

Study and Simulation of IEEE 9 Bus System with UPFC for Transient Stability Analysis

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ABSTRACT

This paper deals with transient stability study of power system with the insertion of UPFC. Flexible A.C transmission line FACTS controllers which is the result of recent developments of power electronics produce solutions to the challenges faced power system operation. They are capable of controlling the network parameters to improve transient stability of the network. In this paper the optimal location and parameter settings of UPFC have been studied. the identification of the most weakest bus is done and design consideration have been done using a MATLAB program to obtain the parameters of UPFC needed, mainly series and shunt voltages with their angles and their respective power in order to obtain the equivalent resistance and reactance of UPFC necessary for simulation. The transient stability study have been done by simulation the UPFC in a power world simulator program which appears the improvement on transient stability. Different faults on line and bus are implemented for the purpose of system transient stability study.

KEYWORDS: Weakest bus identification, transient stability, UPFC model, power world simulator.

INTRODUCTION

In recent years, the incremental demand of electrical power has led the modern power system networks to operate under difficult and stressed situations. These difficulties produce a limited expansion of electrical power generation and transmission because of limited environmental restrictions and resources.

Thus, some transmission lines get over loaded and power stability becomes a power transfer limiting factor and other serious stability issues and produced knowing that stability is the heart of any system and has to be kept at all circumstances to ensure operation of power system effectively without any reduction of system security and quality of supply[1].

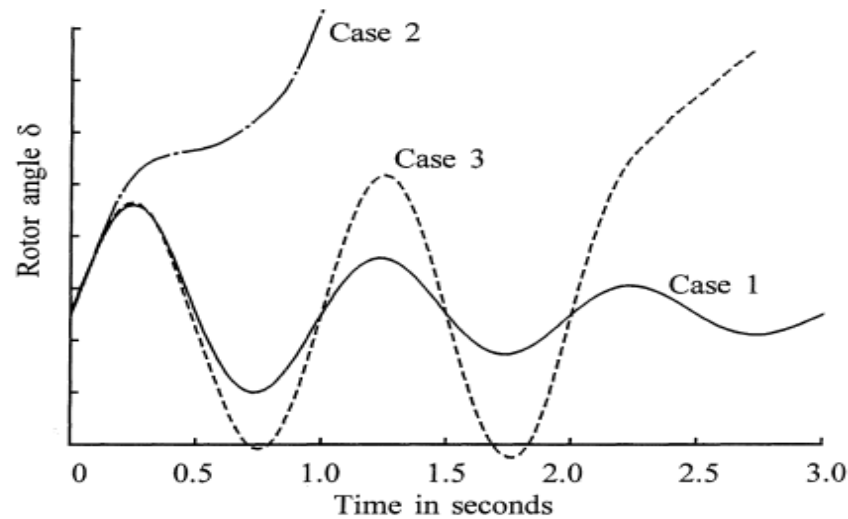


Fig. 1: Rotor Angle Response to a Transient Disturbance

The given figure shows the rotor angle response for two unstable states and one stable state.

Usually the rotor angle stability concerns with the stability of synchronous generator as it is considered the heart of power system. It refers to the capability of synchronous machine to remain in synchronism after being attributed to a disturbance. If the disturbance is close to the generator, the generator can collapse of step as it has been accelerated during fault[2].

Case (1) represents the stable state because rotor angle oscillates between maximum and minimum values until reaches stable state. Case (2) represents the unstable state because rotor angle continue to increase until loss of synchronism and it is called first swing. In case(3) ,the system is stable in first swing but becomes unstable due to consequent oscillations[3].

The first swing is not always responsible for system instability because the system is stable at first and then superposition of several modes of oscillations resulting large trips of rotor angles beyond to first swing.

Modern developments of power electronics put in the employ of flexible A.C transmission system (FACTS) controllers in power system.

The unified power flow controller (UPFC) is the most many sided device in the FACTS types which can furnish an efficient control of power system parameters such as transmission voltage , line impedance and phase angle . Furthermore, UPFC can provide either negative or positive real and reactive power injections. So, they can enhance system operation because it allows for more efficient control of power flow, superior control system and voltage stability. In order to get all these benefits an accurate procedures for optimal location and parameter settings of UPFC is studied taking into consideration the enhancement of system transient stability

2.UPFC Mathematical Modeling:

A UPFC usually consists of two voltage source converters representing fundamental components of output voltages of the two converters with impedances of two coupling transformers as shown [4].

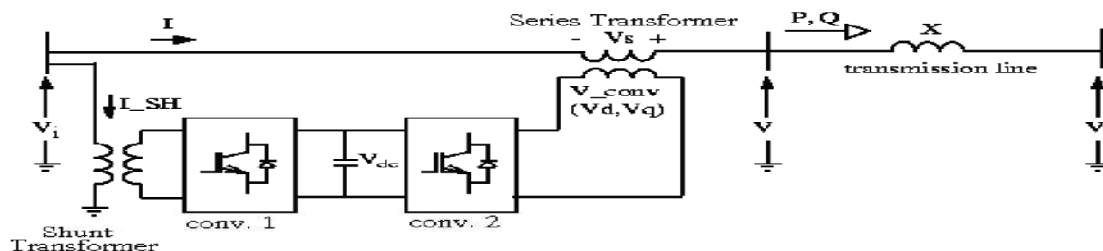


Fig. 2: Single Line Diagram of the UPFC

The series voltage source converter produce the main function of UPFC. Suppose that a series voltage source is connected between two buses *i* and *j* in certain network. The series voltage source is modeled as an ideal voltage source in series with a reactance X_{se} as shown.

