Design of Special Protection System Against Voltage Instability

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Key words: special protection system (SPS), voltage instability, voltage instability indictor, optimum load shedding

Abstract
Detection of contingencies and performing corrective actions on time for prevention of power system collapse needs to protective plans that addition to original protective plans equipments of power system supervise whole power network in necessary times, so that performs protective and preventive actions; these protective plans are named special protection system (SPS). First of all, suitable SPS designs for system. Next, a mechanism for SPS will design so that SPS can performs corrective action against short time voltage instability. As short time voltage instability happen for 1-3 seconds, operator and system don't have enough time. Therefore, most important contingencies can happen for system and cause to voltage instability consider off-line. After that, a list of corrective actions for every important events prepare for operator and system. This list uses in contingency conditions. For every important event calculates maximum loading system. Then, maximum loading system in every important events compare with minimum acceptable loading system. If loading system was less than minimum acceptable loading, load shedding performs for against voltage instability. Load shedding follows two pourpose.1) Cost of load shedding must be minimum.2) most impressive of load shedding against of short time voltage instability. Therefore, A objective function define.

$$\min_{\Delta P} \sum_{i \in N_L} \Delta P_i.(LMP)_i$$

$$\lambda_{P_i} \geq \lambda_{min}$$

other constrains power flow

LMP: Local Marginal Price
Loading system for deferent ΔP λ_{P_i} :

λ_{min} : Minimum acceptable loading system
Optimization of objective function performs by genetic algorithm. At the end, amount of load shedding for every load bus define. And operator or system performs this recommends against short time voltage instability.

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Abstract :
Load shedding is one of the most important tools to prevent voltage instability. Performing corrective actions on time in order to prevent short time voltage instability need to have protective plans in addition to original equipment protections that supervise whole power network in emergency conditions. These protective plans are called Special Protection System (SPS). In this paper, first of all, a suitable SPS is designed for power system. Next, a mechanism that considers two factors in load shedding, effective loads in voltage instability and low price loads, will be designed for SPS. This method can perform real time by system or manual by operators of power system.

I. Introduction

Nowadays competition of electric industry has caused an increase in financial problems and competition in electric industry. Also, the increasing of demand transmission service, causes power company for the maximum use of existing transmission facilities. Therefore, probability of fault increases in power network. In the other hand SPS is necessary in these situations.

For the performance of power system with a suitable security margin, the estimation of maximum load ability in power network is necessary. Maximum load ability of a power system is not constant and depends on some factors such as structure of network, availability of reactive sources and location of them. Therefore, definition of maximum load ability is faced limitation of voltage stability. In the other hand, for preventing short time voltage instability, the design of SPS against voltage stability is necessary [1]. Also, cost of SPS is too much less than establishment of new transmission lines. Therefore, SPS is a suitable alternative of the establishing of new transmission lines, because establishment an SPS helps to use maximum capacity of transmission lines [2]. The proposed load shedding schemes can be classified in three categories. The first group, the amount of load to be shed is fixed [3]. The minimum amount of load to be shed is determined using time simulation analysis. The second group, minimum load shedding is determined using estimating dynamic load parameters [4]. The third group, load shedding is performed to obtain a feasible solution while voltage is modelled through the using of voltage and power transfer limits which is determined off line. This paper proposes an optimal under-voltage load shedding scheme. First, a predefined voltage stability margin is defined. And then, load shedding based on technical and economical priority is performed.

II. VOLTAGE INSTABILITY

Transmission lines which have heavy load and long length, increase the probability of voltage instability specially in emergency conditions, The lack of power transmission capacity, trip of power plant and increasing of demand have caused transmission lines to transmit more current to centers of load. Financial problems and competition in power system, stresses the transmission lines to transmit more power and this case increases probability of voltage instability. Weakness of power system to protect bus voltage in limitation of allowable operation after contingency in power system is called voltage instability [5].

The basic reason for voltage instability is that the network does not have enough reactive sources that it causes to decrease bus voltage severely. Lack of reactive sources in some network areas have two important reasons 1) The increasing in load consumption smoothly causes some areas do not have sufficient reactive power. 2) The changing of network structure that changes power flow and causes the lack of reactive power in some network areas.

