Application of Optimal Reactive Power Dispatch Using Differential Evolution for Voltage Improvement

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Abstract **– Economic load dispatch (ELD) is the method of allocation generation from the present generation units in such a manner to fulfill the demand of load and satisfied constraints to minimized total generation price of power plant. Reactive power plays a very important role in power system. In any power system when reactive power absorbed more or less than reactive power generated, then voltage of the system decreases or increases from normal operating value. To obtain the demand at minimum cost while satisfying the constraints for easy and simplicity, the cost function for each unit in economic dispatch problems are approximately shown by a single quadratic functions and is solved using mathematical programming techniques. ELD has the objective of generation allocation to the power unit generators in such a manner that the total fuel cost is minimized and all operating constraints are satisfied reactive power dispatch (RPD) is most important role in the operation and control of power system. This paper presents a differential evolution (DE) based technique for solving optional reactive power dispatch with voltage improvement in power system the monitoring technology for voltage improvement on the L- index of load buses of power system. The main aim is to minimize the real powerless subjected to limits on generator reactive and real power outputs, transformer taps, bus voltages and shunt power control devices like SVCS The proposed algorithm applied to IEEE. 30 bus system to determine the optional reactive power control variables under safe voltage satiability limit and it is very suitable for this task to a large extent the optional reactive power allocation gives the results using differential evolution are compared with other method.**

Keywords: - Economic load dispatch, Algorithm, Reactive Power Dispatch, Differential evolution voltage improvement, L-index, Shunt power controlled device.

I. INTRODUCTION

The purpose of the reactive power dispatch (RPD) in power system is to identify the control variables which minimize the given objective function while satisfying the unit and system constraints. The goal is achieved by proper adjustment of reactive power variables like generator voltage magnitudes and transformer tap setting. The main objective of optimal reactive power dispatch (ORPF) of electric power system is to minimize an active power loss via the optimal adjustment of the power system control variables, while at the same time satisfying various equality and inequality constraints.
Also the DE algorithm has been applied to minimize loss with both continuous and discrete variables [1, 2].

Differential Evolution (DE) algorithm has been considered a novel evolutionary computation technique used for optimization problems. The DE and some other evolutionary techniques exhibit attractive characteristics such as its simplicity, easy implementation, and quick convergence [3].

Differential evolutionary strategy (DE) uses a greedy and less stochastic approach in problem solving. DE combines simple arithmetical operators with the classical operators of recombination, mutation and selection to evolve from a randomly generated starting population to a final solution.

In the present paper and efficient DE algorithm method with another form of differential mutation operator [15] is used to improve the quality of solution leading to the near global optimum, and gets the best solution with both continuous and discrete control variables. The form of the fitness function is reduced by removing the inequality constraints of reactive power of generating units, It's Treated separately in the load flow solution method.

The continuous control variables are generator bus voltage magnitudes. While the discrete variables are transformer tap setting and reactive power of shunt compensators.

The objective of voltage profile enhancement is to minimize total voltage deviation in load buses (PQ Bus), that's improving the quality of service in electrical network.

This method has been tested on the IEEE 30-bus standard system with two cases, one problem without voltage deviation minimization, the other with voltage deviation minimization.

This paper is organized as follows: the problems of optimal reactive power dispatch and voltage profile control are formulated in section II. III gives a review of differential evolution algorithm; the application of DE algorithm in ORPD is detailed in section IV.

II. PROBLEM FORMULATION

The OPF problem is considered as a general minimization problem with constraints, and can be written in the following form: -
Minimize $f(x,u)$
Subject to $g(s,u)=0$ And $h(x,u) \leq 0$

Where $f(x,u)$ is the objective function. $g(x,u)$ and $h(x,u)$ are respectively the set of equality and inequality constraints. X is the vector of state variables, and u is the vector of control variables. The state variables are the load buses (PQ buses) voltages, angle, the generator reactive powers and the slack active generator power. The control variables are the generator bus voltages the shut capacitors /reactors and the transformers tap settings. The reactive power optimization problem is subjected to the following constraints.

