4.1 INTRODUCTION

The power system protection, proposes schemes desired to isolate faults in transmission network components. The larger size and complexity of the power system grid makes the electrical system vulnerable to wide spread cascade failures leading to the collapse under critical situation of multiple outages. In the current power system operation, the transmission networks have been operated at their maximum permissible limits, due to which, in the system operation, day to day challenges are faced by the control centre operator. Recent wide area disturbances have raised many questions, when the causes and remedies for such occurrences demonstrate the vulnerability of the interconnected power system, when operated outside its intended permissible limits. Blackout prevention/mitigation and power system security, are the order of the day. Handling of outage events, congestion management in generation evacuation and load distribution, load generation balancing, monitoring of overloads and maintaining of grid parameters in safe limits, are some of the key factors of successful system operation.

The transmission sector mission especially is to develop technologies and policy option that will contribute to maintaining and enhancing the reliability of the state and central electrical power system network in this new era of open access and 2003 electricity act. To address these issues and improve the performance of the grid system, the application of SPS (Special Protection Scheme) found its place. The SPS also called the RAS (Remedial Action Scheme) are the special protection schemes that are designed to detect the abnormal system conditions, typically contingency related, and actuates the predetermined corrective action plan to mitigate the consequence of abnormal condition and provide acceptable performance [51]. Today, in many parts of the world, the network is stressed in its operation, due to the increased complexity of the network operations on account of many factors such as abnormal growth in load at some areas and more generation injections concentrated in few pockets of the grid, changes in the market strategies and increase in exports and imports of power transfer. Hence, the SPS requirement has become inevitable.

The events potentially leading to emergency conditions are shown in Fig.4.1.

Primary (cause) - dangerous overloading of a transmission grid elements, due to outage of certain critical transmission lines.

Secondary (consequences) - As a reaction to the primary events, with cascade-wise development – the main cause of mass-scale tripping of power plants [52].

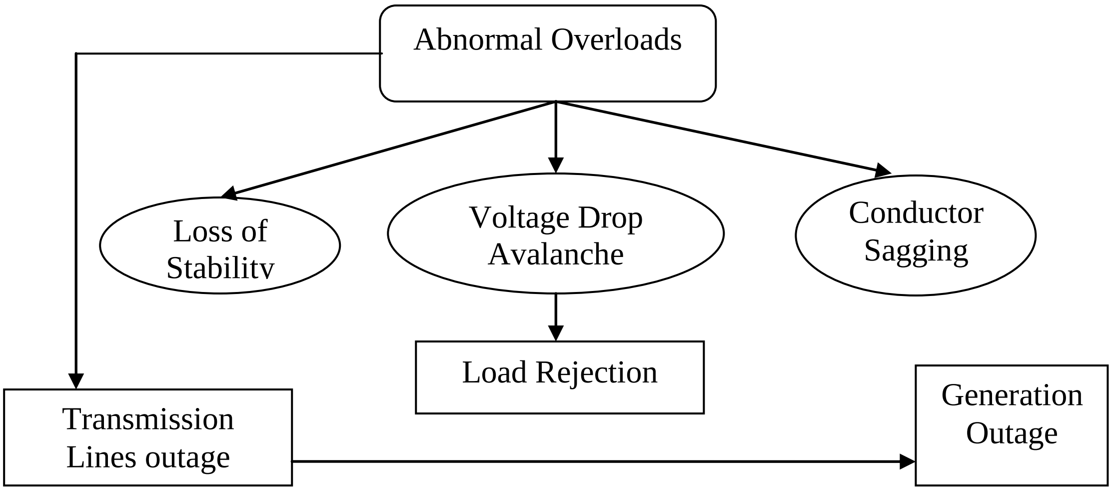

Fig. 4.1: Primary and secondary emergency events

The protection is complex, against blackouts, and should comply with the control schemes adapting new principles for preventive and fast removal of the root cause of blackouts. The hierarchical integration of existing protections suitable for this purpose in the new complexities allows avoiding the creation of parallel protection structures. When choosing the protective structure, the psychological and technical aspects of implementation should be observed; therefore, to elucidate the causes of secondary emergency initiation and to find out the prospective protection elements, this thesis is focused on studying and designing of the remedial action measures to be implemented in the event of triggering the emergency conditions.

4.2 MOTIVATION

The various approaches in this field proposed so far are costly and require the implementation of complex tools for the real-time estimation and the assessment of system operation condition and also it is observed that the principles of SPS and its practical design details were not found. The aim of this research work is precisely to meet the need of utilities by development of simpler and cost effective methods for retaining the system integration in the event of critical lines outages and preventing its cascade effects, thereby avoiding the total power plant blackout.

4.21 Some Occurrences of Major Failures

1. Grid tripping occurred on 16-4-2009 at 220 kV CNP substation by blasting of CT in B Phase of LV ICT of 315 MVA, 400/220 kV, creating bus fault resulting in tripping of all the generator units at RTPP (Rayalaseema Thermal Power Plant of 1050MW capacity) and other associated transmission lines.
2. Grid tripping occurred on 12-7-2008 on operation of the bus bar protection on both the buses of 220kV CNP substation, the simultaneously tripping of 220kV RTPP-CNP feeders 1 and 2 caused the outage of all the generators at RTPP with the loss of generation of the total RTPP power plant and other associated transmission lines.

4.3 TRADITIONAL PROTECTION AND SPECIAL PROTECTION SCHEMES

Some conventional relaying protections that are adopted in the power system are:

1. **Line Protection**: The distance relays are commonly used for protection of transmission lines. The operating principle is based on the detection of the distances to the fault which is proportional to the measurement of the impedance at the fault location, using the voltage and current inputs. Most of the faults are single line to ground fault. For the same type of fault occurring at different section of the network results in different fault currents and then different impedance magnitudes would be measured for the same fault. Selectivity in distance protection scheme is achieved by providing suitable zonal settings of zone 1, zone 2, zone 3 and zone 4, with proper time gradation.
2. **Over Current Relays**: The over current relays operate when the relay currents exceed the preset value at a time determined by the relay characteristics. Hence,

the relay initiates tripping of the associated circuit breaker after time delay which in many cases is inversely proportional to the value of the over current.

3. **Differential Relay**: The protection scheme is based on the equality between the entering and leaving currents in the closed circuits under normal conditions. The protection is activated when the induced voltage on the primary and secondary side CT attains different values as a result of different current values at each terminal. For transformer, the percentage differential relay with harmonic restraint is used for desensitizing the relay for magnetizing in rush currents and make it operative for transformer internal faults. Thus, the fundamental component of spill current is filtered and used to develop the tripping torque. The non-fundamental component of spill current aids the un-filtered circulating current, in developing the restraining torque. This makes the relay stable on in rush, while at the same time not effecting its operation in case of actual internal faults.

4. **Generator Protection**: The generators are provided with the protection relays for various types of faults which includes the stator winding faults, rotor winding faults and also to take care of mechanical system failures like loss of prime mover, over speeding and protection against the loss excitation. Thus, the conventional power system protection is mainly based on the protection of power system equipment from damage by isolating the faults.

4.31 SPS Versus Conventional Protection

While the type of protection schemes presented in this thesis is of special type which is used to protect the power system against the partial or total collapse. To obtain this objective, the protective measures are taken when abnormal conditions are identified for these instants, no traditional faults situation is present, but the system itself may be in transition to dangerous situations, such as wide area disturbance or complete system blackout. Accordingly, the protection measures are used to counteract this transition and bring the system back to safe operating conditions. Thus, the special protection schemes are designed to detect the abnormal system condition and to take predetermined corrective action (other than the simple isolation of faulted elements) to provide acceptable system performance. The SPS includes the following main functions

1. First, the scheme collects the input data from the power system.
2. The scheme evaluates the input data and makes the decision for the actions to be taken.
3. The typical actions may be load or generator shedding.

The Special Protection Schemes are of two types:

1. Event based SPS
2. Response based SPS

- **Event based SPS**

React first upon recognition of the number of critical events which are easy to identify and detect. This application includes the power systems where the severity of the event exceeds the system permissible limitations and immediate control action is found required.

The event based SPS is characterized as open-loop type. The remedial actions are designed and evaluated using the off line simulation studies of the power system performance and the system response to the events or contingency. Depending upon the system response, the power system attains an acceptable state.

- **Response based SPS**

It is based on the power system to a specific contingency where the measured electrical value (power voltage, frequency etc.) is used as input to the SPS. The specific input variables are selected according to the type and severity of the system wide disturbances. The SPS tripping initiates, proper protection action after disturbance has caused the measured variables deviating to abnormal values. This is most dependable and secure. Since, the effect of unintended SPS operation is minimal due to restricted and localized action.

4.4 CONCEPT OF SPS

The special protection scheme is structured with the different components as shown in the Fig. 4.2.

The main modules are, the input module, decision process module, and action module. The input module is used for receiving the input signal from the measurands. In this module, the MW transducers are adopted.

The decision module is developed with the decision tree incorporating the required logic for taking up the necessary action in the event of occurrences of the disturbances. The action module will take the corrective action from the output of the decision module for initiating the actuator. In this module, the generation rejection is the actuator that is adopted.

