INVESTIGATION OF VOLTAGE STABILITY LIMIT VALUES IN ELECTRICAL POWER SYSTEMS USING GENETIC ALGORITHM

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ABSTRACT

In this study, initially, critical values of voltage stability have been found by a method in which determinant of jacobian matrix, which is obtained by using the load flowing analysis, is zero. Then the same values have been found with genetic algorithm which is a modern optimization method. Accordingly, the results have been evaluated and observed that the stability critical values are found much more easily and reliable with genetic algorithm.

I. INTRODUCTION

The highest active power values that could be transferred to load bus and the voltage amplitude and phase values at this situation are determined by the critical values in electrical power systems. Voltage stability critical values problem is one of the major concerns in power system planning and secure operation[1,2]. In the case of the voltage stability in long distance energy transferring power systems, the critical values calculation have been generally made on Jacabian matrix obtained with load flowing [3-6]. The singular point of a system is searched by means of nonlinear equations constituting the system dynamics and with the Jacabian matrix in which partial differential is used[7,8]. However, it is possible that either any singular point could not be found or there would be more than one singular point. Consequently, solution may be partial or wrong. On the other hand, Genetic Algortihm(GA) doesn't search for the singular point of the function. It obtains the results by exploring the all possible solutions in the solution space. Therefore it is not possible to find wrong solution. Several GA applications related to electrical power systems have been realized[9]. It has been seen that most of these studies have been focused economic dispatch and reactive power optimization[10].

In this study, the theory of GA was shortly presented and how critical values are attained with GA are explained step by step. The critical limit values in the six bus sample power system have been found with the equations obtained with the possible singular Jacobian matrix [11-13] and GA. The solutions are compared to each other.

II. GENETIC ALGORITHM

GA is an optimization method based on the genetic concept. It is a strategy for solving the multi-variable optimization problems which are considered to be difficult by conventional optimization methods[14]. GA starts to run with a lot of possible solution according to the initial population which are randomly prepared. Then it tries to find optimum solutions by using genetic operators such as selection, crossover and mutation[15]. GA doesn't start the solution with one initial point. It starts to search with a lot of initial point called initial population. So the best solutions are selected and worst are eliminated. GA starts the search with the generations of the initial population depending on the represented fitness function (FF) variables. Initial population are generated randomly after coding the variables. Each row of the population is called an individual. Fitness function (FF) values are calculated for each individual. The fitness function (FF), is the difference between the goal function (GF) and the penalty function(PF) consisting constraints functions (CF). After operated elitism, selection, crossover and mutation, a new population is generated according to the fitness function values. With the evaluation of the previous population, the new population is generated till the number of generation Fitness function values are calculated in each new population. The best resulted ones are paid attention among these values. Until the stopping criteria are obtained, these process is repeated iteratively. The stopping criteria may be the running time of the algorithm, the number of generation and for fitness functions to give the same best possible values in a specified time. In this study generation size has been used as the stopping criteria.

III. DEFINING PROBLEM

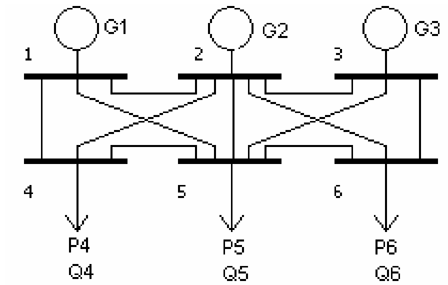

Figure1. An examples of six bus power system

Table 1. Line data of six bus system

Line Number	R (b)	X (b)	B (b)
1.-2	0.1	0.2	0.04
1.-4	0.05	0.092	0.04
1.-5	0.08	0.2	0.06
2.-3	0.05	0.25	0.06
2.-4	0.05	0.1	0.02
2.-5	0.1	0.3	0.04
2.-6	0.07	0.2	0.05
3.-5	0.12	0.26	0.05
3.-6	0.02	0.1	0.02
4.-5	0.2	0.4	0.08
5.-6	0.1	0.3	0.06

Table 2 Data of production bus in a system .

BUS N.	PRODUCTION		VOLTAGE
	P(MW)	Q(MVAr)	V (b)
1	200	50	1..05
2	150	37.5	1..05
3	180	45	1..07

Table 3. Limit values of generators in a system .

BUS N.	ACTIVE POWER LIMITS		REACTIVE POWER LIMITS	
	P_{max} (MW)	P_{min} (MW)	Q_{max} (MVAr)	Q_{min} (MVAr)
1	0	0	100	-100
2	50	0	100	-100
3	60	0	60	-100

Table 4. Load data of six bus system

BUS N.	BUS TYPE	LOAD VALUES		POWER ANGLE
		P(MW)	Q(MVAr)	
4	PQ	70	70	45
5	PQ	70	70	45
6	PQ	70	70	45

Admittance and impedance values: R, X, B of the six bus exemplary power system of which the stability critical values will found is shown in Table 1. These values have been given according to base values being V_{base} = 220 KV and S_{base} = 100 MVA. The data of generators connected to buses numbered: 1, 2 and 3 have been shown Table 2 and Table 3. Also the data of loads connected to buses numbered: 4, 5 and 6 have been shown in Table 4 [16].