Equality Constraints: - The equality constraint g (x,u) of the ORPD problem is represented by the power balance equation, where the total power generation must cover the total power demand and the power losses.

Inequality Constraints: - These constraints represent the system operating constraints. Generator bus voltages (Vgi), reactive power generated by the capacitor variables and they are self-restricted. Load bus voltages (Vload) reactive power generation of generator (Qgi) and line flow limit (S1) are state variables, whose limits are satisfied by adding a penalty terms in the objective function.

The equality constraints are satisfied by running the power flow program. The active power generation (P) (except the gi generator at the slack bus), generator terminal bus voltages (V) and transformer tap-setting (t) are the optimization gi k variables and they are self-restricted by the optimization algorithm. The active power generation at the slack bus (Pgs), load bys voltages (v) and reactive power generation (Q) and voltage stability load gi level (L) are state variables which are restricted through penalty function approach.

Voltage Stability L-Index: - It can be seen that when a load bus approaches a steady state voltage collapse situation, the index L approaches the numerical value 1.0. Hence for an overall system voltage stability condition, the index evaluated at any of the buses must be less than unity. Thus the index value L gives an indication of how far the system is from voltage collapse. This feature of this indicator has been exploited in our proposed algorithm to evolve a voltage collapse margin incorporated RPD routine. The L-indices for a given load condition are computed for all load buses.

III. Evolution Algorithm

Overview: - In 1995, storn and price proposed a new floating point encoded evolutionary algorithm for global optimization and named it differential evolution (DE) algorithm owing to a special kind of differential operator, which they invoked to create new off-spring from parent chromosomes instead of classical crossover or mutation.

Similar to Gas, DE algorithm is a population based algorithm that uses crossover, mutation and selection operators. The main differences between the genetic algorithm and DE algorithm are the selection process and the mutation scheme that makes DE self adaptive. In DE all solutions have the same chance of being selected as parents. DE employs a greedy selection process that is the best new solution and its parent wins the competition providing significant advantage of converging performance over genetic algorithms.

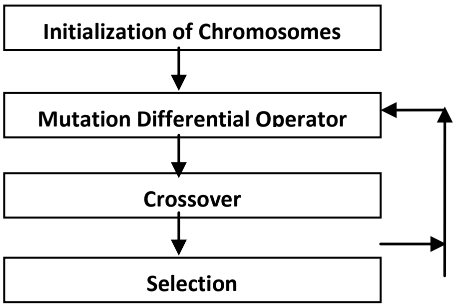

Fig.1.1 - DE Cycle of Stages

DE COMPUTATIONAL FLOW: - DE algorithm is a population based algorithm using three operators' crossover, mutation and selection. Several optimization parameters must also be turned. These parameters have joined together under the common name control parameters. In fact, there are only three real control parameters in the algorithm, which are differentiation (or mutation) constant F, Crossover constant CR, and size of population NP. The rest of the parameters are dimension of problem D that scales the difficulty of the optimization task, maximum number of generations (or iterations) GEN, which may serve as a stopping condition, and low and high boundary constraints of variables that limit the feasible area. The proper setting of NP is largely dependent on the size of the problem. Storn and price remarked that for real – world engineering problems with D control variables, NP=20D will probably be more than adequate, NP as small as 5D is often possible, although optimal solutions using NP,2D should not be expected. Storn and price set the size of population less than the recommended NP=10D in many of their test tasks. It is recommended using of NP≥4D NP=5D is a good choice for a first try, and then increase or decrease it by discretion. So, as a rush principle, several tries before solving the problem may be sufficient to choose the suitable number of the individuals. The DE algorithm works through a simple cycle of stages, presented in fig.1.1 .These stages can be cleared as follow: -

3.1. **Initialization: -** At the very beginning of a DE run, problem independent variables are initialized in their feasible numerical range. Therefore, if the jth variable of the given problem has its lower and upper bound as X1 And X2, then the jth component of the ith population members may be initialized as: - X1,2 (O) = X2 + rand (0,1), (X2-X1). Where, rand (0, 1) is a uniformly distributed random number between 0 and 1.

