CONTINGENCY CONSTRAINED ECONOMIC LOAD DISPATCH USING PARTICLE SWARM OPTIMIZATION FOR SECURITY ENHANCEMENT

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By

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Dedicated to

My

Professor

NATIONAL INSTITUTE OF TECHNOLOGY

ROURKELA

CERTIFICATE

This is to certify that the thesis entitled, **"Contingency constrained economic load dispatch using particle swarm optimisation for security enhancement"** submitted by **K. Hem Kumar (Roll No. 213EE5344)** in partial fulfilment of the requirements for the award of Master of Technology Degree in Electrical Engineering with specialization in Industrial Electronics during 2014 -2015 at the National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

Place: NIT Rourkela

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DECLARATION

I hereby declare that the investigation carried out in the thesis has been carried out by me. The work is original and has not been submitted earlier as a whole or in part for a degree/diploma at this or any other institute/University.

K. Hem Kumar

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ABSTRACT

Power system security plays a very vital role along with the transmission capability. The power system security is mostly influenced by several contingencies. The mean of contingency is any outage of transmission line, outage of transformer, outage of generator etc. from the system. Under contingency the system might get into insecure. Determination of system state that is whether the system is working under secure condition or not that can be deal by security analysis. Insecure of the system means all the components in the system are operating out of the specified limits. If the present operating condition is found that system is not in secure condition then the remedy must be taken to protect the system from the violation of specified limits of particular components under contingency. During the contingency the transmission line power flows will get affected and it might cross the maximum power flow limit. So we have to control the power flows in the transmission lines during the contingency. The power flows in the transmission line can be control by rescheduling of the generators in the system. In this work the particle swarm optimisation technique has been utilised to reschedule the generators for getting optimum cost. While rescheduling the generators under contingency the power flows in the transmission line will get control and they will come within the specified limits and security will get enhance under contingency.

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CHAPTER 1

INTRODUCTION

Chapter 1

Introduction

1.1 Introduction:

Since 1920s, the power system gained its importance in planning, design and at the operation stages. Power system is a complex network, which is compelled to operate under highly stressed conditions closer to their stability limits in the deregulated environment. Under such circumstances, any perturbation could threaten system security and may cause system collapse. Therefore it initiates the power system security assessment for monitoring the system security level and forewarning the operators to take necessary control actions. Power system security is the ability of the system to withstand unexpected failures (Contingencies) and continue to operate without interruption of supply to consumers.

The security Assessment (SA) is also called as Security Evaluation, determines the robustness of the system (security level) to a set of preselected contingencies in its present or future state. It is the analysis carried out to determine whether, and to what extent, a power system is reasonably safe from serious interference to its operation. A power system may face contingencies like outage of transmission line, outage of a generating unit, loss of a transformer, sudden increase in demand, etc. Although many contingencies can occur, only those contingencies with high probability of occurrence are to be considered and such contingencies are called credible contingencies. A set of credible contingencies needs to be given first priority for security analysis.

The contingency analysis involves the simulation of individual contingency for the power system model. In order to make the analysis easier, it consists of three basic steps.

Contingency Creation: It comprises of a set of possible contingency that might occur in a power system. The process consists of creating the contingencies list.

Contingency evaluation: The necessary preventive actions needed to be taken by the operational engineers.

Thus the power system security assessment is an important aspect for power system engineers.

1.2 Research Background:

The contingency analysis plays a vital role in the power system security, the importance of which is discussed in [1]. The use of AC power flow solution in the outage studies have been discussed in [2]. In [3-4], the changes in the line flow for the line and the generator outage has been discussed. The authors in [5] have introduced the method of concentric relaxation for the contingency evaluation.

The concept of contingency analysis was first introduced by Ejebe and Wollenberg where the contingencies are sorted out in the descending order based on the performance index [8]. The load flow solution is carried for the different contingencies and they are ordered based on ranking methods.

The authors in [6] have been discussed that the transmission lines get overload in the presence of contingency. The authors in [7] have been discussed that the line overload can be alleviate by rescheduling the generator. The authors [8-10] have been discussed that the different optimization techniques for economic load dispatch.

The authors in [11] exclusively deals with the PSO method of optimization of an economic load dispatch problem. The authors in [12] gives an insight into the different cost functions used for optimization of an ELD problem. The authors in [13] tells about the recent advances in economic load dispatch such as particle swarm optimization, evolutionary programming, and genetic algorithm and Lagrange method. The authors in [14] takes into consideration transmission losses for a problem. The authors in [15] gives us the PSO, a toolbox used for solving the practical problems using PSO. The authors in [16]-[17] gives the advantages and disadvantages of PSO to solve economic load dispatch problem.

The authors in [18] discussed that the optimal power flow and controlling of real and reactive power flows in transmission line by using linear programming. In [19] the various development techniques have been utilised for optimal power flow. The prediction of location of phase shifters in the network by using mixed integer programming have been discussed in [20]. In [21] they have been discussed about location of FACTS controllers for enhancing the system load ability. In [22] power system security has enhanced by optimal power flow along with phase shifter location. In [23] they have been discussed about genetic algorithm about search, optimisation and machine learning. In [24] authors have been presented about improved genetic algorithm for enhancing the power system security in both normal and contingency states. In [25] authors speaks about refined genetic algorithm for computing the optimal power flow. In [26] a combined genetic algorithm has been introduced for optimal power flow.

In [27] authors have been discussed about particle swarm optimisation technique for economic dispatch of generators by considering the generator constraints. In [28] utilised the application of evolutionary programming for contingency constrained economic load dispatch. In [29] they have made comparisons between evolutionary programming for combined economic emission dispatch with line flow constraints. In [30] they have found economic dispatch by considering the security constraints.

1.3 Motivation of the work:

The power system is a huge complex network, and it always subjected to security problem because of the contingencies occurred in the power system network. These contingencies may lead to complete black out of our power system network. So, there is a need to increment the power system security under these contingencies.

1.4 Objectives of the work:

- Obtain the power flows in transmission lines under the contingencies using Newton-Raphson load flow method.
- Obtain the severity index of each contingency.
- Reduce the over flow in transmission lines by rescheduling the generation to enhance system security.
- Obtain the optimal dispatch of generators with minimum fuel cost along with the minimisation severity index.

1.5 Organisation Of the Thesis:

This work has been categorised into four chapters. All chapters are unique less and they were discussed in detailed manner.

Chapter 1: In this chapter we have introduced the outline of this work and which things made me to select this work.

Chapter 2: In this chapter we have discussed the power security analysis under different contingencies. The load flow solution by using Newton Raphson method has been discussed and severity of each contingency has been computed. The economic load dispatch is also been discussed under with and without valve point loading.

Chapter 3: In this chapter we have discussed the economic load dispatch under contingency constraints and also discussed the security enhancement of power system network under contingencies.

Chapter 4: In this chapter we have discussed the results, conclusion of this work.

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CHAPTER 2

POWER SYSTEM SECURITY

Chapter 2

Power system Security

2.1 Introduction:

In recent times major blackouts has been occurred due to this some million number of peoples were affected. The most reason for this is that not having good security treatment for power system network under the different contingencies. As demand is goes on increasing besides of transmission capacity the power system security also get importance for power system operation. Security of a power system network deals with weather the network is withstanding the contingencies without any limit violation or not. Contingency means any outage of transmission line, generator, transformer etc. from power system network. If the present condition of power system network is found to be insecure then the action must be taken to bring the network into the secure condition. If any transmission line get outage from the network then the power flows in the remaining lines will get affect and it might cross the transmission line power flow limits also. So because of flowing the unsafe power in that transmission lines that lines also might get outage. This process will continue and lead to complete black out if we will not control the power flows in transmission lines under contingency. So the power system security is essential under the contingency to operate the power system network in safe mode. The security of a power system network can be enhance by rerouting of power flows in the transmission lines. The rerouting of power flows in transmission lines can be done by rescheduling of generators.

2.2 Contingency Analysis:

Any outage of equipment from power system network is called contingency. Due to the contingency very severe problems can occur within short time. Security assessment is essential under contingency. Contingency analysis is needed for any power system network because there is no chance to extensive development of power stations for increasing load demand. Contingency analysis should be performed for different and unexpected faults which are occurring in power system network to take particular remedy prior to the fault occur in power system network.

The contingency analysis for considered power system network has been divided into three basic steps. They are as given below.

i. Contingency creation: This is the first step of contingency analysis and it consists of different contingencies which are having most chance to occur in power system network. So finally this process gives the list of different contingencies which are regularly happened in power system network.

ii. Contingency Selection: This is the second step of contingency analysis and in this process we will select severe contingency from the list made in contingency creation process. Severe contingency means the contingencies for which the bus voltage and power limit violates. The severity of each contingency can calculate in terms of severity index and we can filter the very sever contingencies and least sever contingencies in this process.

iii. Contingency evaluation: This is the third step of contingency analysis and in this process we have to take the particular control action or security action for sever contingencies to keep the bus voltage and power within specified limits.

2.3 Power flow solution:

Power flow solution is a solution for considered power system bus network under steady state analysis and it subject to various in equality constrains. Inequality constraints are mainly two types they are hard type and soft type. In power flow solution we considered the soft type inequality constraints they are like nodal voltages and power generation of generators. Power flow studies are essential for controlling the power flows and planning the power station for its future expansion.

