Australian Journal of Basic and Applied Sciences, 10(14) September 2016, Pages: 185-195

AUSTRALIAN JOURNAL OF BASIC AND APPLIED SCIENCES

ISSN:1991-8178 EISSN: 2309-8414
Journal home page: www.ajbasweb.com

Adaptive Neural Fuzzy Inference System Voltage Stability Margin Prediction Model for IEEE 9 Bus System with UPFC

[1]Dr. Rasheed Hameed Al-Rubaiy and [2]Waleed Khalid Al-Jubori

[1]*University of Technology, Electrical Engineering Department*
[2]*Al-Furat Al-Awsat Technical University, Al-Musaib Technical College*

Address For Correspondence:
Dr. RasheedHameed, Al-Rubaiy, University of Technology, Electrical Engineering Department
E-mail: Dr.Rashid 56@yahoo.com

ARTICLE INFO

Article history:
Received 26 July 2016
Accepted 21 September 2016
Published 30 September 2016

Keywords:
ANFIS,voltage stability, UPFC model, UPFC control modes,voltage stability margin.

ABSTRACT

This paper deals with building an Adaptive Neural Fuzzy Inference System (ANFIS) voltage stability margin prediction model for IEEE 9 Bus 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 power and voltage stability of the network. In this paper the optimal location and parameter setting 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 ANFISprediction model have been done using the data set provided by UPFC control modes from MATLAB program as an input data and the corresponding values of voltage stability margin as output data. This model is useful for power system stability prediction for any value of input data.

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 with any reduction of system security and quality of supply. Modern developments of power electronics put in the employ of flexible A.C transmission system (FACTS) controllers in power system. (PoonamSinghal, S.K. Agarwal and NarenderKumar, 2014)

The unified power flow controller (UPFC) is the most many sided devices in the FACTS types which can furnish an efficient control of power system parameters such as transmission voltage, line impendence 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 procedure for optimal location and parameter settings of UPFC is studied taking into consideration the enhancement of power system stability, mainly voltage stability.

ANFIS have been recently one of the wide spread applications as it provides the distance from current operating point at any time to the critical point. It should be taking in consideration that the success of ANFIS

ToCite ThisArticle: Dr. Rasheed Hameed Al-Rubaiy and Waleed Khalid Al-Jubori., Adaptive Neural Fuzzy Inference System Voltage Stability Margin Prediction Model for IEEE 9 Bus System with UPFC. ***Aust. J. Basic & Appl. Sci.,*** *10(14): 185-195, 2016*

applications depends on the selecting highly important features which leads to an efficient ANFIS. (Ramkumar, V., S. Baghya. Shree, 2014)

2.UPFC Mathematical Modelling:

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. (Payam Farhadi, et al., 2013)

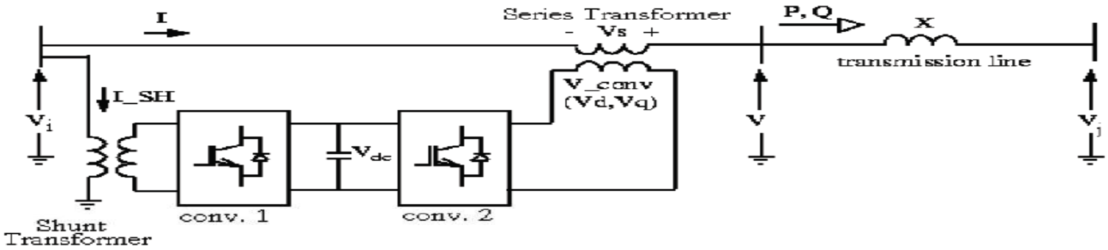

Fig. 1: Single Line Diagram of the UPFC

The series voltage source converter produces 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 modelled as an ideal voltage source in series with a reactance X_{se} as shown.