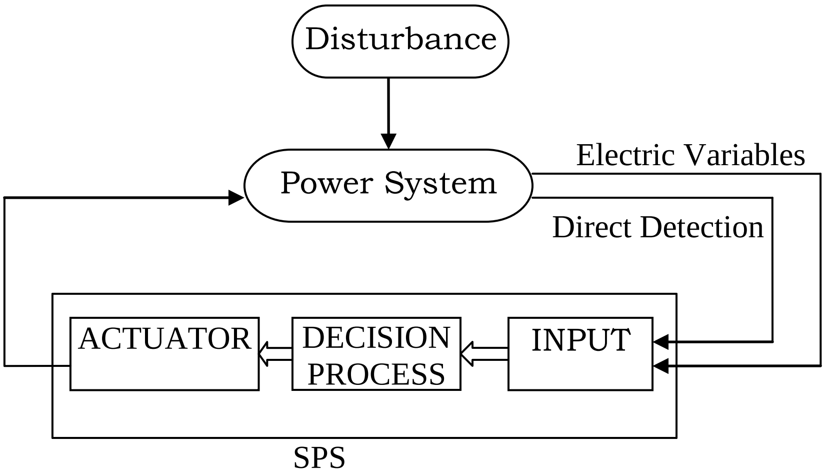

Fig. 4.2: Structural Concept for Special Protection Scheme

4.5 SPS DESIGN CRITERIA

The design criteria for SPS are a very important issue and required to ensure the following, from the reliability point of view.

1. **Dependability**: Certainty that SPS will operate when required. A protection scheme that should act when it is supposed to.
2. **Security**: Certainty that SPS will not operate when not required. A protection scheme that should not act, when it is not supposed to.

3. **Selectivity**: The ability to activate the minimum amount of control action. A SPS control should not be excessive i.e., it should be able to shed the appropriate amount of load or generation in order to keep the system, as much as possible intact.

4. **Robustness**: Ability to operate properly over the entire range of the system conditions.

In this work, it is proposed to design and implement SPS in real-time power system. The typical power plant, in which SPS is adopted, is featured with highest generation capacity and multiple units. The evacuation transmission lines for the power plant depends on two or more outgoing lines. In the absence of the proposed SPS scheme, it is observed that some of the lines outages will cause the blackout of the total power plant. This means that all generators at the plant will accelerate and trip in cascade manner, due to the failure of the evacuation. The SPS is designed here, which is trigged by the outage events, will trip the required generator units at the power plant in order to avoid the out of step condition for remaining units.

The main activities involved in designing the SPS are developed in two stages:

Stage I : Modeling the power system of the state utility

Stage II : Designing the logic decision circuit for SPS operation

STAGE I

1) This is the most fundamental step involved in designing the scheme, as the further analysis and development depends mainly on the outcome results based on this frame work, which will represent the real power system snap shot. Hence, considering these aspects, by collecting the actual field data, the system is modeled with the existing transmission lines of 400kV,220kV and 132 kV voltages, power transformers of 315 MVA at rated voltages of 400/220kV,250 MVA power transformers at rated voltages of 400/220kV,200MVA power transformers at rated voltages of 400/220kV in 400kV network. The Power transformers of 160MVA at rated voltages of 220/132,100 MVA power

transformers at rated voltages of 220/132, in 220kV network are considered in modeling of the transmission system. The existing of thermal, hydro and gas generators are considered in modeling the generators with their with rated MVA capacities, rated voltage and permissible ‘Q’ (reactive power) limits. The distributed loads incident on 132 kV substations are considered for load modeling with constant loads ‘P’ and ‘Q’. This is the total integrated system modeling for performing the required studies.

2) Performing the load flow studies to represent the base case of the real-time system, for maximum demand conditions .This step requires the preparation of the input quantities of the real power injections at the various generators and the load demand fed from each of the substations in real-time system to meet the peak demand of the state utility, for which the proposed SPS is to be designed.

    (a) The main task is obtaining the power flows in the modeled system for the real-time operation conditions meeting the maximum demand of the system. To determine the base case power flows, the power flow studies were conducted using the CYMEFLOW software adopting the fast decoupled method.

The computational details are described below. The power flow solutions are obtained from the data input to various buses under consideration. The types of buses considered for representing the system generators and loads at the ith bus are (Table 4.1),

1. Generator Bus – P_i, $|V_i|$
2. Load Bus – P_i, Q_i
3. Slack Bus – $|V_i|$, θ_i

Table 4.1: Bus Configuration

Nature of the Bus	**Known values**	**Unknown values**
Slack Bus	$|V_i|$, θ_i	P_i, Q_i
Generator Bus	P_i, $|V_i|$	Q_i, θ_i
Load Bus	P_i, Q_i	$|V_i|$, θ_i

Where P_i is the real power generation at generator bus, V_i is the voltage magnitude at the generator bus which are known before solving power flow equations. At the load bus P_i is the real power load and Q_i is the reactive power load at the load bus. By solving the power equation we will get the unknown quantities at these buses i.e., $|V_i|$, θ_i at the load bus. θ_i is the voltage angle at the ith bus. At the slack bus $|V_i|$, θ_i are specified and by solving the load flow equation we will get the unknown P_i, Q_i at the slack bus which is considered as the major power station with variable generation provision to accommodate total power system losses.

(b) **The power flow problem statement**

The modeled network represents the transmission lines and power transformers mathematically shown in the admittance matrix as

$$Y_{ik} = G_{ik} + jB_{ik} \qquad \ldots (4.1)$$

Where G is the conductance and B is susceptance. Basically we need to solve the set of equations, f(x) = 0

$$\sum_{k=1}^{m} |V_i||V_k| \left(G_{ik} \cos\theta_{ik} + B_{ik} \sin\theta_{ik} \right) - P_i = 0 \qquad \ldots (4.2)$$

$$\sum_{i=1}^{m} |V_i||V_k| \left(G_{ik} \sin\theta_{ik} + B_{ik} \cos\theta_{ik} \right) - Q_i = 0 \qquad \ldots (4.3)$$

Where,

V_i = Voltage at the i^{th} bus

V_k = Voltage at the k^{th} bus

θ = voltage angle

P_i = real power at the i^{th} bus

Q_i = reactive power at the i^{th} bus

f(x) = objective function

The aim is to solve for x,

f(x) = 0

Let f(x) = x – h(x) then

x = h(x)

The value of x is found literately using

$X^{k+1} \leftarrow h(x^k)$

Here k = iteration count.

When the solution converges the solution $x^* = h(x^*)$, when

$$\left\| x^{k+1} - x^k \right\| \le \varepsilon$$

Where ε is the specified tolerance value

In the N-R algorithm the voltage angle and magnitudes are obtained from the Jocobian Matrices ‘J’, which are the partial derivatives of the respective function with their variables.

$$\begin{bmatrix} \Delta\theta^k \\ \Delta V^k \end{bmatrix} = \begin{bmatrix} J_{11}^k & J_{12}^k \\ J_{21}^k & J_{22}^k \end{bmatrix}^{-1} \begin{bmatrix} \Delta P\left(\theta^k, |V|^k\right) \\ \Delta Q\left(\theta^k, |V|^k\right) \end{bmatrix} \qquad \ldots (4.4)$$

Considering v = 1∠0 as initial start the updated values of θ and v in every iteration is applied to find the latest power flows till the power mismatches obtained fall within the tolerance value ε. For the large power systems network matrix, the size of n bus system, the Jocobian matrix size may be 2(n – 1) x 2(n-1). It needs to be reevaluated and take the inverse of Jocobian matrix at every iteration.

For Indices p ≠ q

$$j_{pq}^{11} = \frac{\partial p_p(x)}{\partial \theta_q}$$

$$= |V_p||V_q|\left(G_{pq}\sin\theta_{pq} - B_{pq}\cos\theta_{pq}\right) \qquad \ldots (4.5)$$

$$j_{pq}^{21} = \frac{\partial Q_p(x)}{\partial \theta_q}$$

$$= |V_p||V_q|(G_{pq} \cos\theta_{pq} + B_{pq} \sin\theta_{pq})$$

… (4.6)

$$j_{pq}^{12} = \frac{\partial P_p(x)}{\partial(|V_q|)}$$

$$= |V_p|(G_{pq} \cos\theta_{pq} + B_{pq} \sin\theta_{pq})$$

... (4.7)

$$j_{pq}^{22} = \frac{\partial Q_p(x)}{\partial(|V_q|)}$$

$$= |V_p|(G_{pq} \sin\theta_{pq} - B_{pq} \cos\theta_{pq})$$

... (4.8)

for p = q

$$j_{pq}^{11} = \frac{\partial P_p(x)}{\theta_p}$$

$$= |V_p||V_q|(-G_{pq} \sin\theta_{pq} + B_{pq} \cos\theta_{pq}) + \frac{\partial}{\partial \theta_p} |V_p|^2 G_{pp}$$

$$= |V_p||V_q|(B_{pq} \cos\theta_{pq} - G_{pq} \sin\theta_{pq}) + 0$$

… (4.9)

Substituting from equation (4.3)

$$j_{pp}^{11} = -Q_p - B_{pp} |\mathrm{V_p}|^2$$

… (4.10)

$$j_{pq}^{21} = \frac{\partial Q_p(x)}{\partial \theta_p}$$

$$= \frac{\partial Q_p(x)}{\partial Q_p}$$

$$= |V_p||V_q|(G_{pq} \cos\theta_{pq} + B_{pq} \sin\theta_{pq}) + 0$$

$$\because \frac{\partial}{\partial \theta_p}\left(-V_p^2 B_{pp}\right)=0$$

$$j_{pp}^{21}=P_p-G_{pp}V_p^2 \qquad \ldots (4.11)$$

$$j_{pp}^{12}=\frac{\partial P_p(x)}{\partial |V_p|}$$

$$=\frac{\partial |V_p||V_q|\left(G_{pq}\cos\theta_{pq}+B_{pq}\sin\theta_{pq}\right)}{\partial V_p}+\frac{\partial |V_p^2|}{\partial V_p}G_{pp}$$

$$=|V_q|\left(G_{pq}\cos\theta_{pq}+B_{pq}\sin\theta_{pq}\right)+2V_pG_{pp}$$

$$=\frac{P_p}{|V_p|}+\frac{G_{pp}|V_p^2|}{V_p}$$

$$j_{pp}^{12}=\frac{P_p}{V_p}+G_{pp}V_p \qquad \ldots (4.12)$$

$$j_{pp}^{22}=\frac{\partial Q_p(x)}{\partial |V_p|}+\frac{Q_p}{|V_p|}-B_{pp}|V_p|$$

$$=\frac{\partial}{\partial v_p}|V_p||V_q|\left(G_{pq}\sin\theta_{pq}-B_{pq}\cos\theta_{pq}\right)-\frac{\partial\left(|V_p|^2 B_{pp}\right)}{\partial V_p}$$

$$=V_q\left(G_{pq}\sin\theta_{pq}-B_{pq}\cos\theta_{pq}\right)-2V_pB_{pp}$$

$$=\frac{Q_p}{V_p}-B_{pp}|V_p| \qquad \ldots (4.13)$$

The Jacobian Matrix can be modified for rewriting as shown in the equation (4.14).