In term of speed, voltage instability is divided in two groups [6]: 1) the short time voltage instability that is continued 1-3 seconds [7]. 2) The long term voltage instability that is continued from decades of seconds to some minutes [8].

III. THE PROPOSED METHOD

The most important action of SPS against voltage instability and preventing voltage collapse in emergency conditions is load shedding. In order to design a suitable mechanism, proposed method considers two points. First, cost of load shedding should be minimized. Second, effective loads in voltage instability should be shed. In order to consider these points, voltage instability indicator and cost indicator are defined as follows:

a) Voltage instability indicator

Voltage instability margin is maximum power that is added to present operation point of system subject to power flow equations have a solution. This indicator is named as load ability indicator (λ_{min}). Suppose that the operation point of system according to Fig. 1 in the normal condition is point (1), after a contingency, the operation point is changed from point (1) to point (2) in p-v curve. Point (2) has lower load ability margin in contrast with point (1) since maximum load ability system is reduced. Therefore, system will face to decrease of load ability margin in compare maximum load ability that has defined for system (1.4 times its base case). Therefore, in order to overcome to this decrease of load ability it should be shed some loads in a short time. Also, limitation of transmission power or limitation of voltage should not be violated. The state of load shedding and proposed voltage instability indicator is shown in Fig.1.

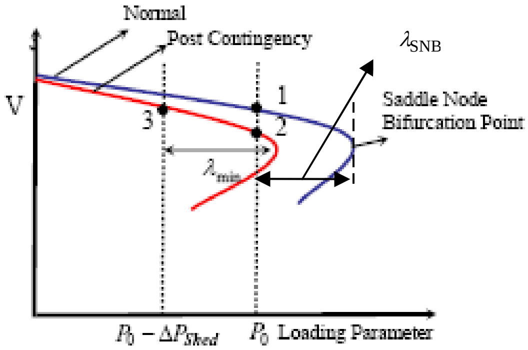


Fig. 1 State of proposed load shedding

b) Cost indicator

Competition in power system and increase in demand are created new problems that need to have more investigation. For example, management of emergency conditions are important more than past. When coordinator of power market wants to shed loads it should consider cost of load shedding. One important tool for coordinator of power market is local marginal price (LMP). In the other hand, local marginal price is helped to decrease load shedding cost.

IV. FORMULATION OF PROPOSED METHOD

For performing load shedding, first of all, problem of load shedding is considered as an optimization problem:

$$\min_{\Delta p} \sum_{i=1}^{N_L} (\Delta p)_i .(lmp)_i \qquad (1)$$

Subject to:

$$\lambda_{p_i} \geq \lambda_{\min} \qquad (2)$$

Normal power equation:

$$\left.\begin{aligned} P_{Gi}^0 - P_{Di}^0 + \Delta P_{Di} &= \sum_{j=1}^{N} |V_i|.|V_j|.|Y_{ij}|.Cos(\gamma_{ij} + \delta_j - \delta_i) \\ Q_{Gi}^0 - Q_{Di}^0 + \Delta Q_{Di} &= -\sum_{j=1}^{N} |V_i|.|V_j|.|Y_{ij}|.Sin(\gamma_{ij} + \delta_j - \delta_i) \end{aligned}\right\} \forall j \in Bus \quad Num \qquad (3)$$

Stressed power flow equation:

$$\left.\begin{aligned} (1+\lambda)(P_{Gi}^0 - P_{Di}^0 + \Delta P_{Di}) &= \sum_{j=1}^{N} |V_i^C|.|V_j^C|.|Y_{ij}|.Cos(\gamma_{ij} + \delta_j^C - \delta_i^C) \\ Q_{Gi}^0 - (1+\lambda)(Q_{Di}^0 - \Delta Q_{Di}) &= -\sum_{j=1}^{N} |V_i^C|.|V_j^C|.|Y_{ij}|.Sin(\gamma_{ij} + \delta_j^C - \delta_i^C) \end{aligned}\right\} \qquad (4)$$

Voltage limits:

$$\left.\begin{aligned} V_i^{\min} &\leq V_i \leq V_i^{\max} \\ V_i^{C-\min} &\leq V_i \leq V_i^{C-\max} \end{aligned}\right\} \quad 1 \leq i \leq N_L \qquad (5)$$