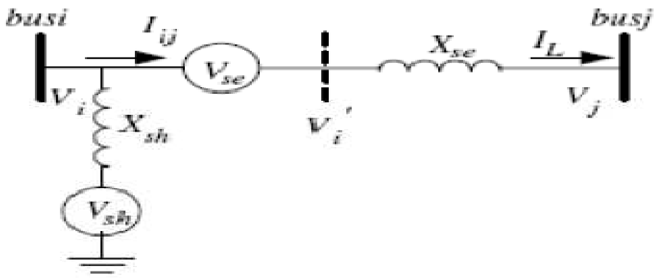

Fig. 2: Equivalent model of UPFC between two buses

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

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

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

I_{se}= -j$b_{se}V_{se}$ (2)

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

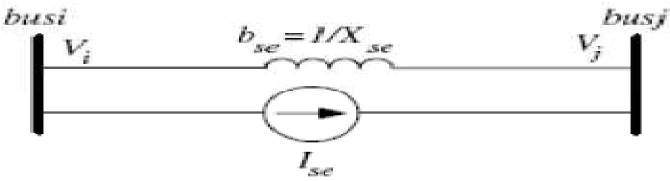

Fig. 3: Modeling of Series Voltage Source into anEquivalent current source

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

S_{is}= V_i (-I_{se})* (4)

S_{js}=V_j (I_{se})* (5)

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

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

According to Euler's identity, which states that

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

And eq. (2.6) takes the form

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

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

And it reduces to

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

Australian Journal of Basic and Applied Sciences, 10(14) September 2016, Pages: 185-195

This equation can be separated into series real and imaginary part

S_{is}=P_{is}+ j Q_{is} , (11)

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

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

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

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

As S_{js} =P_{js} + jQ_{js} , therefore

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

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

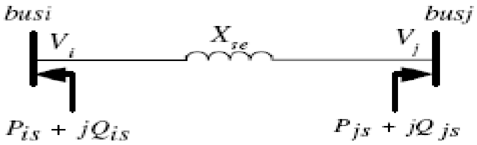

Fig. 4: Equivalent power injectionEquivalent power injectionof shunt branch at busiof series branch at bus j

The apparent power by the series converter is calculated as

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

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

Q_{series}= - $V_i V_j b_{se}$r $\cos(\theta_i - \theta_j + \gamma)$+ r $b_{se}{V_i}^2 \cos\gamma$ +$r^2 b_{se}{V_i}^2$ (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 $\sin(\theta_i - \theta_j + \gamma)$ (20)

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

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

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

The elements of the equivalent power injections without losses are

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

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

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

$Q_{j,UPFC} = -V_i V_j b_{se}$r $\cos(\theta_i - \theta_j + \gamma)$ (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 voltage stability. (MeteVural, A., Mehmet Tumay, 2007)

3. Identification of Weakest Load Bus Using Voltage Stability Margin:

When studying voltage stability for the purpose of bus identification, it is clear that there are two approaches to resolving this problem of power system. The first is static and the second one is dynamic. Usually P-V and Q-V tools represent a static approach and as a result represent the static voltage stability limit. It is more precise to use the dynamic approach in order to support the weakest load bus identification by using different loading conditions. (Mahdi, M.M. El-arini, Raef S.S. Ahmed)

Voltage Stability Margin represents an indicator for stability state. This indicator depends on critical apparent power in a certain load with respect to its normal value in specified operating conditions: (Prof. Rai, D.K., 2012)

$(VSM)_k = \frac{(S_k^{cr} - S_k^{\circ})}{S_k^{cr}}$ (28)

In order to estimate the relation of critical bus loading, it is useful to use the V-I polynomial equation which is described below:

Let the relation between voltage and current in a certain load bus represented by the following m^{th}order polynomial:

V= f (I) =a_0+$a_1 I$+a_2I²+……………… +$a_m I^m$ (29)

Since the apparent power is the product of voltage and current magnitudes, it equals;

S=V I=f_i (I) = $a_0 I$+$a_1 I^2$+$a_2{}^3$+……………. +$a_m I^{m+1}$ (30)

The maximum condition is written as

$\frac{\partial S}{\partial I} = 0$ Which leads to the equation below

$a_0+2a_1I+3a_2{}^{2}+\ldots\ldots\ldots\ldots\ldots\ldots (m+1)a_mI^m=0$ (31)

The solution of this equation gives the value of maximum critical current and as a result the critical apparent power is function of this current, means:

$S^{cr} = f_i\,(I^{cr})$ (32)

So, these relations are used to calculate the critical apparent power in each load bus. Different loading conditions with power flow studies give a specific values of current coefficients. Also these values can be found in power system planning center. In this thesis the loading of load buses is used.