3.2. **Mutation: -** In each generation to change each population member_Xi (t), a donor vector, which demarcates between the various DE Schemes. To create a donor vectors _vi(t) for each ith member, three parameter vectors Xr1, Xr2 and Xr3 Are select randomly from the current population and not coinciding with the current xi. Next, a scalar number F Scales the difference of any two of the three vectors and the scaled difference is added to the third one whence the donor vector _vi(t) is obtained. The usual choice for F is a number between 0.4 and 1.0.

3.3. **Crossover: -** To increase the diversity of the population, crossover operator is carried out in which the donor vector exchanges its components with those of the current member _Xi (t). Two types of crossover schemes can be used with DE technique. These are exponential crossover and binomial crossover. Although the exponential crossover was proposed in the original work of storn and price, the binomial variant are much more used in recent applications.

3.4. **Selections: -** Selection is a step to choose the vector between the target vector and the trial vector. The fitness value of target vector is compared with the fitness value of trial vector. The best vector having the best fitness value is chosen for the next generation. The selection process is repeated for each pair of target/ trail vector until the population for the next generation is complete.

IV. Implementation of DE for Reactive Power Optional Dispatch.

The details of the proposed algorithm are as follows: -

- Initialize population
- While stopping criteria are not satisfied,
- Create mutant vector with the difference vector and scaling constant.
- Generate trial vectors applying the selected crossover scheme.
- Select next generation members according to competition performance.

4.1. Initialization

The first step in the DE optimization process is to create an initial population of candidate solutions by assigning random values to each decision parameter of each individual of the population such values must lie inside the feasible bound of the decision variable and can be generated by given equation. In case basic solutions available adding normally distributed random deviations to the normal solution unless generates the initial population.

4.2. Algorithm of ORPD-Differential Evolution(DE)

Step 1: Select the DE parameters Np; F, Rc, Kmax,
D= dimension of vector control variables U.

Step 2: Initialize at random Np individuals within their limits.

Step 3: Calculate fitness function of each initial individuals X1
Using objective function FT.

Step 4:Set iteration K=1;

Step 5: Set Xgbest to the best particle have the best fitness in all individuals Xi

Step 6: Apply differential mutations to find Yi

Step 7: Apply crossover operator to find Zi

Step 8: Calculate new fitness function of each individual Zi using objective function FT

Step 9: Apply selection operator to select the new vector Xi in the next generation

Step 10: If k<Kmax ,set K=K+1 and go to step 5, otherwise go to step 11

Step 11: take Ubest=Xgbest and runni9ng load flow to determine real slack power .active power loss, and other elements of state variables.

To calculate the fitness function of each individual xi set the vector control variables U=Xi, and running load flow and fitness function.

The procedure of differential evolution optimization technique can be shown in flowchart,

