A Hybrid Genetic Algorithm based on Differential Evolution Approach for Voltage Stability Improvement

D.Godwin Immanuel
Research Scholar
Sathyabama University
Chennai

G.Selva Kumar, Ph.D
Vice Principal
Excel Engineering College
Salem

C.Christober Asir Rajan, Ph.D
Associate Professor
Pondicherry Engineering College
Puducherry

ABSTRACT
Voltage stability plays a vital role in operation and control of power system. In this paper an optimal reactive power and voltage control based on hybrid Genetic Algorithm assisted Differential Evolution algorithm for voltage stability improvement is proposed. In this approach the voltage stability index is formulated to identify the most vulnerable bus at stressed conditions. The bus with the value of maximum VSI is considered as the most critical bus. To maintain the stability of the system the severity of the load buses has to be minimized. This can be achieved by the optimal settings of control variables. The effectiveness of the proposed approach has been examined on the standard IEEE 30 bus test system.

Keywords
Newton Raphson Power Flow, Genetic Algorithm, Differential Evolution, Volt Ampere Reactive, Voltage Stability Index .

1. INTRODUCTION
Voltage stability is the ability of the system to maintain the acceptable voltage levels in all buses at all conditions even after a small disturbance. The instability of the system due to various factors may leads to voltage collapse. This can be remedied by the proper control of reactive power and voltage wherever necessary. To maintain the stability of the system effectively the system operator must be aware of voltage instability conditions. To predict these conditions several methods are available by calculating the voltage stability margin.

In this paper an accurate and fastest approach is proposed to calculate the voltage stability index of all buses. To understand the phenomenon of voltage instability and the preventive measures to protect the power system under critical conditions has suggested in [1-2]. To maintain the system stability, the control variables taken into consideration are generator bus voltages, transformer tap settings and switchable VAR sources. Several conventional methods are available for reactive power control problems. The quadratic programming for optimal reactive power control is suggested in [3]. In [4] the reactive power planning with non-linear programming is implemented. Mixed integer programming is developed and implemented in [5] for reactive power and voltage control. All these techniques have lot of problems such as converged in minimal solution; more number of iterations etc. These problems can be overcome by the introduction of intelligent techniques. In [6], the biogeography waste optimal VAR control is discussed. The general quantum algorithm is used in [7]. In [8], the optimal reactive power dispatch based on differential evolution algorithm is implemented. Recently Differential Evolution algorithm has been implemented to solve reactive power optimization problems. In this paper, a hybrid intelligent algorithm for the objective functions minimization of real power losses and minimization of voltage stability index are considered.

2. PROBLEM FORMULATION
2.1 Objective Functions
The basic strategies of reactive power control problem are to identify the optimal control variables which can minimize the objective functions. In this hybrid formulation the following objective functions are considered.

2.1.1 Minimization of voltage stability index
The formulation of the voltage stability index is discussed below. It uses the information from the load flow analysis by Newton Raphson method. Consider an n-bus system, the relationship between the current and voltage is expressed as

$$\begin{bmatrix} I_G \\ I_L \end{bmatrix} = \begin{bmatrix} Y_{GG} & Y_{GL} \\ Y_{LG} & Y_{LL} \end{bmatrix} \begin{bmatrix} V_G \\ V_L \end{bmatrix} \qquad (1)$$

Where

I_G & I_L are the generators and load bus current

V_G & V_L are the generators and load bus voltages

Rearranging the above equation we get,

$$\begin{bmatrix} V_L \\ I_G \end{bmatrix} = \begin{bmatrix} Z_{LL} & F_{LG} \\ K_{GL} & Y_{GG} \end{bmatrix} \begin{bmatrix} I_L \\ V_G \end{bmatrix} \qquad (2)$$

Here,

$$F_{LG} = [Y_{LL}]^{-1}[Y_{LG}] \qquad (3)$$

The objective function voltage stability index is given by

$$VSIj = \left| 1 - \sum_{i=1}^{ng} F_{ji} \frac{V_i}{V_j} \right| i = ng+1,....., n \qquad (4)$$

The values of F_{ji} are obtained from Y bus matrix. The voltage stability indices are calculated for all the load buses under the given loaded condition.