From the equation (4.4)

$$\begin{bmatrix} J_{11}^k & J_{12}^k \\ J_{21}^k & J_{22}^k \end{bmatrix}^{-1} \begin{bmatrix} \Delta\theta^k \\ \Delta|V|^k \end{bmatrix} = \begin{bmatrix} \Delta P\left(\theta^k,|V|^k\right) \\ \Delta Q\left(\theta^k,|V|^k\right) \end{bmatrix}$$

Taking out the common factor |V| in J_{22} and J_{12} the above equation can be written as

$$\begin{bmatrix} J_{11}^k & |V|^k \tilde{J}_{12}^k \\ J_{21}^k & |V|^k \tilde{J}_{22}^k \end{bmatrix}^{-1} \begin{bmatrix} \Delta\theta^k \\ \Delta|V|^k \end{bmatrix} = \begin{bmatrix} \Delta P(\theta^k, |V|^k) \\ \Delta Q(\theta^k, |V|^k) \end{bmatrix}, \quad |V| \equiv \begin{bmatrix} |V_2| & . & . & 0 \\ . & . & & . \\ . & & . & . \\ 0 & . & . & |V_n| \end{bmatrix}$$

This can be rewritten as

$$\begin{bmatrix} J_{11}^k & \tilde{J}_{12}^k \\ J_{21}^k & \tilde{J}_{22}^k \end{bmatrix}^{-1} \begin{bmatrix} \Delta\theta^k \\ \dfrac{\Delta|V|^k}{|V|^k} \end{bmatrix} = \begin{bmatrix} \Delta P(\theta^k, |V|^k) \\ \Delta Q(\theta^k, |V|^k) \end{bmatrix}, \quad \frac{\Delta|V|}{|V|} \equiv \begin{bmatrix} \dfrac{\Delta|V_2|}{|V_2|} \\ \cdot \\ \cdot \\ \dfrac{\Delta|V_n|}{|V_n|} \end{bmatrix} \qquad \dots (4.14)$$

At normal operating conditions the $\theta^0 = 0$, $|V| = 1$ (i.e., the voltage should be constant with 1pu and angular difference should be very small)

J_{21} and J_{12} are quite small and the Jacobian matrix can be decoupled

In the Jacobian matrix J_{21} and J_{12} can be approximated as

$$J_{pq}^{12} = \frac{\partial Q_p(x)}{\partial \theta_q} = -|V_p||V_q|\left(\underbrace{G_{pq}}_{\substack{\downarrow \\ 0}} \cos\theta_{pq} + B_{pq} \underbrace{\sin\theta_{pq}}_{\substack{\downarrow \\ 0}} \right)$$

$$J_{pq}^{21} = \frac{\partial P_p(x)}{\partial |V_q|} = -|V_p|\left(\underbrace{G_{pq}}_{\substack{\downarrow \\ 0}} \cos\theta_{pq} + B_{pq} \underbrace{\sin\theta_{pq}}_{\substack{\downarrow \\ 0}} \right) \qquad \dots (4.15)$$

$$J = \begin{bmatrix} J_{11} & J_{12} \\ J_{21} & J_{22} \end{bmatrix} \approx \begin{bmatrix} J_{11} & 0 \\ 0 & J_{22} \end{bmatrix} \Rightarrow \begin{bmatrix} J_{11}^k & 0 \\ 0 & J_{22}^k \end{bmatrix} \begin{bmatrix} \Delta\theta^k \\ \Delta|V|^k \end{bmatrix} = \begin{bmatrix} \Delta P(\theta^k, |V|^k) \\ \Delta Q(\theta^k, |V|^k) \end{bmatrix} \qquad \dots (4.16)$$

The Decoupled Mismatch Equation will be

$$\begin{bmatrix} J_{11}^k & 0 \\ 0 & J_{22}^k \end{bmatrix}\begin{bmatrix} \Delta\theta^k \\ \Delta|V|^k \end{bmatrix} = \begin{bmatrix} \Delta P(\theta^k, |V|^k) \\ \Delta Q(\theta^k, |V|^k) \end{bmatrix}$$

$$\begin{aligned} J_{11}^k \Delta\theta^k &= \Delta P(\theta^k, |V|^k) \\ J_{22}^k \Delta|V|^k &= \Delta Q(\theta^k, |V|^k) \end{aligned} \qquad \ldots (4.17)$$

From the considerations that the conductance of a transmission line G is quite small and is negligible and when θ is small sin(θ) ≈ θ. Hence sin(0) = 0.

$$J_{pq}^{11} = \frac{\partial P_p(x)}{\partial \theta_q} = -|V_p||V_q|\left(\underbrace{G_{pq}}_{\substack{\downarrow\\0}}\sin\theta_{pq} - B_{pq}\underbrace{\cos\theta_{pq}}_{\substack{\downarrow\\1}}\right)$$

$$J_{pq}^{22} = \frac{\partial Q_p(x)}{\partial |V_q|} = -|V_p|\left(\underbrace{G_{pq}}_{\substack{\downarrow\\0}}\sin\theta_{pq} - B_{pq}\underbrace{\cos\theta_{pq}}_{\substack{\downarrow\\1}}\right)$$

Now

$$J_{pq}^{11} \approx -|V_p||V_q|B_{pq}$$
$$J_{pq}^{22} \approx -|V_p|B_{pq}$$

The bus admittance matrix Y = G + jB

Now

$$J_{11} = -[|V|]\,\underline{\overline{B}}\,[|V|]$$
$$J_{22} = -[|V|]\,\underline{\overline{B}}$$

Now the power flow equation can be written as

$$-[|V|^k]\,\underline{\overline{B}}\,[|V|^k]\,\underline{\overline{\Delta\theta}}^k = \Delta P(\theta^k, |V|^k)$$
$$-[|V|^k]\,\underline{\overline{B}}\,\Delta|V|^k = \Delta Q(\theta^k, |V|^k)$$

Flat voltage |V| = 1

$$-\left[V^k\right]B\Delta\theta^k = \Delta P\left(\theta^k, |V|^k\right)$$
$$-\left[V^k\right]B\Delta|V|^k = \Delta Q\left(\theta^k, |V|^k\right)$$
$$-B\Delta\theta^k = \Delta\tilde{P}\left(\theta^k, |V|^k\right)$$
$$-B\Delta|V|^k = \Delta\tilde{Q}\left(\theta^k, |V|^k\right)$$

Where

$$\Delta\tilde{P}\left(\theta^k, |V|^k\right) = \frac{\Delta\tilde{P}\left(\theta^k, |V|^k\right)}{|V|^k}, \Delta\tilde{Q}\left(\theta^k, |V|^k\right) = \frac{\Delta\tilde{Q}\left(\theta^k, |V|^k\right)}{|V|^k}$$

The equations become

$$\left[\frac{\Delta P}{|V|}\right] = B \quad \Delta\theta \qquad \left[\frac{\Delta Q}{|V|}\right] = B\left[\Delta|V|\right]$$

$$\left[\frac{\Delta P}{|V|}\right], \left[\frac{\Delta Q}{|V|}\right] \text{ are } \begin{bmatrix} \left[\frac{\Delta P_2}{|V_2|}\right] \\ \vdots \\ \left[\frac{\Delta P_n}{|V_n|}\right] \end{bmatrix} and \begin{bmatrix} \left[\frac{\Delta Q_2}{|V_2|}\right] \\ \vdots \\ \left[\frac{\Delta Q_n}{|V_n|}\right] \end{bmatrix} \qquad \ldots (4.18)$$

We can find B as soon as we have the $Y_{bus.}$ The main advantage of this fast decoupled power flow is, we do not need to update B during the iteration process. We have to invert B only once to solve. The matrix equation is separated into the two decoupled equations and simplified to eliminate the need for recomputation of the sub matrices during each iteration. 1) The real power change ΔP is insensitive to the voltage magnitude ΔV and it will be more sensitive to changes in phase angel Δδ. 2) The reactive power changes ΔQ is less sensitive to the changes in the phase angle Δδ. It will be more sensitive to the changes in the voltage magnitude ΔV. This require less time solve compare to full matrix computation in each iteration. Thus, the fast decoupled power flow method speedup the solution process. The above fast decoupled equations can be further simplified by omitting the phase shifter from B by setting tap to 1.0 at zero degree, the new matrix will be B" then,

$$\left[\frac{\Delta Q}{|V|}\right] = \left[B''\right]\left[\Delta|V|\right]$$

Omitting the elements of B that affects the MVR flows Shunt capacitors, reactors and set the off nominal transformer taps to 1.0 and ignoring the transmission line resistance the new matrix will be $B^{'}$

$$\left[\frac{\Delta P}{|V|}\right] = \left[B^{'}\right]\left[\Delta\theta\right]$$

Thus, the power flows will be obtained for all the buses of modeled system

3) Carrying out the contingency analysis: In this step, to incorporate the outage of the transmission lines, which represents the event under consideration, the transmission model alone is altered considering the removal of the outage lines under consideration for representing the contingency case for further analysis. Again the load flow studies are performed with this contingency model.