In matrix form, the V-I polynomial can be written as

$$\begin{bmatrix} 1 & I_1 \ldots\ldots & I_1^m \\ 1 & I_2 \ldots\ldots & I_2^m \\ 1 & I_k \ldots\ldots & I_k^m \end{bmatrix} \begin{bmatrix} a_\circ \\ a_1 \\ a_m \end{bmatrix} = \begin{bmatrix} V_1 \\ V_2 \\ V_k \end{bmatrix} \quad (33)$$

Let AX=B (34)

Once the coefficients of polynomial or vector X is calculated from the solution of this matrix, the critical load and Voltage Stability Margin can easily determine.

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. (Enrique Acha, et al., 2014)

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

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

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

Assuming the value of $(\frac{1}{b_{se}})$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 valuesare not fixed as they are updated at eachiteration. 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.

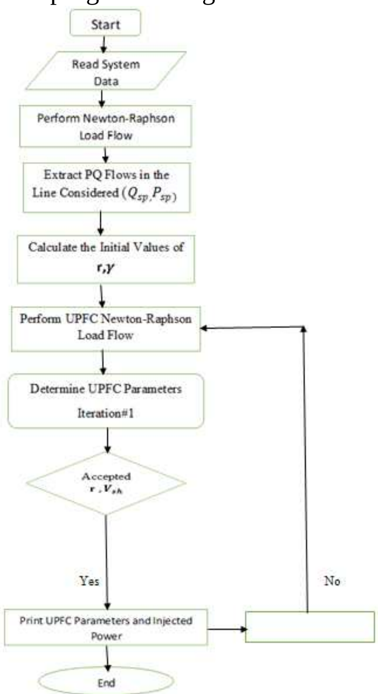

Fig. 5: Flow Chart of UPFC Design Procedure

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 include injected power on buses and line flows between buses and other information needed for selection of suitable UPFC.
- The program provides the facility of using more than one UPFC in the system which helps in more accurate result.

5. Simulation of Power System Using Power World Simulator:

Power world simulator 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. (Thomas Jove bye, 2001)

6. Different UPFC Operating Modes:

The UPFC Newton-Raphson model provides the ability of controlling its constraints simultaneously or individually or in combination. (Prakash G. Burade, Dr. Jagdish B. Helonde, 2012).

The normal operation of UPFC means all constraints are stimulated. These constraints are active and reactive power, voltage magnitude. Another case is control active and reactive power while the voltage magnitude is fixed and so on. The given table shows these different control modes. These modes ensured that the main purpose of installing UPFC in the system is providing the ability of power flow and voltage regulation at the point UPFC connected.

Table 1: UPFC Control Modes

Mode	UPFC Control Variables States
1	Normal UPFC Operation(all variables activated)
2	Control Line Active and Reactive Power(V_{vr}=0)
3	Control Line Active and Reactive Power (V_9=original=0.9955)

The values of constraints indicated are implemented in the program and results are obtained and compared.

The results obtained for each mode are useful in developing an Adaptive Neural Fuzzy Inference System module. This module is used as an identification of system degree to instability. The ANFIS input are series voltage and angle (r and γ) and the output is voltage stability margin

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. (Ali Akbar Mtiebirjandi, KauomarsSabzawari)

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

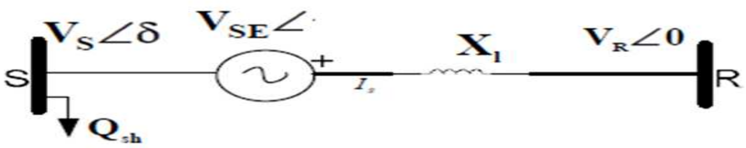

Fig. 6:UPFC in two-bus network

The current flowing in the line is calculated

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

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 ($r\llcorner\gamma$) .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.