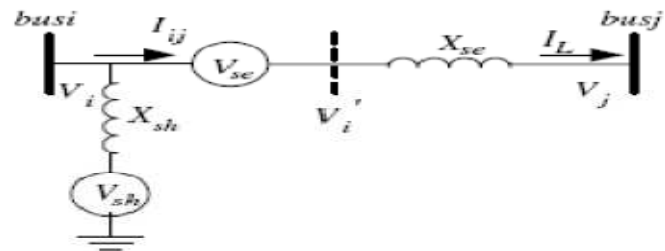


Fig. 3: Equivalent Model of UPFC Between Two Buses

The series voltage is controllable in both magnitude and phase. So, V_{se} can be defined as

$$V_{se} = r V_i e^{j\gamma} \quad (1)$$

r and γ represent the control variables of series voltage component with the range $(0 \ll r \ll \max)$. And $(0 \ll \gamma \ll 2\pi)$. The UPFC injection model is produced by replacing the voltage source in parallel with the line. We have

$$I_{se} = -jb_{se} V_{se} \quad (2)$$

$$b_{se} = \frac{1}{X_{se}} \quad (3)$$

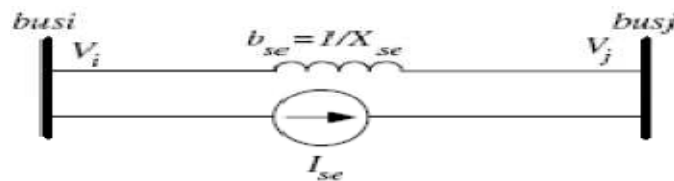


Fig. 4: Modeling of Series Voltage Source into an Equivalent current source

Therefore, the injected power at buses (i) and (j) are

$$S_{is} = V_i (-I_{se})^* \quad (4)$$

$$S_{js} = V_j (I_{se})^* \quad (5)$$

The injected power can be simplified by substituting I_{se} and V_{se}

$$S_{is} = V_i (j b_{se} r V_i e^{j\gamma})^* \quad (6)$$

According to Euler's identity, which states that

$$e^{j\gamma} = \cos \gamma + j \sin \gamma \quad (7)$$

And eq. (6) takes the form

$$S_{is} = V_i (e^{-j(\gamma+90)} j b_{se} r V_i)^* \quad (8)$$

$$S_{is} = V_i b_{se} r \{ \cos(-\gamma - 90) + j \sin(-\gamma - 90) \} \quad (9)$$

And it reduces to

$$S_{is} = -r b_{se} V_i^2 \sin \gamma - j r b_{se} V_i^2 \cos \gamma \quad (10)$$

This equation can be separated into series real and imaginary part

$$S_{is} = P_{is} + j Q_{is} \quad (11)$$

$$P_{is} = -r b_{se} V_i^2 \sin \gamma \quad (12)$$

$$Q_{is} = -r b_{se} V_i^2 \cos \gamma \quad (13)$$

Similar equations can be obtained in bus (j), and it takes the form

$$S_{js} = V_i V_j b_{se} r \sin(\theta_i - \theta_j + \gamma) + j V_i V_j b_{se} r \cos(\theta_i - \theta_j + \gamma) \quad (14)$$

As $S_{js} = P_{js} + j Q_{js}$, therefore

$$P_{js} = V_i V_j b_{se} r \sin(\theta_i - \theta_j + \gamma) \quad (15)$$

$$Q_{js} = V_i V_j b_{se} r \cos(\theta_i - \theta_j + \gamma) \quad (16)$$

So, according to the given equations the power injection of the series connected voltage source can be represented as two independent power injections at buses (i) and (j) as shown.

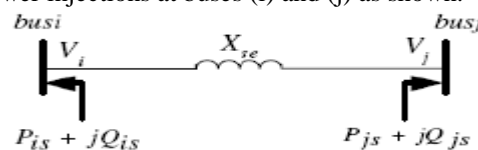


Fig. 5: Equivalent power injection of shunt branch at bus i Equivalent power injection of series branch at bus j

The apparent power by the series converter is calculated as

$$S_{series} = V_{se} I_{ij}^* = r V_i e^{j\gamma} \frac{(V_i - V_j)^*}{jX_{se}} \quad (17)$$

$$P_{series} = V_i V_j b_{se} r \sin(\theta_i - \theta_j + \gamma) - r b_{se} V_i^2 \sin \gamma \quad (18)$$

$$Q_{series} = -V_i V_j b_{se} r \cos(\theta_i - \theta_j + \gamma) + r b_{se} V_i^2 \cos \gamma + r^2 b_{se} V_i^2 \quad (19)$$

In this model, the reactive power delivered or absorbed by converter 1 is not considered in this model. Its main function is to keep the voltage level at bus j within acceptable value. Q_{shunt} is assumed to be equal to zero.

