# Contingency Analysis in Power System and Remedial Actions

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*Abstract*— For practical system operation, apart from ensuring the satisfactory operation of the system at a particular operating condition, it is also equally important to make sure that the system operates with adequate level of security. Broadly, the term 'security' implies the ability of the system to operate within system constraints (on bus voltage magnitudes, current and power flow over the lines) in the event of outage (contingency) of any component (generator or transmission line). The goal of this power system analysis function is to give the operator information about the static security. Contingency analysis is used to calculate violations. In this paper presents contingency analysis of power system is to predict the line outage, generator outage and to keep the system secure and reliable. Whenever the maximum violation is occur in power system, that line and generator is outage element. So we find the maximum violation in the system network. For the generation, transmission, and distribution system, security can be assessed using contingency analysis. This paper describes the power flow analysis of power system network using Power World Simulator and estimating the real and reactive power flows, power losses in the entire network and phase angle using Power World Simulator. This paper shows the example on 6 bus power system which gives information of violations & remedial action to remove violations. In this paper, first contingency conditions are analyzed after that according to severity of contingency a real power flow performance index (PI) sensitivity based approach and the line outage distribution factor has been used to decide optimal location of series FACTS devices.

***Key words:*** Contingency Analysis, Line outage, Generator outage,Optimal location of series FACTS devices

## I. INTRODUCTION

The power system consists of generation, transmission, distribution bundled together. In deregulation unbundlingof power system network for efficiency, reliability and least price of power to the customer [4]. Under deregulationminimum price of power transfer to the utility, that time more number of buyers to buy the power from the generation.But all the transmission lines and generators have some limits [4]. Whenever the demand of power is maximum thancompared with the transfer limits, the line will be damaged. The power demand is reduced then the generator is relivingfrom the power system network . The system security will be collapsed. So the secured dispatch scheduling ofpower market is important due to open access and competition. Before security assessment the contingency analysis isneeded [7]. The contingency limits are based on system operator experience. But this methodology not predicts thesecurity limits. Before secured dispatch scheduling we have to analysis the contingency under single outage of line,generator and multiple outage of combination of both line and generator. Whenever the maximum violation inthe element some line and generator get damaged. So the contingency analysis is essential.

Successful power system operation under normal balanced three-phase steady-state conditions requires the following:

- Generation supplies the demand (load) plus losses.
- Bus voltage magnitudes remain close to rated values.
- Generators operate within specified real and reactive power limits.
- Transmission lines and transformers are not overloaded.

The power-flow computer program (sometimes called load flow) is the basic tool for investigating these requirements. This program computes the voltage magnitude and angle at each bus in a power system under balanced three-phase steady-state conditions. It also computes real and reactive power flows for all equipment interconnecting the buses, as well as equipment losses [6]. The power flow solution is used to evaluate the bus voltage, branch current, real power flow, reactive power flow for the specified generation and load conditions. The results are used to evaluate the line or transformer loading and the acceptability of bus voltages. In general the power flow solutions are needed for the system under the following conditions [6]:

- Various systems loading conditions (peak and off peak).
- With certain equipment outage.
- Addition of new generators.
- Addition of new transmission lines or cables.
- Interconnection with other systems.
- Load growth studies.
- Loss of line evaluation.

## II. POWER SYSTEM SECURITY

One of the most important factors in the operation of any power system is the desire to maintainsystem availability and reliability. Power system security is the ability of the system to withstand one ormore component outages with the minimal disruption of service or its quality. System securityinvolves practices designed to keep the system operating in emergency state when componentsfail and to restore it to its preventive state. For instance, a generating unit may break down orhave to be taken off-line for maintenance purposes [5].

## III. CONTINGENCY ANALYSIS

Contingencies are defined as potentially harmful disturbances that occur during the steady state operation of a power system. Load flow constitutes the most important study in a power system for planning, operation and expansion. The purpose of load flow study is to compute operating conditions of the power system under steady state. These operating conditions are normally voltage magnitudes

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and phase angles at different buses, line flows (MW and MVAr), real and reactive power supplied by the generators and power loss.

