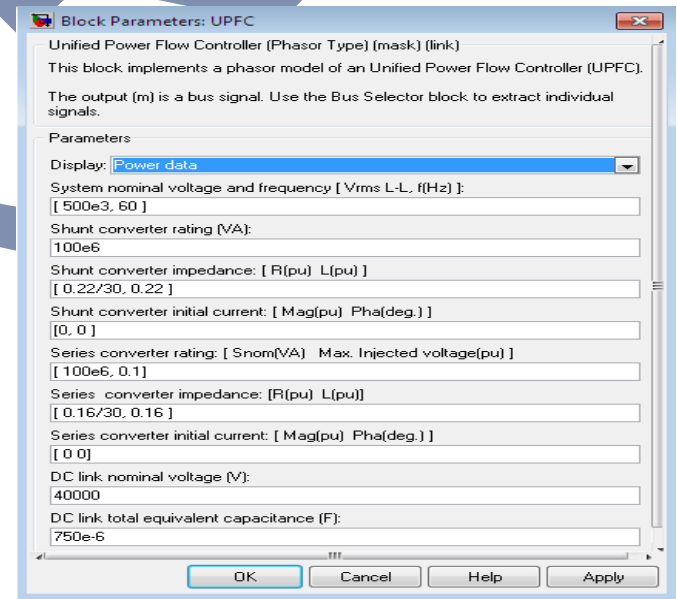


Fig.3.2upfc Dialog Box Power Data Parameters Window

The different parameters are:

System nominal voltage and frequency [Vrms f]:-The nominal line-to-line voltage in Vrms and the nominal system frequency in hertz.

Shunt converter ratings:-The nominal rating of the shunt converter in VA.

Shunt converter impedance [R L]:-The positive-sequence resistance R and inductance L of the shunt converter, in pu based on the nominal converter rating and nominal voltage. R and L represent the resistance and leakage inductance of the shunt transformer plus the resistance and inductance of the series filtering inductors connected at the VSC output.

Shunt converter initial current [Mag Phase]:-The initial value of the positive-sequence current phasor (Magnitude in pu and Phase in degrees). If you know the initial value of the shunt current corresponding to the UPFC operating point you may specify it in order to start simulation in steady state. If you don't know this value, you can leave [0 0]. The system will reach steady-state after a short transient.

Series converter ratings [Snom, Max. Injected voltage]:-The ratings of the series converter in VA and the maximum value of the injected voltage $V_{conversion}$ on the VSC side of the transformer (see single line diagram), in pu of nominal phase-to-ground voltage.

Series converter impedance [R L]:-The positive-sequence resistance and inductance of the converter, in pu, based on the converter rated power and voltage. R and L represent the resistance and leakage inductance of the series transformer plus the resistance and inductance of the series filtering inductors connected at the VSC output.

Series converter initial current [Mag Phase]:-The initial value of the positive-sequence current phasor (Magnitude in pu and Phase in degrees). If you know the initial value of the series current corresponding to the UPFC operating point you may specify it in order to start simulation in steady state. If you don't know this value, you can leave [0 0]. The system will reach steady-state after a short transient.

DC link nominal voltage:-The nominal voltage of the DC link in volts.

DC link total equivalent capacitance:-The total capacitance of the DC link in farads. This capacitance value is related to the UPFC converter ratings and to the DC link nominal voltage. The energy stored in the capacitance (in joules) divided by the converter rated power (in VA) is a time duration which is usually a fraction of a cycle at nominal frequency. For example, for the default parameters, ($C=750 \mu F$, $V_{dc}=40000 V$, $S_{nom}=100 MVA$) this ratio is 6.0 ms, which represents 0.36 cycle for a 60 Hz frequency. If you change the default values of the nominal power rating and DC voltage, you should change the capacitance value accordingly

IV SIMULATION SOFTWARE

In the past few years, SIMULINK (a simulation tool associated with MATLAB) has become the most widely used software package for modeling and simulating dynamic systems. Appearance of SIMULINK has encouraged trying things out. Models can be built from scratch, or existing model can be taken as such for further additional changes. Simulations are interactive in nature which provides an opportunity to change the parameters and verify results. Simulink provides an instant access to all the analysis tools in MATLAB, so results can be taken for analysis and visualization.

