Network Contingency Ranking using Fuzzy Approach under Normal and Line Outages and Voltage Stability Enhancement of the Power System Network using UPFC

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Abstract-Power system stability is the concept in which all operating parameters are within the limits. Sometimes power systems face various network operating problems due to change in network configuration when subjected to line outage contingency due to various reasons. To provide appropriatesecurity, it is desirable to analyse the effect of contingencies and plan suitable steps for enhancing system stability limit. Network contingency ranking is evaluated considering composite criteria based on fuzzy logic approach. Network contingencies not only over load the branches, but also lead to unsatisfactory voltage limit leading tovoltage collapse. This paper presents an approach to choose proper transmission corridor to place the FACTS device-unified power flow controller (UPFC) under normal and line outage contingencies.Thishas been tested under simulated conditions on a Indian power system networkand the results for a 25 node equivalent EHV power network is illustrated.

Key words-stability, voltage collapse, UPFC, improvement, etc.

1.INTRODUCTION

In the present day power systems, voltage stability and voltage collapse occur due to increased line loading of transmission linesaffecting the operation of power system. It has been observed that voltage magnitude is insufficient to indicate proximity either to the stability limit or to the value of the voltage at which it collapses ([1],[2]). Electric power systems routinely experience abnormalities due to various contingency events. Over loading of network branches pose problems during line outage contingency. The bus voltages of the system reach unsatisfactory levels leading to voltage collapse. A proper security needs to be provided to overcome voltage collapse.Thus it becomes necessary to compute the effect of contingencies on voltage stability. Currently the contingency analysis draws considerable attention with respect to power system planning and operation.Ranking is one of the important criteria forassessing on-line security.([3],[4]).Contingency evaluation and ranking helps to determine the most critical line outage from a group of line outage contingencies and rank them based on their severity effect. The post-contingent parameters are presented by fuzzy sets.The fuzzy rules are framedfor contingency ranking and compiled to arrive at the overall system severity index. Judicious power system planning and operation takes care of security maintenance considering certain system constraints[5]. It is important within the security framework to predicteffect of potential failure states on the behavior of the system well in advance. Security analysis is one of main function that is performed at modern Energy Control Centre(ECC). As the system tends to operate closer to stability limits, line outage contingency analysis plays an important role with respect to power system security.

Voltage stability and collapse due to the unpredictable increase in load demand, congestion for transmission lines, becomes major issues in planning and operation of the system. Capabilities of human reasoning can be applied to knowledge based approaches. For example: contingency evaluation of ranking using composite criteria based on fuzzy approach. ([6], [7]). The uncertainties associated with human thinking and reasoning can be eliminated by the theoretical approach of fuzzy logic with a strong mathematical base. This method uses post contingency voltage stability indices at all load buses [(8], [9]) violation of bus voltages will not necessarily overload the line and vice versa.

The FACTS device UPFC controls the active and reactive power and simultaneously is capable of being adaptive to voltage magnitude control. In case of several fully loaded lines the power flows in the network can be controlled both under normal and contingency conditions. This results in improved stability and enhanced performance of the system without making any changes in generation schedule and topographical configuration ([10], [11],[12]).

Suitable location to place UPFC is decided based on minimum singular value and voltage stability index of load buses. The proposed approach has been tested under simulated conditions on a power system and the results for a 25 node practical equivalent EHV power network are presented.

1.1 POWER FLOW ANALYSIS

Newton-Raphson method of power flow is considered for the proposed scheme. Consider a power system having 1, 2,….., n number of buses, where 'n' is the total number of buses, the number of generator buses 1,2,….., g and
the remaining buses (n-g) represent the load buses. Real power generation at a given bus is

$$P_{G_i} = P_{Gschi} - P_{Li} \quad (1.1)$$

$$P_{G_i \min} \geq P_{Gi} \geq P_{Gi\max}$$

Where

P_{Gi} : active power generation at bus i in p.u

P_{Gschi} : active power schedule at bus i in p.u

P_{Li} : activepower of load at buses i in p.u.

Assuming bus '1' as reference bus for required with voltage magnitude and phase angle calculations of other buses, the linearized equations for real power with Newton-Raphson iteration can be written as

$$\begin{bmatrix} \Delta P_1 \\ \Delta P_2 \\ \vdots \\ \vdots \\ \Delta P_n \end{bmatrix} = \begin{bmatrix} \frac{\partial P_1}{\partial \delta_2} & \cdots & \cdots & \frac{\partial P_1}{\partial \delta_n} \\ \frac{\partial P_2}{\partial \delta_2} & \cdots & \cdots & \frac{\partial P_2}{\partial \delta_n} \\ \vdots & & & \vdots \\ \vdots & & & \vdots \\ \frac{\partial P_n}{\partial \delta_2} & \cdots & \cdots & \frac{\partial P_n}{\partial \delta_n} \end{bmatrix} \begin{bmatrix} \Delta \delta_2 \\ \vdots \\ \vdots \\ \Delta \delta_n \end{bmatrix} \quad (1.2)$$

$$\begin{bmatrix} \Delta Q_{ng+1} \\ \Delta Q_{ng+2} \\ \vdots \\ \vdots \\ \Delta Q_n \end{bmatrix} = \begin{bmatrix} \frac{\partial Q_{ng+1}}{\partial V_{ng+1}} & \frac{\partial Q_{ng+1}}{\partial V_{ng+2}} & \cdots & \cdots & \frac{\partial Q_{ng+1}}{\partial V_n} \\ \frac{\partial Q_{ng+2}}{\partial V_{ng+1}} & \frac{\partial Q_{ng+2}}{\partial V_{ng+2}} & \cdots & \cdots & \frac{\partial Q_{ng+2}}{\partial V_n} \\ \vdots & \vdots & & & \vdots \\ \vdots & \vdots & & & \vdots \\ \frac{\partial Q_n}{\partial V_{ng+1}} & \frac{\partial Q_n}{\partial V_{ng+3}} & \cdots & \cdots & \frac{\partial Q_n}{\partial V_n} \end{bmatrix} \begin{bmatrix} \Delta V_{ng+1} \\ \Delta V_{ng+2} \\ \vdots \\ \vdots \\ \Delta V_n \end{bmatrix}$$