The power flow solution determines the nodal voltages, phase angles, active and reactive power flows in each transmission line. The power flow solution is needed for both normal and abnormal conditions. One assumption should be taken during the solving of power flow solution i.e. considered power system is a single phase and it is operating under balancing condition. In power flow solution each bus is associated with four quantities they are voltage magnitude, phase angle, real power and reactive power. The power system network buses have been categorised into three types.

i. Slack bus: This bus can also call as a swing bus and it is used as reference bus. This bus is associated with two known quantities they are voltage magnitude and phase angle. The real power and reactive power are unknown quantities for this bus. One among the generator bus is used as slack bus because the losses of power system network will remain unknown until the power flow solution is complete.

ii. Load bus: These buses are called as PQ buses and these buses are associated with two known quantities they are real power and reactive power generation. The nodal voltage magnitude and phase angle are unknown quantities for this type of buses.

iii. Generator bus or voltage controlled bus: This bus is also call as regulated bus or PV buses. This bus is associated with two known quantities they are real power and voltage magnitude. Reactive power and phase angles are unknown quantities for this type of buses.

The equations of power flow solution are nonlinear in nature and these nonlinear equations can be solve by using following iterative methods.

i. Gauss Siedel method
ii. Fat decoupled method
iii. Newton Raphson power flow method

2.4 Newton Raphson power flow method:

The nonlinear equations in power flow solution can be solve by using the Newton Raphson (NR) method. Because of various advantages NR method is chosen for computing the power flow solution.

The advantages of NR method are as follows:

i. It has strong convergence characteristics when comparing with remaining methods and also it require less computation.

ii. The memory requirement is less so that we can solve the problems for large networks also.

iii. There is no starting problem and it is very sensitive. Because of the good starting condition it reduces the computational time extremely so that solution will fast convergence.

iv. Change of the slack bus will not affect the iterations and there is no need of computing the acceleration factors. It will require very less computational effort even there is any network changes.

v. By using NR method we can easily represent the on load tap changing, phase shifting transformer and remote voltage control.

NR method becomes origin for various methods which are coming recently for optimising the power system operation and evaluation of security analysis and it is well suited for online computation.

Now for considering a power system bus network, the current entering into the bus is represented by below equation.

$$I_i = \sum_{j=1}^{n} Y_{ij} V_j \tag{2.1}$$

In polar form we can represent it as

$$I_i = \sum_{j=1}^{n} \left|V_{ij}\right| \left|V_j\right| \angle \theta_{ij} + \delta_j \tag{2.2}$$

The current at bus I can be express in terms of active and reactive power

$$I_i = \frac{P_i - jQ_i}{V_i^*} \tag{2.3}$$

Substituting the I_i in above two equations (1) & (2) then we will get

$$P_i - jQ_i = \left|V_i\right| \angle -\delta_i \sum_{j=1}^{n} \left|V_{ij}\right| \left|V_j\right| \angle \theta_{ij} + \delta_j \tag{2.4}$$

The active and reactive power of bus I can be represent as

$$P_i = \sum_{j=1}^{n} \left|V_{ij}\right| \left|V_j\right| \left|V_i\right| \cos(\theta_{ij} - \delta_i + \delta_j) \tag{2.5}$$

$$Q_i = \sum_{j=1}^{n} \left|V_{ij}\right| \left|V_j\right| \left|V_i\right| \sin(\theta_{ij} - \delta_i + \delta_j) \tag{2.6}$$

Expanding the real and reactive powers in Taylor series by not considering the higher order terms, then we will get

$$
\begin{bmatrix} \Delta P_2^{(k)} \\ \vdots \\ \Delta P_n^{(k)} \\ \hline \Delta Q_2^{(k)} \\ \vdots \\ \Delta Q_n^{(k)} \end{bmatrix}
=
\left[\begin{array}{ccc|ccc}
\frac{\partial P_2^{(k)}}{\partial \delta_2^{(k)}} & \cdots & \frac{\partial P_2^{(k)}}{\partial \delta_n^{(k)}} & \frac{\partial P_2^{(k)}}{\partial |V_2|} & \cdots & \frac{\partial P_2^{(k)}}{\partial |V_n|} \\
\vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\
\frac{\partial P_n^{(k)}}{\partial \delta_2^{(k)}} & \cdots & \frac{\partial P_n^{(k)}}{\partial \delta_n^{(k)}} & \frac{\partial P_n^{(k)}}{\partial |V_2|} & \cdots & \frac{\partial P_n^{(k)}}{\partial |V_n|} \\
\hline
\frac{\partial Q_2^{(k)}}{\partial \delta_2^{(k)}} & \cdots & \frac{\partial Q_2^{(k)}}{\partial \delta_n^{(k)}} & \frac{\partial Q_2^{(k)}}{\partial |V_2|} & \cdots & \frac{\partial Q_2^{(k)}}{\partial |V_n|} \\
\vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\
\frac{\partial Q_n^{(k)}}{\partial \delta_2^{(k)}} & \cdots & \frac{\partial Q_n^{(k)}}{\partial \delta_n^{(k)}} & \frac{\partial Q_n^{(k)}}{\partial |V_2|} & \cdots & \frac{\partial Q_n^{(k)}}{\partial |V_n|}
\end{array}\right]
\begin{bmatrix} \Delta \delta_2^{(k)} \\ \vdots \\ \Delta \delta_n^{(k)} \\ \hline \Delta |V_2^{(k)}| \\ \vdots \\ \Delta |V_n^{(k)}| \end{bmatrix}
\tag{2.7}
$$

The Jacobian matrix gives the linear relationship between finite changes in $\Delta\delta_i^k$ and voltage magnitude $\Delta|V_i^k|$ with finite changes in real and reactive power ΔP_i^k and ΔQ_i^k.

$$
\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta|V| \end{bmatrix} \tag{2.8}
$$

The diagonal and off diagonal elements of J_1 are

$$
\frac{\partial P_i}{\partial \delta_i} = \sum_{j \neq i} |V_i||V_j||Y_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j) \tag{2.9}
$$

$$
\frac{\partial P_i}{\partial \delta_i} = -|V_i||V_j||Y_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j) \quad j \neq i \tag{2.10}
$$

and Similarly we can compute the remaining elements for j_2, j_3 and j_4.

The terms ΔP_i^k and ΔQ_i^k are difference in power between scheduled and calculated powers. These can be calculated by following equations.

$$
\Delta P_i^k = P_i^{sch} - P_i^{(k)} \tag{2.11}
$$

$$
\Delta Q_i^k = Q_i^{sch} - Q_i^{(k)} \tag{2.12}
$$

For the last step of particular iteration δ_i^k and $\left|V_i^{(k)}\right|$ are calculated by using equation no.(2.7) and new values of these values for next iteration can be calculated by using following equations.

$$\delta_i^{(k+1)} = \delta_i^{(k)} + \Delta\delta_i^{(k)} \tag{2.13}$$

$$\left|V_i^{(k+1)}\right| = \left|V_i^{(k)}\right| + \Delta\left|V_i^{(k)}\right| \tag{2.14}$$

2.4.1 Algorithm for Newton Raphson power flow method:

Step 1:

Form the Y_{BUS} matrix form the given power system network.

Step 2:

Assume the initial values of δ_i^0 , V_i^0 for the bus i (load bus) and for the PV bus assume initial value δ_j^0 for the bus j (PV bus) with the above initial value using the power flow equations calculate the initial value of P_i^0 , Q_i^0 for the load bus and P_j^0 for the PV bus (P,Q are known values for load bus, P is known value for PV bus).

Step 3:

Compare the calculated values with known values or Specified values shown in eqn(2.15).

$$\begin{bmatrix} P_i^{(0)} - P_{is} \\ Q_i^{(0)} - Q_{is} \\ P_j^{(0)} - P_{js} \end{bmatrix} \tag{2.15}$$

Step 4:

Calculate the jacobian matrix with these initial values δ_i^0, V_i^0 and δ_j^0 .

Step 5:

Find the increment values using the NR method.

$$\begin{bmatrix} \Delta\delta_i^{(0)} \\ \Delta V_i^{(0)} \\ \Delta\delta_j^{(0)} \end{bmatrix} = -\begin{bmatrix} \frac{\partial P_i}{\partial \delta_i} & \frac{\partial P_i}{\partial V_i} & \frac{\partial P_j}{\partial \delta_j} \\ \frac{\partial Q_i}{\partial \delta_i} & \frac{\partial Q_i}{\partial V_i} & \frac{\partial Q_j}{\partial \delta_j} \\ \frac{\partial P_j}{\partial \delta_i} & \frac{\partial P_j}{\partial V_i} & \frac{\partial P_j}{\partial \delta_j} \end{bmatrix} \begin{bmatrix} P_i^{(0)} - P_{ij} \\ Q_i^{(0)} - Q_{ij} \\ P_j^{(0)} - P_{ij} \end{bmatrix} \quad (2.16)$$

Step 6:

Calculate next iteration value

$$\delta_i^{(1)} = \delta_i^{(0)} + \Delta\delta_i^{(0)} \quad (2.17)$$

$$\delta_j^{(1)} = \delta_j^{(0)} + \Delta\delta_j^{(0)} \quad (2.18)$$

$$V_i^{(1)} = V_i^{(0)} + \Delta V_i^{(0)} \quad (2.19)$$

Step 7:

Repeat the above steps until the difference between two successive iterations are equal to zero or within the specified value.

Note:

In case of PV bus Q_j is calculated after calculating δ_j by using Newton Raphson (NR) method and substitute this value of δ_j in the power flow equation of Q_j.

2.5 Severity index:

The contingency severity can be express by severity index. It will define the how much the power system network will get stress after the contingency occurring. The severity index can be calculate by eqn (2.20).