With SIMULINK, it is possible to move beyond idealized linear models in order to explore more realistic non-linear models, factoring in friction, air resistance, gear slippage, hard stops, and the other things that describe real-world phenomena. Simulink has the ability to turn a computer into a lab for modeling and analyzing systems that simply would not be possible otherwise.

SIMULINK is a software package for modeling, simulating, and analyzing dynamic systems. It supports linear and non-linear systems.

For modeling, SIMULINK provides a graphical user interface (GUI) for building models as block diagrams, using click-and-

drag operations. With this interface the models can be drawn just as one would with pencil and paper. This is an advantage over previous simulation packages which require formulation of differential equations in a language or program. SIMULINK includes a comprehensive block library of sinks, sources, linear and non-linear components, and connectors.

Models are hierarchical, so they can be built using both top-down and bottom-up approaches. The system can be viewed at a high level, then double-click blocks to go down through the levels to see increasing levels of model detail. This approach provides insight into how a model is organized and how its parts interact.

After a model is defined, it can be simulated using a choice of integration methods, either from the SIMULINK menus or by entering commands in the MATLAB Command Window. The menus are particularly convenient for interactive work, while the command-line approach is very useful for running a batch of simulations. The simulation results can be put in workspace for post processing and visualization. Model analysis tools include linearization and trimming tools, which can be accessed from the MATLAB command line, plus the several tools in MATLAB and its application tool boxes. Since, MATLAB and SIMULINK are integrated; models can be simulated, analyzed and revised in either environment at any point.

4.1 Control Parameters (Shunt Converter)

The different control parameters (Shunt Converter) as displayed in the dialog box of UPFC are shown in Fig.4.3.

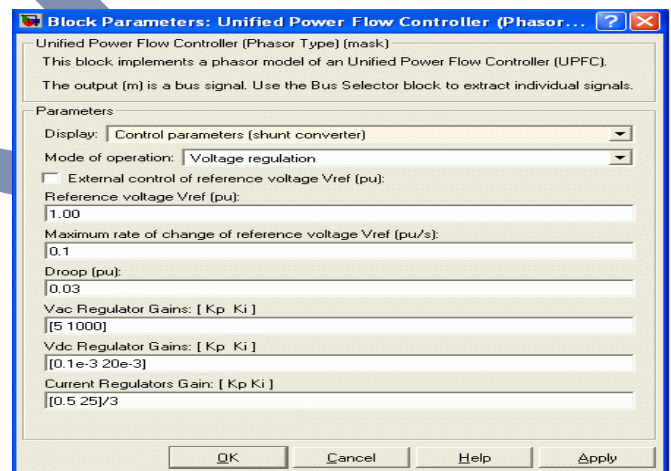


Fig.4.1 UPFC Dialog box Control Parameters (Shunt Converter) Window

Mode of operation:-Specifies the shunt converter mode of operation. Select either Voltage regulation or Var Control.

External control of reference voltage Vref:-If this parameter is checked, a Simulink input named Vref appears on the block, allowing to control the reference voltage from an external signal (in pu). Otherwise a fixed reference voltage is used, as specified by the parameter below.

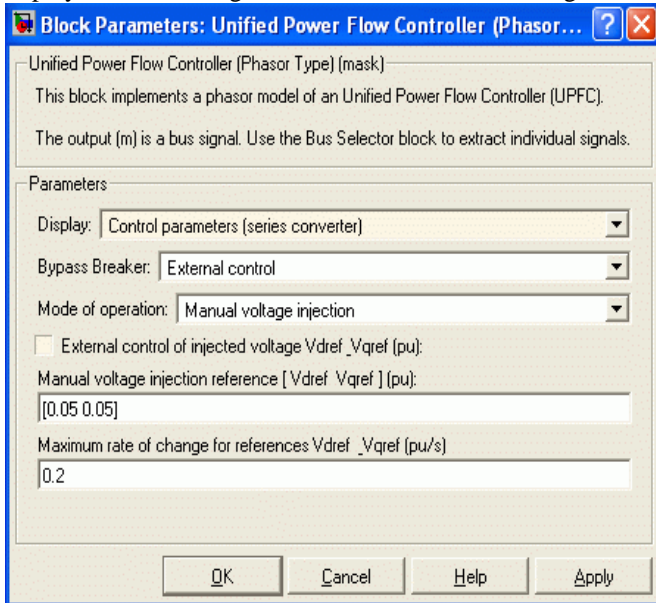
Reference voltage Vref:- This parameter is not visible when the Mode of operation parameter is set to Var Control or when the External control of reference voltage Vref parameter is checked. Reference voltage, in pu, used by the voltage regulator.