(1.3)

Where

$[\Delta P] = [J_1][\Delta\delta]$ (1.4)

$[\Delta Q] = [J_2][\Delta V]$ (1.5)

Where

$$\Delta P^k = P_{spe} - P_{cal}$$

$$\Delta Q^k = Q_{spe} - Q_{cal} \quad (1.6)$$

$$\delta^{k+1} = \delta^k + \Delta\delta$$

$$V^{k+1} = V^k + \Delta V$$

Where 'k' is the iteration within the power flow solution.

The calculated bus voltage 'ΔV' and power are used to evaluate the elements of the Jacobian matrices J_1 and J_2, $\Delta\delta$ and ΔV are solved by iterative process.

1.2 VOLTAGE STABILITY L-INDEX

The method proposed by the authors [1] to compute an indicator to decide stability and voltage collapse is known as point voltage collapse is known as stability L-index. The authors have shown that L-index lies within a unit circle when it takes a value of '0' it represents no-load condition, while a value of '1' indicates the critical condition of voltage collapse (weakest bus). The stability margin is the function of the disturbance from the maximum L-index value of unity (1-L). The voltage stability L-index is calculated using the load flow output for a given operating conditions. The L-index value of individual load buses helps in identifying voltage stability and critical buses. This method gives simple numerical calculation with the result explicitly expressing the desired information.

Consider a power system having
1, 2…..n, where 'n' total number of buses
1, 2…. g where 'g' is generator buses,
g+1, g+2…., (g+s) where's' is the number of Switchable VAr Compensators (SVC) buses
g+s+1, g+s+2 …... n the remaining buses ($r = n - g - s$) and 1, 2…………,t is the number of OLTC transformers.

For a given system operating condition, the voltage stability
L-index is computed using load flow output.

$$L_j = \left| 1 - \sum_{i=1}^{g} F_{ji} \frac{V_i}{V_j} \right| \quad (1.7)$$

Where
j=g+1, g+2….n,.
All the terms on RHS are complex quantities and
'g' buses.

The term F_{ji} are taken from the load flow Y-bus matrix .

For a given operating condition,

$$\begin{bmatrix} I_G \\ I_L \end{bmatrix} = \begin{bmatrix} Y_{GG} & Y_{GL} \\ Y_{LG} & Y_{LL} \end{bmatrix} \begin{bmatrix} V_G \\ V_L \end{bmatrix} \quad (1.8)$$

Where $[I_G]$. $[I_L]$, is the complex current.

$[V_G]$ and $[V_L]$ are the voltage vectors at the nodes of both generator and load.

$[Y_{GG}]$,$[Y_{GL}]$,$[Y_{LG}]$ and $[Y_{LL}]$ represent the partitioned portions of the Y-bus matrix of the network. Also,

$$[I_G] = [Y_{GG}][V_G] + [Y_{GL}][V_L]$$

$$[I_L] = [Y_{LG}][V_G] + [Y_{LL}][V_L]$$

Rearranging the above equation

$$\begin{bmatrix} V_L \\ I_G \end{bmatrix} = \begin{bmatrix} Z_{LL} & F_{LG} \\ Y_{GL} & Y_{GG} \end{bmatrix} \begin{bmatrix} I_L \\ V_G \end{bmatrix} \quad (1.9)$$

Where $[F_{LG}] = -[Y_{LL}]^{-1}[Y_{LG}]$

The equation for L-index at the jth node can be written as

F_{ji} , complex elements of $[F_{LG}]$ matrix.

There are two conditions to be satisfied

(i) The index 'L_j'should not exceed the maximum point limit of 1 at any load node j and

(ii) The stability indicator takes a value of L= max (L_j) for all load buses 'j'.

L_j-index value near to '0' indicates a system with improved stability.

1.3 MINIMUM SINGULAR VALUE [MSV]

Singularityof the load flow Jacobian matrix decides the separation between the operating point and the voltage stability limit under steady state. The distance of MSV from zero at the operating point gives the proximity to voltage collapse. This due to the load that Jacobian matrix of load flow becomes singular at the point of voltage collapse [4].

1.4 FUZZIFICATION OF DIFFERENT CRITERIA FOR CONTINGENCY RANKING

Due to constraints being modelled rigidly in the conventional optimal method, the solution obtained being incapable of representing the practical cases necessitates an alternate approach with reasonable flexibility in modelling.Fuzzy membership functions, fuzzy rules and fuzzy inference are three basic functions of a general fuzzy inference system.Fuzzy rules are framed using IF-THEN statement to formulate the conditional statements. The 'IF' part generally consists of several conditions combined together using logic operators. The 'THEN' part is the conclusion which may contain more than one output. The key input variables considered are the real power line loading, load bus voltage magnitude and voltage stability L-index. Each of these variables are categorized into five linguistic values and later transformed to fuzzy domain. The key input variables assumed are transformed into by using the following membership function in equation (2.10)

$$\mu = \frac{1}{1+\left(\frac{k-a}{A}\right)^2} \quad (1.10)$$

Where 'k' is the variable, 'a' and 'A' are range of membership functions. Figure 1.1, Figure 1.2 and Figure 1.3 represent the membership function for the variables considered.

