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MINIMISING POWER TRANSMISSION LOSSES USING GENETIC ALGORITHM

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Abstract - **This paper presents a new approach to minimize losses using genetic algorithm. While minimizing power losses, the problem is to improve the voltage profile in power system by using control tools such as generator voltage, shunt VAR sources and transformer taps. In this study, the series capacitors are also considered as control tools. Moreover, to locate the series capacitors, the candidate lines are determined by using sensitivity analysis. In this study, both active and reactive power losses are minimized and optimum operating conditions of control variables are determined by using genetic algorithm. The proposed method is applied to IEEE 6-bus standard test system and the results are provided.**

Keywords: FACTS, Reactive Power, Genetic Algorithm.

I. INTRODUCTION

Losses in the transmission of electrical energy are very important. We can decrease the power system losses with the utilization and coordination of reactive sources and other voltage control equipment. By an optimal adjustment of control tools; such as switching VAR sources (shunt and series), changing generator voltages, and adjusting transformer settings, the optimal distribution of reactive power would be obtained. The advantages of reduction of the losses are savings in fuel costs, prevention of overloads on system equipment and improved voltage profiles over the system. Therefore, optimal reactive power planning problem is important for the power system to operate in a reliable and economic way. Many linear and nonlinear optimization techniques may be used to solve this problem [1-4].

In recent years, evolutionary algorithms which are computer-based problem solving systems based on principles of evolution theory have been used in optimization problems in power systems. The most popular form of these algorithms are genetic algorithms (GAs). They have been used to solve difficult problems with objective functions which are multi-modal, discontinuous and non-differentiable. GA optimization mechanism is developed from the concept of natural evolution where the strongest individuals survive. This survival ability is called fitness, which is considered as the objective of the problem. The individuals are variables to be optimized. GAs work with a coding of parameter sets, search from a population of points, use objective function optimization and probabilistic transition rules [5-7].

In this study, a method to minimize losses in transmission lines using genetic algorithm (GA) is proposed. In previous works, VAR sources (shunt), generator voltages, transformer tap ratio settings are used as the control tools. Since development of FACTS devices in recent years enables the fast control of the series compensation, we take series compensation as one of the control tools in this study. In series compensation, first problem is to determine the location that means which line should be compensated and the second problem is to determine the amount of series compensation. Our objective is to minimize power transmission losses so the location of series capacitors is determined by reactive power loss sensitivity index (RPLSI) [8,9,10].

II. OPTIMIZATION PROBLEM

The purpose of the optimization problem which has nonlinear and nonconvex objective function is mainly to improve the voltage profile in the power system by using state variables while minimizing transmission losses. The equality constraints consist of nonlinear power flow equations and the inequality constraints represent equipment ratings and security limits.

The optimization problem can mathematically be represented as

$$
\begin{aligned}
&\text{Minimize } f(x)\\
&\text{such that}\\
&\qquad g_l(x)=0\\
&\qquad l=1,2,\ldots\ldots s<v\\
&\qquad h_m(x)\le 0 \qquad m=1,2\ldots\ldots r
\end{aligned}
\tag{1}
$$

where
$x \in \Re^v$
x : vector of system variables
f(x): objective function
g(x): equality constraints
h(x): limits on x as well as functional constraints [11].

III. POWER SYSTEM TRANSMISSION LOSSES

Active and reactive power losses occur in transmission lines depending on the power to be transmitted. These losses should be minimized in order for the system to work in a reliable and economic way. If the losses are high, then the cost of power generation increases; whereas, power generation reserves decrease. Moreover, generators may operate near their operation limits in order to supply these losses and this is not a desirable condition for system stability.

The active power loss equation of the k^{th} line, between buses i and j can be written as,

$$P_{L-k} = G_k (V_i^2 + V_j^2 - 2\,V_i\,V_j \cos(\delta_i - \delta_j)) \qquad (2)$$

The reactive power loss equation of the k^{th} line, between buses i and j can be written as,

$$Q_{L-k} = B_k (V_i^2 + V_j^2 - 2\,V_i\,V_j \cos(\delta_i - \delta_j)) \qquad (3)$$

where,

G_k ; is k^{th} line conductance,

B_k ; is k^{th} line susceptance,

V_i ; voltage magnitude of i^{th} bus

δ_i ; phase angle of i^{th} bus.

In power system, the total active power loss of all the lines of system is

$$P_L = \sum_{k=1}^{nl} P_{L-k} \qquad (4)$$

and the total reactive power loss of all the lines of system is

$$Q_L = \sum_{k=1}^{nl} Q_{L-k} \qquad (5)$$

where, nl is the total number of lines [4,8].

IV. SERIES COMPENSATION

Series compensation is sometimes required on transmission lines in order to optimize the use of the transmission system. Series compensation reduces line reactance and reactive power loss (I^2X), increases maximum power that can be transmitted on a line, improves power system stability and voltage regulation of transmission line [9].