In a modern Energy Management power system security monitoring and analysis form an integral part but the real time implementation is a challenging task for the power system engineer. A power system which is operating under normal mode may face contingencies such as sudden loss of line or generator, sudden increase or decrease of power demand. These contingencies cause transmission line overloading or bus voltage violations. In electrical power systems voltage stability is receiving special attention these days. During the past two and half decades it has become a major threat to the operation of many systems. The transfer of power through a transmission network is accompanied by voltage drops between the generation and consumption points. In normal operating conditions, these drops are of the order of few percents of the nominal voltage. One of the principle tasks of power system operators is to check that under different operating conditions and/or following credible contingencies (e.g.: tripping of a single line) all bus voltages remain within bounds. In such circumstances, however in the seconds or minutes following a disturbance, voltages may experience large progressive falls, which are so prominent that the system integrity is endangered and power cannot be delivered to the customers. This catastrophe is referred to as voltage instability and its calamitous result as a voltage collapse. Large violations in transmission line flow can result in line outage which may lead to cascading effect of outages and cause over load on the other lines. If such over load results from a line outage there is an immediate need for the control action to be initiated for line over load alleviation. Therefore contingency analysis is one of the most important tasks to be met by the power system planners and operation engineers. But on line contingency analysis is difficult because of the conflict between the accuracy in solution of the power system problem and the speed required to simulate all the contingencies. The simulation of contingency is complex since it results in change in configuration of the system.

Contingency analysis is abnormal condition in electrical network. It put whole system or a part of the system under stress. It occurs due to sudden opening of a transmission line. Generator tripping.Sudden change in generation.Sudden change in load value. Contingency analysis provides tools for managing, creating, analyzing, and reporting lists of contingencies and associated violations. Contingency analysis is therefore a primary tool used for preparation of the annual maintenance plan and the corresponding outage schedule for the power system [3].

Generally, once the current working state of a system is known, contingency analysis can bebroken down into the following steps:

- Contingency definition
- Contingency selection
- Contingency evaluation

Contingency definition involves preparing a list of probable contingencies. This typicallyincludes line outages and generator outages.Contingency selection process consists of selecting the set of most probable contingencies;they need to be evaluated interms of potential risk to the system. Finally, in the contingency evaluation, the selected contingencies are ranked in order of their security, till no violation ofoperating limits is observed.[5]

## IV. Methods of Contingency Analysis

The different methods used for analyzing the contingencies are based on full AC load flow analysis or reduced load flow or sensitivity factors. But these methods need large computational time and are not suitable for on line applications in large power systems. It is difficult to implement on line contingency analysis using conventional methods because of the conflict between the faster solution and the accuracy of the solution. Some important methods are

- AC load flow methods
- DC load flow method.
- Z-bus contingency analysis.
- Performance Index method.

### *A. A.C. Load flow methods:*

The power flow problem is formulated as a set of nonlinear algebraic equation suitable for computer solution. The power flow problem is the computation of voltage magnitude and phase angle at each bus in a power system under balance three phase steady-state conditions.

For solving power flow problem first develop a single line diagram of the power system, from which the input data for computer solutions can be obtained. Input data consist of bus data, transmission line data and transformer data. The four variables associated with each bus: voltage magnitude, phase angle, net real power, reactive power supplied to the bus. There are three bus types in a power transmission network.

- Generator Bus or Voltage Controlled Bus (P, V bus)
- Load Bus (P, Q bus)
- Slack Bus ( Swing Bus or Reference bus)

For a $\pi$ equivalent circuit, transmission line input data includes per unit series impedance Z’ and shunt admittance Y’, the buses to which line is connected, and maximum MVA rating. Transformer input data include per unit winding impedances Z, per unit exciting branch admittance Y, the buses to which windings are connected, and maximum MVA ratings .Input data for Tap changing transformers also include maximum tap settings. The Bus admittance matrix $Y_{bus}$ can be constructed from line and transformer input data. The $Y_{bus}$ is given by following Equation.

$$Y_{bus} = \begin{bmatrix} Y_{11} & \dots & Y_{nk} \\ \dots & \dots & \dots \\ Y_{kn} & \dots & Y_{kk} \end{bmatrix} \quad (1)$$

Using Ybus we can write nodal equations for a power system network as follows.

$$I = Y_{bus}V \quad (2)$$

Where, I is the N vector source currents injected into each bus and V is the N vector of bus voltages. For bus i, the Kth equation is

$$I_i = \sum_{j=1}^{N} Y_{ij}V_j \quad (3)$$

The complex power delivered to bus k is

$$S_i = V_iI_i^* \quad (4)$$

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Equation(3),(4) is used to solve the all load flow problems. The different load flow analysis methods use the basic (3) and (4) for solving power flow problem [6].