Fitness Function

The active and reactive power equations (P_r , Q_r) shown in equations 1 and 2 are obtained according to exemplary system shown in Figure 1[11].

$$P_r = \frac{V_s * V_r(b_1 * cos\delta + b_2 * sin\delta) \quad (a_1 b_1 + a_2 b_2) * |V_r|^2}{b1^2 + b2^2} \qquad (1)$$

$$Q_r = \frac{V_s * V_r(b_1 * sin\delta + b_2 * cos\delta) \quad (a_1 b_2 + a_2 b_1) * |V_r|^2}{b1^2 + b2^2} \qquad (2)$$

In equation 1 and 2, V_s is production bus voltage, V_r is load bus voltage, δ is load bus angle, a_1 and a_2 are real and imaginary parts of constant *A* for long transmission line , b_1 and b_2 are real and imaginary parts of constant *B* for known long transmission line. A and B constant of transmission line are given as $A = a_1 + j * a_2$ and $B = b_1 + j * b_2$ respectively.

Since it has been searched the maximum power values with GA, equation 1 belong to P_r, has been accepted as goal function.

GA runs as an unconstraint optimization method. If there are constraints, constraints are subtracted from the fitness function as penalty function so the problem has been converted to unconstrained optimization problem. With this way fitness function values are constrained. In this study, since solutions are evaluated for constant power values, power angle φ , and so $\tan\varphi = Q_r/P_r$ must be constant. This situation has been taken as constraint. Under light of these explanations, CF will be as in equation 3:

$$CF = Q_r - \tan\varphi * P_r \qquad (3)$$

And PF will be as in equation 4:

$$PF = r * (CF)^2 \quad (4)$$

While GA is running, CF value decreases and lastly takes zero value. In equation 4, r is taken as a proper coefficient and in order to attain much more feasible result it has been taken the square of CF [17].

In this study since the aim is maximization, the FF is the subtraction CF from GF. And also, a proper K value is added to fitness function so that the fitness function doesn't take the negative value. When GA stops, this K constant is subtracted from the result. And the real value are calculated by this way. According to these definitions FF is as the equation 5:

$$FF = K + GF - PF \quad (5)$$

The biggest possible range of V_r and δ are as follows.

$$88 \leq V_r \leq 220 \quad (6)$$

And

$$-1.5 \leq \delta \leq +1.5 \quad (7)$$

Respectively.

Coding of variables

It is necessary to code the GA variables. In this study coding are made by binary system (0,1). The number of the bit belonging to the variable are stated equation 8. In that equation, X_{upper} and X_{lower} respectively shows the upper and lower bounds of variable, and ε shows the increase range [17]. The number of bits for coding the variables are given in Table 5.

$$2^{\ell i} \geq \frac{X_{upper} - X_{lower}}{\varepsilon} + 1 \quad (8)$$

Table 5 Bit numbers of variables to be coded

Variable Range	Inc	Bit Number
$88 < V_r < 220$ KV	0.1	11
$-1.5 < \delta < +1.5$ Radian	0.01	11

Individuals are formed by gathering variables which are randomly coded. The formation of an individual has been given in Table 6. The cumulative bit number of an individual (ℓ) is obtained as 22. And this shows that it can be created 2^{22} different individual. GA starts the solution with the initial population created randomly. The individual number in the initial population is called the population size (PS). PS specifies how many searching number will be in a generation. PS are specified as 42 according to equation 9 [9]. The randomly created initial population is given in Table 7. Each time While GA is started to run, it has been created different initial population.

$$PS = 1.65 * 2^{0.21 * \ell} \quad (9)$$

Table 6 An individual code

Variables	
V_r	δ
1 1 1 0 1 0 1 0 0 1 1	0 0 1 1 0 0 1 0 1 0 0
Individual	
1 1 1 0 1 0 1 0 0 1 1 0 0 1 1 0 0 1 0 1 0 0	

Table 7. Initial Population

Ind. Num.	V_r	δ
1	**10011100011**	**10101100111**
2	**111011100**	**11110011111**
.	.	.
.	.	.
.	.	.
42	**1110001110**	**11100001110**

