OPTIMAL LOAD SHEDDING FOR VOLTAGE STABILITY ENHANCEMENT BY GENETIC ALGORITHM

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Abstract

Outage of a heavily loaded transmission line or tripping of large generating unit may lead the system toward collapse. Under such circumstances, compared to other measures, load shedding procedure is an efficient method to make the power system voltage stable when the system is nearly voltage collapse because of some faults occurred. This paper introduces the concept of the continuation power flow analysis to be used for load shedding using power world simulator.The appropriate load buses for the shedding are identified by sensitivities of voltage stability margin using P-V curves at different buses. Then, the amount of load shedding at each bus is determined by applying GA to solve a nonlinear optimization problem formulated in the optimal power flow framework. It uses the P-V curves to find the knee point of a certain bus. The proposed approach has been tested and examined on IEEE-30 bus test system.

Keywords*- load shedding; voltage stability; genetic algoritm; P-V curves.*

INTRODUCTION

In case of emergency which may occur in an electric power system as a result of a sudden increase in system load demand or unexpected outage of a generator or other equipment, the system frequency will change. Certain control actions are performed in order to prevent the deterioration of the system and to restore it back to normal state. Load shedding is defined as the set of controls, which results in a decrease of load in the power system in order to reach a new equilibrium state. Different techniques have been proposed to solve the load shedding problem in either the dynamic or steady state cases.. Generally, there are two ways to provide voltage stability, which are classified as preventive and corrective actions. In the first approach, the security margin is estimated with respect to credible contingencies with a reasonable probability of occurrence, and then appropriate preventive actions are taken by re-adjusting the most effective controls to provide a sufficient margin when needed. Corrective control actions, on the other hand, are usually used for correction of security acceptable only in the presence operating conditions violate some constraints and no control action is available. According to the classification of power system states (i.e. normal, alert, emergency, extreme emergency and restorative), load shedding would be allowed under the emergency and extreme emergency states, when many system variables are out of their normal ranges, and hence the system is driven toward collapse [5]. The load-shedding schemes proposed so far can be classified into three categories. In the first group, the amount of load to be shed is fixed a priori . This scheme is similar to the under-frequency load shedding scheme. Here, the minimum amount of load to be shed is determined using time simulation analysis, incorporating dynamic aspects of the instability phenomenon [8]. Obviously, dynamic simulation is time-consuming and is suitable for special cases such as transient voltage-instability analysis. In addition, it is more difficult to incorporate a time simulation study into an optimization model.

The second group tries to determine a minimum load for shedding by estimating dynamic load parameters. In this approach, results are very sensitive to dynamic load model parameters. Finally, in the third group, minimum load shedding is determined using optimal power-flow equations based on a static model of the power system. The dynamics associated with voltage stability are often slow, and hence static approaches may represent a good approximation. The basic idea behind this approach is to identify a feasible solution to the power-flow equations [9-12].

THE PROPOSED METHODOLOGY

Voltage instability is generally triggered by either of two types of system disturbances: component outage and load increase. Such disturbances increase the reactive power demand of the transmission network. Outage of a heavily loaded transmission line or tripping of a large generating unit may lead the system toward collapse. Under such circumstances, load shedding is usually initiated after exhausting all other countermeasures in an attempt to arrest a voltage collapse condition. Usually, computation of a minimum load to be shed is carried out through an OPF framework. In this approach, the main objective is “interruption cost minimization”, while voltage stability refers to voltage and transfer limits. However, such an approach cannot guarantee sufficient margin to the collapse point. Here, we attempt to develop a structure to cover these flaws. The main objective is modified to consider both the technical and economic aspects of each load. A loading margin is used to ensure voltage stability. For a particular operating point, the amount of additional load in a specific pattern of load increase that would cause a voltage collapse is called the loading margin. To ensure selection of the most effective loads, we incorporate first-order sensitivity factors of the load margin with respect to active and reactive loads into the objective function. These factors are calculated at the saddle node bifurcation point [14]. To ensure voltage stability, the loading margin is considered as a soft constraint into the model. Using this indicator, the operator ensures that reactive power is provided locally. The overall aim of load shedding is depicted in Fig. 1. Suppose that the system is normally operated at point 1. Following the occurrence of a contingency, the P–V curve changes in such a way that the new margin becomes unsafe, although both voltage and transfer limits are allowable. The aim of load shedding is to readjust the initial operating point to provide a sufficient margin (i.e. moving back P0 (point 2) to P0 −_Pshed (point 3)).