The power world simulator can be set to use a full Newton solution or use a DC load flow method to analysis each contingency. The full Newton approach is not as fast as a DC load flow, but the results tend to be significantly more accurate and allow for gauging voltage/VAR effects. The Newton solution method (also called Newton-Rapsonmethod) is more efficient for large power systems. The number of iteration required to obtain a solution is independent of a system size but more functional evaluation are required at each iteration.

Equation for bus Admittance matrix

$I_i = \sum_{j=1}^{N} Y_{ij} V_j$

In above equation j includes bus i expressing this equation in polar form, we have

$Ii = \sum_{j=1}^{N} Y_{ij} V_j \angle \theta ij + \delta j$ (5)

The complex power at bus

Pi – Qi = Vi* Ii (6)

Substituting from (5) for Ii in (6)

$Pi - Qi = |Vi| \angle -\delta i \sum_{j=1}^{N} Y_{ij} V_n \angle \theta_{ij} + \delta_j$ (7)

Separating the real and imaginary parts

$P i = \sum_{j=1}^{N} |V_i||V_j||Y_{ij}| \cos(\theta ij - \delta i + \delta_j)$ (8)

$Q i = -\sum_{j=1}^{N} |V_i||V_j||Y_{ij}| \sin(\theta ij - \delta i + \delta_j)$ (9)

Equation (8) and (9) constitute of nonlinear algebraic equation in terms of the independent variables, voltage magnitudein per unit and phase angle in radians.

$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \begin{bmatrix} \Delta \delta \\ \Delta |V| \end{bmatrix}$, where J = $\begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix}$ is the Jacobian

Matrix, which gives the linearized relationship betweensmall changes in voltage angle $\Delta\delta$iand voltage magnitude $\Delta|V$i| with small changes in real and reactive power $\Delta P$i and $\Delta Q_i$ elements of jacobian matrix are the partial derivatives of (8) and (9) evaluated at $\Delta\delta$i and $\Delta|V$i|. Accordingly there are (n-1) real power constraints and (n-1-m) reactive power constraints and the jacobian matrix is the order of (2n-2-m) (2n-2-m).

J1 is the order of (n-1) x (n-1)

$\frac{\partial P_i}{\partial \delta_i} = \sum_{j \neq 1}^{N} |V_i||j||Y_{ij}| \sin(\theta ij - \delta i + \delta_j)$

$\frac{\partial P_i}{\partial \delta_j} = -|V_i||V_j||Y_{ij}| \sin(\theta ij - \delta i + \delta_j)\ i \neq j$

J2 is the order of (n-1) x (n-1-m)

$\frac{\partial P_i}{\partial |V_i|} = 2|V_i||Y_{ii}| \cos\theta_{ii} + \sum_{j \neq 1}^{N} |V_i||V_j||Y_{ij}| \cos(\theta ij - \delta i + \delta_j)$

$\frac{\partial P_i}{\partial |V_j|} = |V_i||Y_{ij}| \cos(\theta ij - \delta i + \delta_j)\ ,\ i \neq j$

J3 is the order of (n-1-m) x (n-1)

$\frac{\partial Q_i}{\partial \delta_i} = \sum_{j \neq 1}^{N} |V_i||j||Y_{ij}| \cos(\theta ij - \delta i + \delta_j)$

$\frac{\partial Q_i}{\partial \delta_j} = -|V_i||V_j||Y_{ij}| \cos(\theta ij - \delta i + \delta_j)\quad i \neq j$

J4 is the order of (n-1-m) x (n-1-m)

$\frac{\partial Q_i}{\partial |V_i|} = -2|V_i||Y_{ii}| \sin\theta_{ii} - \sum_{j \neq 1}^{N} |V_j||Y_{ij}| \sin(\theta ij - \delta i + \delta_j)$

$\frac{\partial Q_i}{\partial |V_j|} = -|V_i||Y_{ij}| \sin(\theta ij - \delta i + \delta_j)\ ,\ i \neq j$

The terms $\Delta P$i(k) and ΔQ i(k) are difference between the schedule and calculated values, known as the power residuals,

