# A Multi Objective Hybrid Differential Evolution Algorithm assisted Genetic Algorithm Approach for Optimal Reactive Power and Voltage Control

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**Abstract—To provide a quality and secured power supply in all the load centres is a challenging task. Due to the increase in load and various emergency conditions the voltage level in load centres may vary beyond the acceptable level which leads to voltage collapse and increase the system losses. To maintain the voltage levels within the acceptable range in all load centres reactive power support is very essential. The control centres has to provide the optimal reactive power where ever necessary to prevent these critical situations. To provide the controllable amount of reactive power and voltage in the needy region efficient power flow analysis are required. Many traditional methods are available but it has limitations and converged in poor optimal solution. In this paper an effective hybrid Differential Evolution Algorithm assisted Genetic Algorithm approach with multi objective functions are considered. In this approach the best features of Differential Evolution Algorithm and Genetic Algorithm are combined together and developed. In IEEE 30bus the effectiveness and the superiority of this method is verified**.

**Keyword-**Newton Raphson Power Flow, Genetic Algorithm, Differential Evolution, Volt Ampere Reactive, Voltage Stability Index

## I. INTRODUCTION

Due to the tremendous increase in demand of electricity, maintaining the voltage stability is very difficult task. Because of the uncertainty of increase in load and emergency situation, the system may losses its stability and the voltage deviates across the acceptable level. This can be remedied by proper injection of reactive power optimally wherever needed. Optimal reactive power control plays a vital role in secured and economic operation of power system. It is non-linear problems with a combination of both discrete and continuous variables. This optimal injection of reactive power in the critical situation can minimizes the voltage deviation as well as minimizes the system losses. Once the voltage deviation is minimized, the stability of the system can be maintained.

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 [1]. In [2] the reactive power planning with non-linear programming is implemented. Mixed integer programming is developed and implemented in [3] 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 [4], the biogeography waste optimal VAR control is discussed. The general quantum algorithm is used in [5]. In [6], the optimal reactive power dispatch based on differential evolution algorithm is implemented. The popular work in this area is multi-objective optimization approaches. In [7], the multi-objective optimization of reactive power control based on fuzzy system is suggested. The hybrid real coded genetic algorithm and differential evolution algorithm is applied for optimal power flow in [8]. Most of the work in this area, having only two objective functions is considered. In this paper, a hybrid intelligent algorithm for multi-objective functions minimization of real power losses, minimization of voltage deviation and minimization of voltage stability index are considered.

## II. PROBLEM FORMULATION

### A. 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.

*1) Minimization of real power losses*

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

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

Where

nl : number of lines

$g_k$ : conductance of the $k^{th}$ line

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

$\delta_i$ & $\delta_j$ : voltage phase angle at the buses i & j

*2) Minimization of voltage deviation*

To provide security and service quality the voltage deviation has to be minimized. Then only the voltage stability can be maintained. The objective function minimization of voltage deviation can be calculated by

$$VD = \sum_{i=1}^{NL} \left| V_i - 1.0 \right| \tag{2}$$

Where

NL : number of load buses

$V_i$ : voltage magnitude of bus i

*3) Minimization of voltage stability index*

The stability of the system can be improved by reducing the value of voltage stability index in load buses. The voltage stability index has to be calculated for all the load buses. The load bus which is having the highest value of VSI is the most vulnerable bus. The objective function VSI can be calculated as

$$VSIj = \left| 1 - \sum_{i=1}^{ng} F_{ji} \frac{V_i}{V_j} \right| i = ng + 1, \ldots.., n \tag{3}$$

Where

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

n : number of buses

ng : number of generator buses

### B. Problem Constraint

*1) Equality Constraints*

The equality constraints real and reactive power balance equations at all the bus bars are formulated from Newton Raphson power flow analysis.

$$P_{gi} - P_{di} = \sum_{j=1}^{nb} \left| V_i \right| \left| V_j \right| \left| Y_{ij} \right| \cos(\delta_i - \delta_j - \theta_{ij}) \tag{4}$$

$$Q_{gi} - Q_{di} = \sum_{j=1}^{nb} \left| V_i \right| \left| V_j \right| \left| Y_{ij} \right| \sin(\delta_i - \delta_j - \theta_{ij}) \tag{5}$$