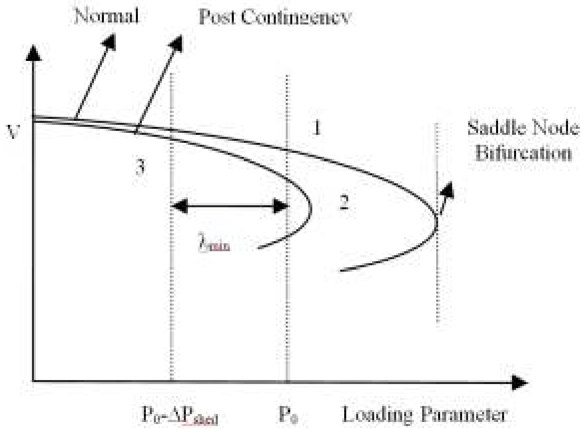

Fig. 1 The load shedding scheme.

A flow chart of the proposed optimal load shedding is shown in Fig. 2. According to this procedure, after occurrence of a contingency, the loading margin and its sensitivities are calculated by a continuation power-flow method. Under such a condition, when this margin is less than a predefined level (λmin), the power system is voltage-unstable.

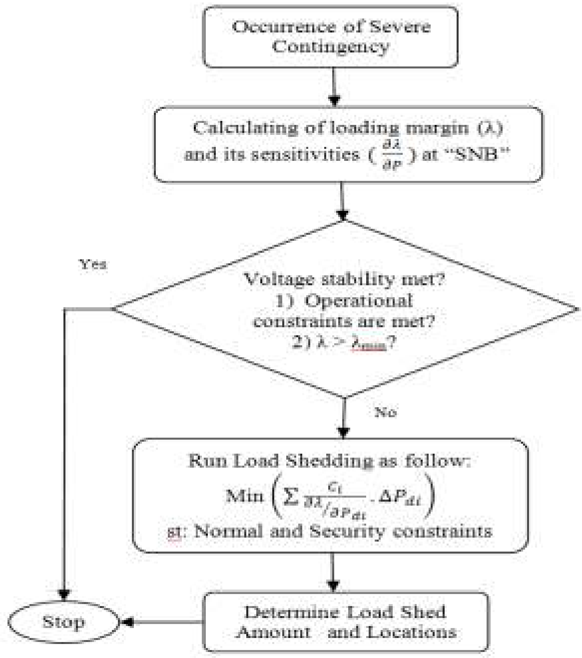

Fig. 2 Flow chart of the load-shedding procedure.

In this situation, load shedding is triggered if the other controls are exhausted. To identify a more sensitive area, the sensitivity of the loading margin with respect to active and reactive power is calculated at each bus ($\partial\lambda/\partial P$).

III. GENETIC ALGORITHM

Genetic Algorithms have recently received much attention as robust stochastic search algorithms for optimization problems. GAs are blind search technique using stochastic operations based on the mechanics of the survival of the fittest. It also works with a population of individuals rather than single point. Operation, involve random number generation (mutation), string copying (reproduction), and partial string exchange (crossover). Each string represents a possible solution. It starts with the formulation of the "fitness function", which represents the objective function for the problem. Based on the fitness of the population strings, two parent strings are selected probabilistically in the reproduction process. Two child strings are then generated from the parent strings in the process of crossover by complementing the child strings at selected bit positions. Mutation is then applied on some of strings to introduce variety of children. The solution is improved through careful choice of the population (number of states in every iteration to search using multiple paths), and the number of generations. This should lead to the possibility of convergence to a global optimal.