Severity index $$I_{sl} = \sum_{l \in L_0}^{n} \left(\frac{S_l}{S_l^{max}} \right)^{2m} \quad (2.20)$$

Where I_{sl} = Severity index of contingency

S_l^{max} = maximum power flow rating of line l

L_0 = set of over load lines

m = integer exponent

The line flows in above equation can be calculate by using NR load flow method. During computing the severity index for contingency only the over loaded lines has been considered for avoiding the masking effects and we fixed the integer exponent value as 1.

In this work we have considered the IEEE-30 bus system and we have calculated the severity of each contingency in terms of severity index by considering integer exponent as 1. The below table shows that the summery of contingency analysis.

Table 2.1: Severity indexes for different contingencies for IEEE-30 bus system

Outage Line	**Overloaded Lines**	**Line flow (MVA)**	**Line-flow limit (MVA)**	**Severity Index**	**Losses (MW)**
1-2	1-3 3-4 4-6	192.1120 180.1815 110.8805	130 130 90	5.6227	24.84
1-3	1-2	181.6383	130	1.9522	13.795
3-4	1-2 2-6	178.8614 65.5192	130 65	2.9090	13.473
2-5	2-6 5-7	76.8053 83.3212	65 70	2.8130	17.807

2.6 Economic load dispatch (ELD):

For keeping the operation of power system bus network in secure condition in the post contingency period we have to alleviate the overflow power in the transmission lines. By rescheduling the generators we can reduce the severity of contingency in the post contingency period. While rescheduling the generators minimisation of severity index also would be the optimisation function along with the minimisation of fuel cost.

The severity of each contingency can be reduce by minimising the below objective function

$$F = min(F_T) + min(I_{sl}) \tag{2.21}$$

Where; F_T = Total fuel cost

I_{sl} = Severity index of each contingency

By minimising the above objective function the power system security can be enhance under contingency analysis.

The economic load dispatch is the planning the generating units such that to reach load demand along with the transmission losses at minimum fuel cost without violating the any system constraints.

The cost function of all available generating units can be express by using the below equation.

$$F_T = \sum_{i=1}^{n} F_i(P_i) \tag{2.22}$$

Where; F_T = Total fuel cost of all available generating units

F_i = Fuel cost of i^{th} generator

System constraints are categorised into two types. They are

i. Equality Constraints
ii. Inequality Constraints

Equality constraints:

$$\sum_{i=1}^{n} P_i = P_d + P_l \tag{2.23}$$

Where; P_d = load demand

P_i = power generation of i^{th} generator

P_l = power loss in system network

By observing the total fuel cost equation we can decide that the fuel cost is mainly depend upon real power not in reactive power . So only the real power balance is the main attention in power system balance.

Inequality constraints:

Inequality constraints are considered as 2 types. They are

i. Hard type
ii. Soft type

Hard type are constraints which are mainly depend on the tapping range of on-load tap changing transformer and soft type are constraints which are mainly depend on the nodal voltages, phase angles, real power and reactive power limits.

The maximum active power limit of generation is depending on the thermal condition and lower limit of the active power generation is depend on the flame instability in the boiler. So for secure operation of the generating unit, the real power generation of that unit should be in the specified limits.

$$P_{imin} < P_i < P_{imax} \tag{2.24}$$

The reactive power constraint is given by

$$Q_{i\min} < Q_i < Q_{i\max} \tag{2.25}$$

Here $Q_{i\min}$ depends upon stability of the generator and $Q_{i\max}$ depends upon the heating of the rotor.

The voltage Constraints is given by

$$V_{i\min} < V_i < V_{i\max} \tag{2.26}$$

The components which are connected to the power system should be maintain with in. If V is less than $V_{i\min}$ then life time of the equipment will reduce. If V becomes more than $V_{i\max}$ then there will severe effect on insulation of the windings.

2.7 Effect of characteristics of generating units:

The input-output characteristics of a boiler turbine of a generating unit can be represented as monotonically increasing or piece wise linear function. However when comes to practical the characteristics of a generating unit is higher order nonlinear because of valve point loading. The valve point loading effect means the input-output characteristics of a generating unit will also depend on the effect of sudden close and open of valve of turbine.

2.7.1 Without valve point loading:

If we will not consider the effect of valve point loading then the cost equation of each generating unit can be represented as smooth quadratic function. The relationship between the fuel cost and power injected into the bus can be represented by fuel cost curve. The smooth quadratic function can represented by below Fig 2.1.

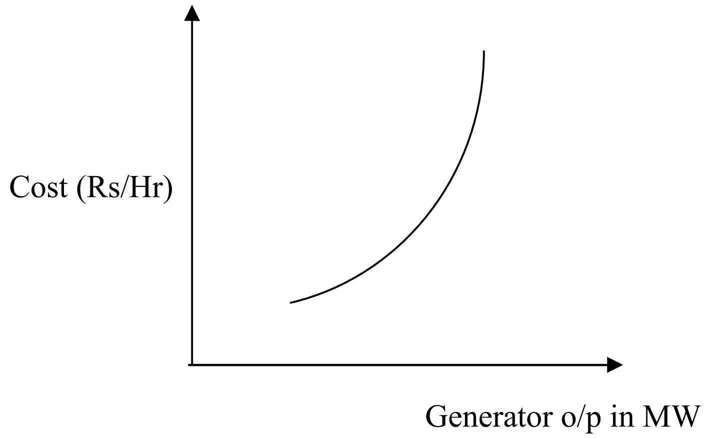

Fig.2.1 Smooth Quadratic fuel cost curve

The Smooth Quadratic fuel cost equation can be represented mathematically as

$$F_i(P_i) = \sum_{i=1}^{n} a_i P_i^2 + b_i P_i + c_i \tag{2.27}$$

Where; a_i, b_i, c_i are cost coefficients of generating unit

P_i = power output of i[th] generating unit in MW

2.7.2 With valve point loading:

Generally the generating units are modelled as smooth quadratic fuel cost function. However when comes into practical this is not enough to represent the generating unit we will require more accurate models during the solution of economic load dispatch. Normally in power plants having number of valve points to control the output power flow of each generating unit. For sudden open of a valve of a generating unit more losses will be registered so that the more ripples will be occur in fuel cost function. This ripple effect in cost function is called as valve point loading effect. The generating unit cost function when considering valve point loading will be highly nonlinear and it can be represented in below Fig 2.2

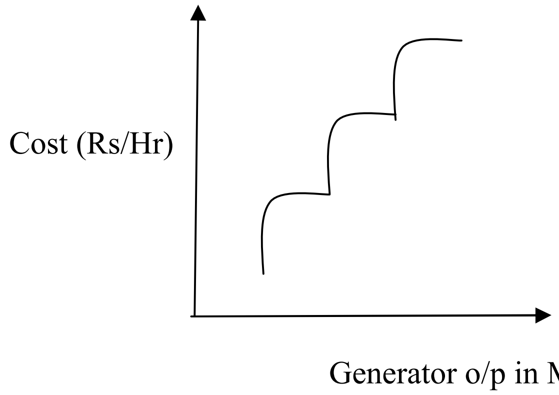

Fig 2.2 Non smooth quadratic fuel cost curve

The fuel cost equation with valve point loading can be represented mathematically as

$$F_i(P_i) = \sum_{i=1}^{n} a_i P_i^2 + b_i P_i + c_i + \left| e_i sin(f_i (P_{i(min)} - P_i)) \right| \quad (2.28)$$

Where; e_i, f_i are cost coefficients with valve point loading

2.7.3 ELD without valve point loading:

Here we have considered IEEE-30 bus system with six generating units and the load demand is 283.4 MW. In Table 1 shown the losses in the transmission lines for different contingencies. So for different contingencies the ELD without valve point loading is shown in Table 2.2 and for ELD with valve point loading is shown in Table 2.3.

Table 2.2: Economic load schedule without valve point loading

Unit O/P in MW	Load Demand in MW			
	308.24MW	297.195MW	296.873MW	301.207MW
P1	80.0000	68.0165	67.8646	69.9090
P2	79.9906	80.0000	80.0000	80.0000
P3	27.7892	29.7653	29.7167	30.3709
P4	54.9906	55.0000	55.0000	55.0000
P5	29.9906	30.0000	30.0000	30.0000
P6	35.4789	34.4132	34.2917	35.9272
Fuel cost (Rs/Hr)	1069.2	1015.0	1013.5	1034.1

2.7.4 ELD with valve point loading:

Table 2.3: Economic load schedule with valve point loading

Unit O/P in MW	Load Demand in MW			
	308.24MW	297.195MW	296.873MW	301.207MW
P1	78.5398	78.5400	78.5399	78.5402
P2	71.3998	58.3365	57.1191	71.3997
P3	44.8799	44.8800	44.8800	37.3999
P4	50.5886	52.6067	53.5008	51.0410
P5	26.9279	26.9279	26.9484	26.9276
P6	35.9039	35.9039	35.9039	35.8986
Fuel cost (Rs/Hr)	1140.7	1106.1	1078.5	1084.8

CHAPTER 3

CONTINGENCY CONSTRAINED ECONOMIC LOAD DISPATCH USING PSO

Chapter 3

Contingency constrained economic load dispatch using PSO

3.1 Introduction:

Under the contingency the power system security can be enhance by rescheduling the generating units. While rescheduling the generators different constraints should take into consideration. The minimum and maximum limits of power flow and nodal voltages of different transmission lines are the main constraints during the rescheduling under contingency. In this work the rescheduling has been done by using an optimisation technique called Particle Swarm Optimisation (PSO).