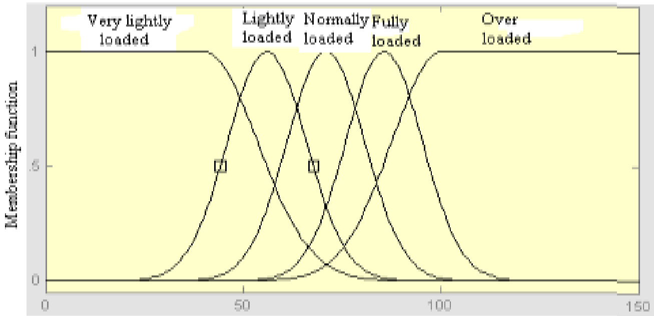


Figure 1.1 Membership function for the Line Loading

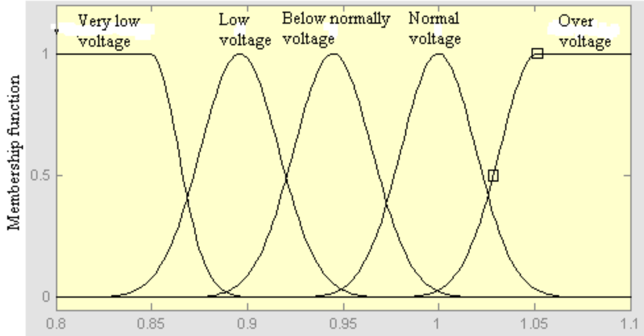


Figure 1.2 Membership function for Load Bus Voltage

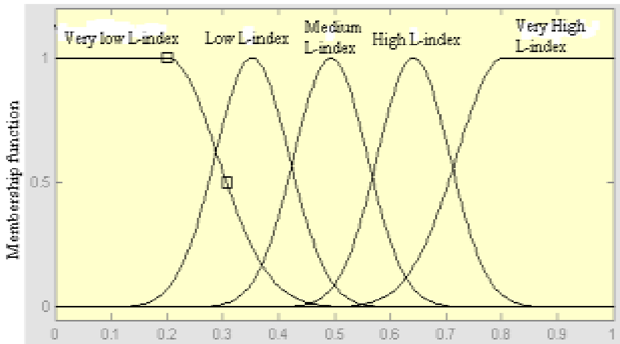


Figure1.3 Membership function for Voltage Stability L-index

2 FORMATIONS OF FUZZY RULES

The state of the system is described by key input variables which are fuzzified each with five linguistic values. Output variable is also fuzzified with five linguistic values. The fuzzy rule statement 'If X is A Then Y is B' is applied to key input key variables. The output expresses the degree of severity of input key variables expressed in fuzzy linguistic values which are shown in the Table 2.1, Table 2.2 and Table 2.3 respectively.

2.1 FUZZIFICATION OF LINE LOADING

The keyinput variable line loading describes the quantum of power flow in the line. The fuzzy linguistic values of Line loading are given in Table 2.1.

Table 2.1 Fuzzy Rules for Line loading

Input linguistic values of the key variable	Output linguistic values(Severity indices)
VLL, LL, NL, FL, OL indicates Very low, Lightly, Normal, Fully and Over loaded.	VLS, LS , BS, AS, MS indicates Very less, Less, Below, Above and More severe

At post contingency of the line outage the severity of line loading can be estimated by firing the fuzzy rules. Overall Severity Index of line loading (OSI_{LL}) is computed by summing up all severity indices for a particular line outage. Assuming a suitable weightage factor the overall severity index is calculated using equation 2.11

$OSI_{LL}=\sum_{i=1}^{nl}\lambda_{LL}SI_{LL}$ (2.11)

Where, 'nl' is the no. of transmission lines

λ_{LL} = weightage factor(for each of severity index).

SI_{LL} = Severity Index of Line Loading.

The weightage factorassumed for severity indices are

λ_{LL}= 0.20 (VLS); 0.40 (LS); 0.50 (BS); 0.75 (AS); 1.0 (MS).

2.2 FUZZIFICATION OF VOLTAGE PROFILE

The voltage magnitude is the input key variable and their effects are expressed in fuzzy linguistic values which are given in Table 2.2.

Table 2.2 Fuzzy Rules for Voltage Profile

Post Contingent Quantities	Severity Index
VLI,LI, MI, HI, VHI indicates Very low,Low Medium,High and Very high L-index	VLS, LS BS, AS, MS indicates Very less, Less ,Below, Above and More severe

At post contingency of the line outage the voltage magnitude at each load bus and severity indices of voltage profile (SI_{VP}) are estimated and finally overall severity index for a particular line outage is computed. Assuming suitable weightage factor for severity indices, the overall severity index is estimated using equation 2.12.

$OSI_{VP}=\sum_{j=g+1}^{n}\lambda_{VP}SI_{VP}$ (2.12)

Where 'n' is the total number of buses and 'j' is the load bus

λ_{VP} = weightage factor for severity index of voltage profile.

SI_{VP} = Severity Index of Voltage Profile.

The weightage factor applicable for the severity indices are

λ_{VP}= 0.20 (MS2); 0.40 (AS); 0.60 (BS); 0.80 (AS); 1.0 (MS1).