Maximum rate of change of reference voltage Vref:-This parameter is not visible when the Mode of operation parameter is set to Var Control. Maximum rate of change of the reference

voltage, in pu/s, when an external reference voltage is used.

4.2 Control Parameters (Series Converter)

The different control parameters (Series Converter) as displayed in the dialog box of UPFC are shown in Fig.4.2.



Bypass Breaker:-Specifies the status of the bypass breaker connected inside the block across terminals A1, B1, C1 and A2, B2, C2. Select either External Control, Open or Closed. If the bypass breaker is in external control, a Simulink input named Bypass appears on the block, allowing to control the status of the bypass breaker from an external signal (0 or 1).

Mode of operation:-Specifies the series converter mode of operation. Select either Power flow control or Manual voltage injection.

External control of power references:-This parameter is not visible when the Mode of operation parameter is set to Manual voltage injection. If this parameter is checked, a Simulink input named PQ ref appears on the block, allowing to control the active and reactive powers from an external signal (in pu). Otherwise, fixed reference power are used, as specified by the parameter below.

Reference active and reactive powers [Pref Qref]:-This parameter is not visible when the Mode of operation parameter is set to Manual voltage injection. Specify references values, in pu.

Maximum rate of change for references Pref _Qref:-This parameter is not visible when the Mode of operation parameter is set to Manual voltage injection. Specify maximum rate of change of Pref and Qref, in pu/s.

Power regulator gains: [Kp Ki]:-This parameter is not visible when the Mode of operation parameter is set to Manual voltage injection. Gains of the PI regulators which control the line active power and reactive power. Specify proportional gain Kp in (pu of Vdq)/(pu of PQ), and integral gain Ki, in (pu of Vdq)/(pu of PQ)/s, where Vdq is the Vd or Vq injected voltage and PQ is the P or Q voltage error.

External control of injected voltage [Vdref Vqref]:-This parameter is not visible when the Mode of operation parameter is set to Power flow control. If this parameter is checked, a Simulink input named Vdqref appears on the block, allowing to control the injected voltage from an external signal (in pu). Otherwise a fixed reference voltage is used, as specified by the

parameter below.

Manual voltage injection reference [Vdref Vqref]:-This parameter is not visible when the external control of injected voltage [Vdref Vqref] parameter is checked or when the Mode of operation parameter is set to Power flow control. Specify the direct-axis and quadrature-axis components of the voltage injected on the VSC side of the series transformer, in pu.

Maximum rate of change for references Vdref _Vqref:-This parameter is not visible when the Mode of operation parameter is set to Power flow control. Specify maximum rate of change of the Vdref and Vqref voltages, in pu/s.

The other main blocks which are used for power system simulation are as follows:

- Synchronous Machine.
- Three-Phase-Transformer.
- Three-Phase-Circuit Breaker.
- Three-Phase Fault.
- Distributed Parameters transmission line.
- Three-Phase V-I measurement.
- Control Block.

From the above discussions on Simulink, it is clear that by using Simulink software, power system can be designed and analyzed by adjusting various parameters.

V. CONCLUSIONS

The complete investigations reveal the following conclusions:

- i) UPFC controller injects current in shunt with the line that changes the reactive power which in turn affects the rotor angle and brings back the system into synchronism.
- ii) The best optimum location of UPFC can be obtained
- iii) From the above case, when a three-phase fault is occurring between bus 5 and bus 4, UPFC finds its best location in the midpoint of the same line i.e. between bus 5 and bus 4 and thus system gets stable very fast..

VI. FUTURE WORK

For In the present thesis work, simulation of multi-machine (3-machine 9-bus) WSCC system with UPFC FACTS controller has been done using MATLAB/Simulink (7.5 version) software. This simulation can also be extended for:

- i) Multiple faults system and
- ii) Complex multi-machine systems.

Simulation of various other FACTS controllers such as SSSC, THYRISTOR based and their combination for changing the transient stability can also be carried out for analyzing the transient stability enhancement.

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