Australian Journal of Basic and Applied Sciences, 10(14) September 2016, Pages: 185-195

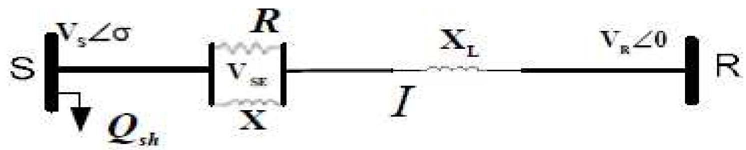

Fig. 7: Modelling of series converter

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.

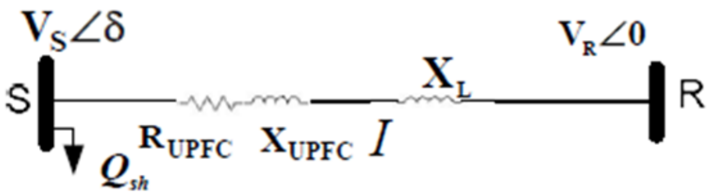

Fig. 8: Modeling of the UPFC in Two-Bus Network

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.

6. IEEE 9-Bus with UPFC:

IEEE-9 bus system is shown in fig. (9). It consists of three generators and three load buses and system data is given in the end of paper .The insertion of UPFC is studied based on the procedures discussed in the previous chapters.

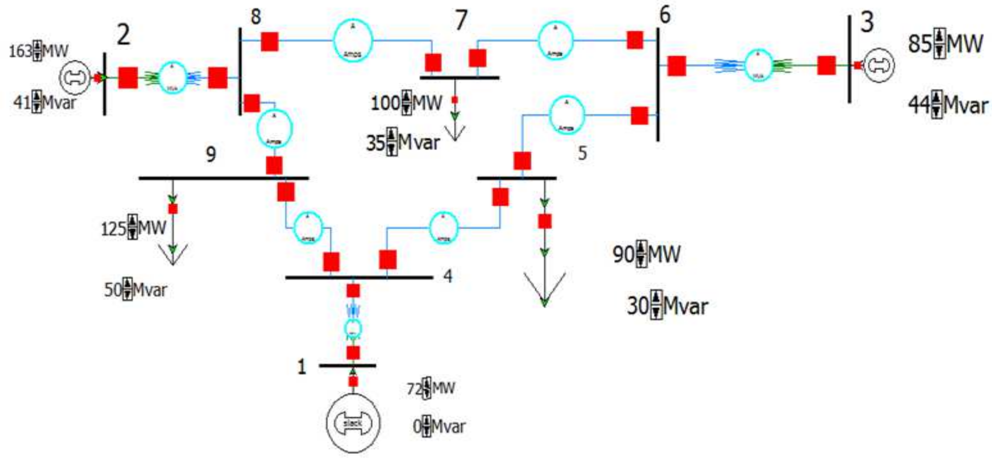

Fig. 9:IEEE-9 Bus Network

So, first it is necessary to identify the weakest bus that UPFC is inserted. The identification is implemented by calculation of voltage stability margin for each load bus The lowest one represents the weakest bus.

Voltage stability margin represents one of main indicators used in voltage stability study and it gives an indication for weakest bus determination. As the value of VSM is near unity, the load bus and the system is stable. The calculation of VSM depends on the values of current and voltage in each load bus. This means that the readings of control centers could be used for this purpose. If these readings are not available, the network can be tested by incremental loading of each load bus and determine the values of voltage and current required. Three values of bus loading (10%, 20% and 30%) are used.

This method is applied to IEEE-9 bus network. The same values of apparent power and bus admittance is used. Currents are calculated and eq. (30) is solved to obtain the (a -constants) in eq. (31) and as a result the value of critical apparent power for each load bus. Finally, the values of VSM of all load buses are calculated and the lowest one represent the weakest load bus. The results are listed in the following table.

Table 2: VSM for Different Load Buses Without UPFC

Bus No.	Apparent Power	VSM
5	0.9+J0.3	0.6628
7	1+J0.35	0.6504
9	1.25+J0.5	0.6056

It is clear that load bus (9) represents the weakest bus and the FACTS device mainly UPFC should be placed at this bus.