$\Delta P$i(k) = Pi(sch)– Pi(k)

ΔQi(k) = Qi(sch) – Qi(k)

The new estimated for bus voltage is

$\delta$i(k+1) = $\delta$i(k) + $\Delta\delta$i(k)

$|V_{i(k+1)}| = |V_{i(k)}| + \Delta|V_{i(k)}|$ [4]

*B. DC load flow method:*

Another solution method in simulator is DC load flow. These factors can be derived in a variety of ways and basically come down to two types:

- Generation outage sensitivity factor (GOSF)
- Line outage sensitivity factor (LOSF) [4]

With the change in system operating conditions, the contingency analysis exercise needs to be carried out again at the new operating point. Thus, for proper monitoring of system security, a large number of outage cases need to be simulated repeatedly over a short span of time. Ideally, these outage cases should be studied with the help of full AC load flow solutions. However, analysis of thousands of outage cases with full AC power flow technique will involve a significant amount of computation time and as a result, it might not be possible to complete this entire exercise before the new operating condition emerges. Therefore, instead of using full non-linear AC power flow analysis, approximate, but much faster techniques based on linear sensitivity factors are used to estimate the post contingency values of different quantities of interest. The basic concept of sensitivity factors is described below. Essentially, the linear sensitivity factors approximately estimate the changesin different line flows for any particular outage condition without the need of full AC power flowsolution.

Basically, there are two types of sensitivity factors and these are:

- Generation outage sensitivity factor (GOSF)
- Line outage sensitivity factor (LOSF)

GOSF relates the approximate change in power flow in line ‘i-j’ (i.e. between bus ‘i’ and ‘j’) due to the outage of generator at bus ‘k’, whereas LOSF helps to calculate the approximate change in power flow in line ‘i-j’ due to outage of line ‘m-n’.

The generation outage sensitivity factoris defined by,

$\alpha_{ij}^{k} = \frac{\Delta f_{ij}}{\Delta P_k}$ (10)

where,

$\alpha_{ij}^{k}$ is GOSF of line ‘i-j’ for generation change at bus ‘k’

$\Delta fij$is Change in power flow in line ‘i-j’

$\Delta Pk$is Change in generation at bus ‘k’

The factor $\alpha_{ij}^{k}$denotes the sensitivity of the line flow on line ‘i-j’ due to change in generationat bus ‘k’. In equation (10), it is assumed that the generation lost at bus ‘k’ would be exactlycompensated by the reference or slack bus. Now, if the generation at bus ‘k’ was generating anamount of power equal to $P_k^0$then to represent the outage condition, $\Delta Pk = -P_k^0$.

Hence, the new power flow over the line ‘i-j’ would be given as,

$f_{ij}^0 + \Delta f_{ij} = f_{ij}^0 + \alpha_{ij}^{k} \Delta P_k \quad f_{ij}^{n} = f_{ij}^0 - \alpha_{ij}^{k} P_k^0$ (11)

The factor$\alpha_{ij}^{k}$would be pre-calculated and stored in the memory. As we will see later, the values of $\alpha_{ij}^{k}$depend only on the network parameters and therefore, are constant. However, it should be noted that for any particular line ‘i-j’,

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the factors $\alpha_{ij}^{k}$and $\alpha_{ij}^{m}$ (for generation outage at bus 'm') are different and therefore need to be pre-calculated separately. Once these factors are pre-calculated and stored, the new values of line flow over any line can easily be estimated very quickly from equation (11). If the new power flow over any line is found to be more than the corresponding limit, then the operator can be alerted for taking an appropriate pre-emptive action. In equation (11), it is assumed that the lost generation at bus 'k' would be taken up by theslack bus. However, it is also quite possible that the lost generation would be compensated by all the remaining 'on-line' generators combinedly, in which, each of the 'on-line' generators would take up some fraction of the lost generation in some particular ratio. One of the most frequently used methods assumes that the 'on-line' generators share the lost generation in proportion to their maximum MW rating. Thus, the proportion of generation picked up by generation 'g' is given by $g$ x $k$,

$$\gamma_{gk} = \frac{P_g^{max}}{\sum_{\substack{a=1 \\ \neq k}}^{M} P_a^{max}} \qquad (12)$$

where,

M is Total number of generators in the system

$\gamma_{gk}$isProportionality factor for generation 'g' to pick up generation when unit 'k' fails

$P_a^{max}$is Maximum MW rating for generator 'a'.