Reactive power generation limits:

$$\left.\begin{aligned} Q_{Gi}^{\min} &\leq Q_{Gi} \\ Q_{Gi}^{C} &\leq Q_{Gi}^{\max} \end{aligned}\right\} \quad 1 \leq i \leq N_G \qquad (7)$$

Active power consumption limits: (8)

$$\Delta P_{Di}^{\min} \leq \Delta P_{Di} \leq \Delta P_{Di}^{\max} \quad 1 \leq i \leq N_L$$

Fixed power factor:

$$\frac{\Delta P_{Di}}{P_{Di}^0} = \frac{\Delta Q_{Di}}{Q_{Di}^0} \qquad (9)$$

N_L : Number of load bus;
N : Number of bus;
λ : Index of load ability
$\lambda_{\min}$: Minimum of load ability margin
λ_{pi} : Present load ability
Index “0”: Parameters at initial state
Index “c”: Parameters after increase of load
D_i, G_i : Amounts of consumption and generation at bus i

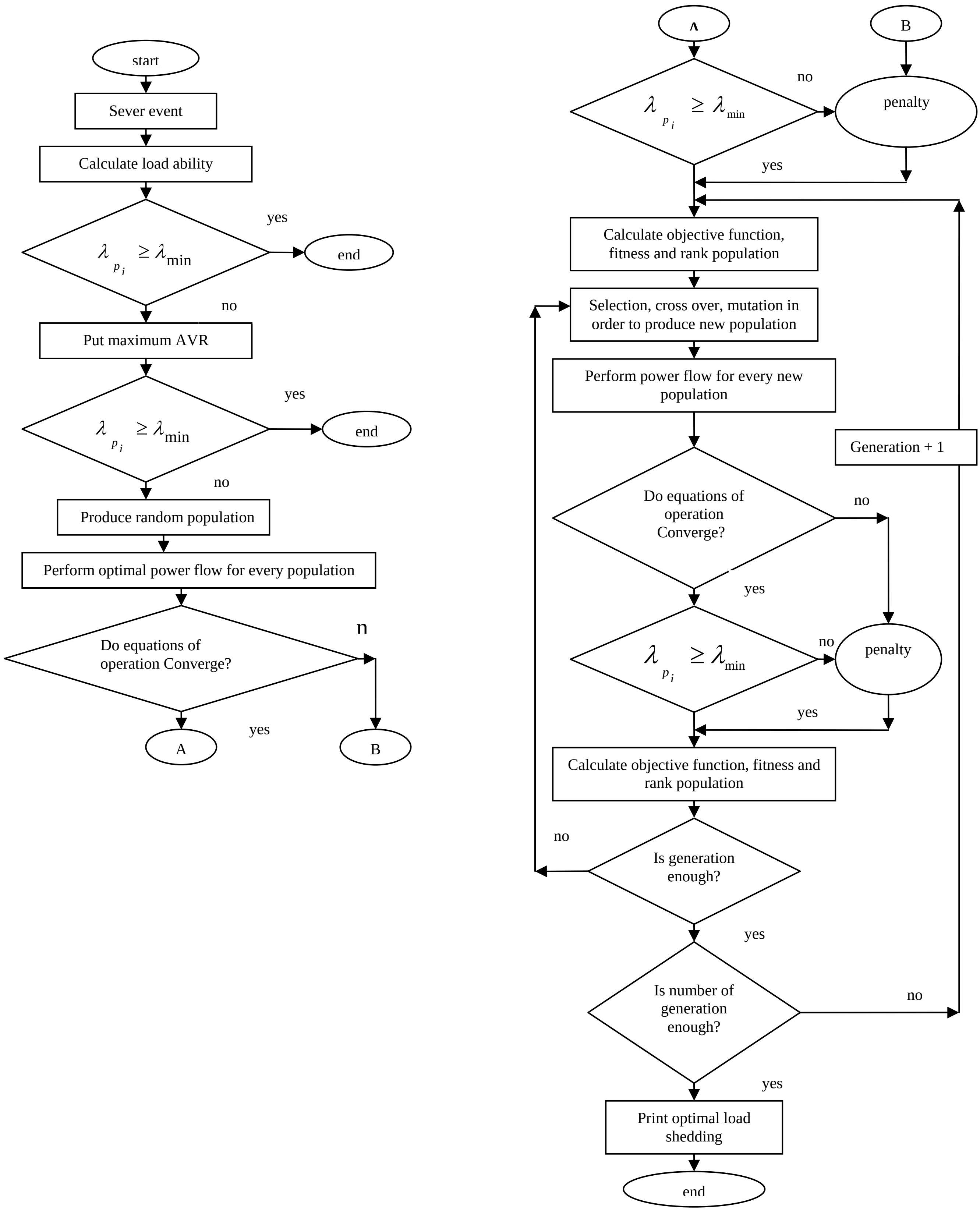


Fig.2 Flowchart of proposed method

Flowchart of proposed method is shown in Fig. 2. According to this procedure after occurrence of a severe contingency, load ability margin is calculated using continuation power flow. If load ability margin is less than a predefined level (λ_{min}), the power system is faced voltage instability. First of all, AVR of the generator units are put on the maximum and then, load ability margin of power system is computed again and compared to predefined level. If load