3.2 Particle Swarm Optimisation (PSO):

PSO is a population based optimisation technique and it is adopted from the simulation of the fish schooling and birds flocking. PSO having some inherent capability so that it will take less time to compute and require less memory space. The basic consideration behind the PSO technique is that birds are finding their food by flocking as a group. The PSO is also same as some other evolutionary algorithms. The problem is first initialised with stochastic solutions (swarm). The potential solution of each stochastic solution can call as particle (agent) and it is associated with stochastic velocity and it is flying through the problem space. Each particle have some amount knowledge with that they will move around the problem space. All the particles have memory and each particle keeps track with its previous best position (Pbest) and corresponding the fitness value. The best of all particles of Pbest will be global best position (Gbest). The position of each particle will be updated by updating their velocity by following equation.

$$V_1^{k+1} = WV_1^k + c_1 * rand_1() * (P_{best1} - S_1^k) + c_2 * rand_2() * (G_{best} - S_1^k) \qquad (3.1)$$

The position of the particle will be updated by using above equation by

$$S_1^{k+1} = S_1^k + V_1^{k+1} \qquad (3.2)$$

Where; V_1^k = The velocity of individual i at iteration k

k = The pointer of iterations

W = The weighting factor

c_1, c_2 = The acceleration coefficients

S_1^k = The current position of individual I at iteration k

$Pbest_1$ = The best position of individual at iteration k

$Gbest_1$ = The best position of the group

$rand_1(), rand_2()$ are the random numbers between 0 and 1.

c_1 has a range between 1.5 and 2, which is called self confidence range.

c_2 has a range 2 and 2.5, which is called swarm range.

The coefficients c_1 and c_2 pull each particle towards Pbest and Gbest positions.

The term $c_1 * rand_1() * (P_{best1} - S_1^k)$ is called particle memory part which represents the personal thinking of each particle itself. Maximum allowed particle velocity V^{max} determines the resolution or fitness with which regions are to be searched between the present position and target position. The choice of a value for V^{max} is often set to 10-20% of the dynamic range of the variables for each problem. By considering the proper value of inertia weight W will provide balance between global and local positions. By selecting the suitable inertia weight will reduce the number of iterations to obtain optimal solutions.

$$W = W_{max} - \frac{W_{max} - W_{min}}{iter_{max}} \times iter \qquad (3.3)$$

Where; W_{max} = initial weight

W_{min} = final weight

$iter_{max}$ = maximum iteration number

$iter$ = current iteration number

3.3 PSO Algorithm:

Algorithm steps for PSO technique.

- Initialise the population with random values and velocities.
- Computing the fitness of each agent (particle) and assign the position of particles to P-best position and fitness of particle to P-best fitness.
- Identify the best value among the P-best and store the fitness value as a G-best.
- Update the Velocity and position of each particle (agent) by using below equations.

$$V_1^{k+1} = WV_1^k + c_1 * rand_1() * (P_{best1} - S_1^k) + c_2 * rand_2() * (G_{best} - S_1^k)$$

$$S_1^{k+1} = S_1^k + V_1^{k+1}$$

- Check the velocities and positions whether it will be within the range or not then again find the fitness of each particle (agent).
- Compare the current fitness value with its previous P-best. If present value is better than the P-best then update the P-best as a current value.
- Now compare the present value with the G-best. If present value is better than the G-best then update the G-best as a present value.
- Repeat the above steps until to get sufficiently good G-best or until to reach maximum number of iterations

3.4 Flow Chart:

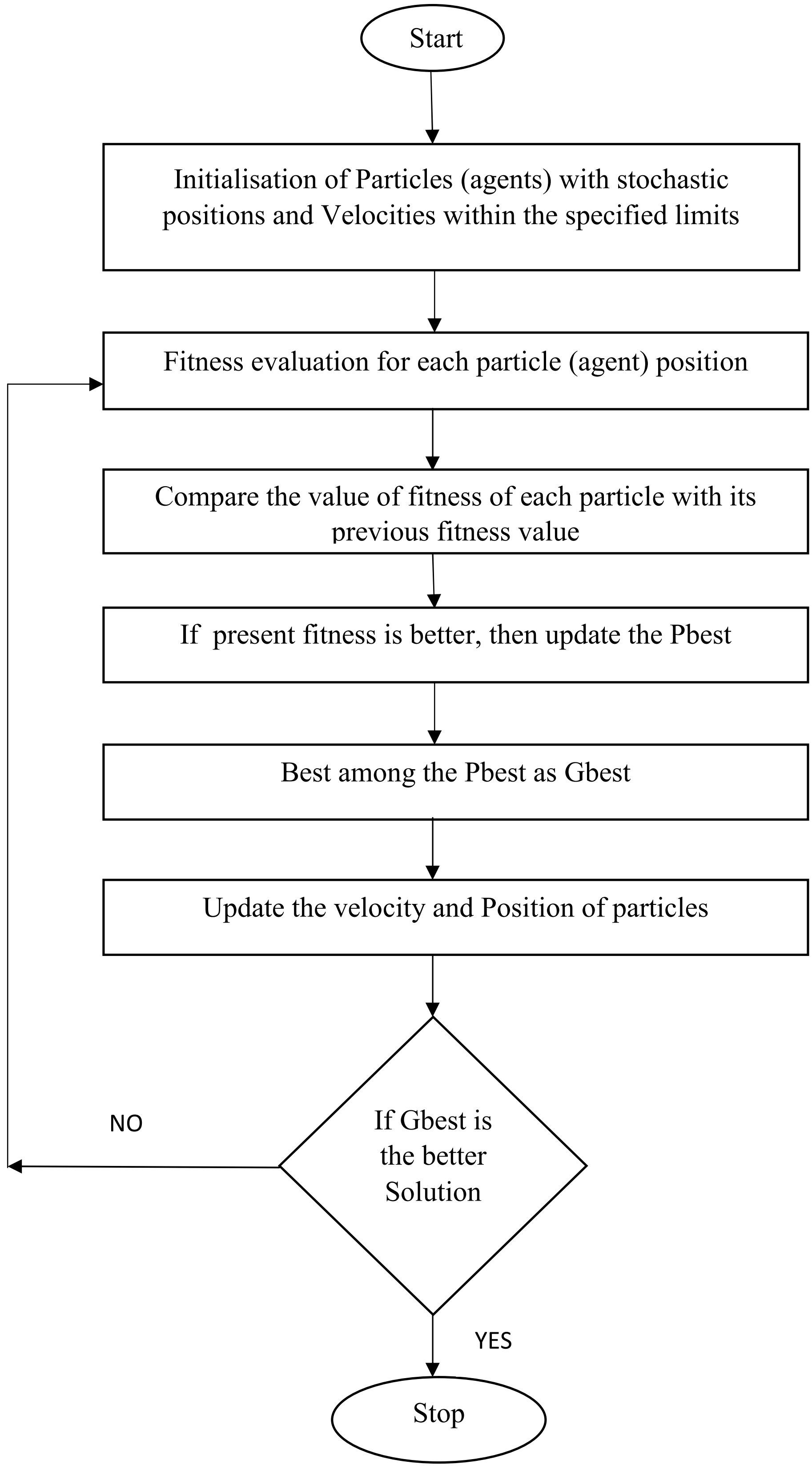

Fig 3.1: Flowchart for PSO algorithm

3.5 Contingency constrained ELD:

In Chapter 2 we have discussed the different contingency analysis. In Table No:1(Severity indexes for different contingencies for IEEE-30 bus system) shown that the severity of each contingency and also shown that which lines are getting overload under different contingencies. Because of overloaded lines the total power system may get effect. So we have to reduce the loading effect in overloaded lines for that we have to reschedule the generating units. While rescheduling the generators we have taken the severity index also one of the constraint so that the power flow in overloaded lines will come under specified limits.

During the rescheduling the generation by utilising PSO optimisation technique will be as follows;

Step 1

We have calculated the Severity index for each contingency by running the load flow with contingency.

Step 2

The Rank has been given for different contingencies according to the Severity index.

Step 3

We have initialised the generating units with random values along with velocities within specified limits expect for slack unit.

Step 4

We have calculated the power flow in each transmission line by using the NR load flow method and also calculated the fuel cost and severity index.

Step 5

We have chosen the Gbest vector for particle position vector which has given the minimum fuel cost and minimum severity index and rest of all position vectors has been considered as Pbest.

Step 6

Updated the particle position by updating the position velocity. So that we got new population for next iteration.

Step 7

We have calculated the fuel cost and severity index with new population members by running the NR load flow method with single line outage.

Step 8

We have updated the Gbest and Pbest values by comparing previous values of Gbest and Pbest values.

Step 9

Completed the procedure up to maximum iterations has been reached.

Step 10

The iteration values of Gbest is the best solution for particular contingency.

CHAPTER 4

RESULTS

Chapter 4

Results

The security of the power system network has been improved under contingency analysis. The optimisation technique PSO has been used to rescheduling the generators. The results have been compared between the pre-contingency period and contingency period and also taken the cases with valve point loading and without valve point loading. In all the cases losses have been computed by using NR load flow method.

4.1 Results:

Here we have considered the IEEE-30 bus system which is having 6 generating units. The cost function of each generating unit in Rs/Hr is given as.