The elements of the equivalent power injections including losses are

$$P_{i,UPFC} = 0.02 r b_{se} V_i^2 \sin \gamma - 1.02 V_i V_j b_{se} r \sin(\theta_i - \theta_j + \gamma) \quad (20)$$

$$P_{j,UPFC} = V_i V_j b_{se} r \sin(\theta_i - \theta_j + \gamma) \quad (21)$$

$$Q_{i,UPFC} = -r b_{se} V_i^2 \cos \gamma \quad (22)$$

$$Q_{j,UPFC} = V_i V_j b_{se} r \cos(\theta_i - \theta_j + \gamma) \quad (23)$$

The elements of the equivalent power injections without losses are

$$P_{i,UPFC} = V_i V_j b_{se} r \sin(\theta_i - \theta_j + \gamma) \quad (24)$$

$$P_{j,UPFC} = -V_i V_j b_{se} r \sin(\theta_i - \theta_j + \gamma) \quad (25)$$

$$Q_{i,UPFC} = -r b_{se} V_i^2 \cos \gamma \quad (26)$$

$$Q_{j,UPFC} = -V_i V_j b_{se} r \cos(\theta_i - \theta_j + \gamma) \quad (27)$$

Depending on these equations, an injected active and reactive power are calculated and they represent part of UPFC design values. Also these values can be used in simulation of the studied network for the purpose of transient stability [5].

3. Identification of Weakest Load Bus Using ($\frac{dS}{dY}$) Factor:

Consider the given simplified circuit of local load bus and the rest of the system is treated as thevenin equivalent circuit. This is a representative of simple radial feed to load which serves a certain large system through a transmission line [6].

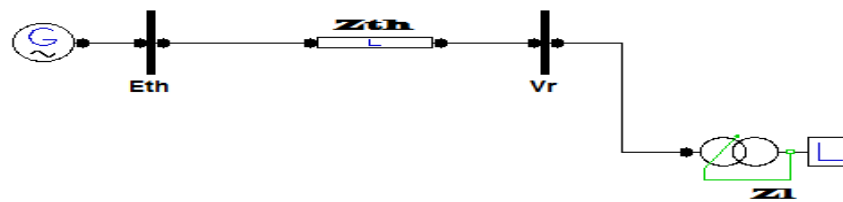


Fig. 6: Simplified Thevenin Equivalent Circuit of a Local Bus

The magnitude of current is given by:

$$I = \frac{E_{th}}{\sqrt{(Z_{th} \cos \theta + Z_l \cos \phi)^2 + (Z_{th} \sin \theta + Z_l \sin \phi)^2}} \quad (28)$$

And this may be simplified as:

$$I = \frac{E_{th}}{\sqrt{Z_{th}^2 + Z_l^2 + 2 Z_{th} Z_l \cos(\theta - \phi)}} \quad (29)$$

Where:

θ = phase angle of impedance Z_{th} and ϕ = phase angle of impedance Z_l

The receiving end voltage of the system is given by

$$V_r = Z_l I = \frac{E_{th} Z_l}{\sqrt{Z_{th}^2 + Z_l^2 + 2 Z_{th} Z_l \cos(\theta - \phi)}} \quad (30)$$

The apparent power supplied to the load is

$$S = V_r^2 Y \quad \text{where } Y = \frac{1}{Z_l}$$

Therefore

$$S = \frac{E_{th}^2 Z_l}{Z_{th}^2 + Z_l^2 + 2 Z_{th} Z_l \cos(\theta - \phi)} \quad (31)$$

The increase in load leads to an incremental value of load admittance until reaching maximum. For higher load demand, the action is different and unstable load variation is present with increase of load.

So, taking the derivative of apparent power S with respect to admittance Y results

$$\left(\frac{dS}{dY}\right) = \frac{Eth^2(1 - Y^2Zth^2)}{(1 + Y^2Zth^2 + 2ZthY \cos(\theta - \phi))^2} \quad (32)$$

For maximum load condition, $\left(\frac{dS}{dY}\right) = 0$ leads to the solution for critical voltage instability point when $Zth = Z_l$ (33)

The same result is obtained when the condition of maximum load apparent power is written as

$$\left(\frac{dS}{dZ_l}\right) = 0 \text{ leads to the same criterion of } Zth = Z_l. [7]$$

From eq. (32) it is clear that the factor $\left(\frac{dS}{dY}\right)$ depends on Thevenin parameters and also load admittance power factor. Since the factor $\left(\frac{dS}{dY}\right)$ equals unity at no load ($Y=0$) due to $Eth^2 \cong 1$ and equals zero at critical maximum load when $Zth = Z_l$, it is more accurate to use the factor $\left(\frac{dS}{dY}\right)$ for calculation operating points and identify the operating conditions of the system. Points below the maximum loading represent the favorable operating conditions. Therefore the factor $\left(\frac{dS}{dY}\right)$ can be used for the identification of weakest load bus and as a result the optimal location of FACT device. The load is increased slightly and the factor $\left(\frac{dS}{dY}\right)$ is calculated.

The suggested method can be used for on-line monitoring of electrical power system for identification of weakest load bus by collection of data from electrical load centers. In this paper the required data is provided by imperceptible increase in electrical bus load. The calculation is based on loading the three load buses (5, 7, 9) from normal loading to (1.5) loading in steps of 10% increase in load. IEEE-9 bus system is shown in fig. (6). It consists of three generators and three load buses and system data is given in appendix and the network is modeled using power world simulator program which will be explained in section (5). Generator (1) is selected as the slack bus.