I. PROBLEM FORMULATION

The solution of optimal load shedding involves the determination of the effective locations and optimal load reductions subject to various system constraints. This optimization task can be carried out in two stages: planning and operation. In the planning stage, system behaviours of different scenarios are analyzed and if necessary different control strategies may be determined. During the operation, an optimization algorithm is used to suggest the efficient operation scheme as per grid requirements.

In the OPF framework, the main objective of optimization is to minimize the cost of power interruption at buses:

minimize $f(\Delta p_d) = \sum_{i\in n_s} C_i \cdot \left(\frac{\Delta p_{di}}{\partial\lambda/\partial p_{di}}\right)$

subject to

a) Load bus voltage limits

Base condition

$$u_{Li,b}^{min} \le u_{Li,b} \le u_{Li,b}^{max} \qquad \forall i \in n_{pq}$$

Max. loading condition

$$u_{Li,m}^{min} \le u_{Li,m} \le u_{Li,m}^{max}$$

a) Line power flow limits

Base condition

$$s_{Li,b}^{min} \le s_{Li,b} \le s_{Li,b}^{max} \qquad \forall i \in n_l$$

b) Max. loading condition

$$s_{Li,m}^{min} \le s_{Li,m} \le s_{Li,m}^{max}$$

c) Fixed power factor

$$\frac{\Delta p_{di}}{p_{di}^0} = \frac{\Delta q_{di}}{q_{di}^0} \qquad \forall i \in n_s$$

d) Allowable load curtailment

$$\Delta p_{di}^{min} \le \Delta p_{di} \le \Delta p_{di}^{max} \qquad \forall i \in n_s$$

e) Voltage stability margin limit

$$1 \le \lambda_0 + \sum_{i=1}^{N} \frac{\partial\lambda}{\partial p_{di}} \Delta p_{di} + \sum_{i=1}^{N} \frac{\partial\lambda}{\partial q_{di}} \Delta q \le 1.06$$

V. SIMULATION RESULTS

The IEEE 30-bus system is used throughout this paper. The IEEE 30-bus network topology, as well as data for generators, loads and transmission lines, can be found in [2]. It has 2 generators, 4 synchronous compensators and 22 loads. This system is simulated using Power World Simulator and loaded according to base case [16].

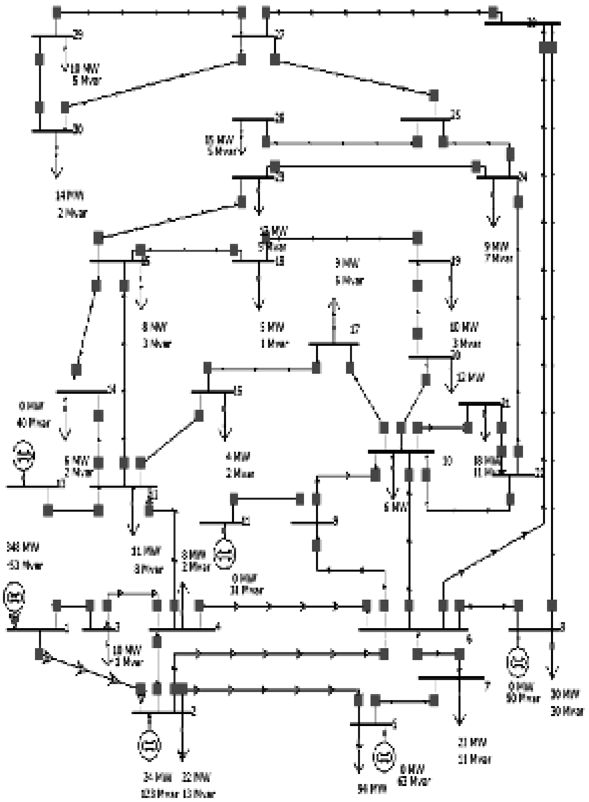

Fig. 3 Simulation diagram of the IEEE 30-bus system.