Where

nb : number of buses

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

$\delta_i$&$\delta_j$ : angle of bus voltages of bus i and bus j respectively

$\theta_{ij}$ : admittance angle between the buses i and j

$Pg_i$&$Qg_i$: real and reactive power generation at bus i

$Pd_i$&$Qd_i$: real and reactive power demand at bus i

*2) Inequality Constraints*

The inequality constraints of the control variables are formulated by

$$P_s \min \le P_s \le P_s \max \tag{6}$$

$$Q_{gi} \min \le Q_{gi} \le Q_{gi} \max \tag{7}$$

$$V_{gi} \min \le V_{gi} \le V_{gi} \max \tag{8}$$

$$T_i \min \le T_i \le T_i \max \tag{9}$$

$$Qc_i \min \le Qc_i \le Qc_i \max \tag{10}$$

$$S_l \min \le S_l \le S_l \max \tag{11}$$

Where

| | | |
|---|---|---|
| Ps min and P smax | : | minimum and maximum slack bus real powers. |
| $Qg_i$ min and $Qg_i$ max | : | minimum and maximum reactive power generation. |
| $Vg_i$ min and $Vg_i$ max | : | minimum and maximum values of generator voltages. |
| $T_i$ min and $T_i$ max | : | minimum and maximum ranges of tap changing transformer. |
| Qci min and Qci | : | minimum and maximum allowable outputs of reactive power compensation equipment. |
| Sl min and Sl max | : | minimum and maximum line flow limits |

## III. Hybrid Genetic Algorithm and Differential Evolution Algorithm

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.

### *A. Initialization*

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

### *B. 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.

### *C. 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.

### *D. 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.

## IV. 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 are 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.

## V. Results and Discussions

The proposed hybrid algorithm has been verified in IEEE 30 bus system. In this system it is having 1 slack bus, 5 generator buses, 24 load buses, 4 on load tap changing transformers, 5 static compensators and 41 transmission lines. The proposed hybrid algorithm is applied in the above system with the stressed condition of 125% of load. The most critical buses are first identified by the voltage stability index. The buses have the highest value of VSI is the most critical bus. The buses 30,29,26,25 and 24 are identified as the most critical buses. Connect the static VAR compensation in these buses. Apply the hybrid algorithm and get the optimal solution.

TABLE-I CONTROL VARIABLES AND OPTIMAL SOLUTION OF IEEE30 BUS TEST SYSTEM

| Sl. No. | Control variables | Min limit | Max limit | Initial Setting | Optimal setting using GA | Optimal setting using DE | Optimal setting using GA-DE |
|---|---|---|---|---|---|---|---|
| 1 | Vg1 | .95 | 1..05 | 1.0500 | 1.0500 | 1.050 | 1.050 |
| 2 | Vg2 | .95 | 1.05 | 1.0400 | 1.0256 | 1.028 | 1.037 |
| 3 | Vg3 | .95 | 1.05 | 1.0100 | 1.0063 | 1.008 | 1.026 |
| 4 | Vg4 | .95 | 1.05 | 1.0100 | 0.9895 | 1.018 | 1.010 |
| 5 | Vg5 | .95 | 1.05 | 1.0500 | 1.0584 | 1.030 | 1.000 |
| 6 | Vg6 | .95 | 1.05 | 1.0500 | 1.0806 | 1.030 | 1.005 |
| 7 | T1 | .9 | 1.1 | 0.9780 | 1.0500 | 0.971 | 0.978 |
| 8 | T2 | .9 | 1.1 | 0.969 | 0.9000 | 0.935 | 0.969 |
| 9 | T3 | .9 | 1.1 | 0.9320 | 0.9250 | 0.900 | 0.932 |
| 10 | T4 | .9 | 1.1 | 0.9680 | 0.9500 | 0.954 | 0.968 |
| 11 | Q30 | 0 | 5 | 0 | 5 | 4 | 4 |
| 12 | Q29 | 0 | 5 | 0 | 5 | 5 | 5 |
| 13 | Q26 | 0 | 5 | 0 | 5 | 1 | 3 |
| 14 | Q25 | 0 | 5 | 0 | 1 | 1 | 2 |
| 15 | Q30 | 0 | 5 | 0 | 3 | 4 | 2 |
| **P Loss (MW)** | | | | **10.760** | **10.55** | **10.422** | **10.413** |
| **VSI** | | | | **0.1978** | **0.1807** | **0.1713** | **0.1711** |
| **Voltage Deviation (p.u)** | | | | **-** | **-** | **0.2281** | **0.2154** |