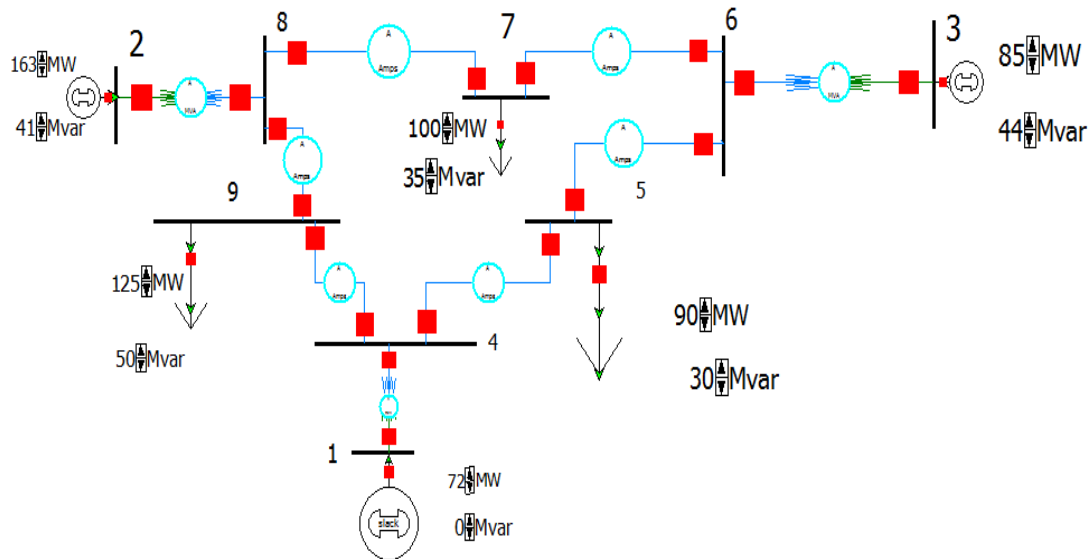


Fig. 7: IEEE 9-Bus Network

In each step the factor $\left(\frac{dS}{dY}\right)$ is calculated as it equals:

$$\left(\frac{dS}{dY}\right) = \frac{S_2 - S_1}{Y_2 - Y_1} \quad (34)$$

The results are listed in the given table below:

Table 1: $\left(\frac{dS}{dY}\right)$ Variation of IEEE 9-Bus with Bus Loading

BUS NO.	BUS LOADING				
	10%	20%	30%	40%	50%
5	0.906	0.9054	0.8634	0.8571	0.8317
7	0.9018	0.8858	0.8855	0.8506	0.8294
9	0.8424	0.795	0.7545	0.7447	0.7231

It is clear from the results in the table given that load bus (9) is the weakest bus in the system and represent the best location for UPFC placement. A graph is plotted in fig. (7) represents the relation between $\left(\frac{dS}{dY}\right)$ factor and different load bus loading which indicates the same conclusion.

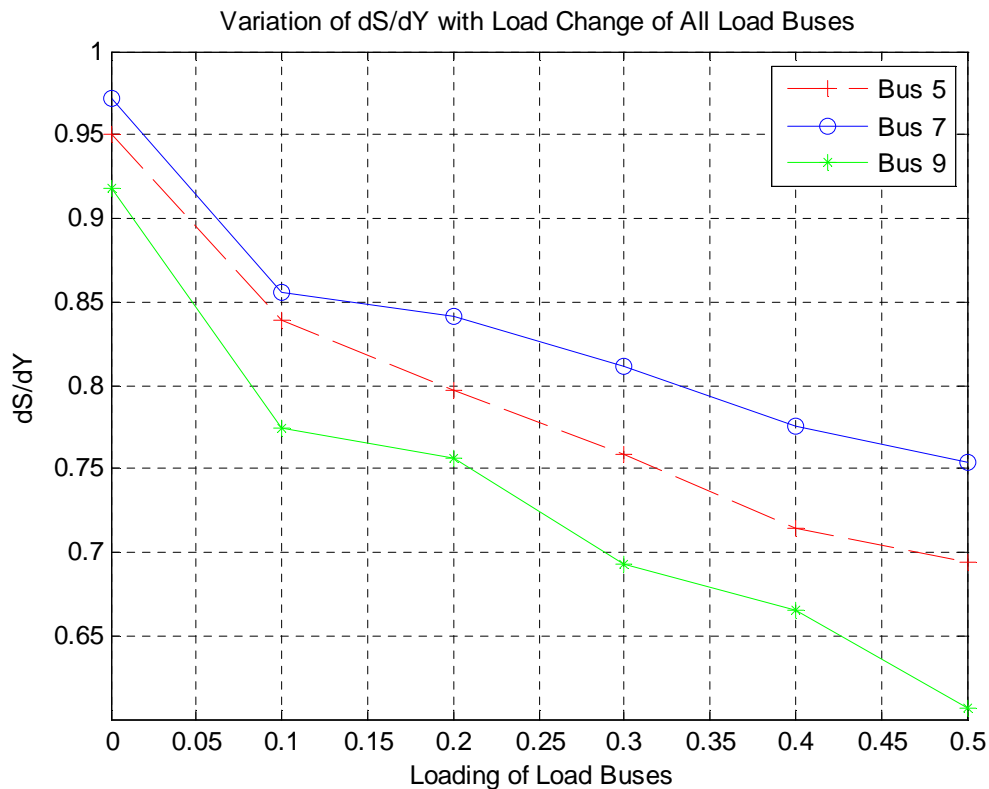


Fig. 8: Variation of $\left(\frac{dS}{dY}\right)$ Factor with Bus Loading

4. Determination of UPFC Parameters:

Power system solution is iterative using load flow methods. So, it is important to estimate initial values as starting points for the solution. A Newton - Raphson power flow program is used to calculate the unknowns of the system with the inclusion of UPFC. As the magnitude of the series-injected voltage decide the controlled power flow, it is necessary to specify initial values of this voltage. [8]