Series compensation is given as the percentage, describing how much the line is compensated.

$$K_S = \frac{X_C}{X} 100 \quad (\%) \qquad (6)$$

where K_S is the percentage of series compensation and X_C, is the compensation reactance and X is the l line reactance. Determining series compensation requires the analysis on sub-synchronous reactance and the protection system. The upper limit of series compensation may be taken %70 as suggested in [9].

Traditional series capacitors can provide some degree of transmission line reactance control by switching of capacitor segments. In newly developed series compensation systems, it is likely that one or more of the series capacitor modules may themselves be controlled in a more precise way, thereby providing an almost continuous variation of series reactance. There are some methods of series capacitor control which have been developed and implemented:

- Mechanically switched series capacitors (MSSC)
- Thyristor switched series capacitors (TSSC)
- Thyristor controlled series capacitors (TCSC) [10].

Reactive Power Loss Sensitivity Index

Application of series compensation has a big effect on reactive power losses in the system especially in the compensated line. This fact can be utilized in devising an index. A reactive power loss sensitivity index (RPLSI) in each line was designed in [8]. The index is basically the rate of change in reactive power loss with respect to line reactance. By the use of RPLSI, the most suitable line, from the reactive power losses reduction point of view can be found for the series compensation.

The sensitivity of the reactive power loss with respect reactance of the k^{th} line is

$$\frac{\partial Q_L}{\partial X_k} = \frac{R_k^2 - X_k^2}{(R_k^2 + X_k^2)^2} (V_i^2 + V_j^2 - 2\,V_i\,V_j \cos(\delta_i - \delta_j)) \qquad (7)$$

where R_k and X_k are kth line resistance and reactance respectively. This equation can be used as reactive power loss index to determine a location for series compensation devices [8,10].

The variation of the total reactive power loss of the 6-bus test system of Ward and Hale [12] is given in Fig. 1. The test system itself is given in appendix A. It can be seen from Fig. 1 that the reactive power losses vary about linearly with respect to degree of the line compensation, hence RPLSI is a suitable index to use.

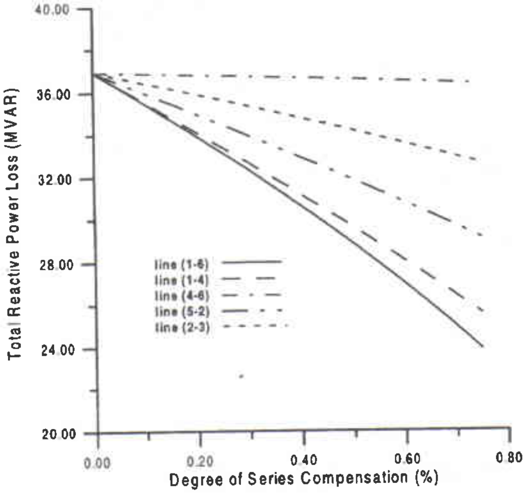

Fig. 1: Total reactive power loss versus degree of compensation.

V. PROBLEM FORMULATION WITH GENETIC ALGORITHM

Genetic algorithms are search algorithms based on mechanics of natural selection and natural genetics. They consist on a population of strings (chromosomes) transformed by genetic operators such as crossover and mutation.. Chromosomes are called individuals and are made up of sequence of genes from a certain alphabet. Each chromosome represents a possible solution to the problem being optimized and each gene represents a value for some variable of the problem. These solutions are classified by an evaluation function, giving better values, or *fitness*, to better solutions. Each solution must be evaluated by the fitness function to produce a value [6] .

The use of genetic algorithm includes the determination of the fitness function (objective function), chromosome representation, selection function, genetic operators, and initial population and termination criterion.

In this study, we consider three cases for objective function: to minimize active power losses only to minimize reactive power losses only and to minimize together active and reactive power losses. Therefore the objective function which includes the quadratic penalty terms is given for the third case by,

$$F_{obj} = w_1 \cdot P_L + w_2 \cdot Q_L + w_3 \cdot f(V) \qquad (8)$$

Here, P_L and Q_L are the total active and reactive losses in the system respectively and w_1, w_2, and w_3 are the weighting factors [7].

$$f(V) = \sum_{i=N_l} \lambda_i \cdot (V_i - Sat(V_i))^2 \qquad (9)$$

where, N_l ,are number of load buses λ_i , are the penalty weights and Sat(V) is the saturation function defined in [13]

$$Sat(V) = \begin{cases} V_{min} & \text{if } V < V_{min} \\ V & \text{if } V_{min} \le V \le V_{max} \\ V_{max} & \text{if } V > V_{max} \end{cases} \qquad (10)$$

The equality constraints are the real and reactive power balance of the power system, which can be solved by calling the load flow program. The inequality constraints are given below.

$$\begin{aligned} & V_i^{min} \le V_i \le V_i^{max} \\ & Q_i^{min} \le Q_i \le Q_i^{max} \\ & t_i^{min} \le t_i \le t_i^{max} \\ & X_{C-i}^{min} \le X_{C-i} \le X_{C-i}^{max} \end{aligned} \qquad (11)$$

where, V_i are bus voltages, Q_i are generator and shunt capacitor powers, t_i are transformer tap settings and X_{Ci} are series capacitor reactances [7,13,14]. As you can see, the objective function only includes the bus voltage inequality constraint as a penalty function since other inequality constraints are taken into account while generating the initial population in genetic algorithm.