Now PV curves for bus 30 is plotted by continuation power flow method such that power factor remains constant.

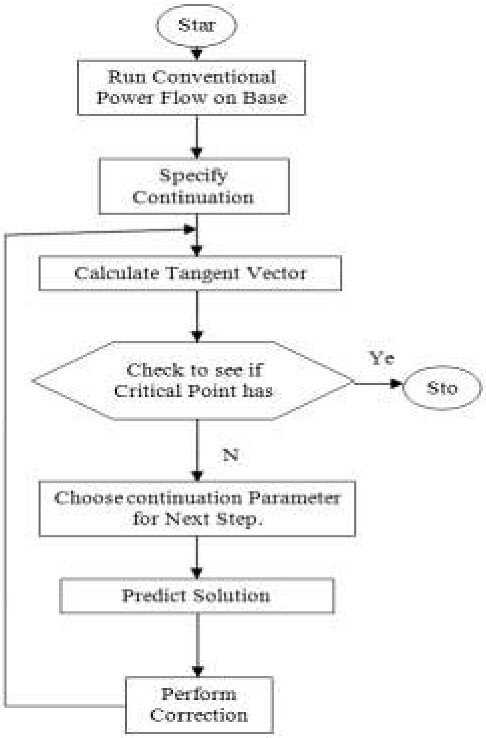

Fig 4 A flow chart of the continuation power flow

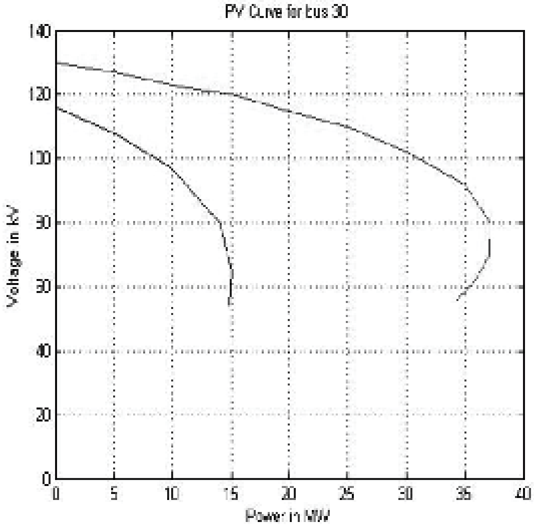

Fig. 5 PV Curve for bus 30 using CPF.

Fig. 5 shows that current operating point is (20MW, 118kV) and bifurcation point is (36MW, 80kV) for normal condition. So loading margin during normal condition is 16MW. In this system a sudden disturbance causes the outage of transmission lines 23-24 and 25-27. Post-Contingency curve shows that bifurcation point is (15MW, 60kV) and current operating point loading is more than this so it moves system towards voltage instability.

Table 1 Power flow of IEEE 30-bus system during Normal Conditions

Bus No.	Volt(kV)	Angle (Deg)	Load MW	Load Mvar	Gen MW	Gen Mvar
1	138	0			348.38	-52.88
2	138	-8.38	21.7	12.7	24	122.88
3	131.33	-11.23	10	1.2		
4	130.28	-13.73	7.6	1.6		
5	136.834	-19.36	94.2	1.9	0	62.5
6	129.668	-16.06				
7	131.389	-17.99	22.8	10.9	0	
8	129.936	-17.07	30	30		50
9	129.092	-21.4				
10	124.536	-24.33	5.81	2	0	
11	138	-21.4	31.6	5		31.03
12	130.349	-23.61	11.2	7.5	0	
13	138	-23.61				39.6
14	126.757	-25.13	6.2	1.6		
15	124.48	-25.42	8.2	2.5		
16	128.103	-24.48	3.5	1.8		