2.3 FUZZIFICATION OF VOLTAGE STABILITY L-INDEX

The key input variable voltage stability L-index and its effect on line outage contingencies are expressed in fuzzy linguistic values which are given in Table 2.3.

Table 2.3 Fuzzy Rules for Voltage Stability L-index

Post contingent quantities	Severity Index
VLV, LV, BNV, NV, OV indicates Very low, Low , Belownormal, Normal And Over voltage	MS2, AS, BS,LS, MS1 indicates Very less, Above ,Below , Low and More severe

At post contingency of the line outage the voltage stability L-index at each load bus and its voltage stability Severity Indices (SI_{VSI}) are estimated. Finally overall voltage Stability Severity Index (OSI_{VSI}) for a particular line outage is computed. Assuming suitable weightage factors severity indicesand the overall severity index is calculated using equation 2.13.

$OSI_{VSI}=\sum_{j=g+1}^{n}\lambda_{VSI}SI_{VSI}$ (2.13)

λ_{VSI} = weightage factor severity index of voltage stability index.

SI_{VSI}= Severity Index for Voltage stability index.

The weightage factor used for the severity indices are

λ_{VSI}= 0.20 (VLS); 0.40 (LS); 0.60 (BS); 0.80 (AS); 1.0 (MS).

2.4 COMPUTATION OF OVERALL NETWORK RANKING USING SEVERITY INDICES OF KEY INPUT VARIABLES

The membership function for each post contingency variable of line loading, bus voltage magnitude and voltage stability L-index are used to calculate the network ranking and overall severity index for line contingency. This is shown in Figure 2.4. For a given contingency, the post contingency quantities such as line loading, voltage profile and voltage stability index are combined toobtain FuzzyInference System [FIS]. The fuzzy inference is evaluated for each input key variables OSI_{LL}, OSI_{VP} and OSI_{VSI}using fuzzy rules. *T*he overall network contingency ranking is computed by adding all overall severity index of input key variables using equation 2.14. Fuzzy inference system for obtaining the OVERALL NETWORK RANKING is shown in Figure 2.4.

OSI= $\sum(OSI_{LL}+OSI_{VP}+OSIVSI)$ (2.14)

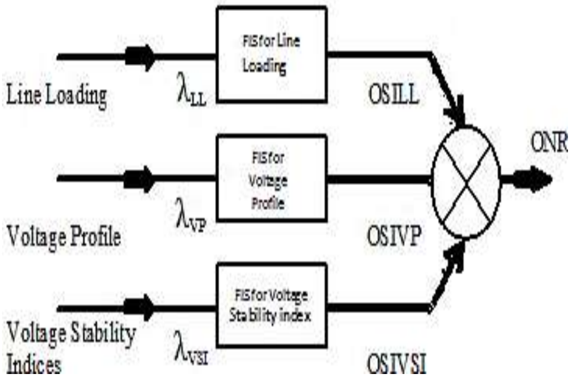


Figure 2.4 Composite Criteria to determine overall network ranking

2.5 COMPUTATIONAL STEPS FOR CONTINGENCY RANKING

Step 1: load flow is performed to obtain initial values of loading on each line,voltage profile and voltage stability L-index atload buses.
Step 2: Fuzzification of input key variables.
Step3: Fuzzification of output variables (here, it is severityofinput key variables)
Step 4: Apply the line outage contingency of the network
Step 5: Computation of severity indices of the key variables
Step 6: Sum up all the severity index of the key variables and determine the overall, network contingency ranking
Step 7: Arrange the overall severity indices and rank them in ascending order
Step 8: Stop

2.6 TEST SYSTEM ANALYSIS

The proposed method based on fuzzy expert system to determine contingency line outage ranking has been tested under simulation condition on a practical 25 bus.

2.6.1 25 BUS EHV INDIAN PRACTICAL SYSTEM

The power system network consists of 25-bus practical system with 4 generator buses and 21 other buses. The load is represented on the 220 kV side of 400kV/200kV, on eight buses. The contingency testing has been applied and the estimated severity indices of voltage profiles, voltage stability L-index and line loading are indicated in Table 2.4 and Table 2.5.Considering the line outage $L_{24\text{-}18}$which exhibits worst condition, and needs more attention to overcome the collapse of the system. For $L_{24\text{-}18}$ line outage the most critical values of voltage stability L-index, minimum voltage magnitude and MSV are 0.8432, 0.7011 and 0.3042 respectively.

Table2.4 25-Bus EHV System:
Severity indices and network overall ranking

Line Outage		Severity index of voltage profile SI_{VP}	Severity index of L-index SI_{VSI}	Severity index of line loading SI_{LL}	Network Overall Severity Index NOSI	Ranking
From Bus	To Bus					
22	23	14.96	11.87	15.30	65.08	2
22	18	14.12	10.94	12.75	56.94	3
17	24	11.12	9.86	10.20	46.48	7
24	18	16.52	13.24	15.95	69.64	1
23	20	13.20	10.50	13.25	56.83	4
15	16	13.60	11.04	12.55	56.02	5
24	16	10.08	9.76	10.70	46.59	6
18	20	9.88	10.23	9.65	44.24	8

Table 2.5 25-Bus EHV System:
Voltage magnitude, Voltage stability index, MSV and Transmission losses at each line outage

Line Outage			V_{min}(p.u)	L-index L_{max}	MSV	P_{loss}	Ranking
L. No	From Bus	To Bus					
1	22	23	0.7153	0.8192	0.4631	83.30	2
2	22	18	0.7517	0.7126	0.5204	80.10	3
3	17	24	0.8428	0.5380	0.5072	64.57	6
4	24	18	0.7011	0.8432	0.3042	93.03	1
5	23	20	0.7477	0.5957	0.5166	75.40	5
6	15	16	0.8298	0.5762	0.5452	82.41	4
7	24	16	0.8454	0.5112	0.6770	64.79	7
8	18	20	0.8576	0.5251	0.7573	61.86	8

3 IDENTIFICATION OF TRANSMISSION CORRIDOR FOR UPFC LOCATION UNDER NETWORK CONTINGENCY ANALYSIS.

The installation of FACTS devices like UPFC which is modelled as PQ and PV buses in AC transmission networks has brought in many appreciable changes in the operation of a modern power system [11]. The model is shown in Figure 3.2.The proper transmission corridor for placing UPFC is decided based on computed performance parameters.