CASE 1: Without valve point loading

$$F_1 = 0.02P_1^2 + 2P_1 + 0$$

$$F_2 = 0.0175P_2^2 + 1.75P_2 + 0$$

$$F_3 = 0.0625P_3^2 + 1P_3 + 0$$

$$F_4 = 0.00834P_4^2 + 3.25P_4 + 0$$

$$F_5 = 0.025P_5^2 + 3P_5 + 0$$

$$F_6 = 0.025P_6^2 + 3P_6 + 0 \tag{4.1}$$

CASE 2: With valve point loading

$$F_1 = 0.02P_1^2 + 2P_1 + 0 + \left|300 * \sin(0.2(P_{1\min} - P_1))\right|$$

$$F_2 = 0.0175P_2^2 + 1.75P_2 + 0 + \left|200 * \sin(0.22(P_{2\min} - P_2))\right|$$

$$F_3 = 0.0625P_3^2 + 1P_3 + 0 + \left|150 * \sin(0.42(P_{3\min} - P_3))\right|$$

$$F_4 = 0.00834P_4^2 + 3.25P_4 + 0 + \left|100 * \sin(0.3(P_{4\min} - P_4))\right|$$

$$F_5 = 0.025P_5^2 + 3P_5 + 0 + \left|200 * \sin(0.35(P_{5\min} - P_5))\right|$$

$$F_6 = 0.025P_6^2 + 3P_6 + 0 + \left|200 * \sin(0.35(P_{6\min} - P_6))\right| \quad (4.2)$$

The constraints for each generating unit is mentioned below

$$0MW \le P_1 \le 80MW$$

$$0MW \le P_2 \le 80MW$$

$$0MW \le P_3 \le 50MW$$

$$0MW \le P_4 \le 55MW$$

$$0MW \le P_5 \le 30MW$$

$$0MW \le P_6 \le 40MW \quad (4.3)$$

For IEEE-30 bus system we have considered the load demand 283.4MW. For each contingency power flows and losses in transmission line have been calculated by using NR load flow method. The below table shows the transmission line losses under different contingencies.

Table 4.1: Power losses in transmission lines under different contingencies

S.No	Outage line	Losses in MW
1	1-2	24.84
2	1-3	13.795
3	3-4	13.473
4	2-5	17.807

We have scheduled the generating units under each contingency losses to meet the load demand without considering the severity index in both cases with and without valve point loading.

CASE 1: Without valve point loading

Table 4.2: Scheduling of generating units under different contingencies without valve point loading

Unit O/P in MW	Load Demand in MW			
	308.24MW	297.195MW	296.873MW	301.207MW
P1	80.0000	68.0165	67.8646	69.9090
P2	79.9906	80.0000	80.0000	80.0000
P3	27.7892	29.7653	29.7167	30.3709
P4	54.9906	55.0000	55.0000	55.0000
P5	29.9906	30.0000	30.0000	30.0000
P6	35.4789	34.4132	34.2917	35.9272
Fuel cost (Rs/hr)	1069.2	1015.0	1013.5	1034.1

Fuel Cost Minimisation curves for without valve point load under contingency:

Plot 1:

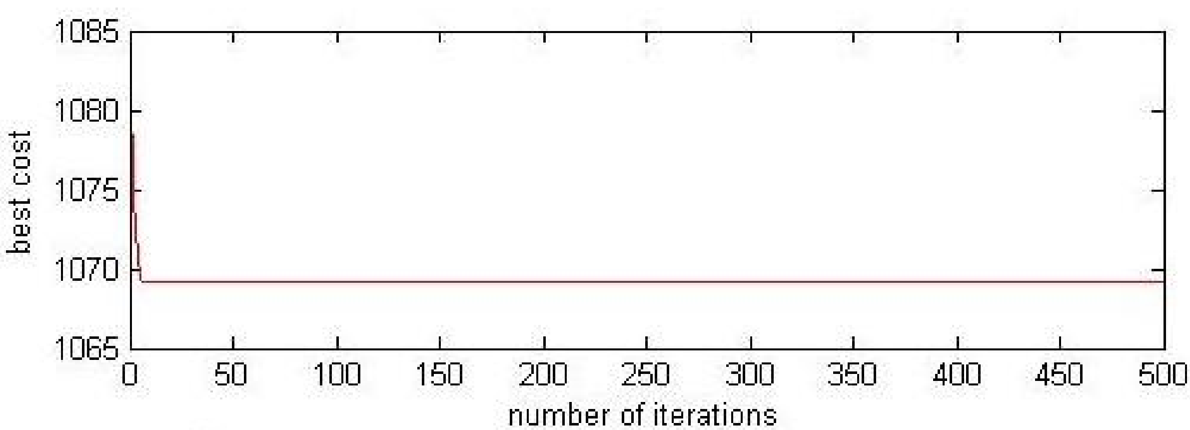

Fig.4.1 No. of iterations Vs best cost without valve point Loading (load demand=308.24MW)

Plot 2:

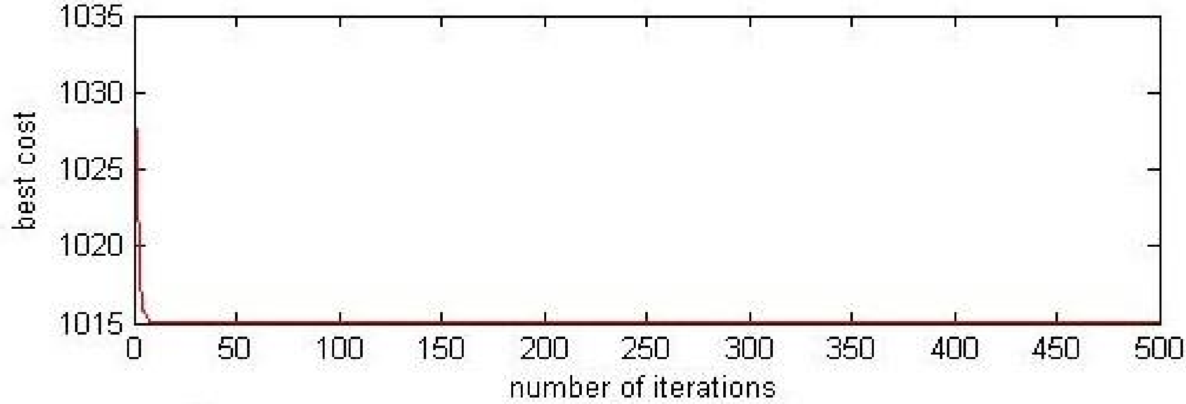

Fig 4.2 No. of iterations Vs best cost without valve point Loading (load demand=297.195MW)

Plot 3:

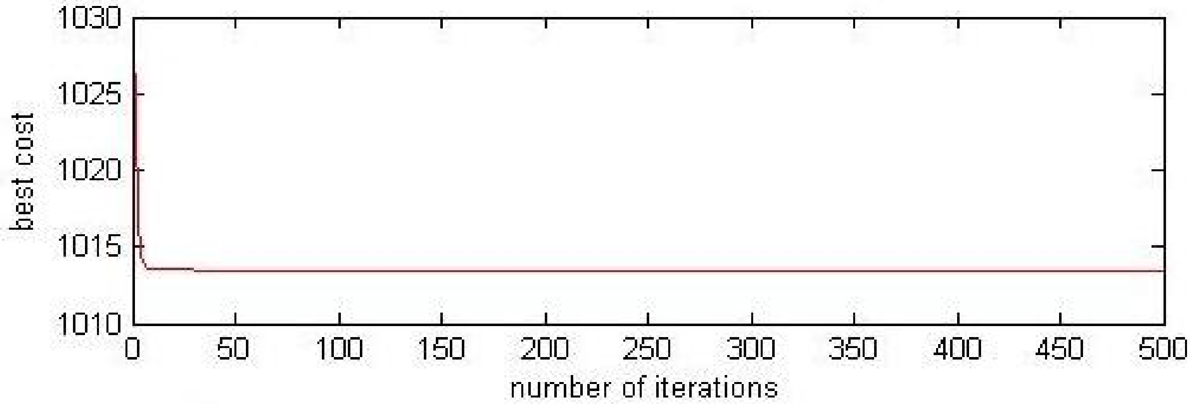

Fig 4.3 No. of iterations Vs best cost without valve point Loading (load demand=296.873MW)

Plot 4:

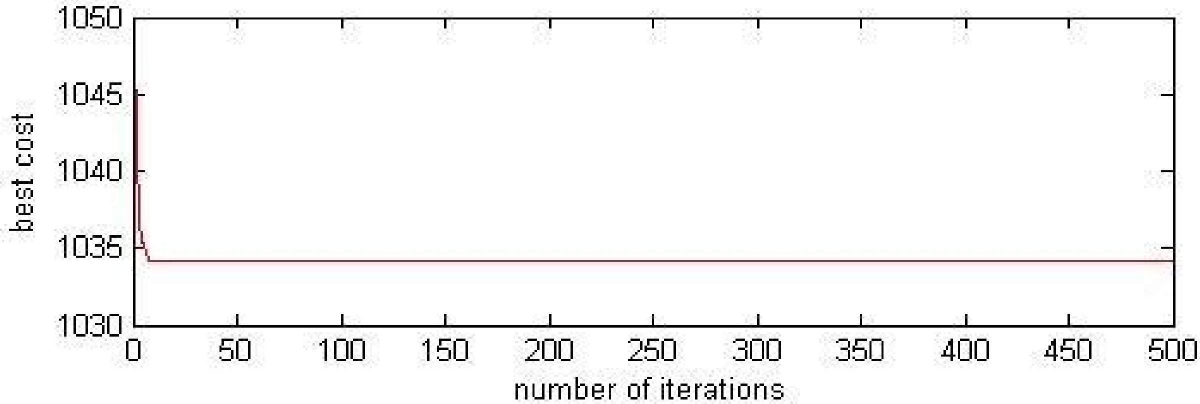

Fig 4.4 No. of iterations Vs best cost without valve point Loading (load demand=301.207MW)

CASE 2: With Valve Point Loading

Table 4.3: Scheduling of generating units under different contingencies with valve point loading.