Let P_{sp} and Q_{sp} are specified active and reactive power at bus i , and assuming $V_i = 1$ p.u then the values of estimated series voltage (r and δ) according to equations (12) and (13) are:

$$r = \frac{1}{b_{se}} \sqrt{(P_{sp}^2 + Q_{sp}^2)}, \text{ and} \quad (35)$$

$$\gamma = \tan^{-1} \frac{P_{sp}}{Q_{sp}} \quad (36)$$

Assuming the value of $\left(\frac{1}{b_{se}}\right)$ equals 0.1 p.u, then the initial values of r and γ are calculated and used as input values in the program. The shunt voltage source is not a critical matter and the value of initial V_{sh} equals 1 p.u with zero angle and these values are not fixed as they are updated at each iteration. The solution stopped when the values of series and shunt voltages are out of their prescribed limits. The program used incorporate the UPFC model within Newton-Raphson power flow program. The given flowchart represents the procedure of design. [9]

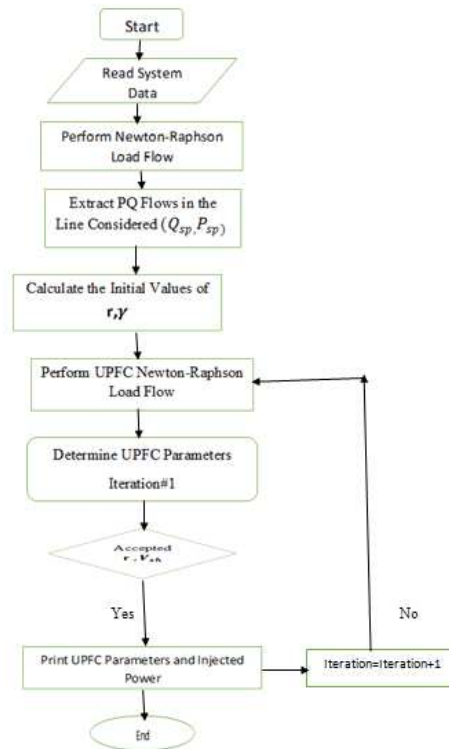


Fig. 9: Flow Chart of UPFC Design Procedure

It should be noted that:

- ❖ When implementing the program, iteration is increased one at each step and ensure that the values of r, V_{sh}, δ are within acceptable limits.
- ❖ The results includes injected power on buses and line flows between buses and other information needed for selection of suitable UPFC.

5. Simulation of Power System Using Power World Simulator:

This is a platform to simulate power systems in an easy manner. Its graphical user interface makes it easy to use. There are two modes of operation of the simulator. The Edit Mode and Run Mode. In the first one it is possible to create a new system, modify or edit it. In the second simulations can be performed as if it were a true system. [10]

6. How to Module UPFC in Power World Simulator:

The UPFC consists of two voltage source converters (VSCs) in order to provide dynamic and static compensation of A.C transmission systems.

The series converter which is usually operated as a SSSC provides the main function of UPFC. It injects active and reactive power to the network using injected series voltage at system frequency controlled in magnitude and phase. The UPFC series converter is modeled by a negative resistance which represents the injected active power of series converter to the network and the injected reactive power is modeled by an inductive or capacitive reactance. [11]

Consider the following figure which represent the UPFC in two-bus network one machine module as shown.

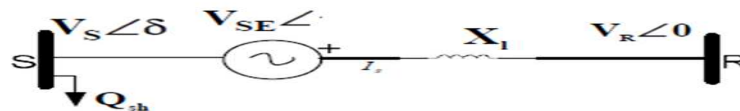


Fig. 10: UPFC in Two-Bus Network

The current flowing in the line is calculated

$$I = \frac{V_S \angle \delta + V_{se} \angle \gamma - V_R \angle 0}{jX_l} \quad (37)$$

And the apparent power injected by the series converter is expressed as:

$$S_{se} = V_{se} * I^* \quad (38)$$

Where (V_{se}) represents the series injected voltage $(r \angle \gamma)$. So, the active and reactive power injected by series converter are

$$P_{se} = \frac{V_s * V_{se}}{X_L} \sin(\delta - \gamma) + \frac{V_r * V_{se}}{X_L} \sin(\gamma) \quad (39)$$

$$Q_{se} = \frac{V_s * V_{se}}{X_L} \cos(\delta - \gamma) - \frac{V_r * V_{se}}{X_L} \cos(\gamma) + \frac{V_{se}^2}{X_L} \quad (40)$$

The given figure represents the modelling of active and reactive power by a parallel combination of resistance and reactance.

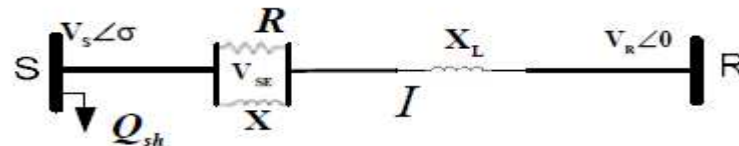


Fig. 11: Modeling of Series Converter

And the values of resistance and reactance are

$$R = \frac{V_{se}^2}{P_{se}} = \frac{V_{se} * X_L}{V_s \sin(\delta - \gamma) + V_r \sin(\gamma)} \quad (41)$$

$$X = \frac{V_{se}}{Q_{se}} = \frac{V_{se} * X_L}{V_s \cos(\delta - \gamma) - V_r \cos(\gamma) + V_{se}} \quad (42)$$

The simulation of this module is performed by converting parallel elements to series elements as shown.