4) Determining critical lines and finding out the SPS arming limits, i.e. the main task in designing the SPS is to set the

Arming conditions for SPS

IF<condition>…….. and

Actuate function of SPS

THEN <SPS Action>

In this step, the main functional activity of SPS is to be developed, based on the algorithm i.e., the SPS should sense the arming event and then actuate the logic circuit for initiating the control action. In this stage, the power flow on the lines are considered for assigning the arming limits, then comes the aspect of fixing these limits based on the algorithm shown in flow chart (Fig. 4.4).

When the disturbance event is identified, the generation of actuating signal for control should take the required control action. Here, to what extent the generation rejection should be done is the design criteria.

STAGE II

Though, the stage-I provides the required design requirements and algorithm it is the logic circuit which takes the corrective action. This is designed with combination of AND, OR and NOT gates. The functionality assigned is, that the trip signal should be generated only in the event of DC lines outage(here it is the 220kV double circuit of RTPP-CNP) and when the power flow on the critical lines is exceeding i.e., greater than 225MW, for one generator unit tripping, and the power flow greater than 275 MW for two generator units tripping. The output of AND gate will be high only when the inputs of RTPP-CNP and RTPP-ATP will make their respective OR gates output high. This is because, the logic circuit should take care of the SPS action only when it is required, and should not act when not required by the system .This is how the logic process is developed for SPS action as shown in Fig. 4.3.

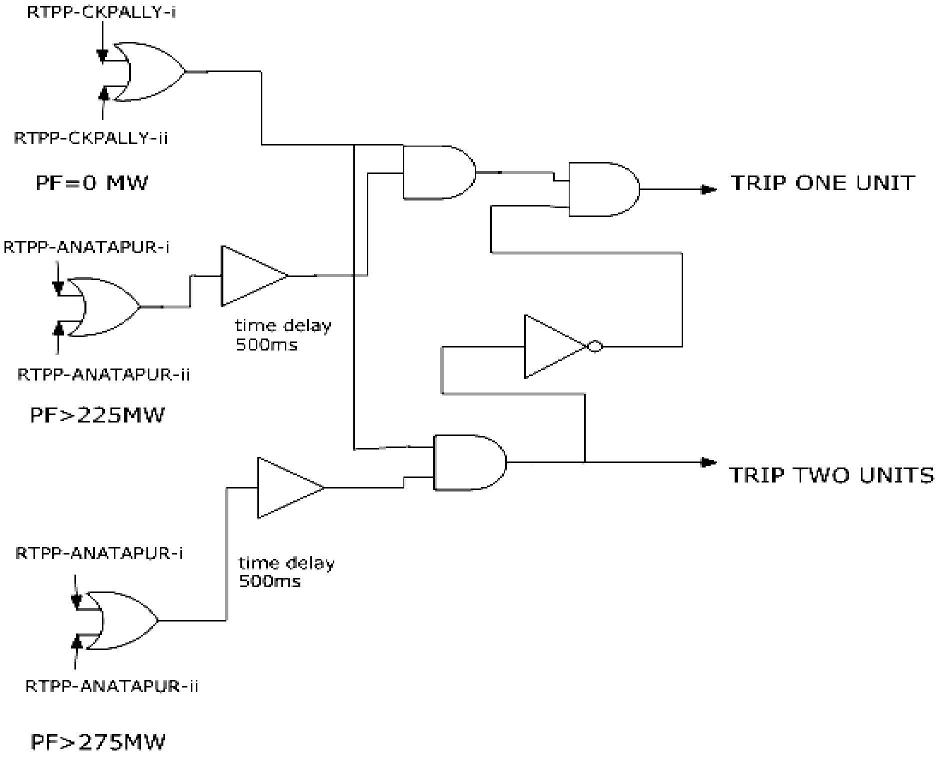

Fig. 4.3: Logic architecture-special protection scheme of GRS

4.6 ALGORITHM FOR DETERMINATION OF THE CRITICAL LINES

1. The algorithm is proposed by considering the various units at the power plant of the generator bus considered in the system modeling for which the SPS is to be designed. The power flow study is carried out in determining the P_{max} on the m-number of evacuation lines.

   a. The system data for the network loads and generators of the total integrated system will be given as input to the CYME edit and the power flows are computed by running the CYMEFLOW studies.

   b. From these power flows, the power flows P_{ik} $i = 1 \dots m$ pertaining to the k^{th} bus of the power plant under consideration for designing of SPS will be evaluated for determining the P_{ikmax}.

      $P_{ikmax} = \max(P_{ik}, i = 1 \dots q \dots m)$, and
      P_{ik} = power injection from k^{th} bus to i^{th} bus
      P_{Gj} = generation of the j^{th} unit
      L_{ik} = transmission line from the k^{th} bus to i^{th} bus

2. Contingency event is applied for this particular evacuation line and the power flows are determined on all outgoing lines to find out the maximum power flow which will be the critical line requiring the SPS action.

   Applying contingency event $L_{qk} = 0$
   Again the load flow is run with the outage event.

3. The power flow on the critical line is compared with the threshold preset power, to asses the arming limits of generation rejection to be provided by the SPS.

   $$\underset{i \neq q}{\text{Max}}\ P_{ik} = \underset{i \neq q}{\max}(P_{ik}, i = 1 \dots q \dots m)$$

   The Max P_{ik} is compared with the threshold power limit P_c i.e.,

   if Max $P_{ik} > P_c$

   then initiate SPS action,

   if not no SPS action

4. Control action of SPS

The SPS action which is initiated in the event of occurrence of disturbance, is controlled in its action for tripping of the required generation units as per the system needs.

With $P_{G1} = 0$, the load flow is to be computed with generation rejection of one unit

Compute Max P_{ik} = max(P_{ik}, i = 1….q…m)

$i \neq q$ $i \neq q$

The Max P_{ik} is compared with the threshold power limit P_c i.e.,

if Max $P_{ik} > P_c$

then initiate SPS action for additional generation rejection,

if not Stop SPS action.

4.7 LOAD FLOW DIAGRAM FOR DETERMINATION OF CRITICAL LINES AND ARMING LIMITS

From the basic load flow result, it is found that whenever the RTPP power plant is in its full capacity generation and the outage of 220 kV DC line of RTP-CNP will result in the abnormal flow of power into the RTPP-ATP DC lines. From the results of base case study, it is observed that the flow will be around 337 MW on each line. This is the most severe and abnormal power flow condition leading to the disturbance. As these lines tripping on overload will further result into tripping of the other healthy lines in and around, along with the pulling of all the generator units at the power plant resulting into blackout of the power plant.

The need of remedial action plan is found essential to avert further propagation of cascaded outages. The SPS designed will actuate to trip two units simultaneously so that the power flow will be reduced to around 150MW on each line of the RTPP-ATP. But in actual circumstances, when the RTPP is not to its full generation capacity, the tripping of two will be unwanted from the generation loss