Unit O/P in MW	**Load Demand in MW**			
	308.24MW	297.195MW	296.873MW	301.207MW
P1	78.5398	78.5400	78.5399	78.5402
P2	71.3998	58.3365	57.1191	71.3997
P3	44.8799	44.8800	44.8800	37.3999
P4	50.5886	52.6067	53.5008	51.0410
P5	26.9279	26.9279	26.9484	26.9276
P6	35.9039	35.9039	35.9039	35.8986
Fuel cost (Rs/hr)	1140.7	1106.1	1078.5	1084.8

Fuel Cost Minimisation curves for with valve point load under contingency:

Plot 1:

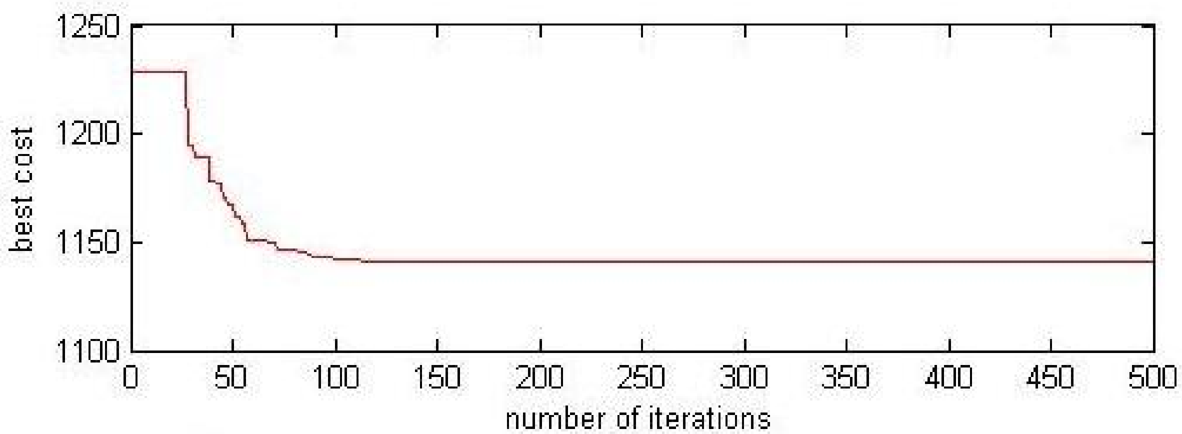

Fig 4.5 No. of iterations Vs best cost with valve point Loading (load demand=308.24MW)

Plot 2:

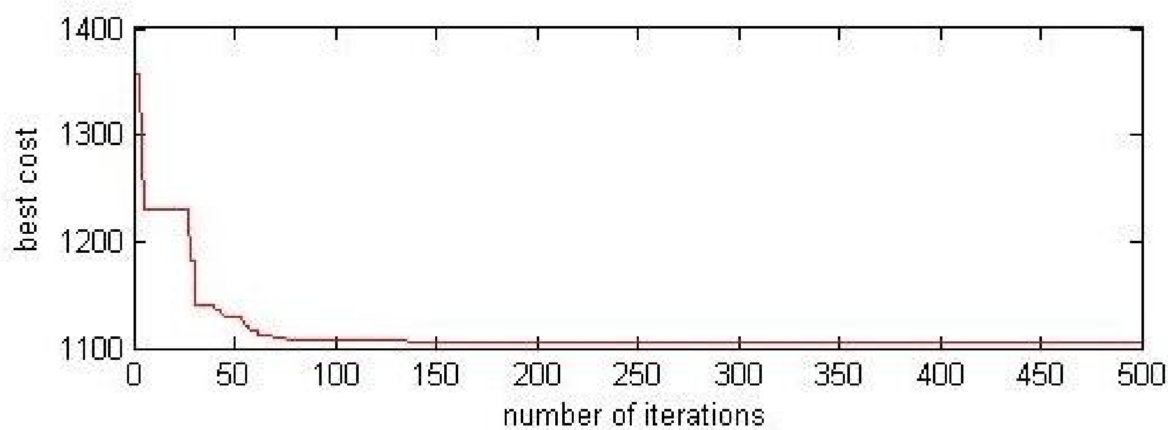

Fig 4.6 No. of iterations Vs best cost with valve point Loading (load demand=297.195MW)

Plot 3:

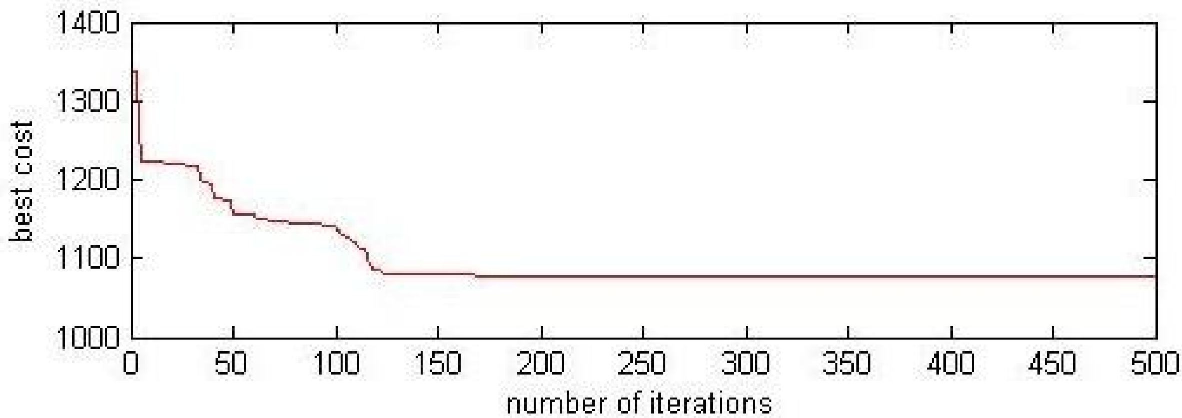

Fig 4.7 No. of iterations Vs best cost with valve point Loading (load demand=296.873MW)

Plot 4:

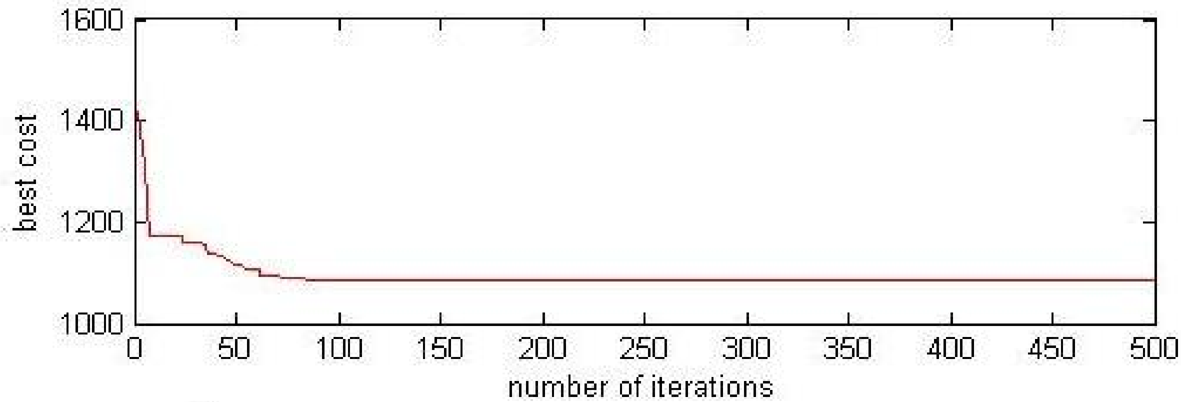

Fig 4.8 No. of iterations Vs best cost with valve point Loading (load demand=301.207MW)

Now we have analysed the performance of the system under contingencies so that we can know that how many transmission lines get overloading and also we can know that how much excess power is flowing in that transmission lines and also can know that losses of the network. The below table shows information regarding to transmission lines flows under contingencies.

Table 4.4: Analysis of transmission line flows under contingencies

Outage line	Overloaded lines	Line flow (MVA)	Line Flow limit (MVA)	Losses (MW)
1-2	1-3 3-4 4-6	192.1120 180.1815 110.8805	130 130 90	24.84
1-3	1-2	181.6383	130	13.795
3-4	1-2 2-6	178.8614 65.5192	130 65	13.473
2-5	2-6 5-7	76.8053 83.3212	65 70	17.807

By observing the above Table5, by outage of 1-2 transmission line from the network the lines are 1-3,3-4 & 4-6 are getting overload. The flows in those transmission lines are 192.1120MVA, 180.1815MVA & 110.8805MVA respectively but in that transmission lines the maximum power flow limit is 130MVA, 130MVA & 90MVA respectively. So all these specified lines are getting overloading and the severity of each contingency we have calculated by using eqn(2.20).

To increase the security of the power system network under different contingencies we have to reschedule the generators to control the line flows in the transmission lines. The rescheduling generating power is shown in below.

CASE 1: OUTAGE 1-2

Table 4.5: Rescheduling of generating units under 1-2 contingency.