Now, as the sensitivity factors shown in equation (10) are linear in nature, the effects of simultaneous generation change in several generators on a particular line can be obtained by following superposition principle. Hence, the new line flow in the line 'i-j' becomes,

$$f_{ij}^{n} = f_{ij}^{0}+\alpha_{ij}^{k}\Delta P_k - \sum_{a=1}^{m} \alpha_{ij}^{a}\Delta P_{a\gamma ak} \qquad (13)$$

In equation (13) it is assumed that no remaining 'on-line' generation hits thE generation limit.

The line outage distribution factorsare also defined similarly. The LOSF is defined by,

$$\beta_{ij,mn} = \frac{\Delta f_{ij}}{f_{mn}^{0}} \qquad (14)$$

Where, $\beta ij, mn$ is Line outage distribution factor for line 'i-j' under outage of line 'm-n'.

$f_{mn}^{0}$is Power flow over line 'm-n' in the pre-outage condition.

Therefore, for the outage of line 'm-n', the new flow over line 'i-j' is given by,

$$f_{ij}^{n} = f_{ij}^{0}+\beta_{ij,mn}f_{mn}^{0} \qquad (15)$$

## V. LINE LOADABILITY

Line Loadability can be defined as Transmission-line voltages decrease when heavily loadedand increase when lightly loaded. When voltages on EHV lines are maintained within ±5% of rated voltage, corresponding to about 10% voltage regulation, unusual operating problems are not encountered. Ten percent voltage regulation for lower voltage lines including transformervoltagedrops is also considered good operating practice. In addition to voltage regulation, line loadability is an important issue.

Three major line-loadinglimits are:

- the thermal limit,
- the voltage-drop limit, and
- the steady-state stability limit.

The maximum temperature of a conductor determines its thermal limit. Conductor temperatureaffects the conductor sag between towers and the loss of conductor tensile strength due to annealing. If the temperature is too high, prescribed conductor-to-ground clearances may not be met, or the elastic limit of the conductor may be exceeded such that it cannot shrink to itsoriginal length when cooled. Conductor temperature depends on the current magnitude and its time duration, as well as onambient temperature, wind velocity, and conductor surface conditions.

The loadability of short transmission lines (less than 80 km in length) is usually determined bythe conductor thermal limit or by ratings of line terminal equipment such as circuit breakers. For longer line lengths (up to 300 km), line loadability is often determined by the voltage-drop limit. Although more severe voltage drops may be tolerated in some cases, a heavily loadedline with VR/VS ≥ 0.95 is usually considered safe operating practice. For line lengths over 300 km, steady-state stability becomes a limiting factor [5].

## VI. SIMULATION

Before the secured dispatch scheduling the contingency analysis is the important one for selection ofcontingency element in the maximum violation of the system network. The following steps to involve in the contingency analysis[4].

### A. *Contingency Analysis Algorithm*

Step 1: Draw the Simulink one line diagram in new case window of power world simulator for the given power System in edit mode.
Step 2: Save the case with apt name.
Step 3: Select run mode.
Step 4: Play or Run the one line diagram in tool menu.
Step 5: Select CONTINGENCY ANALYSIS in tool menu, then the contingency analysis dialogue box is open.
Step 6: Right click on label and select auto insert contingencies through insert special option.
Step 7: Verify that single transmission line or transformer is selected.
Step 8: If can limit the contingencies inserted to only those meeting a definedfilter.
Step 9: We want to insert contingencies for all branches and generators so nofiltering is desired.
Step 10: To check the following conditions

- Remove the checkmark in use area/ zone filters.
- Verify no other options are selected.

Step 11: Click do insert contingencies button to accept the all contingencies.
Step 12: Click YES to get the contingencies.
Step 13: Now the contingency analysis dialog shows contingencies.

- Right click on the list display on the contingency tap and select insert special and click auto insert to the local menu
- Select single generating unit then click the do insert contingencies button. Click YES to complete.

Step 14: The auto insert tool did not insert a contingency for the generator connected to the slack bus.
Step 15: Click 'start run' on the contingencies tab click start on summary tab or Run contingency.

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Step 16: Select the maximum violation of contingency analysis taken for account in the secured dispatch of deregulation of power market[4].