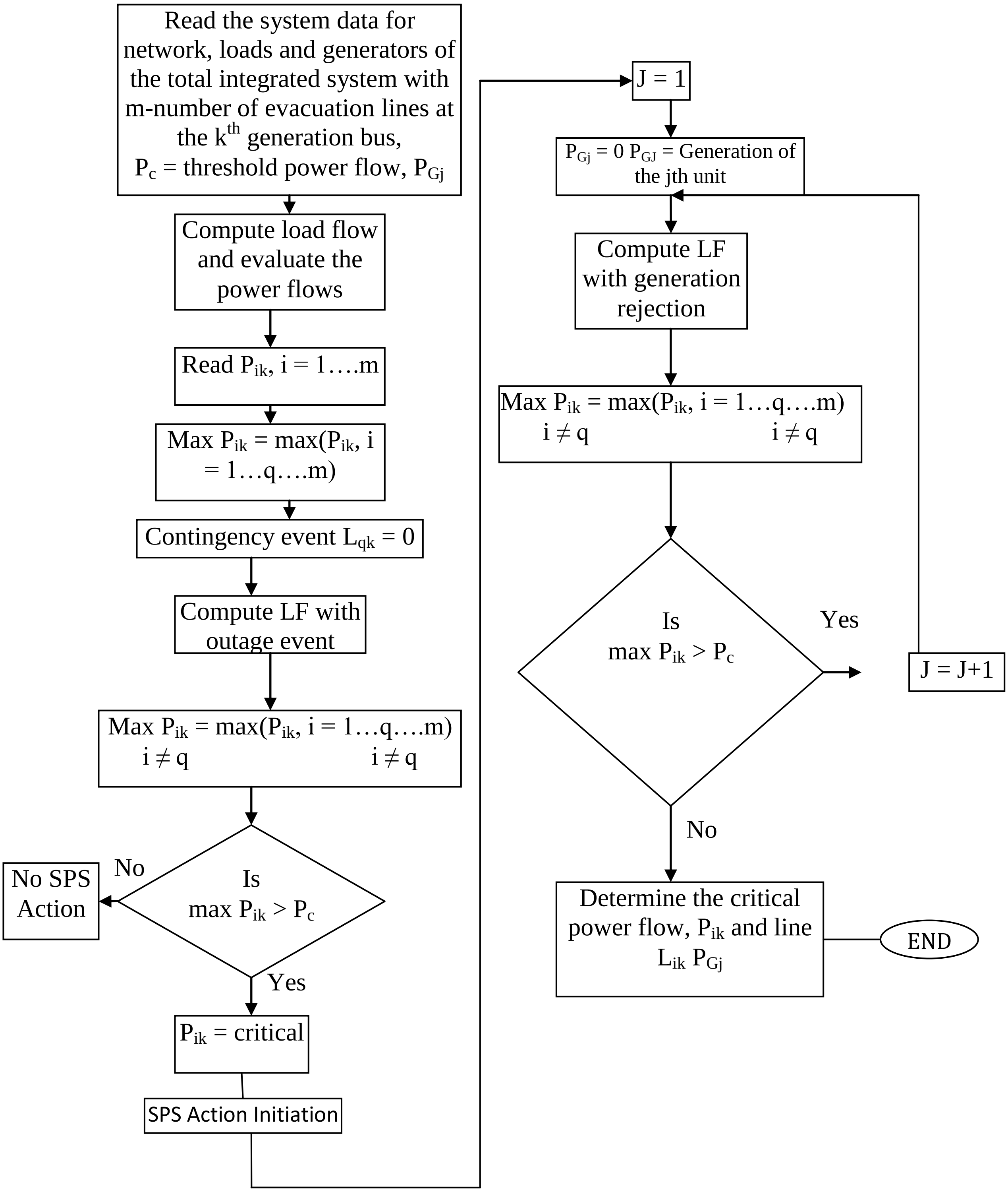

Fig. 4.4: Flow chart for determination of critical lines and SPS action

point of view to the system. From the power flow study results, it is observed, that the outage of RTPP-CNP DC line and one unit at RTPP outage, the power flow was around 240MW on RTPP-ATP line. In these circumstances, the required SPS actions should be limited to one unit tripping only. This means, the control feature is required to be incorporated in SPS action limiting its action of generation rejection, to the extent needed.

From the results of power flow study, the maximum possible power flow on RTPP-ATP was either 337 .23MW or 240 MW in the event of contingency. From the thermal limit load limit, for consideration of single moose conductor, the P_c is set at 225 MW.

1) That is whenever the power is 337.23MW the required tripping is two units.

2) Whenever the power flow on critical lines is 240MW the required tripping will be one unit. To provide safer limits, it is proposed to design, to set the arming limits as 225MW and 275MW to trip the one unit or two units of RTPP power plants. The limits are set based on the power flow study results and not on the basis of percentage on positive side or negative side 240MW flow. When ever the contingency of critical lines occurs, the power flow on the evacuation lines of RTPP-ATP was around 337.23MW (from the power flow study results) without the initiation of SPS action.

3) When one unit is tripped, it was observed that the power flow was around 242MW. To limit the power flow around its thermal capacity of 225MW, two generators tripping was found needed. Thus the required limits are set at 225MW and 275MW to trip one or two units of generators show that $225 < 242 < 275 < 337$.

4.8 SIMULATION AND RESULTS

The simulation study is carried out for the major power plant RTPP (Rayalaseema Thermal Power Plant). The power plant is having five numbers of generator units, each unit of 210 MW generation capacities. The existing evacuation transmission scheme consists of the following transmission lines:

(1) 220 kV RTPP-CNP DC Line

(2) 220 kV RTPP-YGT DC Line

(3) 220 kV RTPP-ATP DC Line

(4) 220 kV RTPP-PULIVE DC Line

The SPS scheme is proposed for preventing the total RTPP power plant blackout in the event of the critical DC line outage. The simulations are carried out for the various cases.

Case I: The simulations for the base case consisting of the RTPP power plant with all the evacuation lines in service with the total power generation by all the units.

Case II: The simulations with the contingency event application. In this scenario, the effect of the contingency event application on the evacuation lines of the RTPP power plant, when the power plant is in its full generation capacity.

Case III: The simulations with the contingency event application and the actuation of SPS with two units of generation rejection.

Case IV: The simulations with the contingency event application and the actuation of SPS with one unit of generation rejection.

CASE I

The object of simulation is to analyze the behavior of the real-time system of the state utility under various scenarios. For this, CYMFLOW software package is used. The inputs of the loads at various EHT substations are given as load buses and EHT transmissions lines of 400 kV 220 kV and 132 kV are provided considering the R, X, B parameters based on the type of conductor used. The actual generation at various generating plants injecting into the grid system at peak demand are presented at various generating buses. By running the software with these data inputs, the power flow in each of the line and the transformers in the network are computed in the steady-state conditions. The RTPP is a power plant with the generation capacity of 1050 MW. The main evacuation lines are 220 kV RTPP-CNP, RTPP-ATP, RTPP- PULIVE and RTPP-YGT. The base case power flows in the critical lines under consideration are shown in the Table 4.2.

Table 4.2: Base Case (Power Flows in the event DC line and critical lines under consideration)

Sl.No	Name of the Feeder	Power Flow in MW
1	220kV RTPP (Bus no 256) to CNP (Bus no 206) DC line	2 x 248MW
2	220kV RTPP (Bus no 256) to ATP (Bus no 258) DC line	2 x 89.96Mw

Most of the loads for this power plant evacuation, are concentrated in the Kadapa and Chittor districts of Andhra Pradesh, most of the power flow is found on the 220 kV RTPP-CNP lines under normal conditions and hence the most care is taken during the planning of the evacuation scheme by recommending 220 kV twin moose conductors for this lines, thus satisfying the N-1 criteria also. Hence, the base case is simulated with the existing network and load demand condition, and the results are given in the Fig. 4.5 and Table 4.6.

The load flow diagram Fig. 4.5 for RTPP evacuation in normal operating state, consists of all the five generators with their output of 190MW each, and all the evacuation lines in service.

The simulation results in table 4.6 shows that the total RTPP power plant generation is evacuated along the RTPP – ATP lines, with power flow of 89.96 MW on each of the DC line, RTPP-CNP DC line, with power flow of 248.27MW on each of the line, RTPP-YGT DC line, with power flow of 90.62MW on each of the line and RTPP-PULIVE lines with power flow of 47.16MW on each of the line. The loadings on all evacuation lines were observed to be with in the limits without any abnormalities and the system will be in normal state.

CASE II

The effect of the contingency event application on the evacuation lines of the RTPP power plant, when the power plant is in its full generation capacity, is simulated. With the simultaneous outage of two lines from the RTPP to CNP the power flows are computed for assessing the criticality and identifying the critical lines. The power flows with the contingency event under consideration, are presented in the Table 4.3.

Table 4.3: Application of Contingency Event (Power Flows, with DC line outage and in the critical lines under consideration)

Sl.No	Name of the Feeder	Power Flow in MW
1	220kV RTPP (Bus no 256) to CNP (Bus no 206) DC line	0 MW
2	220kV RTPP (Bus no 256) to ATP (Bus no 258) DC line	2 x 337 MW

From the results, it is observed that with the simulation of outages of 220 kV DC line of RTPP-CNP, the 220 kV RTPP-ATP are getting abnormally overloaded, making the system to progress from emergency state to extremes, causing the blackout of the total power plant.

With the simultaneous outage of two lines from the RTPP to CNP, the simulated power flows depicts the criticality, and the results are given in Fig. 4.6 and in Table 4.7.

The load flow diagram Fig. 4.6 for RTPP evacuation with outage of 220kV DC line RTPP-CNP, consists of all the five generators with their output of 190MW each, with outage of 220kV DC transmission line RTPP-CNP, keeping all the other evacuation lines in service.

The simulation results in table 4.7 shows that the total RTPP power plant generation is evacuated along the RTPP – ATP lines, with power flow of 337.22 MW on each of the DC line, RTPP-YGT DC line, with power flow of 90.62MW on each of the line and RTPP-PULIVE with power flow of 47.16MW on each of the line. The power flow on each of the RTPP-CNP lines was zero, as the two lines were under outage. The power flow on the RTPP-ATP lines was 337.22 MW, against its thermal rating of 225 MW.

CASE III

The effect of the contingency event application and the actuation of SPS with two units of generation rejection on the evacuation lines of the RTPP power plant, when the power plant is in its full generation capacity, is simulated. The power flows with the contingency event under consideration, with SPS actuation are presented in the Table 4.4.

Table 4.4: Application of Contingency Event and actuation of SPS with two units generation rejection (Power Flows, with DC line outage and in the critical lines under consideration)

Sl.No	Name of the Feeder	Power Flow in MW
1	220kV RTPP (Bus no 256) to CNP (Bus no 206) DC line	0
2	220kV RTPP (Bus no 256) to ATP (Bus no 258) DC line	2 x 147

With the implementation SPS, when the abnormal conditions are detected, the actuation of SPS for tripping of generators of two units, should bring back the system to normal state. For investigation of this scenario, again the simulation is carried out with the tripping of generating units 4 and 5 with the event of outage 220 kV DC line of RTPP-CNP. For this simulated power system condition, again the load flow study is carried out for knowing the power flow on various evacuation lines.

The SPS actuation prevented the total RTPP power plant blackout by bringing down the abnormal overloadings on the critical evacuation lines. The results are given in Fig. 4.7 and in Table 4.8.

The load flow diagram Fig. 4.7 for RTPP evacuation with outage of 220kV DC line RTPP-CNP, and with two generator units of generation rejection, consists of all the five generators, out of which two units were tripped, and the remaining generators generating with their output of 190MW each, with the outage of 220kV DC transmission line RTPP-CNP, keeping all the other evacuation lines in service.