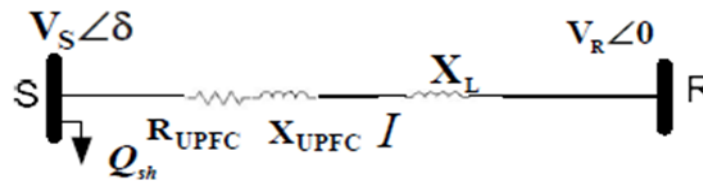


Fig. 12: Modeling of the UPFC in Two-Bus Network

And the impedances related to this representation are

$$R_{UPFC} = \frac{R * X^2}{R^2 + X^2} \quad (43)$$

$$X_{UPFC} = \frac{X * R^2}{R^2 + X^2} \quad (44)$$

Therefore, using the values of series injected voltages, buses voltages, and the active and reactive power of series converter, the values of resistance and reactance are calculated and implemented in power world simulator program .The values of active and reactive power of series converter are part of the mat lab program used for the solution of the network.

5.IEEE 9-Bus with UPFC Simulation and Results:

The insertion of UPFC in 9 IEEE Bus network is studied based on the procedures discussed in the previous chapters. A load-flow mat lab program with and without UPFC is produced for the purpose of comparison. This network is modeled using power world simulator with and without UPFC to implement transient stability study.

5.2 Design Specification of UPFC Parameters:

According to design procedure, active and reactive power must be specified based on load flow results in the weakest bus line and calculation of related (r, γ) is performed. The line flows between the weakest bus and other load buses is useful in power specification .The given table shows the branch data from load flow results of 9-bus without UPFC.

Table 2: Branch Data of 9-Bus without UPFC

Branch No.	From Bus	To Bus	P(MW)	Q(MVAR)
1	1	4	71.7	27.1
2	2	8	163	7.2
3	6	3	-85	15.5
4	4	5	30.8	0.9
5	9	4	-40.6	-38.8
6	5	6	-59.3	-13.6
7	7	6	-24.2	-23.7
8	8	7	76.3	-0.1
9	8	9	86.7	-8.5

Now, considering branch (5) of line (9-4) the values of (Q_{sp}, P_{sp}) and the related (r, γ) according to equations (35) and (36) are given in the following table.

Table 3: Specified Values of UPFC Parameters

P_{sp} (p. u)	Q_{sp} (p. u)	r	γ (deg.)
-0.5	-0.5	0.07071	45

These values are used as input data in mat lab program which its solution gives the designed values of different UPFC parameters needed and helps in providing the data for simulation. The program is executed for three iterations.

Table 4: UPFC Parameters for IEEE 9-Bus

Item	Iteration#1	Iteration#2	Iteration#3
Series Voltage $r \perp \gamma$	$r=0.0707$ $\gamma=-44.9967$	$r=0.0344$ $\gamma=-172.6892$	$r=0.0862$ $\gamma=56.4366$
Shunt Voltage $V_{sh} \perp \Theta$	$V_{sh}=1$ $\Theta=0$	$V_{sh}=0.9422$ $\Theta=1.4524$	$V_{sh}=0.9522$ $\Theta=1.7315$
Series Active Power (p. u)	-----	$P_{cr}=0$	$P_{cr}=-0.0324$
Series Reactive Power (p. u)	-----	$Q_{cr}=0.05$	$Q_{cr}=-0.0039$
Shunt Active Power (p. u)	-----	$P_{vr}=0$	$P_{vr}=-0.0638$
Shunt Reactive Power (p. u)	-----	$Q_{vr}=0$	$Q_{vr}=-0.5443$

Using the results obtained for the parameters of series converter, the values of R_{UPFC} and X_{UPFC} are calculated according to equations (41), (42), (43) and (44) as listed below.

Table 5: UPFC Equivalent Parameters for Simulation

R (p. u)	X (p. u)	R_{UPFC} (p.u)	X_{UPFC} (p. u)
-0.2293	-1.9052	-0.22601	-0.0272

The application of the previous UPFC equivalent parameters is done using power world simulator as this program provides all the futures needed for load flow study and transient stability study.

6. Transient Stability Study of IEEE 9-Bus Network:

The enhancement of power system stability is implemented by insertion of UPFC in the weakest bus and then studied by using power world simulator program. The simulation is implemented by insertion the values of R_{UPFC} and X_{UPFC} in the line connecting between load buses (9) and (4). Different types of faults are purpose of using UPFC is to applied in different places of the network as shown below.

6.1 Three-Phase Fault in Line (8-9):

A three phase fault is applied in line (8-9) at ($t_f=1$ sec.) and the fault is cleared and the system is returned to its previous state at $t_{cr}=1.2$ sec. The rotor angles for three generators are drawn without and with UPFC.