## B. *Test System*

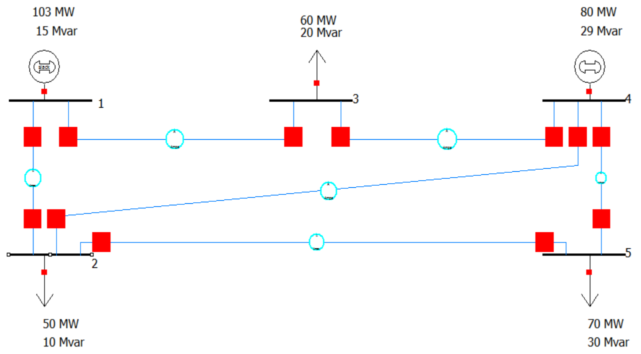


Fig. 1. Base case for 6 bus system

| Line No. | From | To | R | X | B/2 |
|---|---|---|---|---|---|
| 1 | 1 | 2 | 0.02 | 0.06 | 0.030 |
| 2 | 1 | 3 | 0.08 | 0.24 | 0.025 |
| 3 | 2 | 4 | 0.06 | 0.18 | 0.020 |
| 4 | 2 | 5 | 0.04 | 0.12 | 0.015 |
| 5 | 3 | 4 | 0.01 | 0.03 | 0.010 |
| 6 | 4 | 5 | 0.08 | 0.24 | 0.025 |

Table-1 Branch data for 5-Bus test system

| Bus | Voltage (p.u.) | Angle (Deg.) | $P_L$ (MW) | $Q_L$ (MVAR) | $P_G$ (MW) | $Q_G$ (MVAR) |
|---|---|---|---|---|---|---|
| 1 | 1.060 | 0.000 | 0.000 | 0.000 | 103.361 | 14.523 |
| 2 | 1.035 | -2.451 | 50.000 | 10.000 | 0.000 | 0.000 |
| 3 | 1.042 | -2.281 | 60.000 | 20.000 | 0.000 | 0.000 |
| 4 | 1.050 | -1.711 | 0.000 | 0.000 | 80.000 | 28.570 |
| 5 | 0.999 | -4.909 | 70.000 | 30.000 | 0.000 | 0.000 |

Table-2 Bus data for 5-Bus test system

| Line Results | | | | | | | | | Bus Results | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Line No. | From | To | DCLF | ACLF | | | | | Bus No. | DCLF | | ACLF | |
| | | | MW | MW | MVAR | MVA | $P_{loss}$ | $Q_{loss}$ | | | | | |
| 1 | 1 | 2 | 81.78 | 84.74 | 18.55 | 86.7 | 1.5 | -1.2 | | Voltage (p.u.) | Angle (Deg.) | Voltage (p.u.) | Angle (Deg.) |
| 2 | 1 | 3 | 18.22 | 19.12 | 0.65 | 19.1 | 0.3 | -4 | 1 | 1 | 0 | 1 | 0 |
| 3 | 2 | 4 | -9.93 | -9.63 | -7.01 | 11.9 | 0.1 | -3.6 | 2 | 1 | -2.81 | 0.9712 | -2.75 |
| 4 | 2 | 5 | 41.7 | 42.85 | 16.8 | 46 | 0.9 | 0.04 | 3 | 1 | -2.51 | 0.9781 | -2.54 |
| 5 | 3 | 4 | -41.8 | -41.2 | -15.36 | 44 | 0.2 | -1.3 | 4 | 1 | -1.79 | 0.9868 | -1.89 |
| 6 | 4 | 5 | 28.3 | 28.91 | 11.15 | 31 | 0.8 | -2.1 | 5 | 1 | -5.68 | 0.9322 | -5.54 |

Table-3 Load Flow Results

| Line No. | From Bus | To Bus | GSF | | LODF | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | G=1 Trip | G=4 Trip | l=1 Trip | l=2 Trip | l=3 Trip | l=4 Trip | l=5 Trip | l=6 Trip |
| 1 | 1 | 2 | 0.6 | -0.6 | 0 | -1 | 0.5 | 0.4 | -1 | -0.4 |
| 2 | 1 | 3 | 0.4 | -0.4 | -1 | 0 | -1 | -0.4 | 1 | 0.4 |
| 3 | 2 | 4 | 0.4 | -0.4 | 0.7 | -0.7 | 0 | -0.7 | -1 | 0.7 |
| 4 | 2 | 5 | 0.2 | -0.2 | 0.3 | -0.3 | -0 | 0 | -0 | -1 |
| 5 | 3 | 4 | 0.4 | -0.4 | -1 | 1 | -1 | -0.4 | 0 | 0.4 |
| 6 | 4 | 5 | -0.2 | 0.2 | -0.3 | 0.3 | 0.5 | -1 | 0.3 | 0 |