ability margin again is less than a predefined level, in this situation, load shedding is started. Process of optimal load shedding is performed by genetic algorithm. Genetic algorithm is based on population optimization. In genetic algorithm, first a random population is produced. Then, optimal power flow is performed for every population. Next, load ability margin of populations whose optimal power flow were converged, are compared to the predefined level. Then, objective function, fitness and rank of every population are calculated. Next, in order to produce new population selection, crossover and mutation are performed. Then, objective function, fitness and rank of each new population are calculated. These processes are repeated until a predefined generation number. Finally, optimal load shedding is defined.

V. CASE STUDIED

The performance of the proposed method is evaluated using the IEEE 14-Bbus test system, which is shown in Fig.3. The optimization of problem is solved using genetic algorithm. Increase of load is assumed 1.4 times of base case. Also, simulations are performed considering lines 1-2 , 2-4 and G3 generator are out of service.

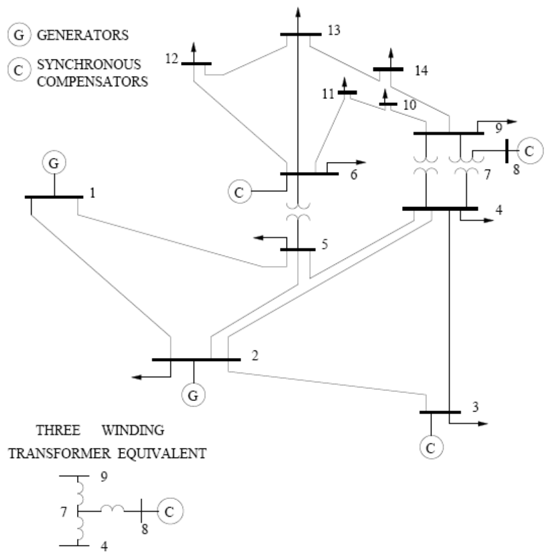
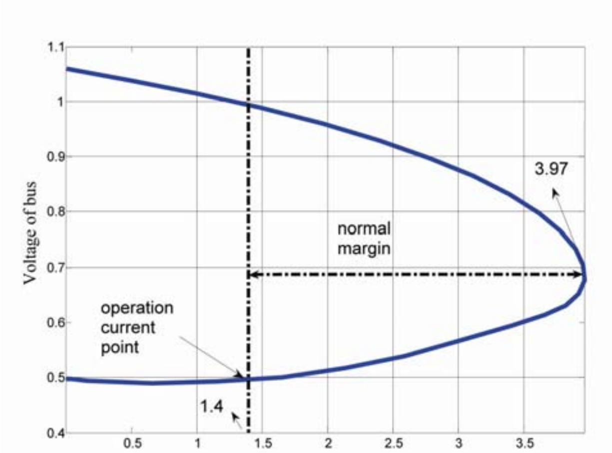