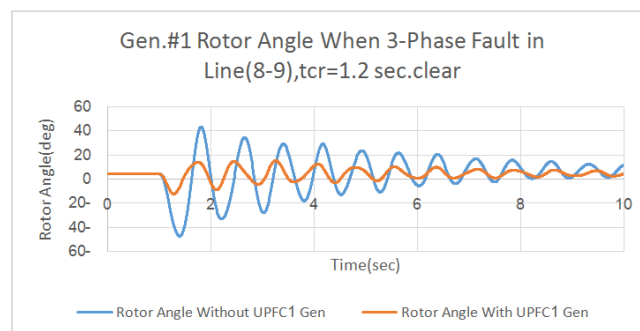


Fig. 13: Gen. #1 Rotor Angle $t_{cr}=1.2$ sec.

The following figure shows Gen. #1 rotor angle when fault is cleared by opening the line at $t_{cr}=1.15$ sec.

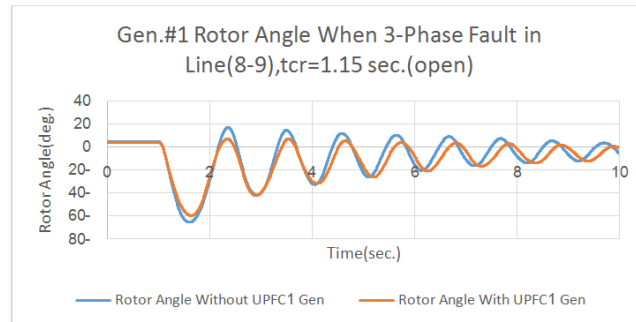


Fig. 14: Gen. #1 Rotor Angle $t_{cr}=1.15$ sec. (open)

The following figure shows Gen. #1 rotor angle when fault is cleared by opening the line at $t_{cr}=1.16$ sec.

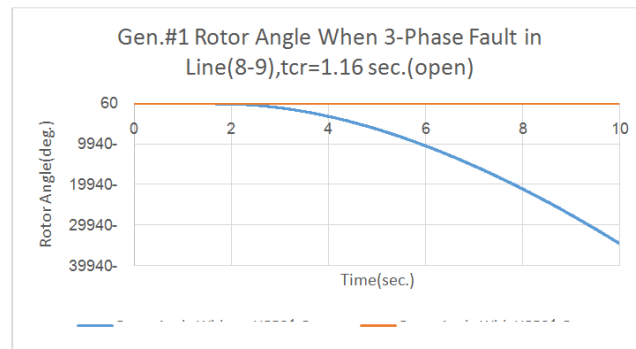


Fig. 15: Gen. #1 Rotor Angle $t_{cr}=1.16$ sec. (open)

From the given figures it is clear that there is an enhancement of rotor angle of Gen. #1 especially in fig. (15) which shows the loss of stability without UPFC at $t_{cr}=1.16$ sec and fault is cleared by opening the line (8-9). The same is done for generator (2) and (3).

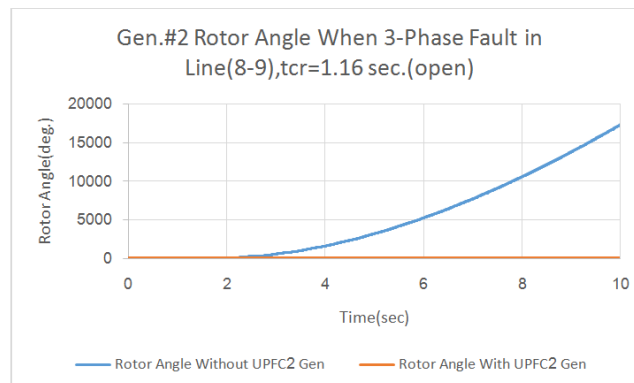


Fig. 16: Gen. #2 Rotor Angle $t_{cr}=1.16$ sec. (open)

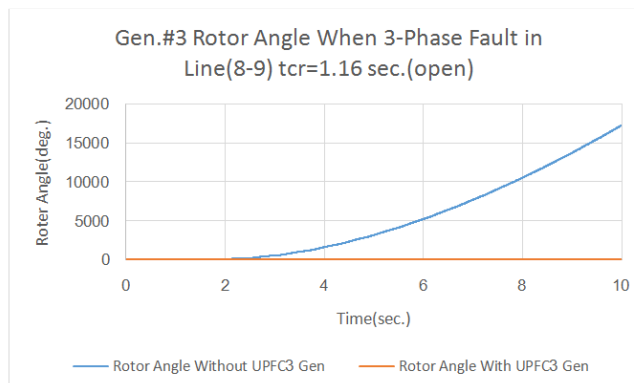


Fig. 17: Gen. #3 Rotor Angle $t_{cr}=1.16$ sec. (open)

6.1 Three Phase Fault in Bus(8):

The given figures show the rotor angles of generators when three-phase fault occurs in bus (8).

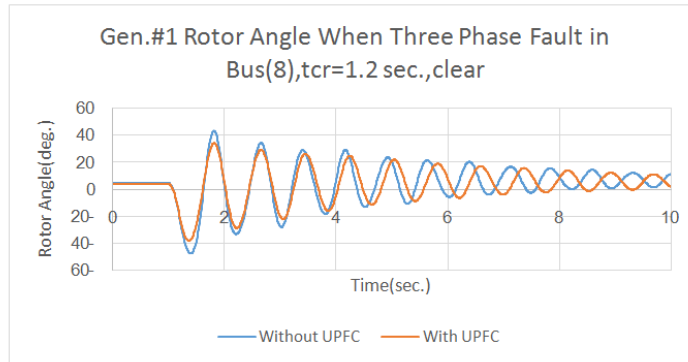


Fig. 18: Gen. #1, Rotor Angle $t_{cr}=1.2$ sec.