Table-4 GSF & LODF for N-1 Contingency

| Line No. | From Bus | To Bus | GSF for G=1 Trip | | | | | | LODF for G=1 Trip | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | L=1 Trip | L=2 Trip | L=3 Trip | L=4 Trip | L=5 Trip | L=6 Trip | L=1 Trip | L=2 Trip | L=3 Trip | L=4 Trip | L=5 Trip | L=6 Trip |
| 1 | 1 | 2 | 0 | 1 | 0.4 | 0.5 | 1 | 0.5 | 0 | -1 | 0.5 | 0.4 | -1 | -0.4 |
| 2 | 1 | 3 | 1 | 0 | 0.6 | 0.5 | 0 | 0.5 | -1 | 0 | -0.5 | -0.4 | 1 | 0.4 |
| 3 | 2 | 4 | 0 | 0.67 | 0 | 0.5 | 0.7 | 0.5 | 0.67 | -0.7 | 0 | -0.7 | -0.7 | 0.7 |
| 4 | 2 | 5 | 0 | 0.33 | 0.4 | 0 | 0.3 | 0 | 0.33 | -0.3 | -0.5 | 0 | -0.3 | -1 |
| 5 | 3 | 4 | 1 | 0 | 0.6 | 0.5 | 0 | 0.5 | -1 | 1 | -0.5 | -0.4 | 0 | 0.4 |

Table-4 GSF & LODF for N-1-1 Contingency

| Line No. | From Bus | To Bus | GSF for G=4 Trip | | | | | | LODF for G=4 Trip | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | L=1 Trip | L=2 Trip | L=3 Trip | L=4 Trip | L=5 Trip | L=6 Trip | L=1 Trip | L=2 Trip | L=3 Trip | L=4 Trip | L=5 Trip | L=6 Trip |
| 1 | 1 | 2 | 0 | -1 | -0.39 | -0.5 | -1 | -0.5 | 0 | -1 | 0.52 | 0.35 | -1 | -0.4 |
| 2 | 1 | 3 | -1 | 0 | -0.61 | -0.5 | 0 | -0.5 | -1 | 0 | -0.52 | -0.35 | 1 | 0.35 |
| 3 | 2 | 4 | 0 | -0.67 | 0 | -0.5 | -0.7 | -0.5 | 0.67 | -0.7 | 0 | -0.65 | -0.67 | 0.65 |
| 4 | 2 | 5 | 0 | -0.33 | -0.39 | 0 | -0.3 | 0 | 0.33 | -0.3 | -0.48 | 0 | -0.33 | -1 |
| 5 | 3 | 4 | -1 | 0 | -0.61 | -0.5 | 0 | -0.5 | -1 | 1 | -0.52 | -0.35 | 0 | 0.35 |

Table-5 GSF & LODF for N-1-1 Contingency

# VII. REMEDIAL ACTIONS

Remedial Action Schemes (RAS) are the key components for any power system utility planning. These are the steps which the utilities need to take in order to get the system back to its normal operation. Remedial Action Scheme (RAS) as the name suggests are the necessary actions which need to be taken to solve the violations caused by a contingency. Remedial Action Schemes are also defined as Special Protection Schemes (SPS) or System Integration Schemes (SIS). The RAS is designed to mitigate specific critical contingencies that initiate the actual system problems. There may be a single critical outage or there may be several critical single contingency outages for which remedial action is needed. There may also be credible double or other multiple contingencies for which remedial action is needed. Each critical contingency may require a separate arming level and different remedial actions. The terms SPS and RAS are often used interchangeably, but WECC generally and this document specifically uses the term RAS. Automatic single-phase or three-phase reclosing following temporary faults during stressed operating conditions may avoid the need to take remedial action. Appropriate RAS action may still be required if reclosing is unsuccessful [3].