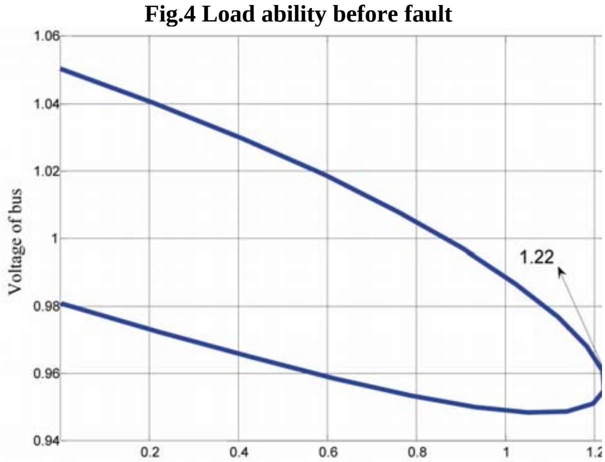
Fig.3 IEEE 14 bus standard network [9]

Load ability before and after fault is shown in Fig. 4 and 5 respectively.



Load parameter (p.u.)

Fig.4 Load ability before fault



Load parameter (p.u.)

Fig. 5 Load ability after fault

Maximum of load ability before fault is 3.97, while the maximum of load ability after fault is 1.22. Maximum of load ability after fault is less than predefined load ability margin. Therefore, some of load for preventing voltage instability should be shed. Magnitude of voltage for load ability margins $\lambda_{min} = 0$ and $\lambda_{min} = 0.1$ are shown in Fig. 6. It is clear when the load ability margin is increased, voltages of bus are more increased.

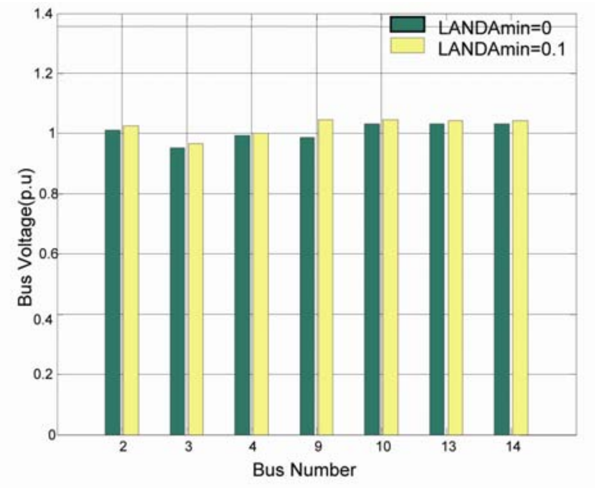


Fig. 6: Amplitude of voltage for load ability $\lambda_{min} = 0, \lambda_{min} = 0.1$

Convergence of genetic algorithm for load ability $\lambda_{min} = 0.06$ is shown in Fig. 7. Genetic algorithm after 50 iterations is converged and amount of optimal load shedding in this situation is 46.9 MW.

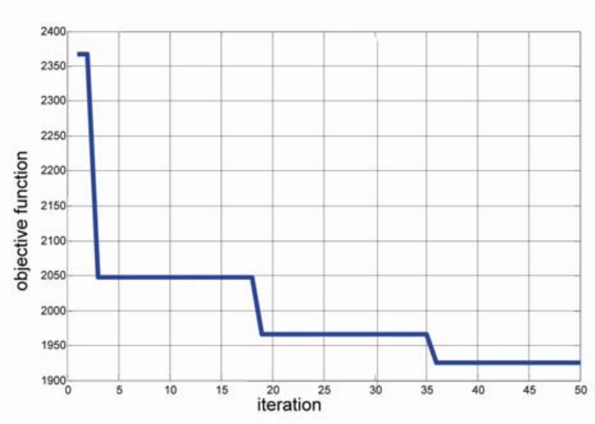


Fig. 7 Convergence of genetic algorithm

Changes of reactive power considering different load ability margin are shown in Fig. 8.

When load ability margin is increased, reserve reactive power is increased too. Increase of reactive power reserve help to increase reliability of voltage stability.

Amount of optimal load shedding for different faults that can happen for studied system is shown in Table I. This table is shown that just a few sever faults need load shedding while some cases have not needed to load shedding.