The line data and bus data of IEEE 30 bus test system is taken from [9].Apply the proposed hybrid algorithm and get the optimal solution of all objectives. The test results of the proposed hybrid algorithm are compared with the existing methods given in [10]and [11]. Table-1 shows the optimal settings of the control variable for IEEE 30 bus test system. By this hybrid algorithm the real power loss is minimized, the voltage stability index of the most critical bus is reduced and the voltage deviation is minimized so that the stability of the system is improved. From these simulation results the hybrid intelligent algorithm works satisfactorily and shows the potentiality.

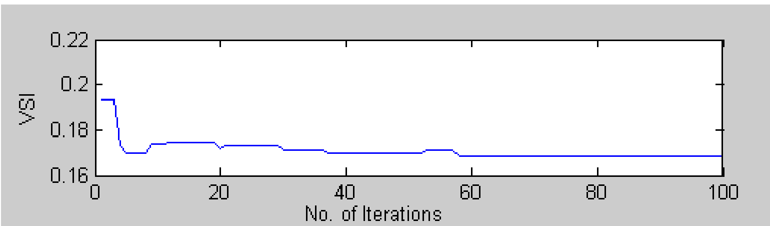


Fig.1.Convergence characteristics of voltage stability index

The Fig.1 shows the convergence curve of voltage stability index of the multi objective function .It converged with a global solution of 0.1711.

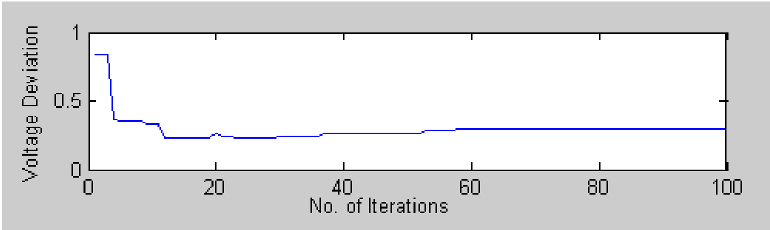


Fig.2.Convergence characteristics of voltage deviation

The Fig.2 shows the convergence curve of voltage deviation of the multi objective function. The voltage deviation is minimized to an optimal value of 0.2154 p.u.

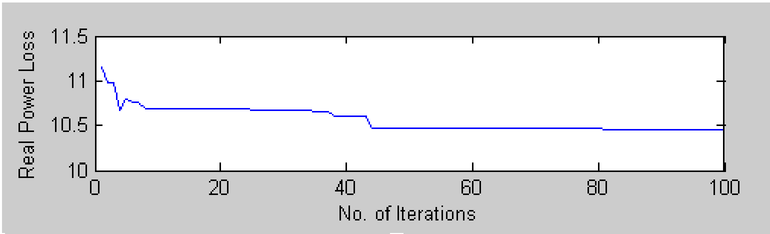


Fig. 3.Convergence characteristics of real power loss

The Fig.3 shows the convergence curve of real power loss minimization of multi objective function. The real power loss is minimized to a global value of 10.413 MW

## VI.CONCLUSION

In this paper a hybrid Differential Evolution Algorithm based Genetic Algorithm has been developed and applied successfully to solve reactive power control problem. This problem has been formulated with the multi objective function minimization of real power losses, minimization of voltage deviation 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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