17	123.789	-24.49	9.03	5.8		
18	121.272	-26.59	5	0.9		
19	120.069	-26.86	9.6	3.4		
20	120.319	-26.59	12	5		
21	121.944	-25.2	17.62	11.2		
22	121.842	-25.26				
23	119.244	-26.92	13	5		
24	117.237	-26.82	54	6.7		
25	113.275	-28.41				
26	102.338	-32.58	15	5		
27	116.273	-27.27				
28	127.589	-17.16				
29	104.862	-32.3	10	5		
30	105.121	-33.18	13.96	1.9		

Table 1 shows that all parameters like voltage profile and line flows are within specified limit. From PV curve loading margin can be found out i.e. maximum load at a bus which can be added without voltage collapse. If loading crosses saddle node bifurcation point, system moves towards instability. In this loading condition a sudden disturbance causes the outage of transmission lines 23-24 and 25-27. It results in unstable case where voltage profile on buses 25, 26, 29 and 30 are below specified limits as shown in Table 4.3. If no control action is taken voltage collapse on buses 26 and 30 is inevitable.

Table 2 Load Shedding for IEEE 30-bus system

Bus No	Amount of load shedding(MW)
10	13
16	28
24	9
25	20
26	2

For the voltage stability enhancement load shedding scheme is employed as control tool. In this case three buses are selected for load shedding which are found out using Genetic Algorithm. The optimal amounts of load shed for different buses are tabulated in Table 2.

Table 3 Voltage Comparison for IEEE 30-bus system

Bus No	Voltage(kV) Pre-contingency	Voltage(kV) Post-contingency	Voltage(kV) After load Shedding
1	138	138	138
2	138	138	138
3	131.33	131.193	131.797
4	130.28	130.122	130.811
5	136.834	136.77	137.835
6	129.668	129.541	130.301
7	131.389	131.286	132.177
8	129.936	129.947	130.707
9	129.092	127.48	128.544
10	124.536	121.434	123.214
11	138	138	138
12	130.349	130.341	131.095
13	138	138	138
14	126.757	126.871	127.833
15	124.48	124.67	125.814
16	128.103	127.511	128.706
17	123.789	120.864	122.582
18	121.272	120.251	121.662
19	120.069	118.343	119.904
20	120.319	118.235	119.863
21	121.944	117.411	119.65
22	121.842	116.882	119.252
23	119.244	120.989	122.169
24	117.237	106.316	110.459
25	113.275	95.382	99.881
26	102.338	82.343	87.222
27	116.273	111.137	114.016
28	127.589	126.27	129.049
29	104.862	102.337	102.919
30	105.121	103.587	104.567

Table 3 shows voltage profiles of all buses for different conditions. After outage of transmission lines 23-24 and 25-27 voltage profiles at the buses 24, 25, 27, 29 and 30 are below specified limit. After load shedding voltage profiles of these buses have improved as shown in Fig. 6.

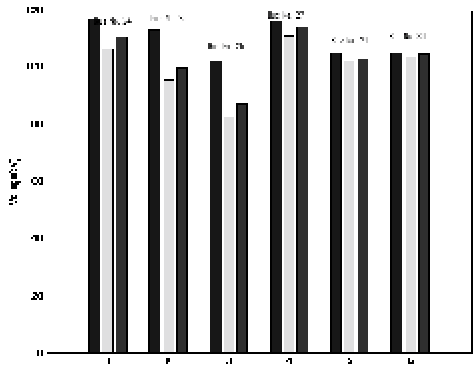

Fig. 6 Voltage analyses at weak buses

VI. CONCLUSIONS

This paper presents a genetic algorithm for optimal load shedding problem to enhance power system voltage stability for IEEE 30-bus system. The developed GA is applied to solve the optimization problem formulated in the optimal power flow framework-with the full consideration of various network constraints.

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