For any GA, chromosome representation is needed to describe each individual in the population of interest. Each individual is made up of a sequence of genes from a certain alphabet which can consist of binary digits, floating point of numbers, integers, etc. This representation determines how the problem structured in GA and the operators to be used We used floating numbers representation instead of binary representation in order to prevent discretisation errors.

Crossover is the main genetic operator and consists of swapping chromosome parts between individuals. Crossover may not be performed on every pair of individuals. Its frequency is controlled by a crossover probability. In this study simple crossover is applied with the probability of 0.6.

Mutation changes a random part of the string representing the individual. Some important bit values (genes) may be lost during selection and mutation can bring them back, if necessary. In this study uniform mutation is applied with the probability of 0.01.

A probabilistic selection function, a roulette wheel representation, which allows the better individuals to have more chance to be selected is used.

Initial population is randomly generated and consists of 50 individuals. The algorithm is terminated after 100 generations.

The features of the genetic algorithms given above are within the GAOT, genetic optimization toolbox developed in Matlab [15].

VI. SIMULATION RESULTS

In this study, a genetic algorithm based method for minimizing of losses is applied to Ward-Hale 6-bus test system. The 6-bus test system has two generators and four load buses. Generator buses are numbered as 1 and 2.

First by using RLPS index, the ordering of lines is determined to locate series capacitor as

$$\{(1-4),(1-6),(5-2),(2-3),(4-6)\}$$

This result is supported by Fig.1. The first line that is from bus 1 to bus 4 is chosen to locate the series capacitor [10].

Table 1: Limits on the variables and the results of the studies on the 6-bus system

Variable	**Limits**		**Initial State**	**Final state results**		
	Low	**High**		**min P_L**	**min Q_L**	**Min P_L+ Q_L**
State Variables						
V_1 (pu)	1.000	1.100	1.050	1.086	1.063	1.065
V_2 (pu)	1.100	1.150	1.100	1.134	1.150	1.15
tap_{6-5}	0.900	1.100	1.025	0.939	0.946	0.949
tap_{4-3}	0.900	1.100	1.100	0.982	0.987	0.987
Q_{C-4} (MVAR)	0.00	5.00	0	3.595	4.93	1.526
Q_{C-6}(MVAR)	0.00	5.50	0	5.5	5.5	5.475
$K_{S-(1-4)}$ (%)	0.0	70	0	31.8	70	70
Dependent Variables						
V_3 (pu)	0.900	1.000	0.855	1.000	1.000	0.999
V_4 (pu)	0.900	1.000	0.953	1.000	1.000	1.000
V_5 (pu)	0.900	1.000	0.901	1.000	0.999	0.997
V_6 (pu)	0.900	1.000	0.933	0.974	0.972	0.973
P_L (MW)			11.612	8.9	9.158	9.258
Q_L (MVAR)			36.91	27.48	22.43	22.58

The limits on system variables and the results obtained from GA-based method for three cases, are given in Table 1. In case 1, transmission active power losses decrease to 8.9 MW, which is satisfactory. In case 3, the active power losses decrease to 9.258 MW and reactive power losses decrease to 22.58 MVAR. In all cases, the voltages were improved to more desired values about 1.0 pu.

VII. CONCLUSION

A genetic algorithm based method is used to minimize transmission losses in a power system. Genetic algorithm tries to find an operation condition that the system variables are within limits and losses are minimal. In addition, this method used TCSC compensating ratio as a control variable together with other control variables; such as generator voltage magnitudes, shunt capacitor values and tap values of transformers. The method is applied to a test system and the results are found to be satisfactory.

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APPENDIX A

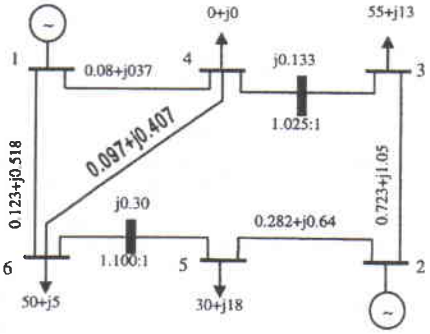

Fig A.1. Ward-Hale 6-bus test system.