The simulation results in table 4.8 shows that the total RTPP power plant generation, with tripping of two units during the outage of 220kV line RTPP-CNP lines was evacuated along the RTPP – ATP lines, with power flow of 147.23MW on each of the DC line, RTPP-YGT DC line with power flow of 90.62MW on each of the line and RTPP-PULIVE lines, with power flow of 47.16MW on each of the line. The power flow on each of the RTPP-CNP lines was zero, as the two lines were under outage.

The simulated model with the outage contingency event and actuation of the SPS action by tripping of two units at RTPP power plant has reduced the power flow on the critical lines from 337 MW to 147 MW bringing the system to normal state.

CASE IV

The simulations with the contingency event application and the actuation of SPS in controlled manner to trip one unit of generation.

To make the SPS more wiser and limit its action, based on the intelligent decision of tripping of only one unit in the event of RTPP-CNP DC line and overloading of the other evacuation lines, to minimize the loss of generation in the system, the SPS is restricted in its operation. The power flows with the contingency event under consideration, with SPS actuation in controlled manner, are presented in the Table 4.5.

Table 4.5: Application of Contingency Event and with one unit out of service at RTPP Power Plant (Power Flows, with DC line outage and in the critical lines under consideration)

Sl.No	Name of the Feeder	Power Flow in MW
1	220kV RTPP (Bus no 256) to CNP (Bus no 206) DC line	0
2	220kV RTPP (Bus no 256) to ATP (Bus no 258) DC line	2 x 242

It is observed that, at times the generation may not be to its full capacity of the power plant. In the event of one unit under shutdown, whenever the RTPP-CNP

DC line occurs, it results in the overloading of RTPP-ATP line. But, the required action of SPS for tripping of two units simultaneously is not required as only one unit generation rejection is enough to bring back the system into normal state. In this case, the power flows are again computed on various outgoing evacuation lines with the event of 220 kV CNP-RTPP DC line outage and with one unit shut down for determining the SPS arming limits to trip only one circuit. The results are given in Fig. 4.8 and in Table 4.9.

The load flow diagram Fig. 4.8 for RTPP evacuation with outage of 220kV DC line RTPP-CNP, and with one generator unit of generation rejection, consists of all the five generators, out of which one unit was tripped and the remaining generators generating with their output of 190MW each, and with the outage of 220kV DC transmission line RTPP-CNP, keeping all the other evacuation lines in service.

The simulation results in table 4.9 shows that the total RTPP power plant generation, with tripping of one unit during the outage of 220kV line RTPP-CNP lines, was evacuated along the RTPP – ATP lines, with power flow of 242.23MW on each of the DC line, RTPP-YGT DC line, with power flow of 90.62MW on each of the line and RTPP-PULIVE with power flow of 47.16MW on each of the line. . The power flow on each of the RTPP-CNP lines was zero, as the two lines were under outage.

The simulated model with the outage contingency event and actuation of the SPS action by tripping of one unit at RTPP power plant has reduced the power flow on the critical lines from 242 MW to 147 MW bringing the system to normal state, when the RTPP power plant was generating only 760 MW and not to its full capacity. Thus the SPS action generation rejection could be restricted to the limited extent to fulfill the need of the system without losing the additional unit (i.e., tripping of two units in case of just to fulfill SPS the action requirements) when the rules are framed between the lines, without the decision algorithm.

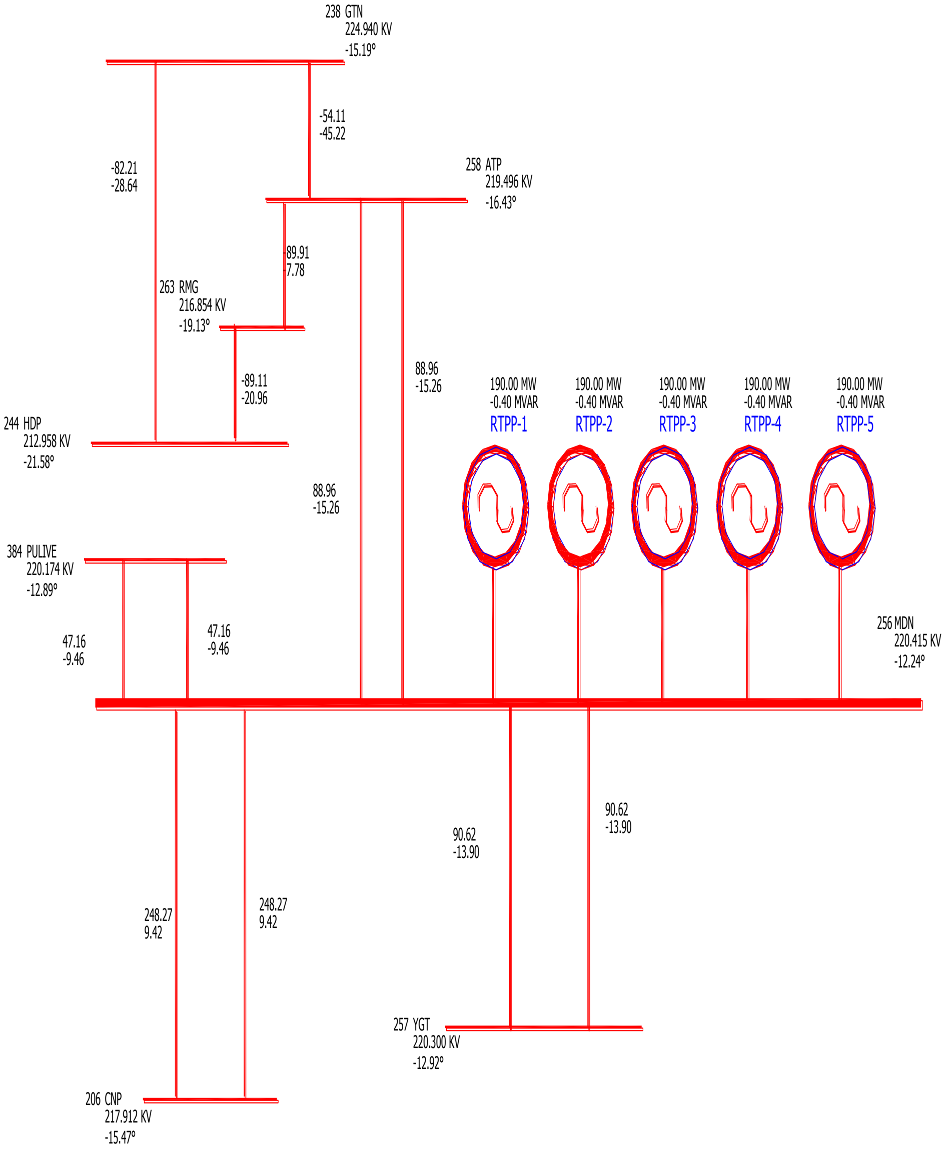

Fig. 4.5: (Case I) Load flow diagram for RTPP evacuation in normal operating state

Tabe 4.6: (Case I) Base case simulation study with the existing system in normal operating state