## A. *Types of Remedial Actions*

- Shunt capacitor switching
- Generation Re-dispatch
- Load shedding
- Under load tap changing (ULTC) Transformer
- Distributed
- By locating FACTS Devices

# VIII. FACTS DEVICES

## A. *Flexible AC Transmission System*

The static and dynamic limits of transmission system restricted the power system transactions leading to underutilization of existing transmission lines. Previously traditional devices like fixed shunt, series reactors and capacitors were used to alleviate this problem however slow

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response; mechanical wear and tear confined their usage. The greater need for more efficient system has given rise to the development of alternative technology made of solid state, fast response devices. The other reasons like recent restructuring of power systems, difficulty in construction of new transmission lines and modified environmental and efficiency regulations have further fuelled the need for such devices. The invention of semiconductor devices like SCR opened the doors to the development of FACTS controllers.

Flexible Alternating Current Transmission Systems are used for control of voltage, phase angle and impedance of high voltage transmission lines. The strategic benefits of incorporating FACTS devices are improved reliability, better utilization of existing transmission system, improved availability, increased transient and dynamic stability and increased quality of supply. Due to dynamic nature of load and generation patterns, heavier line flows and higher losses are occurred causing security and stability problems. To overcome these problems in the present deregulated scenario more sophisticated control using FACTS devices is essential.

According to IEEE definition FACTS devices are power electronic base or other static controllers incorporated in AC transmission systems to enhance controllability and increase power transfer capability.

*B. Types of FACTS Controllers*

FACTS controllers are classified as series controllers, shunt controllers, combined series–series controllers and combined series-shunt controllers.

*1) Series Controllers*

These devices are connected in series with the lines to control the reactive and capacitive impedance there by controlling or damping various oscillations in a power system. The effect of these controllers is equivalent to injecting voltage phasor in series with the line to produce or absorb reactive power. Examples are Static Synchronous Series Compensator (SSSC),Thyristor controlled Series Capacitor (TCSC), Thyristor-Controlled Series Reactor (TCSR). . They can be effectively used to control current and power flow in the system and to damp system's oscillations.

*2) Shunt Controllers*

Shunt controllers inject current in to the system at the point of connection. The reactive power injected can be varied by varying the (SSG), Static VAR Compensator (SVC).

*3) Combined Series-Series Controllers*

This controller may have two configurations consisting of series controllers in a coordinated manner in a transmission system with multi lines or an independent reactive power controller for each line of a multi line system. An example of this type of controller is the Interline Power Flow Controller (IPFC), which helps in balancing both the real and reactive power flows on the lines.

*4) Combined Series-Shunt Controllers*

In this type of controller there are two unified controllers a shunt controller to inject current in to the system and a series controller to inject series voltage. Examples of such controllers are UPFC and Thyristor-Controlled Phase-Shifting Transformer (TCPST).

*C. Optimal Placement of FACTS Controllers*

The main considerations for incorporating the FACTS devices in power transmission system are improvement of system dynamic behavior, reliability and control of power. For the location of FACTS controller one of the following objectives may be chosen:

– To reduce real power loss of a line.
– To reduce Total real power loss of a system.
– To reduce the total reactive power loss of the system.
– To alleviate congestion by controlling power flow.

Sensitivity factors can be used for the first three objectives. To alleviate congestion and to improve transfer capability trial error methods can be used.

## IX. CONCLUSION

For any power system network it is necessary to carry out power flow analysis. It will be helpful to us in power system planning and design. It will be also useful to us in future expansion of network, contingency analysis and fault analysis. Contingency analysis study helps to strengthen the initial basic plan. It is also helpful to develop system operators to improve their ability to resolve problem. This tool helps especially the busy power system operators. The Newton"s method based contingency analysis algorithm is high accuracy and better efficiency. The contingency analysis in power world simulator is easy to run the power system and more reliable than compared with state estimation based contingency analysis. The security limits described from maximum violation of the element of test system and sensitivity analysis of both line outage distribution factor and generation shift factor. In feature power world simulator based contingency analysis is widely used for secured dispatch scheduling and the demand response improvement of deregulated power market. Transmission Companies should adopts the (Flexible AC Transmission),FACT devices as they can improve the lines active power capability in any contingency event as have faster switching than the traditional compensation devices.

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