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 ($\mathbf{r},\boldsymbol{\gamma}$) 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 3: 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 ($\mathbf{r},\boldsymbol{\gamma}$) according to equations (35) and (36) are given in the following table.

Table 4: 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 5: UPFC Parameters for IEEE 9-Bus

Item	Iteration#1	Iteration#2	Iteration#3
Series Voltage r ∟γ	r=0.0707 γ= -44.9967	r=0.0344 γ=-172.6892	r=0.0862 γ=56.4366
Shunt Voltage V_{sh}∟ϴ	V_{sh}=1 ϴ=0	V_{sh}=0.9422 ϴ=1.4524	V_{sh}=0.9522 ϴ=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

6. ANFIS Prediction Model Using UPFC Control Modes:

The UPFC has different modes of operation based on activation of certain parameters and others are not. These control modes provide the input data needed for ANFIS (r and γ) with related output which is voltage stability margin. This model is useful for the purpose of prediction of network stability according to certain values of (r and γ).

The training data sets for ANFIS are generated using three different modes of operation of UPFC in the systemduring load flow solution.The UPFC program is implemented for each mode and the corresponding$\boldsymbol{R_{UPFC}}$and $\boldsymbol{X_{UPFC}}$ are calculated in order to implement the networks with power world simulator

Australian Journal of Basic and Applied Sciences, 10(14) September 2016, Pages: 185-195

program for the purpose of voltage stability margin calculation.Collection of these data put together the training data set.

Table 6: Sets of Data for ANFIS Model

Mode	r	γ	R_{UPFC}	X_{UPFC}	VSM
#1,All Variables Controlled	0.0862	56.4366	-0.22601	-0.0272	0.7795
#2,Control P and Q, V_{vrsta}=0	0.0869	59.9192	-0.2328	-0.02992	0.6495
#3,Control P and Q,V_9=0.9955	0.0848	58.9808	-0.2188	-0.0239	0.6065

The ANFIS is implemented and the error result is (6* E -7) which is acceptable and the following figures shows the detail analysis.