3.1 UPFC EQUIVALENT CIRCUIT

UPFC is modelled as dual converters i.e series and shunt as shown in Figure 3.1 interconnected by a DC link. The series converter in series with the transmission injects an voltage V_{cR} where phase angle varies between 0-2π degrees with respect the terminal voltage. The magnitude of V_{cR} varies between '0' to maximum value which is device rating dependent. The shunt converter connected parallel through shunt transformer supplies real power and also independently acts as a reactive power compensators to maintain specified voltage magnitude. The three parameters voltage magnitude, phase angle of series injected voltage and shunt reactive power can be controlled to achieve the desired results.

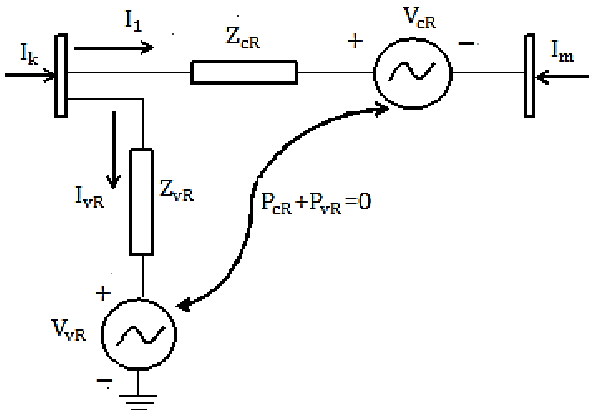


Figure3.1 Equivalent circuit of UPFC

The UPFC equivalent circuit for steady state model is shown in Figure 3.1. The equivalent circuit consists of two ideal voltage sources namely,

$$V_{cR} = V_{cR}\angle\theta_{cR}$$
$$V_{vR} = V_{vR}\angle\theta_{vR}$$

Where V_{vR} and θ_{vR} are the controllable voltage magnitude ($V_{vRmin} \leq V_{vR} \leq V_{vRmax}$) and angle ($0 \leq \theta_{vR} \leq 2\pi$) of the shunt voltage source. The magnitude V_{cR} and angle θ_{cR} of the series voltage source are controlled between the limits ($V_{cRmin} \leq V_{cR} \leq V_{cRmax}$) and angle ($0 \leq \theta_{cR} \leq 2\pi$) respectively.

3.2 UPFC POWER EQUATIONS

Based on the equivalent circuit shown in Figure 3.1, the active and reactive power equations are given below.

At node k:

$$P_k = V_k^2 G_{kk} + V_k V_m (G_{km}\cos(\theta_k - \theta_m) + B_{km}\sin(\theta_k - \theta_m)) + V_k V_{cR}(G_{km}\cos(\theta_k - \theta_{cR}) + B_{km}\sin(\theta_k - \theta_{cR})) + V_k V_{vR}(G_{vR}\cos(\theta_k - \theta_{vR}) + B_{vR}\sin(\theta_k - \theta_{vR}))$$

(3.1)

$$Q_k = -V_k^2 B_{kk} + V_k V_m (G_{km}\sin(\theta_k - \theta_m) - B_{km}\cos(\theta_k - \theta_m)) + V_k V_{cR}(G_{km}\sin(\theta_k - \theta_{cR}) - B_{km}\cos(\theta_k - \theta_{cR})) + V_k V_{vR}(G_{vR}\sin(\theta_k - \theta_{vR}) - B_{vR}\cos(\theta_k - \theta_{vR}))$$

(3.2)

At node m:

$$P_k = V_m^2 G_{mm} + V_m V_k (G_{mk}\cos(\theta_m - \theta_k) + B_{mk}\sin(\theta_m - \theta_k) + V_m V_{cR}(G_{mm}\cos(\theta_m - \theta_{cR}) + B_{mm}\sin(\theta_m - \theta_{cR}))$$

(3.3)

$$Q_k = -V_m^2 G_{mm} + V_m V_k (G_{mk}\sin(\theta_m - \theta_k) - B_{mk}\cos(\theta_m - \theta_k)) + V_m V_{cR}(G_{mm}\sin(\theta_m - \theta_{cR}) + B_{mm}\cos(\theta_m - \theta_{cR}))$$

(3.4)

Series converter:

$$P_{cR} = V_{cR}^2 G_{mm} + V_{cR} V_k (G_{km}\cos(\theta_{cR} - \theta_k) + B_{km}\sin(\theta_{cR} - \theta_m)) + V_{cR} V_m (G_{mm}\cos(\theta_{cR} - \theta_m) + B_{mm}\sin(\theta_{cR} - \theta_m))$$

(3.5)

$Q_{cR} = -V_{cR}^2 B_{mm} + V_{cR} V_k (G_{km}\sin(\theta_{cR} - \theta_k) - B_{km}\cos(\theta_{cR} - \theta_m)) + V_{cR} V_m (G_{mm}\sin(\theta_{cR} - \theta_m) - B_{mm}\cos(\theta_{cR} - \theta_m))$ (3.6)