<table>
<tr><th colspan="6">Global Summary Report (TOTAL)</th></tr>
<tr><th colspan="4">GENERATION</th><th colspan="2">LOAD</th></tr>
<tr><th colspan="2">MW</th><th colspan="2">MVAR</th><th>MW</th><th>MVAR</th></tr>
<tr><td colspan="2">11354.24</td><td colspan="2">-123.18</td><td>10934.00</td><td>4842.00</td></tr>
<tr><th colspan="6">Bus Report</th></tr>
<tr><th rowspan="2">FROM BUS</th><th rowspan="2">TO BUS</th><th colspan="2">VOLTAGE</th><th colspan="2">LOAD</th></tr>
<tr><th>KVOLT</th><th>DEGREE</th><th>MW</th><th>MVAR</th></tr>
<tr><td>256MDN</td><td></td><td>220.415</td><td>-12.2</td><td>0.00</td><td>0.00</td></tr>
<tr><td>256MDN</td><td>206CNP</td><td></td><td></td><td>248.27</td><td>9.42</td></tr>
<tr><td>256MDN</td><td>206CNP</td><td></td><td></td><td>248.27</td><td>9.42</td></tr>
<tr><td>256MDN</td><td>257YGT</td><td></td><td></td><td>90.62</td><td>-13.90</td></tr>
<tr><td>256MDN</td><td>258ATP</td><td></td><td></td><td>88.96</td><td>-15.26</td></tr>
<tr><td>256MDN</td><td>258ATP</td><td></td><td></td><td>88.96</td><td>-15.26</td></tr>
<tr><td>256MDN</td><td>258ATP</td><td></td><td></td><td>88.96</td><td>-15.26</td></tr>
<tr><td>256MDN</td><td>384PULIVE</td><td></td><td></td><td>47.16</td><td>-9.46</td></tr>
<tr><td>256MDN</td><td>384PULIVE</td><td></td><td></td><td>47.16</td><td>-9.46</td></tr>
<tr><td>256MDN</td><td>9030MDN</td><td></td><td></td><td>-190.00</td><td>11.68</td></tr>
<tr><td>256MDN</td><td>9031MDN</td><td></td><td></td><td>-190.00</td><td>11.68</td></tr>
<tr><td>256MDN</td><td>9032MDN</td><td></td><td></td><td>-190.00</td><td>11.68</td></tr>
<tr><td>256MDN</td><td>9033MDN</td><td></td><td></td><td>-190.00</td><td>11.68</td></tr>
<tr><td>256MDN</td><td>9034MDN</td><td></td><td></td><td>-190.00</td><td>11.68</td></tr>
<tr><td>384PULIVE</td><td></td><td>220.174</td><td>-12.9</td><td>0.00</td><td>0.00</td></tr>
<tr><td>384PULIVE</td><td>256MDN</td><td></td><td></td><td>-47.04</td><td>1.91</td></tr>
<tr><td>384PULIVE</td><td>256MDN</td><td></td><td></td><td>-47.04</td><td>-1.91</td></tr>
<tr><td>384PULIVE</td><td>1504PULIVE</td><td></td><td></td><td>47.04</td><td>1.91</td></tr>
<tr><td>384PULIVE</td><td>1504PULIVE</td><td></td><td></td><td>47.04</td><td>-1.91</td></tr>
<tr><td>244HDP</td><td></td><td>212.958</td><td>-21.6</td><td>0.00</td><td>0.00</td></tr>
<tr><td>244HDP</td><td>238GTN</td><td></td><td></td><td>-82.21</td><td>-28.64</td></tr>
<tr><td>244HDP</td><td>263RMG</td><td></td><td></td><td>-89.11</td><td>-20.96</td></tr>
<tr><td>244HDP</td><td>1051HDP</td><td></td><td></td><td>57.11</td><td>16.53</td></tr>
<tr><td>244HDP</td><td>1051HDP</td><td></td><td></td><td>57.11</td><td>16.53</td></tr>
<tr><td>244HDP</td><td>1051HDP</td><td></td><td></td><td>57.11</td><td>16.53</td></tr>
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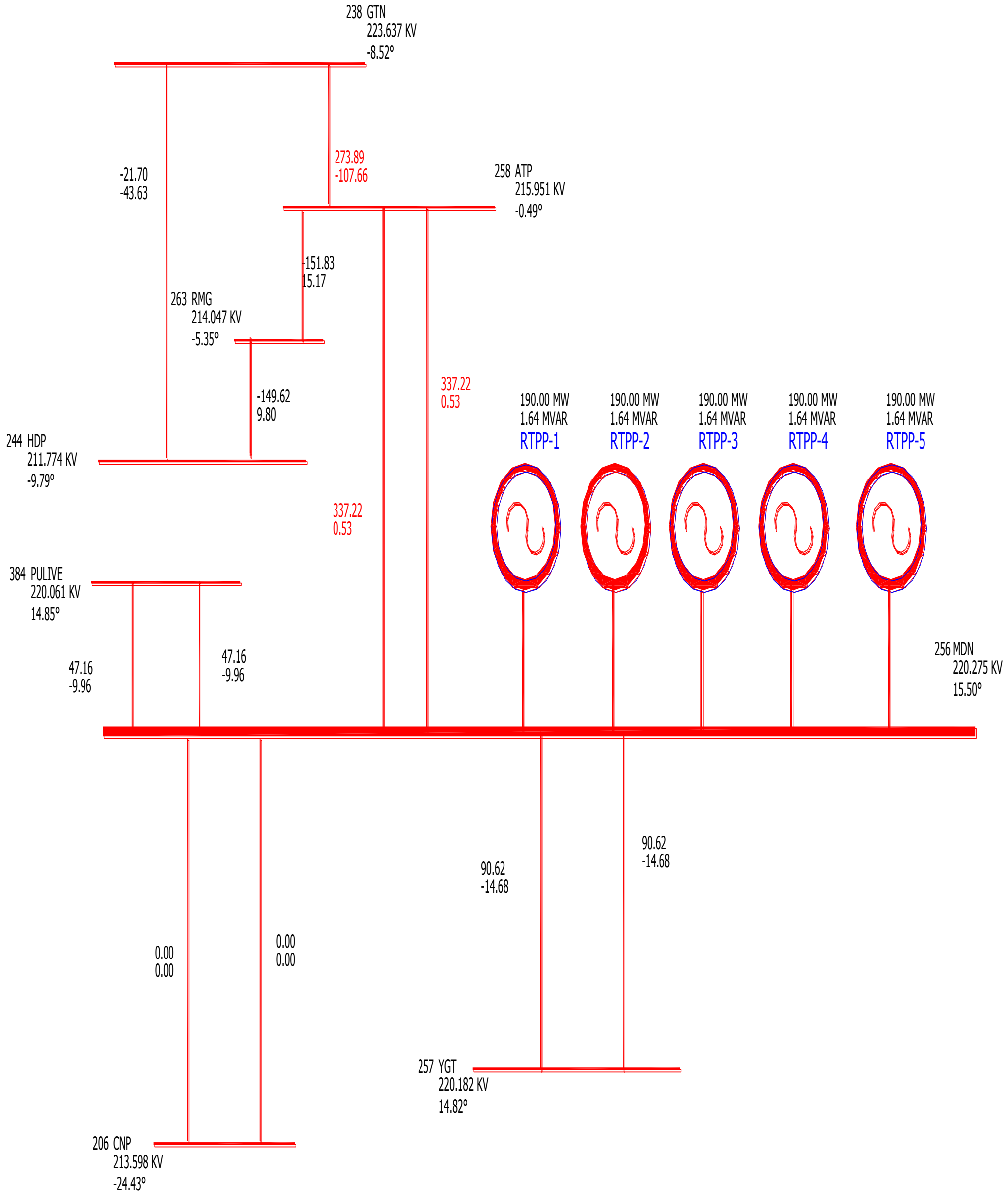

Fig. 4.6: (Case II) Load flow diagram for RTPP evacuation with the outage of 220 kV DC Line RTPP-CNP.

Table 4.7: (Case II) Simulation study with the contingency event application

Contingency simulation study

Global Summary Report (TOTAL)			
GENERATION		**LOAD**	
MW	**MVAR**	**MW**	**MVAR**
11411.93	317.59	10934.00	4842.00

Bus Report					
FROM BUS	**TO BUS**	**VOLTAGE**		**LOAD**	
		KVOLT	**DEGREE**	**MW**	**MVAR**
256MDN		220.275	15.5	0.00	0.00
256MDN	206CNP			0.00	0.00
256MDN	206CNP			0.00	0.00
256MDN	257YGT			90.62	-14.68
256MDN	258ATP			90.62	-14.68
256MDN	258ATP			337.22	0.53
256MDN	258ATP			47.16	0.53
256MDN	384PULIVE			47.16	-9.96
256MDN	384PULIVE			337.22	-9.96
256MDN	9030MDN			-190.00	9.65
256MDN	9031MDN			-190.00	9.65
256MDN	9032MDN			-190.00	9.65
256MDN	9033MDN			-190.00	9.65
256MDN	9034MDN			-190.00	9.65
384PULIVE		220.061	14.8	0.00	0.00
384PULIVE	256MDN			-47.04	2.42
384PULIVE	256MDN			-47.04	2.42
384PULIVE	1504PULIVE			47.04	-2.42
384PULIVE	1504PULIVE			47.04	-2.42
244HDP		211.774	-9.8	0.00	0.00
244HDP	238GTN			-21.70	-43.63
244HDP	263RMG			-149.62	9.80
244HDP	1051HDP			57.11	11.28
244HDP	1051HDP			57.11	11.28
244HDP	1051HDP			57.11	11.28

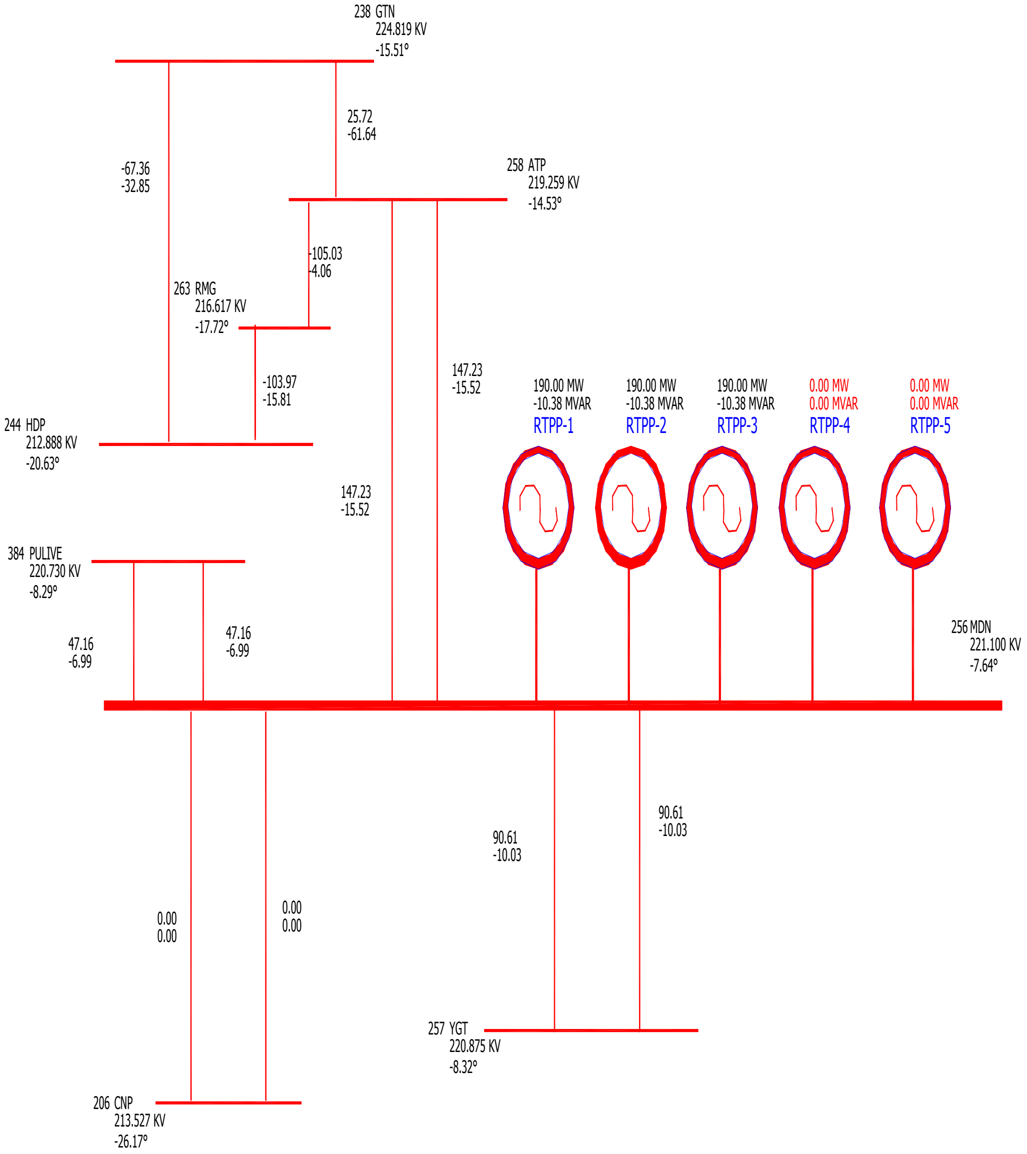

Fig. 4.7: (Case III) Load flow diagram for RTPP evacuation with the outage of 220 kV DC Line RTPP-CNP, and with two generator units of generation rejection.