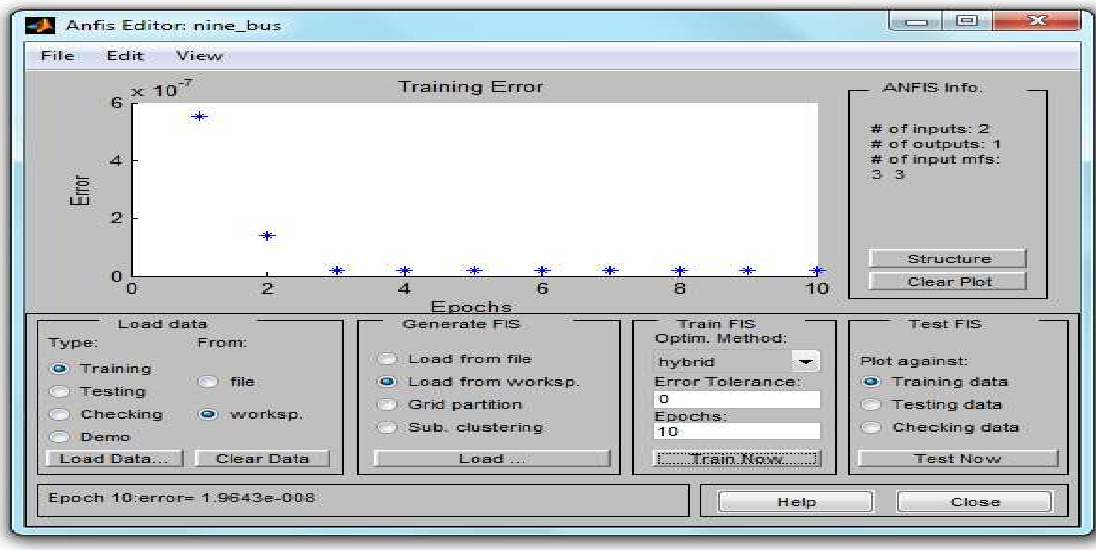

Fig. 10:IEEE 9-Bus Training Error

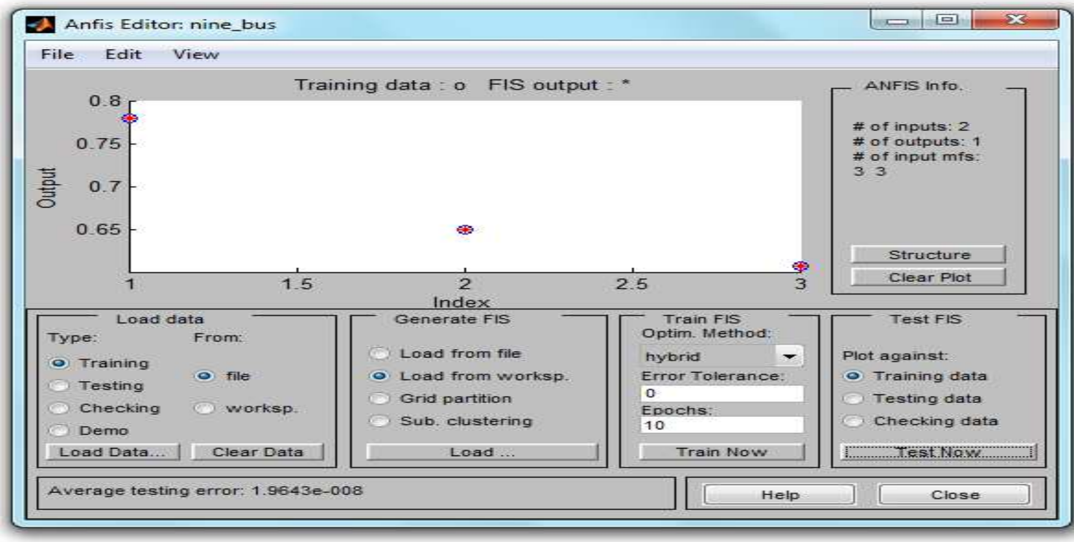

Fig. 11:IEEE 9-Bus Training Data

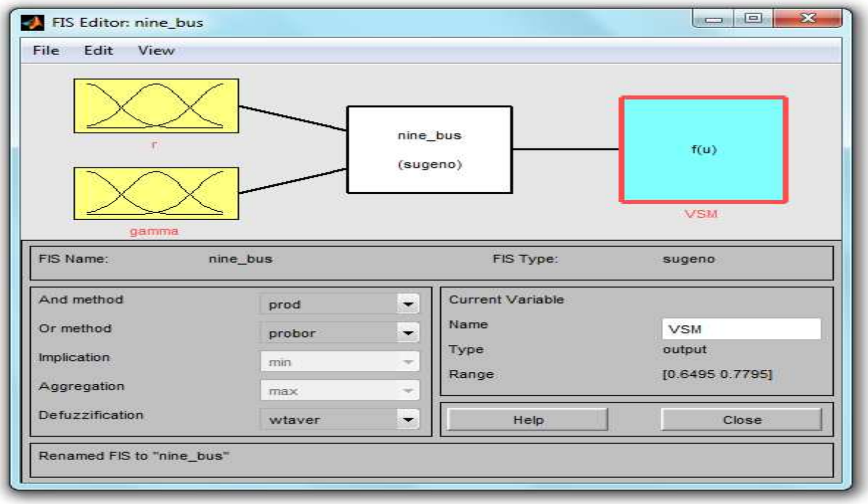

Fig. 12:IEEE 9-Bus Input-Output Membership Function

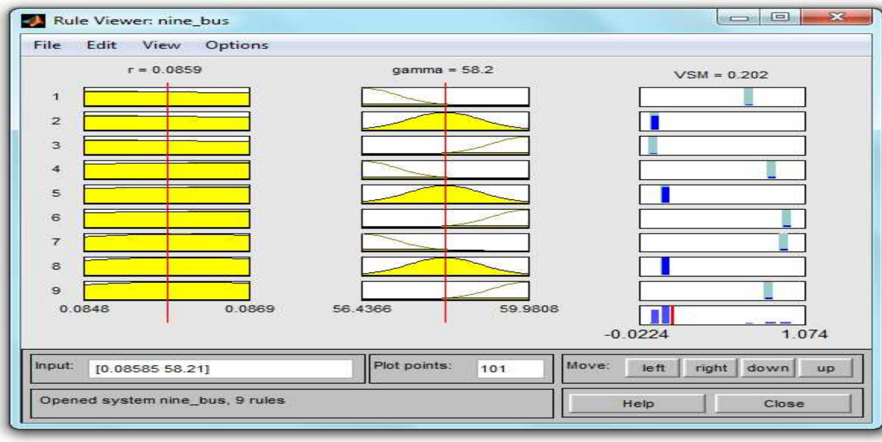

Fig. 13:IEEE 9-Bus Model Rules

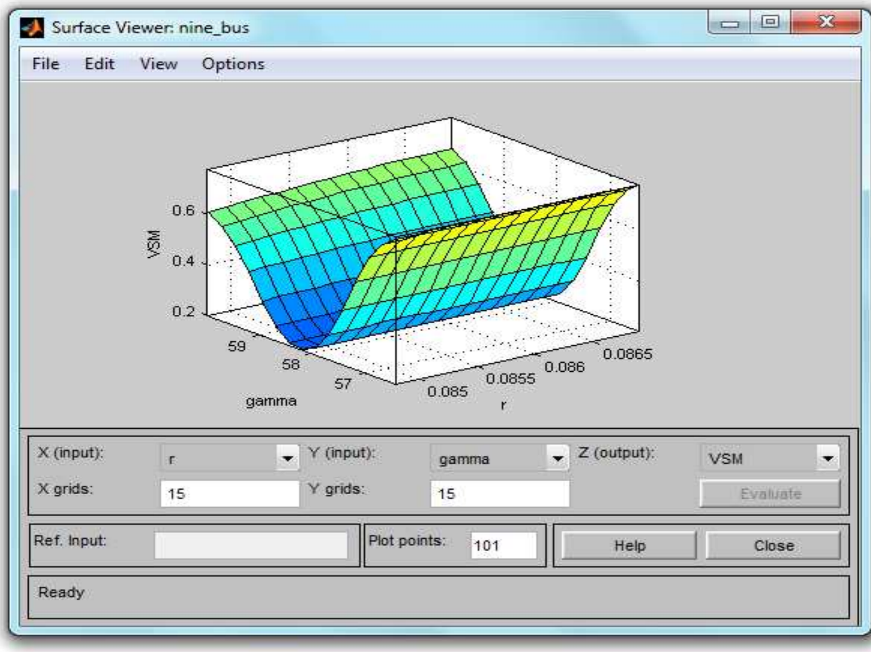

Fig. 14:IEEE 9-Bus Model Surface Viewer

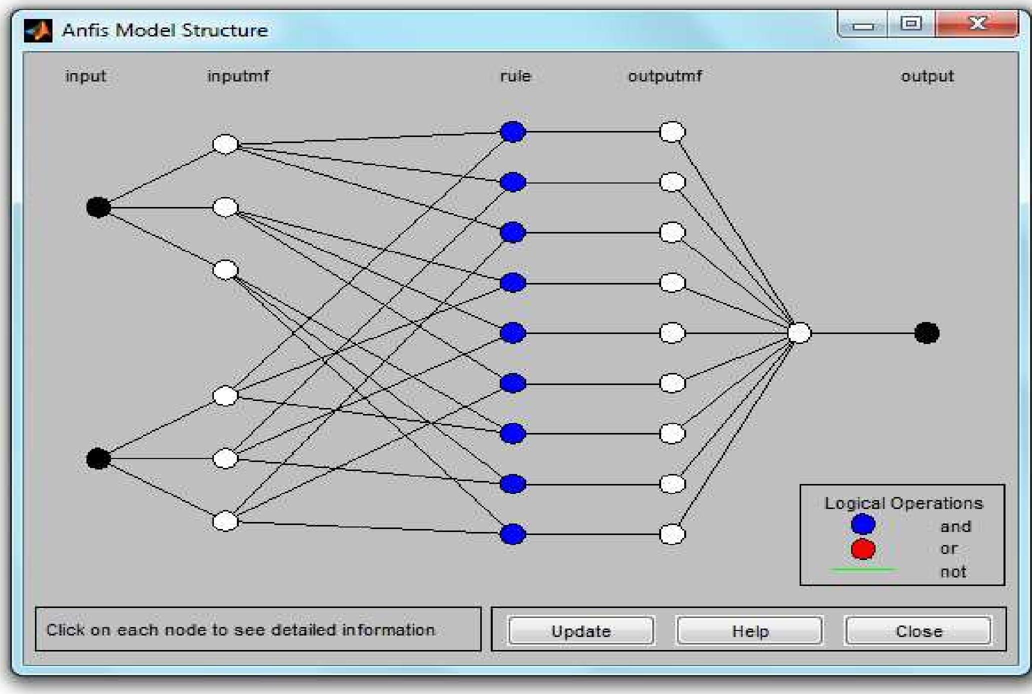

Fig. 15:IEEE 9-Bus Model Structure

It is evident from fig. (13) that this model provides the capability of VSM prediction for any value of (r and γ) without any need of further calculations. Any value obtained of VSM gives an indication of degree of power system stability. The surface viewer helps in representation of the maximum and minimum system input values (r and γ). This model is accepted due to its low error.

Conclusion:

This paper presents an implementation procedure for UPFC placement and design consideration. The UPFC load flow mat lab program provides the design data needed for selection of UPFC. Voltage stability margin helps in identification of the weakest bus in the network. The UPFC provides the facility of different mode of operation based on certain conditions. The