Shunt converter:

$P_{vR} = -V_{vR}^2 G_{vR} + V_{vR} V_k (G_{vR}\cos(\theta_{vR} - \theta_k) + B_{vR}\sin(\theta_{vR} - \theta_k))$ (3.6)

$Q_{vR} = V_{vR}^2 B_{vR} + V_{vR} V_k (G_{vR}\sin(\theta_{vR} - \theta_k) - B_{vR}\cos(\theta_{vR} - \theta_k))$ (3.7)

Where

$$Y_{kk} = G_{kk} + jB_{kk} = z_{cR}^{-1} + z_{vR}^{-1}$$
$$Y_{mm} = G_{mm} + jB_{mm} = z_{cR}^{-1}$$
$$Y_{km} = Y_{mk} = G_{km} + jB_{km} = -z_{cR}^{-1} \quad (3.8)$$
$$Y_{vR} = G_{vR} + jB_{vR} = -z_{vR}^{-1}$$

The operation of the converter is assumed to be loss less and the UPFC does not inject or absorb any active power. Thus, the active power demanded by the series converter, P_{cR} must satisfy active power supplied to the shunt converter P_{vR}, i.e

$P_{vR} + P_{cR} = \Delta P_{bb} \cong 0$ (3.9)

3.3UPFC JACIBIAN EQUATIONS

The state variables representing UPFC and the network voltages and angles are combined to arrive at a unified solution based on Newton-Raphson method. UPFC state variable are automatically adjusted to satisfy the specified power flows and voltage magnitude. The modified linear power equations are combined with the corresponding linearized equations of the remaining part of the network.

$[f(x)] = [J][\Delta X]$(3.10)

Where

$$[f(x)] = [\Delta P_k \ \ \Delta P_m \ \ \Delta Q_k \ \ \Delta Q_m \ \ \Delta P_{mk} \ \ \Delta Q_{mk} \ \ \Delta P_{bb}]^T$$

The term ΔP_{bb} *in* equation 3.9 gives the mismatch in power and T indicates transposition, $[\Delta X]$ – solution vector and $[J]$- Jacobian matrix.

3.4 UPFC INITIAL CONDITION

Initial condition is to be defined properly to obtain the solution for a set of non-linear algebraic equations by N-R techniques. Assumed initial conditions are 1 p.u voltage magnitude for all buses and '0' voltage angles.A set of equations giving good initial estimates for UPFC, is obtained by assuming lossless UPFC, coupling transformer and null voltage angles in equations 3.11 to 3.14.

3.3.1 SERIES SOURCE INITIAL CONDITIONS

For specified nodal powers at node m, the solution of equation 3.11 and 3.12 are

$$\theta_{cR}^{0} = arctan\left(\frac{P_{mref}}{[C_1]}\right)$$

$$V_{cR}^{0} = \left(\frac{X_{cR}}{V_m^0}\right)\sqrt{P_{mref}^2 + C_1^2} \quad (3.11)$$

Where

$$C_1 = Q_{mref} - \frac{V_M^0}{X_{cR}}(V_m^0 - V_k^0) \text{if} V_m^0 \neq V_k^0$$

$$C_1 = Q_{mref}$$

If$V_m^0 = V_k^0$ (3.12)

An equation for initializing the shunt voltage angle source is given by

$$\theta_{vR} = -arcsin\left(\frac{(V_k^0 - V_m^0)\, V_{cR}^0 X_{vR} \sin(\theta_{cR}^0)}{V_{vR}^0 V_k^0 X_{cR}}\right) \quad (3.13)$$

The inductive reactance of the shunt source is given by X_{vR}. The voltage magnitude of the shunt source is considered as the target value when the shunt converter behaves as a voltage regulator. The target value is updated at each iteration. When it is not operating as a voltage regulator the voltage magnitude takes a fixed value with the set limits, ($V_{vRmin} \leq V_{vR} \leq V_{vRmax}$) for the whole iterative process.

3.3.2 LIMIT REVISION OF UPFC CONTROLLABLE VARIABLES.

The power mismatches equations normally used for limit revisions andhelps indetermining the device parameters which can be controlled accurately. The mismatch power is estimated using equation 3.14.

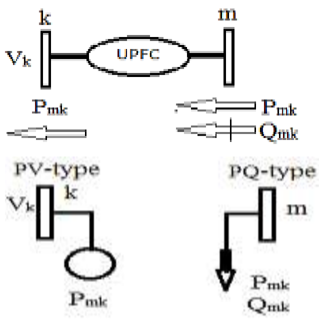
$$\Delta P_{bb} = P_{vR} + P_{cR} \quad (3.14)$$

When limit is violated the magnitude of voltage is fixed at this value and the regulated variable is eliminated.

3.4 DECOUPLED UPFC MODEL.

A continuous UPFC power flow model proposed by [14] is capable of regulating the power flow from node m to k and also to regulate the voltage magnitude at node k. In this situation, assuming loss free UPFC operation and neglecting the resistance of voltage source impedances, the

UPFC and coupling transformers can be modeled as load bus and generator bus. The UPFC is modeled with two terminals P-Q bus at sending end, whilst the receiving end is represented as PV bus. At P-Q bus terminal, active and reactive powers are controlled andat P-V bus terminal, real power and voltage magnitude are controlled. A basic load flow and an additional set of nonlinear equations is iteratively solved to compute the UPFC parameters. A schematic and equivalent P-Q model is shown in Figure 3.2 and Figure 3.3.