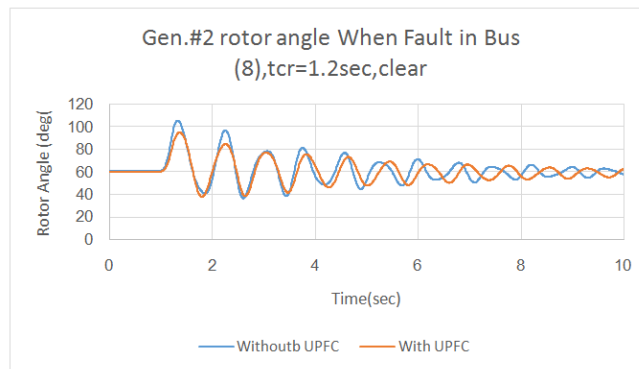


Fig. 19: Gen. #2, Rotor Angle $t_{cr}=1.2$ sec.

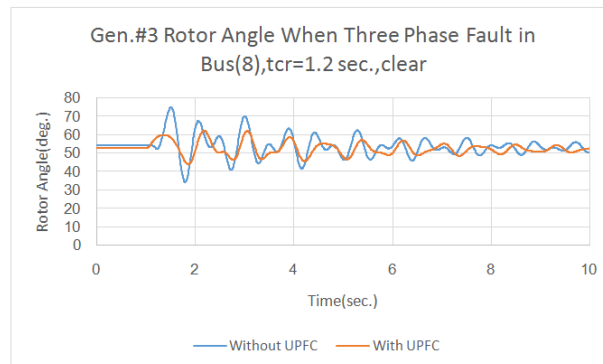


Fig. 20: Gen. #3, Rotor Angle $t_{cr}=1.2$ sec.

When the fault at bus(8), this fault is cleared by reclosing of bus(8) to the network. The reduction in rotor angles of the three generators is obvious and represents an enhancement in rotor angle stability. Power world simulator program provides the capability of implementation of any other type of fault and at any position in the system.

Conclusions:

This paper discussed the transient stability study of IEEE 9 bus network with the insertion of UPFC fact devices. Facts represent an incremental importance in electrical power systems and it is necessary to study transient stability with UPFC fact device. The results obtained show the enhancement in rotor angle of the three generators when using this device. Figures 15, 16 and 17 show the loss of stability for the three generators without UPFC and the stable states with UPFC. The design consideration of UPFC and accurate simulation using power world simulator helps in studying stability for any disturbance. Power world simulator provides a lot of tools for this purpose such as applying disturbances in generators, buses and transmission lines. A lot of

parameters to be studied such as active and reactive and reactive power,frequency,bus voltages and other parameters.The placement of UPFC based on an accurate procedures is important in implementing power system stability study.

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Appendix

Implemented 9-Bus System Data

Table (A.1): IEEE 9-Bus Data

Bus No.	V (p.u)	P _i (MW)	Q _i (MVAR)	P _G (MW)
1	1.04	0	0	-
2	1.025	0	0	163
3	1.025	0	0	85
4	1	0	0	0
5	1	90	30	0
6	1	0	0	0
7	1	100	35	0
8	1	0	0	0
9	1	125	50	0

Table (A.2): IEEE 9-Bus Line Data

From Bus	To Bus	Voltage Rating (KV)	Frequency Rating(Hz)	R (p.u)	X (p.u)	B (p.u)
1	4	16.5	60	0	0.0576	0
8	2	18	60	0	0.0625	0
3	6	13.8	60	0	0.0586	0
4	5	230	60	0.017	0.092	0.158
5	6	230	60	0.039	0.17	0.358
6	7	230	60	0.0119	0.1008	0.209
7	8	230	60	0.0085	0.072	0.149
8	9	230	60	0.032	0.161	0.306
9	4	230	60	0.01	0.085	0.176

Table (A.3): IEEE 9-Bus Machine Data

Item	Generator Number		
	Generator #1	Generator#2	Generator #3
Power Rating(MW)	0.0	163	85
Machine Module	Active-GENROU	Active-GENROU	Active-GENROU

H	4.728	2.56	3.01
D	0.9456	0.0	0.0
Ra	0.0	0.0	0.0
Xd	0.73	2.2395	1.3125
Xq	0.4845	2.161	1.2578
Xdp	0.304	0.2995	0.1813
Xqp	0.4845	0.4992	0.25
Xdpp	0.304	0.225	0.15
X1	0.152	0.15	0.12
Tdop	8.96	6.0	5.89
Tqop	8.0	0.535	0.6
Tdopp	0.31	2.0	2.0
Tqopp	0.31	2.0	2.0

Table (A.4): IEEE 9-Bus Exciter Model

Item	Generator Number		
	Generator #1	Generator#2	Generator #3
Exciter Module	Active-IEEET1	Active-IEEET1	Active-IEEET1
Tr	0.0	0.0	0.0
Ka	20	20	20
Ta	0.0	0.0	0.0
Vrmax	3.0	3.0	3.0
Vrmin	-3.0	-3.0	-3.0
Ke	1.0	1.0	1.0
Te	2.0	2.0	2.0
Kf	0.063	0.063	0.063
Tf	2.0	2.0	2.0
E1	2.8	2.8	2.8
SE1	0.3034	0.3034	0.3034
E2	3.73	3.73	3.73
SE2	1.2884	1.2884	1.2884