GA Operators

In GA, in order to create the next generation population some operators such as elitism, selection and crossover have been used. With the elitism operator, two individuals which have the best fitness functions values are guaranteed to be included in the next generation. The first two individuals of each new population are the best two individuals of the previous generation[18]. Selection is process for finding the much more proper parents generating the new generations. In this study, since the PS is 42, 20 pairs as parents will be selected with the selection operator and 40 new individual will be generated by these parents. And two individual will be selected by elitism. In this study tournament selection has been used. According to this method, randomly a group of individuals are selected from the population and the one of them, which has the best fitness function value, is selected to be one of parent and the others are returned to the population. The second member of parent and all parents are selected by the same strategy [19]. Crossover operator is the operation to generate the candidate individuals for the possible next generation with gene crossover. In this study uniform crossover method has been used. In this method, a mask individual which has the same bit number of an individual are created for each parent pair. First candidate individual is created in such a way that if the mask individual bit is 1, the bit of first pair is copied and if the mask individual bit is 0, the bit of second pair is copied. Second candidate individual is created in such a way that if the mask individual bit is 1, the bit of second pair is copied and if the mask individual bit is 0, the bit of first pair is copied[20]. Some bits of candidate individuals are randomly changed so that they do not become copy of their parent. This process is called mutation. After mutation candidate individuals are now individuals of new population. The mutation rate is given as follows:

$$\frac{1}{PS} < MR < \frac{1}{\ell} \qquad (10)$$

In this study, mutation rate (MR) has been taken 0.04 according to Equation 10 [21]. The processes of generating new individuals by : selection, crossing and mutation have been shown in Table 8 and Table 9.

Table 8. Uniform Cross Over

Mask Ind.	**11101010011111100010001**
Parent 1	10011101100110011110001
Parent 2	11001000111101100101111
Candidate Parent1 (Child I)	10001000100110100101111
Candidate Parent2 (Child II)	11011101111110101110001

Table 9. Mutation Operator

Candidate Ind. 1 before mutation
11001010110111101000110
Candidate Ind. 1 after mutation
10001011110111101000110

After completing the all individuals of each new generation, the fitness function values are calculated. This process is repeated for the generation number. In this study generation size(number) has been selected as 500. When running GA at least 20 times, it has been observed that the optimum solution has been obtained from the half of the generation size and no new optimum solution has been found.

IV. RESULTS AND DISCUSSION

As an examples, critical values of the buses numbered: 4, 5 and 6 in the system with six bus have been found by GA and conventional methods and they are shown in Table 10. The variation of FF, while searching the critical values of bus 4, is shown in Figure 3. Moreover the values of variables for bus four shown in Figure 4. The constant K has been selected to be $6*10^6$ to prevent that the fitness function may take the negative values.

Table 10 Stability critical values for with six bus power system.

N	Critical Values Found with Formulas			Critical Values Found with GA		
	P_{rkrtk} (MW)	V_{rkrtk} (KV)	δ_{rkrtk} (Rad.)	P_{rkrtk} (MW)	V_{rkrtk} (KV)	δ_{rkrtk} (Rad.)
4	198,46	128,27	0,27	199,00	125,84	0,26
5	167,19	128,57	0,28	168,91	129,95	0.25
6	146,13	144,29	0.24	146,10	145,36	0,28

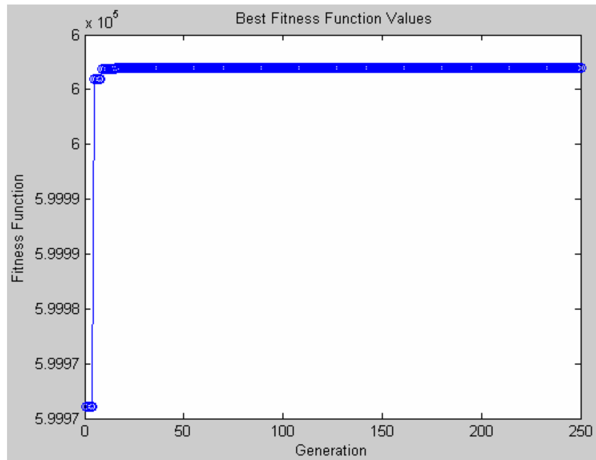

Figure 2. Fourth Numbered Load Bus Fitness Functions Values

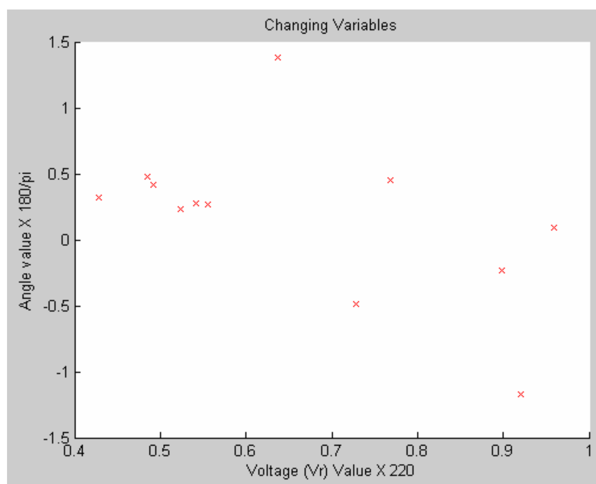

Figure 3. The changing of the variables, when exploring the best fitness function with GA.

In this study, it has been aimed to accurately find the critical values in electrical power systems. As can be seen in the results, the critical values have been obtained the more reliable and accurately. It also has been showed that GA has the capacity to find such critical values.

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