(a) *(b)*

Figure 3.2 Schematic (a) and equivalentPV-PQ model (b)of UPFC

4 RESULT ANALYSIS

The phenomenon of line outage contingency leading to overloading of network branches and unsatisfactory voltage levels finally leads to voltage collapse. To provide proper security of the systems, it is desirable to compute contingency effect to enhance system stability. The fuzzy based contingency ranking and system stability improvement with proper location of UPFC are discussed under simulated conditions on a 25 bus EHV power system network.In the contingency process only those line outage contingencies giving very serious problems are considered. A set of the line outage contingencies affecting the system stability arranged in a descending ranking order need immediate security. A UPFC model derived is used in different transmission system to identify suitable transmission corridor for different order of ranking. The most suitable transmission corridor for UPFC model is one in which the stability limits are within the range.

4.1 TEST SYSTEM 25 BUSES INDIAN PRACTICAL POWER SYSTEM NETWORK.

The FACT device UPFC is multi variable controller used in the power system.Required power flow control and suitable location for placing UPFC under contingency of line outage is presented. In the 25 bus system, line connected between buses 15-24, 24-23 and 21-19 are double line circuit. Analysis is made for outage of one line of the double line circuit to overcome over loading of the line. Also single line outage anticipated during maximum power transmission is also carried out.

4.1.1 CASE (I): ONE LINE OUTAGE OF DOUBLE CIRCUIT CONNECTED BETWEEN BUSES 15-24.

In this type of contingency one of the line of a double circuit connected between buses 15-24 is open and remaining single lines carry real power of 379.6 MW which is more than the normal power. Table 4.1 indicates the first rank-5 list of line outage. The transmission lines chosen for placing UPFC under this type of contingency are 17-24, 24-18 and 22-23.The location of UPFC based on contingency rank-1 is given in Table 4.2. From the Table 4.2 it can be observed that the UPFC location at line 17-24, Vmin=0.8821 p.u, L_{max}= 0.4559 and L_{loss} = 55.9682 MW, which indicates an improvement in system stability. Minimum voltage magnitude and voltage stability index is better compared to other UPFC placement lines. Therefore the line 17-24 is the suitable position for placement of UPFC under this case. Table 4.2 shows the initial (without UPFC) and final (with UPFC) bus voltage profiles and voltage stability of the system. Figure 4.1,4.2 and 4.3 show the initial and final bus voltage profilesin this case.

4.1.2 CASE (II): ONE LINE OUTAGE OF DOUBLE CIRCUIT CONNECTED BETWEEN BUSES 24-23.

In this case, the following are noted.V_{min}=0.8444 p.u and the maximum voltage stability L-index, L_{max} = 0.5452. The possible placement of UPFC is lines connected between the buses 17-24, 24-18 and 22-23. The details of results with UPFC placement under each case are given in Table 4.1. It can be observed that for the UPFC position in the line 23-20, V_{min}=0.8932 p.u, L_{max}= 0.4278 and L_{loss} = 39.0514 MW, an acceptable improvement compared to other position of UPFC in this case.

4.1.3 CASE (III): ONE LINE OUTAGE OF DOUBLE CIRCUIT CONNECTED BETWEEN BUSES 21-19.

In this contingency, for peak load condition, the total real power loss is 46.3602 MW. The minimum voltage is 0.8782 p.u and the maximum voltage stability index is 0.4955. The chosen transmission lines for possible UPFC placements are the lines connected between buses 22-19 and 23-20. The details of results with UPFC placement under this case are given in Table 4.1. It can be observed that the UPFC placement in the line 22-19 has minimum voltage magnitude of 0.8782 and voltage stability index 0.4955. Therefore the line 22-19 is the suitable location for placement of UPFC under this contingency.

Table 4.1 The Line outage Contingency Ranking

Sl. No.	Double circuit	Real power (MW)	Performance parameters		
			V_{min} (p.u)	L_{max}	Power loss(MW)
1	15-24	486.1	0.8576	0.5261	61.8551
	24-23	496.1			
	21-19	349.5			
	One line outage of double circuit 15-24				
	Before placing UPFC	379.6	0.8444	0.5452	70.2416
	After UPFC Placing				
2	17-24	240.4	0.8821	0.4559	55.9682
3	24-18	207.3	0.8929	0.4689	51.8961
4	22-23	249.2	0.8703	0.5183	50.7120
	One line outage of double circuit 24-23				
	Before placing UPFC	419.3	0.7945	0.6348	77.9243
	After UPFC Placing				
5	22-23	207.9	0.8609	0.5259	48.9575
6	24-18	340.4	0.8535	0.4983	55.9354
7	23-20	149.2	0.8932	0.4278	39.0514
	One line outage of double circuit 21-19				
	Before placing UPFC	316.7	0.8061	0.6220	70.0886
	After UPFC Placing				
8	22-19	183.1	0.8782	0.4955	46.3602
9	23-20	266.2	0.8318	0.5033	55.8029

Table4.2:Summary of results with and without UPFC under contingency

Sl. No	Line Outages		Severity Indices			Over All Severity Indices $OS_{indices}$	Network Over all Ranking (NOR)
	From Bus	To Bus	Severity index of Voltage Profile S_{ivpr}	Severity index of L-index S_{ilind}	Severity index of Line Loading S_{illd}		
1	22	23	14.96	10.39	14.70	40.05	2
2	22	18	14.12	9.46	12.15	35.73	3
3	24	18	16.52	12.13	15.35	44.00	1
4	15	16	13.60	10.30	11.40	35.30	4
5	23	20	13.20	9.39	12.10	34.69	5