2.1.2 Minimization of real power losses

The objective function minimization of real power loss can be calculated by

$$P_{Loss} = \sum_{k=1}^{nl} g_k [V_i^2 + V_j^2 - 2V_i V_j \cos(\delta_i - \delta_j)] \qquad (5)$$

Where

nl : is the number of lines

g_k : is the conductance of the kth line

V_i & V_j : are the voltage magnitude at the buses i & j

δ_i & δ_j : are the voltage phase angle at the buses i & j

2.2 Problem Constraints

2.2.1 Equality Constraints

The equality constraints are the real and reactive power balance equations at all the bus bars. The equality constraints can be formulated as

$$P_{gi} - P_{di} = \sum_{j=1}^{n} |V_i| |V_j| |Y_{ij}| \cos(\delta_i - \delta_j - \theta_{ij}) \qquad (6)$$

$$Q_{gi} - Q_{di} = \sum_{j=1}^{n} |V_i| |V_j| |Y_{ij}| \sin(\delta_i - \delta_j - \theta_{ij}) \qquad (7)$$

Where

n : number of buses

Y_{ij} : mutual admittance between node i and j

δ_i & δ_j : the bus voltage angle of bus i and bus j respectively

θ_{ij} : the admittance angle of line between buses i and

P_{gi} & Q_{gi} :the real and reactive power generation at bus i P_{di} & Q_{di} : the real and reactive power demand at bus i

2.2.2 Inequality Constraints

The inequality constraints can be formulated as follows

$$P_s \min \le P_s \le P_s \max \qquad (8)$$

$$Q_{gi} \min \le Q_{gi} \le Q_{gi} \max \qquad (9)$$

$$V_{gi} \min \le V_{gi} \le V_{gi} \max \qquad (10)$$

$$T_i \min \le T_i \le T_i \max \qquad (11)$$

$$Qc_i \min \le Qc_i \le Qc_i \max \qquad (12)$$

$$S_l \min \le S_l \le S_l \max \qquad (13)$$

Where

P_s min & P_s max : min and max real power of slack bus.

Q_{gi} min & Q_{gi} max : min and max value of reactive power generation.

V_{gi} min & V_{gi} max : min and max value of generator voltages.

T_i min & T_i max : min and max range of tap changing transformer.

Qc_i min & Qc_i max : min and max output of var sources.

S_l min & S_l max : min and max output of var sources.

3. HYBRIDALGORITHM APPROACH

In this hybrid algorithm, the best features of Genetic Algorithm and Differential Evolution Algorithm is combined. The best factors selection and cross-over are taken from Genetic Algorithm and the best factor mutation is taken from Differential Evolution Algorithm are combined together and gives the efficient solution. The step by step process of this algorithm is discussed below.

3.1 Initialization

Create a population with n number of chromosomes. Initialize random values for all chromosomes within the limits of control variables.

3.2 Selection

The process of selecting best fitness chromosome from the population is called as selection. The Roulette Wheel selection approach is used in this hybrid algorithm.

3.3 Cross-over

It is the process of generating new off-spring by exchanging the information among the best chromosomes. In this process, the single point cross-over technique is applied in this hybrid algorithm.

3.4 Mutation

It is the process of mutating all the chromosomes and generates a donor vector. In this algorithm, the most commonly used best mutation strategy DE/rand/1 is applied to improve the mutation process.

4. IMPLEMENTATION OF PROPOSED HYBRID ALGORITHM

The proposed hybrid algorithm has been developed and applied using MATLAB software. In this hybrid algorithm, a population of 30 chromosomes is created. In each chromosome, it has 14 genes. There are 5 genes of generator buses, 4 genes of tap changing transformer and 5 genes of static capacitors. Run the NR power flow analysis for each chromosome and get the dependent and independent variables. All the constraints are checked for these chromosomes, whether it is within the limit are not. The chromosomes which are not in the limit are rejected from the population. The minimum and maximum limits of generator voltages are 0.95 and 1.1 p.u. The transformer tap setting ranges in between 0.9 and 1.1 p.u. and the switchable VAR sources varies in between 0 and 5 with each step of 1.

Calculate the objective functions for all chromosomes in the population and select the best chromosome from the matting pool by Roulette Wheel approach. The cross-over constant used in this hybrid algorithm is 0.4. Generate a random number to each chromosome and check if it is less than 0.4. If it is less, then it is selected for matting. The single point cross-over is used in this algorithm. After the cross-over process, mutation can be done for all chromosomes in the population. The DE/rand/1 rule is applied in mutation process and the scaling factor 0.9 is considered. A target vector is selected for mutation. The same process selection, cross-over and mutation are repeated until the stopping criteria reached. The stopping criteria selected in this hybrid algorithm is 100 generations.