Generating units	Power flows before rescheduling	Power flows after rescheduling	
		Without valve point loading(308.24MW)	With valve point loading(308.24MW)
P1(MW)	191.591	80	78.5423
P2(MW)	48.84	79.9830	71.3071
P3(MW)	21.51	31.7811	44.8403
P4(MW)	22.15	54.9830	50.8035
P5(MW)	12.14	29.9830	26.9055
P6(MW)	12.00	31.5090	35.8414
COST(RS/Hr)		1069.2	1147.5
MVA(1-3)	192.1120	60.8239	59.1134
MVA(3-4)	180.1815	56.6432	55.0124
MVA(4-6)	110.8805	34.6783	35.6972
SI	5.6227	0	0

By Rescheduling the generators in both cases of without valve point loading and with valve point loading under 1-2 contingency the power flows in the transmission lines came into the specified power limits of the transmission lines. So that the overloaded lines under the contingency has been protected by rescheduling the generators and the severity of that contingency has been minimised to 0 because no line get overloaded after rescheduling the generators. Fuel cost minimisation curve under 1-2 contingency:

i. Without valve point loading:

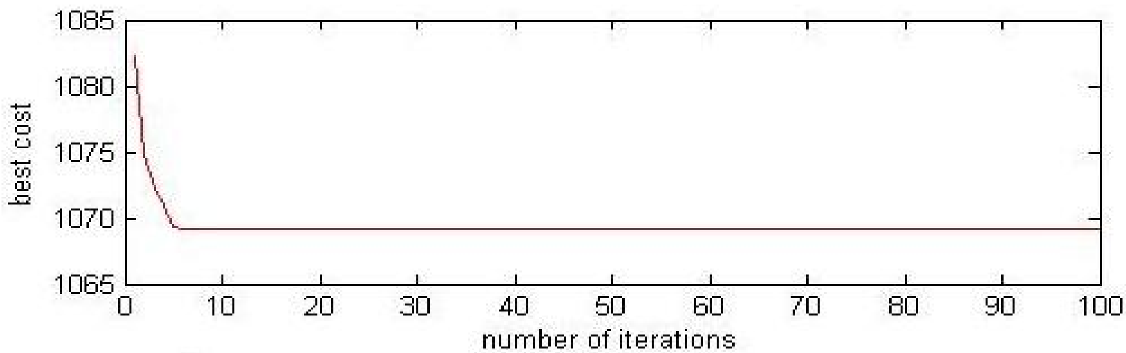

Fig 4.9: No. of iterations Vs best cost without valve point Loading under 1-2 contingency

ii. With valve point loading:

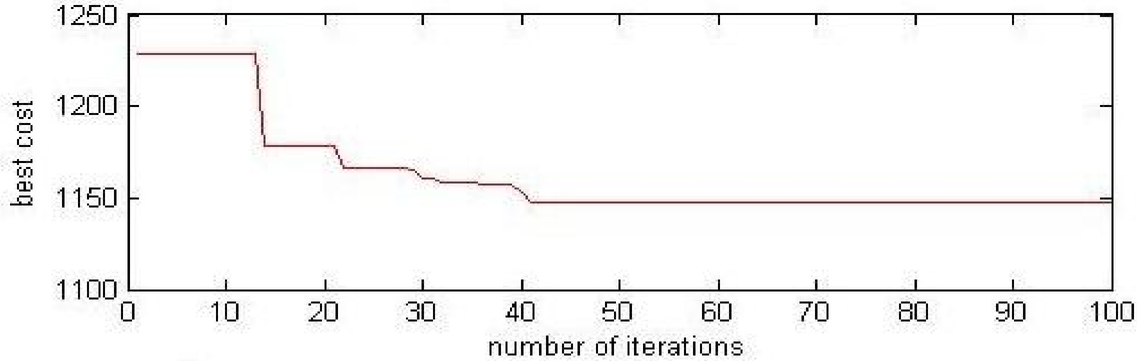

Fig 4.10: No. of iterations Vs best cost with valve point Loading under 1-2 contingency

CASE 2: OUTAGE 1-3

Table 4.6: Rescheduling of generating units under 1-3 contingency.

Generating units	Power flows before rescheduling	Power flows after rescheduling	
		Without valve point loading(297.195MW)	With valve point loading(297.195MW)
P1(MW)	180.555	68.0163	78.6409
P2(MW)	48.84	80	57.9747
P3(MW)	21.51	29.7669	44.8803
P4(MW)	22.15	55	52.4470
P5(MW)	12.14	30	26.9781
P6(MW)	12.00	34.4118	36.2741
COST(RS/Hr)		1015.0	1121.7
MVA(1-2)	181.6383	60.2788	69.8114
SI	1.9522	0	0

By rescheduling the generators in both cases of without valve point loading and with valve point loading under 1-3 contingency the power flows in the transmission lines came into specified the power limits of the transmission lines. So that the overloaded lines under the contingency has been protected by rescheduling the generators and the severity of that contingency has been minimised to 0 (zero) because no line get overloaded after rescheduling the generators.

Fuel cost minimisation curve under 1-3 contingency:

i. Without valve point loading:

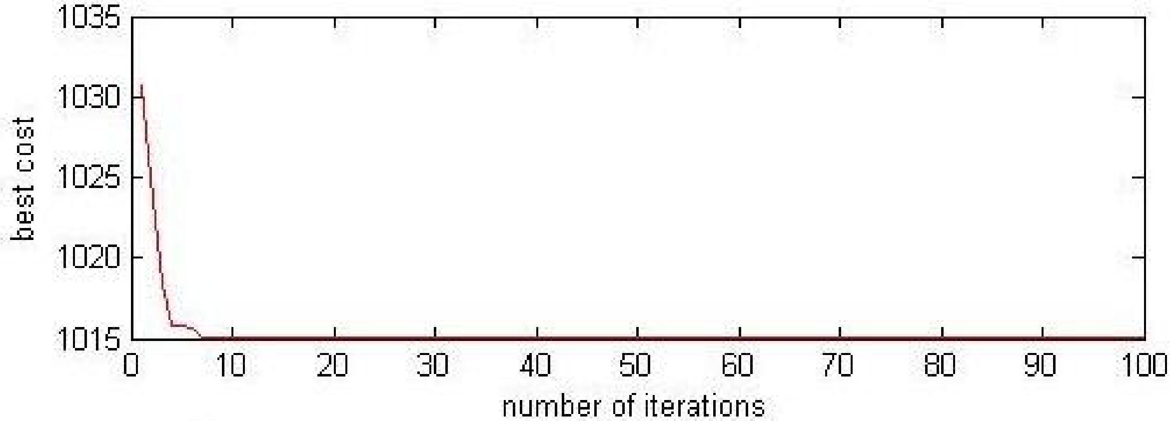

Fig 4.11: No. of iterations Vs best cost without valve point Loading under 1-3 contingency

ii. With valve loading:

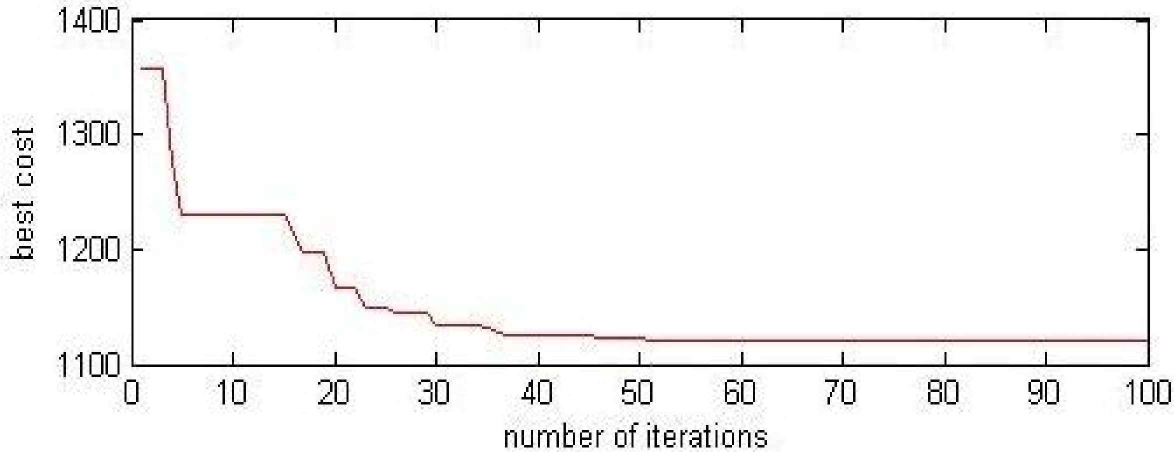

Fig 4.12: No. of iterations Vs best cost with valve point Loading under 1-3 contingency

CASE 3: OUTAGE 3-4

Table 4.7: Rescheduling of generating units under 3-4 contingency.

Generating units	Power flows before rescheduling	Power flows after rescheduling	
		Without valve point loading(296.873MW)	With valve point loading(296.873MW)
P1(MW)	180.34	67.8702	78.6164
P2(MW)	48.84	80	57.2154
P3(MW)	21.51	29.7122	45.1043
P4(MW)	22.15	55	52.3842
P5(MW)	12.14	30	27.6532
P6(MW)	12.00	34.2906	35.8994
COST(RS/Hr)		1013.5	1120.1
MVA(1-2)	178.8614	58.1608	67.6921
MVA(2-6)	65.5192	32.3381	30.6661
SI	2.9090	0	0

By rescheduling the generators in both cases of without valve point loading and with valve point loading under 3-4 contingency the power flows in the transmission lines came into specified the power limits of the transmission lines. So that the overloaded lines under the contingency has been protected by rescheduling the generators and the severity of that contingency has been minimised to 0 because no line get overloaded after rescheduling the generators.