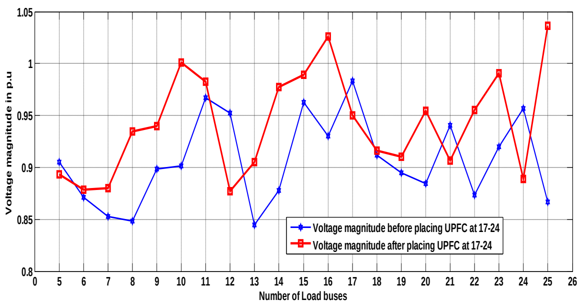


Figure 4.1 Voltage magnitude variation with andwithout UPFC at line 17-24 for single line between 15-24

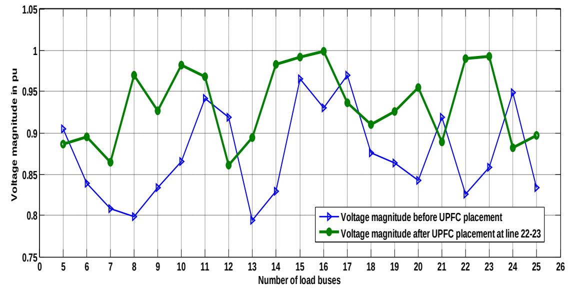


Figure4.2 Voltage magnitude variation with andwithout UPFC at line 22-23 for single line between 24-23

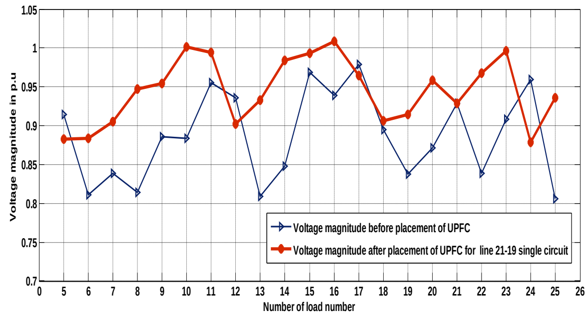


Figure 4.3 Voltage magnitude variation with andwithout UPFC at line 22-19 for single line between line 21-19

4.2 SINGLE LINE CIRCUIT OUTAGE

In this section line outage contingency of single line connected between buses are analyzed. The contingency ranking of line outages of a 25 bus system is given in Table 4.1. For different single line outage contingency ranking is assigned based on the value NOR. The network overall ranking is computed by all severity indices for each line outage. The criterion considered to compute network overall rankings are line loading, voltage profile and voltage stability index. For each line outage contingencies the following procedures are followed toidentify suitable transmission corridor for UPFC positions.

1. For the selected transmission corridor perform load flow and analyze the voltage stability with connected UPFC device.
2. Compute the stability parameters to decide best transmission corridor for UPFC device.

Table 4.1shows the stability parameters considered and system losses for each line outage. The line outage 24-18 is the worst case having transmission losses of 93.03 MW, minimum voltage of V_{min}=0.7011, maximum voltage stability indexL_{max}=0.8432 and Minimum Singular Value, MSV=0.3042. The other line outages and stability parameters are indicated in the Table 4.1.The different UPFC location and stability parameters are shown in Table 4.2. For rank-1of line outage, the UPFC position at 22-19 shows better results compared to other positions. For rank-2 of line outage the UPFC position at 21-20 shows better location based on stability parameters indicated in the Table 4.2.

Table4.3: Stability parameters for Line outages

Sl. No	Line Outages		Minimum Voltage, V_{min} (p.u)	V_{min} Bus Number	Maximum L-index, L_{max}	L_{max} Bus Number	Minimum Singular Value, (MSV)	System Loss, PL (MW)
	From Bus	To Bus						
1	22	23	0.7153	13	0.8192	13	0.4631	83.30
2	22	18	0.7517	13	0.7126	13	0.5204	80.10
3	24	18	0.7011	10	0.8432	10	0.3042	93.03
4	15	16	0.8298	13	0.5762	8	0.5452	82.41
5	23	20	0.7477	7	0.5957	7	0.5166	75.40

Table 4.4: Stability parameters for Line outages rank-1

rank 1, Line outage 24-18					
Sl. No	UPFC location	Performance Parameters			
		V_{min}	L_{max}	MSV	Power Loss(MW)
1	22-19	0.8293	0.6441	0.5749	46.3269
2	23-20	0.8311	0.5388	0.4591	51.1639
3	21-20	0.7902	0.6240	0.5632	57.2266

Table 4.5: Stability parameters for Line outages rank-2

rank 2, line outage22-23					
Sl. No.	UPFC location	Performance Parameters			
		V_{min}	L_{max}	MSV	Power Loss(MW)
1	21-20	0.7903	0.6138	0.5872	54.7455
2	22-18	0.8040	0.6683	0.4791	56.5101
3	24-18	0.7815	0.7531	0.3219	61.6145

V. CONCLUSIONS

Thepaper presented arrives at asuitable location for placing UPFC to control real power flow,maintain voltage magnitude to mitigate the overloading of the line and to improve the system stability/securityunder network contingencies. The level of severity of the line outage ranking based on fuzzy approach considering composite criteria for each line outage has been evaluated. The performance of the system achievement is checked by stability index parameters like MSV, L-index and transmissionlosses. The results obtained are appreciable and algorithm developed iswell suited to any size of the network. Simulated results for 25 bus Indian network are tabulated as an illustration.

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