Table 4.8: (Case III) Simulation study with the SPS action in event of disturbance

Global Summary Report (TOTAL)			
GENERATION		**LOAD**	
MW	**MVAR**	**MW**	**MVAR**
11388.90	236.42	10934.00	4842.00

Bus Report					
FROM BUS	**TO BUS**	**VOLTAGE**		**LOAD**	
		KVOLT	**DEGREE**	**MW**	**MVAR**
256MDN		221.100	-7.6	0.00	0.00
256MDN	206CNP			0.00	0.00
256MDN	206CNP			0.00	0.00
256MDN	257YGT			90.61	-10.03
256MDN	258ATP			90.61	-10.03
256MDN	258ATP			147.23	-15.53
256MDN	258ATP			147.23	-15.53
256MDN	384PULIVE			47.16	-6.99
256MDN	384PULIVE			47.16	-6.99
256MDN	9030MDN			-190.00	21.70
256MDN	9031MDN			-190.00	21.70
256MDN	9032MDN			-190.00	21.70
384PULIVE		220.730	-8.3	0.00	0.00
384PULIVE	256MDN			-47.04	-0.62
384PULIVE	256MDN			-47.04	-0.62
384PULIVE	1504PULIVE			47.04	0.62
384PULIVE	1504PULIVE			47.04	0.62
244HDP		212.889	-20.6	0.00	0.00
244HDP	238GTN			-67.36	-32.85
244HDP	263RMG			-103.97	-15.82
244HDP	1051HDP			57.11	16.22
244HDP	1051HDP			57.11	16.22
244HDP	1051HDP			57.11	16.22

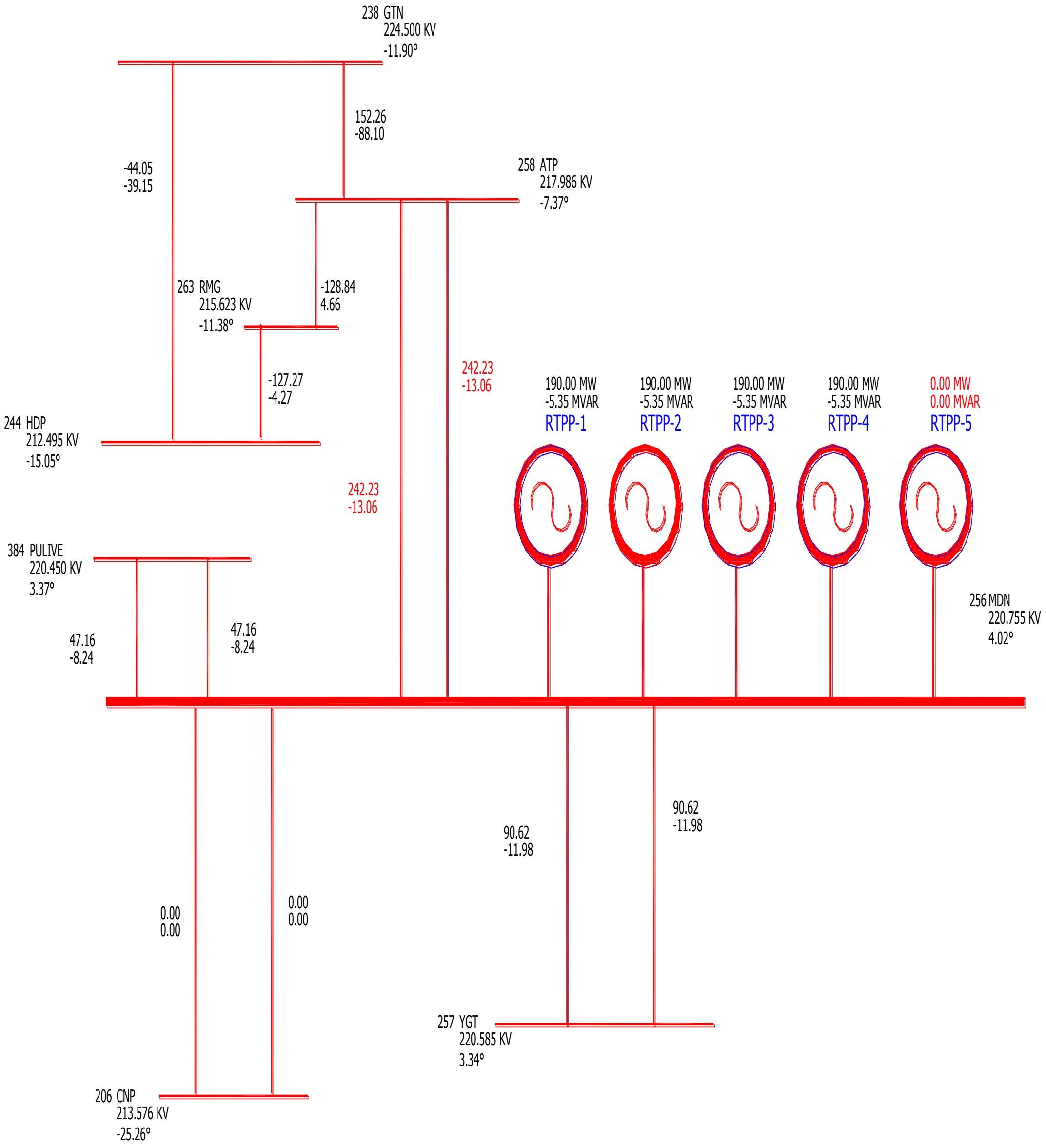

Fig. 4.8: (Case IV) Load flow diagram for RTPP evacuation with the outage of 220kV DC Line RTPP-CNP, and with one generator unit outage.

Table 4.9: (Case IV) Simulation study with one unit outage at the power plant in the event disturbance

Global Summary Report (TOTAL)			
GENERATION		**LOAD**	
MW	**MVAR**	**MW**	**MVAR**
11393.93	236.48	10934.00	4842.00

Bus Report					
FROM BUS	**TO BUS**	**VOLTAGE**		**LOAD**	
		KVOLT	**DEGREE**	**MW**	**MVAR**
256MDN		220.755	4.0	0.00	0.00
256MDN	206CNP			0.00	0.00
256MDN	206CNP			0.00	0.00
256MDN	257YGT			90.62	-11.98
256MDN	258ATP			90.62	-13.06
256MDN	258ATP			242.23	-11.98
256MDN	258ATP			242.23	-13.06
256MDN	384PULIVE			47.16	-8.24
256MDN	384PULIVE			47.16	-8.24
256MDN	9030MDN			-190.00	16.64
256MDN	9031MDN			-190.00	16.64
256MDN	9032MDN			-190.00	16.64
256MDN	9033MDN			-190.00	16.64
256MDN	9034MDN			0.00	0.00
244HDP		212.495	-15.0	0.00	0.00
244HDP	238GTN			-44.05	-39.15
244HDP	263RMG			-127.27	-4.27
244HDP	1051HDP			57.11	14.47
244HDP	1051HDP			57.11	14.47
244HDP	1051HDP			57.11	14.47
384PULIVE		220.450	3.4	0.00	0.00
384PULIVE	256MDN			-47.04	0.66
384PULIVE	256MDN			-47.04	-0.66
384PULIVE	1504PULIVE			47.04	0.66
384PULIVE	1504PULIVE			47.04	-0.66

4.9 The Economic Analysis

In the absence of the SPS application and with the earlier experience of outage of the total power plant, it was observed that in all the occasions of the occurrence of critical event under consideration, it was observed that the total loss of power was around 190 x 5 i.e., 950 MW.

The average restoration time for bringing back the total units into service was 3 hours.

With the application of SPS, the loss of power at the RTPP power plant was around 190 x 2 i.e., 380 MW, when the power plant was running with full capacity of 950 MW injection.

The net power loss that could be saved on account of the SPS action is 950 – 380 MW i.e., 570 MW

Considering the present average cost of power sold per unit = Rs 4.25

The total MU that could be delivered from this power plant with the application of the SPS = 1.71 MU (Million Units)

The minimum time of restoration during the power plant blackout based on the operational practices = 3hours

Average cost of unit power = Rs. 4.25

The total cost of the power sold, without the total power plant blackout = 1000 x 570 x 4.25 x 3 = Rs 72,675,00

Thus there is a gain of Rs. 72,675,00 by implementation of the SPS duly avoiding cascade outages.

Thus the SPS designed and developed is found, quite good enough to take care of the system in case contingency specified in the objective. The same was implemented for the first time in the real-time power system of the state utility on 10/05/2012 with the approval of the southern Regional protection coordination committee of CEA.