Fuel cost minimisation curve under 3-4 contingency:

i. Without valve point loading:

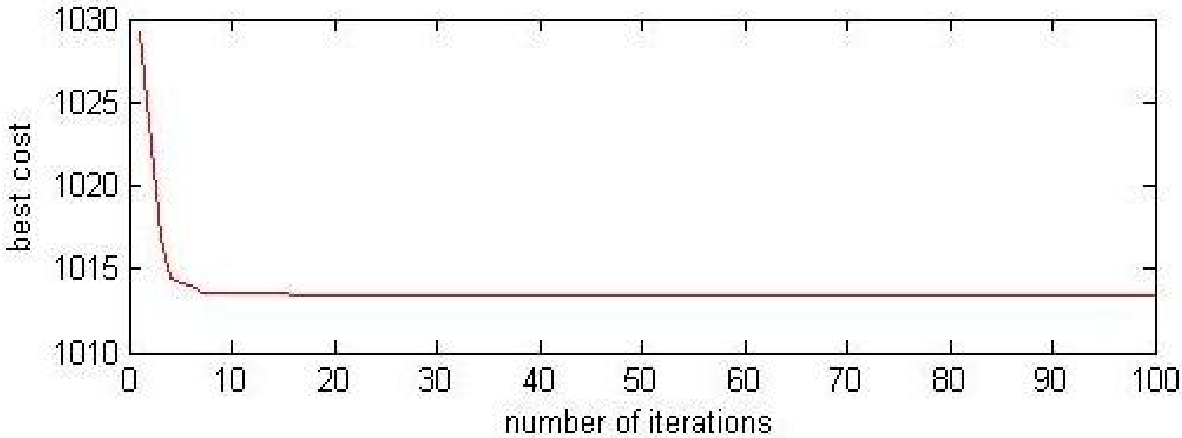

Fig 4.13: No. of iterations Vs best cost without valve point Loading under 3-4 contingency

ii. With valve point loading:

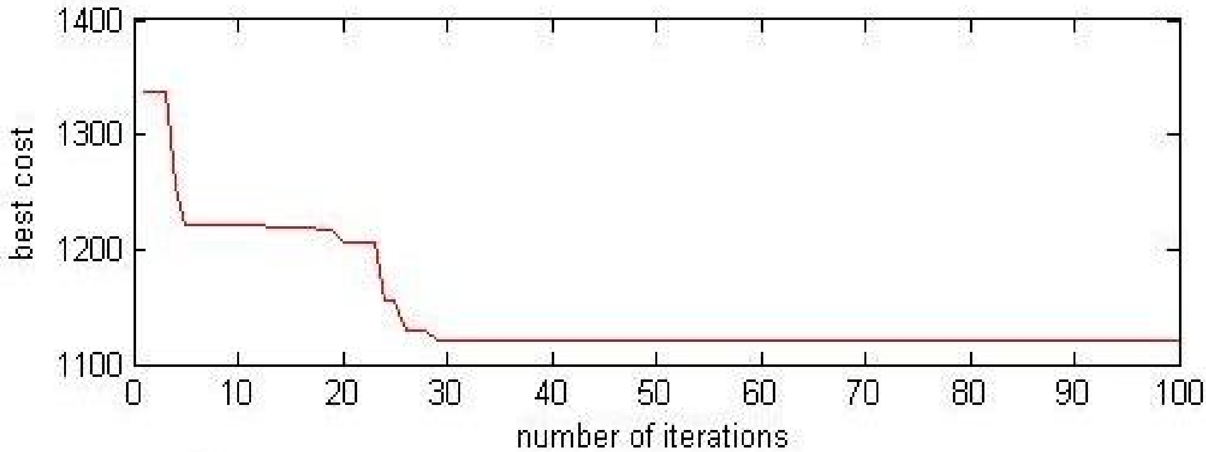

Fig 4.14: No. of iterations Vs best cost with valve point Loading under 3-4 contingency

CASE 4: OUTAGE 2-5

Table 4.8: Rescheduling of generating units under 2-5 contingency.

Generating units	Power flows before rescheduling	Power flows after rescheduling	
		Without valve point loading(301.207MW)	With valve point loading(301.207MW)
P1(MW)	184.567	69.9096	78.4733
P2(MW)	48.84	80	71.2985
P3(MW)	21.51	30	37.3969
P4(MW)	22.15	55	51.5153
P5(MW)	12.14	30	26.6457
P6(MW)	12.00	35.9280	35.8772
COST(RS/Hr)		1034.4	1101.00
MVA(2-6)	76.8053	46.9307	45.8614
MVA(5-7)	83.3212	71.9452	63.9371
SI	2.8130	1.0277	0

By rescheduling the generators in both cases of without valve point loading and with valve point loading under 2-5 contingency the power flows in the transmission lines came into the power limits of the transmission lines. But the transmission line 2-6 didn't come under the power limit. So that the severity index of that transmission line still is at 1.0277 because the power limit in that transmission line is 70MVA but after rescheduling the generating units the power flow in that transmission line is 71.9452MVA.

Fuel cost minimisation curve under 2-5 contingency:

i. Without valve point loading:

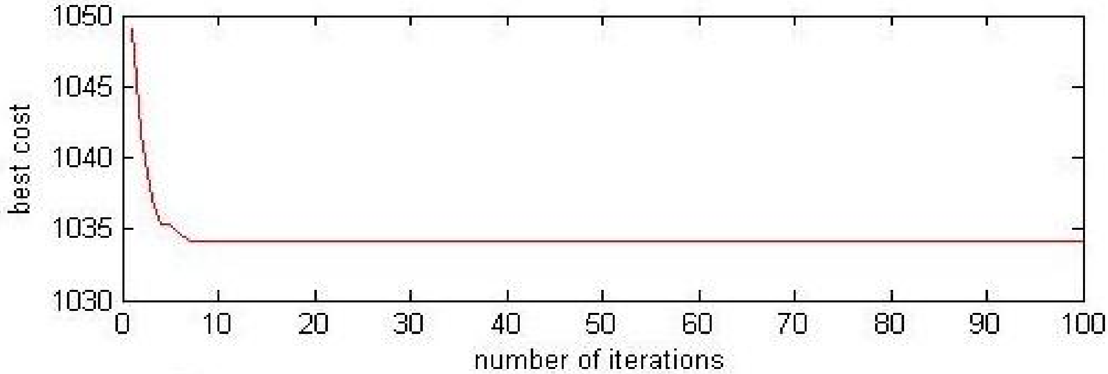

Fig 4.15: No. of iterations Vs best cost without valve point Loading under 2-5 contingency

ii. With valve point loading:

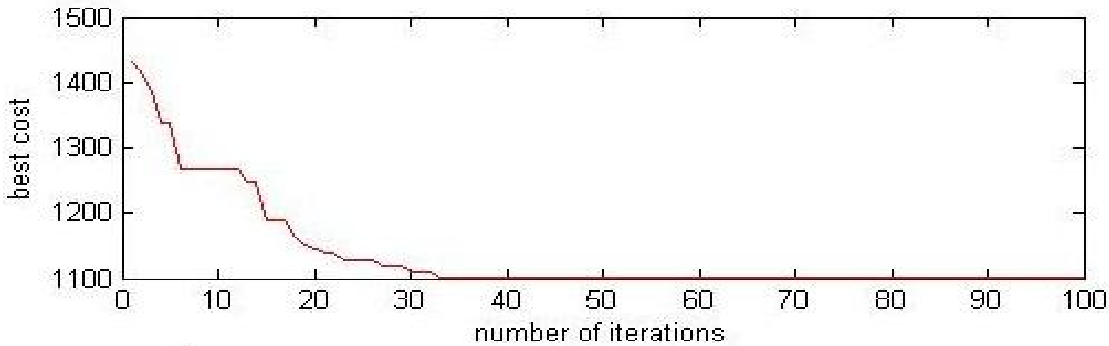

Fig 4.16: No. of iterations Vs best cost with valve point Loading under 2-5 contingency

The below table shows the summery of severity indexes of different contingencies

Table 4.9: Summery of SI of different contingencies before and after rescheduling.

Contingency	SI before rescheduling	SI after rescheduling	
		Without valve point loading	With valve point loading
1-2	5.6227	0	0
1-3	1.9522	0	0
3-4	2.9090	0	0
2-5	2.8130	1.0277	0

Therefore by rescheduling the generators the severity of each contingency has been reduced to zero except for the contingency 2-5 without valve point loading. During the rescheduling the power flows in the transmission lines has been controlled and maintained in the specified limits but for the contingency 2-5 the power flow in the transmission line (5-7) is 71.9452MVA and the maximum limit for power flow in that transmission line (5-7) is 70MVA. So after rescheduling also somewhat exceeding power is flowing in 5-7 transmission line. But before rescheduling the generators the power flow in that transmission line is 83.3212MVA. So the severity of this contingency before rescheduling the generators is 2.8130. After rescheduling the generators the power flow in transmission line 5-7 is reduced 83.3212MVA to 71.9452MVA so the severity of 2-5 contingency has been reduced 2.8130 to 1.0277. The rest of all contingencies of severity are reduced to zero after rescheduling the generators.

CHAPTER 5

CONCLUSION AND FUTURE SCOPE

Chapter 5

Conclusion and Future scope

5.1 Conclusion:

There is an essential need to improve the power system security under any circumstances along with the transmission capability. Here we are enhancing the power system security under contingency analysis. The performance of power system network under contingency has been predicted by using NR method and the severity of each contingency has been calculated. During the contingency period we have notified the transmission lines which are getting over flow. Because of these over flow power lines might lead the network to complete blackout. So we have to increase the power system security under the contingencies, it can be done by rescheduling the generators. Here we have rescheduled the generators by using particle swarm optimisation technique. After rescheduling the generators the severity of each contingency has been reduced, So that the power system security has been enhanced under different contingencies and the generation is also at minimum cost.

5.2 Future Scope:

During this work we have taken IEEE-30 bus system in future it can be extended to more than 30 bus system. In this work during the rescheduling of generators we have utilised the PSO optimisation technique. In future for different bus systems generators can be rescheduled by using different optimisation technique and comparisons can be done between the different optimisation techniques.

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