results of these UPFC control modes give a set of data needed for ANFIS building model. This is useful in voltage stability margin prediction for any value of input data. Adaptive Neural Fuzzy Inference System is recently a useful approach in power system stability prediction.

REFERENCES

PoonamSinghal, S.K.Agarwal and NarenderKumar, 2014. "Optimization of UPFC Parameters Using Bacterial Foraging Technique For Enhancing Power System Stability", International Journal of Advancements in Technology, 5: 2.

Ramkumar, V., S.Baghya.Shree, 2014. "Voltage Stability Monitoring Using Adaptive Neuro-Fuzzy Inference System", InternationalJournal of Innovative Research in Scince, Engineering and Technology, 3: 3.

Payam Farhadi,MohsenZiaei,MostafaBayati,EhsanRamezani,TinaSojoudi, 2013. "Fuzzy Control Performance on Unified Power Flow Controller to Increase Power System Stability", 4th International Conference on Power Engineering, Energy and Electrical drives.

MeteVural, A., Mehmet Tumay, 2007. "Mathmaticalmodelling and analysis of unified power flow controller: comparison of two approaches in power flow studies and effects UPFC location", ELSEIVER, Electrical power and energy systems, 29: 617- 629.

Mahdi, M.M.El-arini,Raef S.S. Ahmed, "Optimal Location of Facts Devices to Improve Power Systems Performance", Journal of Electrical Engineering,Zagazig University, Faculty of Engineering, Electrical Power Department

Prof.Rai,D.K., 2012. "Maximum Permissible Loading and Static Voltage Stability Limit of a Power System Using V-I Polynomial "International Journal of Computational Engineering Research, 2: 5.

Enrique Acha,ClaudioR.Fuerte-Equivel,HugoAmbriz-Perez,Cesar Angeles-Camacho, 2004. "FACTS Modelling and Simulation in Power Networks", Copyright 2004,John Wiley and Sons Ltd.

Thomas Jove bye, 2001. "Power World Simulator", University of Illinois at Urbana-Champaigen.

PrakashG.Burade, Dr.Jagdish B.Helonde, 2012. "Optimal Placement of FACTS Device to Maximize the Loadability of Transmission Lines", International Journal of Scince and Engineering Investigations, 1: 3.

Ali Akbar Mtiebirjandi, KauomarsSabzawari,"The modelling of UPFC based on circuit elements in an exact transmission line model", International Journal of Engineering, (IJE), 4: 2.

Appendix:
Implemented 9-Bus System Data:

Table A.1: Bus Data

Bus No.	V (p.u)	P_L(MW)	Q_L(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: 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