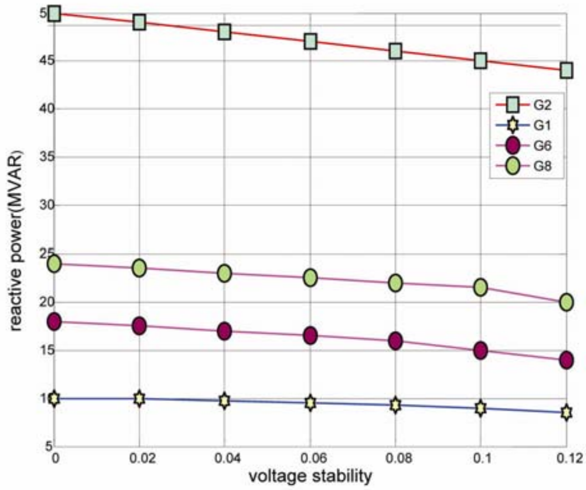


Fig. 8 Changes of reactive power considering different load ability

TABLE I
SOME FAULTS CAN HAPPEN FOR SYSTEM

λ_{min} (voltage stability margin)	amounts of optimal load shed (MW)
0	37.9
0.02	40.9
0.04	43.9
0.06	46.9
0.08	52.9
0.1	56.9

Amounts of optimal load shedding considering different load abilities margin is shown in Table II. It is clear when load ability margin of system is increased, optimal load shedding is increased too.

TABLE II
AMAUNT OF OPTIMAL LOAD SHEDDING CONSIDER ING DIFFERNT LOAD ABILITY

Kind of fault	Maximum load ability	Range of voltage	Minimum load shedding(MW)
Cut lines 1–2 And 2–4 at the same time	1.23	1.05 - 0.978	43
Cut line 1-2	1.24	1.05 - 0.989	40
Cut line 2-3	2.12	1.05 - 1.055	Load shedding no need
Cut line 6-11	4	1.05 - 1.01	Load shedding no need
Cut G6	4.17	1.05 - 1.022	Load shedding no need
Cut G2	4.17	1.05 - 1.04	Load shedding no need
Cut G2 And G8 at the same time	3.9	1.05 - 0.99	Load shedding no need
Cut lines 2–4,3-4 And 2–5 at the same time	1.62	1.05 - 1.01	Load shedding no need
Cut lines 1–2 And 2–5 at the same time	1.1	1.05 - 0.954	77.11
Cut lines 1–2,2-3 And 2–4 at the same time	1.12	1.05 – 0.967	71.5

VI. CONCLUSION

In this paper an optimal under-voltage load shedding scheme is proposed to prevent short time voltage instability. This method considers two factors in load shedding: 1) Loads that are shed must be more effective on voltage instability. 2) Low price load should be shed.

Results of simulation show that load ability is a reliable indicator because it causes to increase reserve reactive power. Also, using LMP indicator decreases cost of load shedding. This method can be used easily for every power system. The proposed method is designed to prevent short time voltage instability and it can perform real time by system or manual by operators of power system.

References

[1] Cig. Task Force 38.02.19, “System Protection Schemes in Power Networks”, Final Draft, Vol. 5, 2000

[2] H. Arabian, A. Ranjbar and B. Mozafari, “An Improved Model for Optimal Under Voltage Load Shedding: Particle Swarm Approach”, IEEE Transactions on Power Systems, Vol. 21, No. 2, pp. 471-478, May 2006

[3] C.W. Taylor, “ Concepts of Under-voltage Load Shedding for Voltage Stability” IEEE Trans. On Power Delivery Vol. 7, pp. 480-488, 1992

[4] S. Granville,. J. C. o. Mello, and A. C. G. Mello “Application of interior point methods to power flow solvability ” , IEEE Trans. On power systems, Vol. 11, No.2, pp. 1096 -10102, 1996

[5] W. Fu, S. Zhao and J. D. Mc Calley , “ Risk Assessment for Special Protection Systemes ”, IEE Proc. Gene. Trans. Distr. Vol. 149, No. 2, March 2002

[6] P. Cote and M. Locroix, “ Benefits of Special Protection Systems in Competitive Market”, IEE Proc. Gene. Trans. Distr. Vol. 148, No.1, May 2001

[7] P.M. Anderson and B.K. Lervend, “Industry Experience with Special Protection Schemes”, IEEE Transactions on Power Systems, Vol. 11, No. 3, pp. 401- 408, Aug. 1996

[8] P. Crossley, F. Ilar and D. Karlsson, “System Protection schemes in Power Networks” Conference Publication, No. 479, IEE 2001

[9] Power System Test Case Archive, Available www.ee.Washington.edu