5. RESULTS AND DISCUSSIONS

Table-1 optimal settings of control variables

Sl. No	Control variables	Initial settings	Optimal setting using GA	Optimal setting using GA-DE
1	V_1	1.050	1.050	1.050
2	V_2	1.040	1.025	1.043
3	V_3	1.010	1.006	1.014
4	V_4	1.010	0.989	1.032
5	V_5	1.050	1.058	1.027
6	V_6	1.050	1.080	1.021
7	T_1	0.978	1.050	0.981
8	T_2	0.969	0.900	0.973
9	T_3	0.932	0.925	0.920
10	T_4	0.968	0.950	0.953
11	Q_{30}	0	5	5
12	Q_{29}	0	5	5
13	Q_{26}	0	5	3
14	Q_{25}	0	1	1
15	Q_{24}	0	3	4
P Loss (MW)		10.76	10.55	10.357
VSI		0.1978	0.1807	0.1781

The proposed hybrid algorithm has been tested on standard IEEE 30-bus test system. The system having 41 transmission lines, 4 tap changing transformers, 6 generators and 5 static VAR compensators. The line data bus data and initial setting of control variables of IEEE 30 bus test system is taken from [9].In this reactive power control optimization problem the optimal solution of the proposed algorithm can be demonstrated under the stressed condition of 125 % of loaded condition in IEEE 30 bus test system. Calculate VSI for all the load buses and it is ranked according to the severity, the bus which is having maximum value of VSI is the most vulnerable bus. The most critical load bus is 30 and the value of voltage stability index is 0.1978. Select the most critical five buses, the buses are load bus 30, 29, 26, 25 and 24. Inject the reactive power in these particular buses by VAR sources. Apply the proposed algorithm and obtain the optimal settings of control variables to get the best solution. After the implementation of the proposed algorithm the VSI of load bus 30 is reduced to 0.1781 and the voltage level of all the load buses are increased and shown in Fig.1. Hence it is observed that the performance of the system is improved.

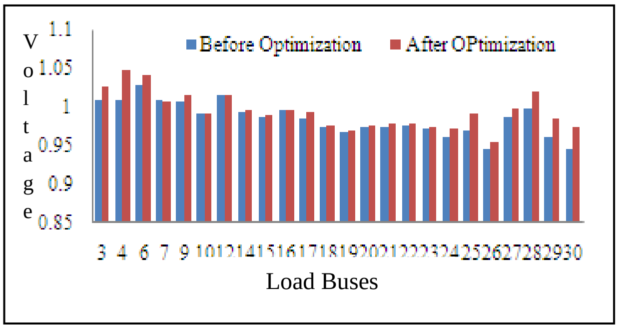

Fig 1: Voltage profile improvement

5.1 Convergence Characteristics

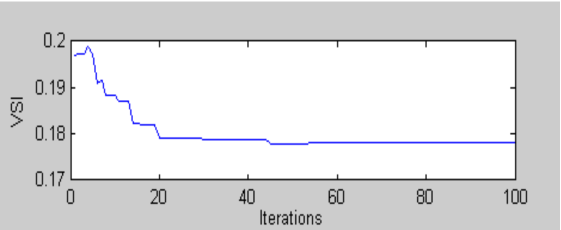

Fig 2: VSI variations for hybrid approach

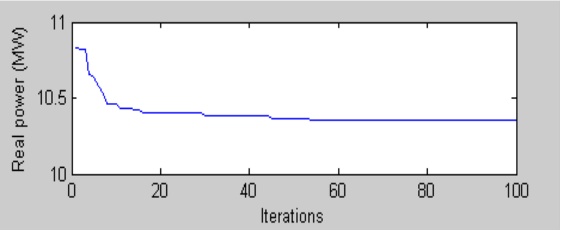

Fig 3: Power loss variations for hybrid approach

The convergence characteristics for the objective function minimization of voltage stability index is shown in Fig.2and the convergence characteristic of real power loss minimization is shown in Fig.3.

6. CONCLUSION

In this paper a hybrid Differential Evolution Algorithm based Genetic Algorithm has been developed and applied successfully to solve reactive power control problem for voltage stability improvement. This problem has been formulated with the objective function minimization of real power losses and minimization of voltage stability index. The limitations of the individual Differential Evolution Algorithm and Genetic Algorithm are overcome in this hybrid algorithm. The proposed hybrid algorithm has been tested on IEEE 30 bus test system which gives the optimal solution and satisfies all the equality and inequality constraints. The simulation result shows that the proposed algorithm is superior to the methods compared with the test results.

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