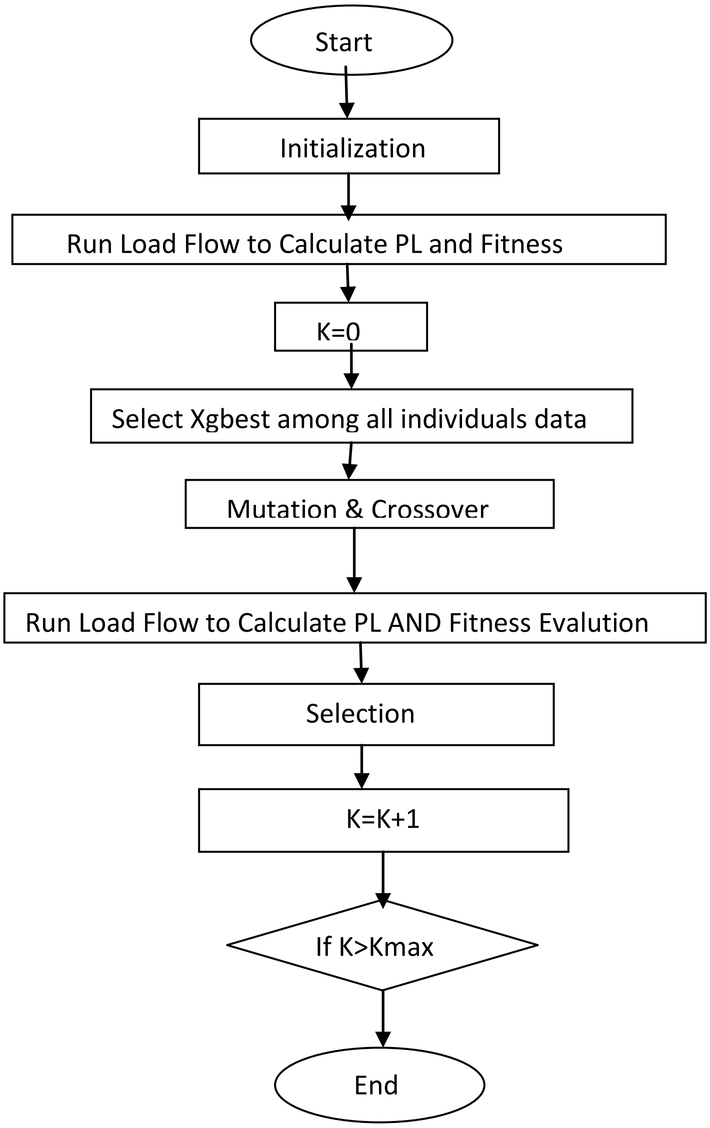

Fig. 2: Flow chart of DE Algorithm for ORPD

In the ORPD problem, the elements of the solution consist of all the control variables, namely, generator bus voltages (V), the gi transformer tap-setting (tk), and the reactive power generation (Qci). These variables are represented continuous variables in the DE population.

Fitness Function: In the ORPD problem under consideration the objective is to minimize the total power loss satisfying the constraints given by equations (12) to (19). For each individual, the equality constraints given by equations (12) and (13) are satisfied by running Newton-Raphson algorithm and the constraints on the state variables are taken into consideration by adding a quadratic penalty function to the objective function.

With the inclusion of penalty function, the new objective function then becomes,

V. SOLUTION TECHNIQUE

The minimization objective function given by equation is transformed to a fitness function(f) to be maximized as, where k is a large constant. This is used to amplify, the value of 1/F which is usually small, so that the fitness value of the chromosome will be in a wider range.

Treatment of discrete variables

The discrete control variables are adjusting by 0.01 step size. Then every transformer setting is rounded to its nearest decimal integer value of 0.01, by utilizing the rounding operator. The same principle applies to discrete reactive power injection of shunt compensators. The rounding operator is only performed in evaluating the fitness function.

The DE parameters used for the optimal power flow solution are given in Table III. They are treated as continuous controls. The results of these simulations are summarized next.

TABLE I

SYSTEM DESCRIPTION OF CASE STUDY

Sl.No.	Variables	30-bus system
1	Buses	30
2	Branches	40
3	Generators	6
4	Generator buses	6
5	Shunts reactors	2
6	Tap-Changing 4 transformers	

TABLE II LIMITS OF VARIABLES FOR IEEE 30-BUS SYSTEM

No.	Description	Units	Lower Limits	Upper Limits
1	Voltage PQ-bus	Pu	0.96	1.06
2	Voltage PV-bus	Pu	0.91	1.11
3	Trans. taps	Pu	0.91	1.11

TABLE III

DE PARAMETERS FOR BEST RESULTS OF OPTIMAL POWER FLOW FOR IEEE 30-BUS SYSTEM

Sl.No.	Parameters of Differential evolution	
	Parameters	Values
1	Population	30
2	Generations	100

TABLE IV CONTROL VARIABLES FOR THE 30-BUS SYSTEM

I. Generator voltages		II. Shunt Compensation		III. Transformer taps	
Gen bus	Value	SVC	Value	Tran. Tap	Value
1	1.0701	Qc10	0.0426	$^{T}6-9$	0.9007
2	1.0628	Qc12	0.0260		0.9007
	1.0447	Qc15	0.0275	T	
5				$6-10$	
	1.0434	Qc17	0.0282		1.0098
8		Qc20	0.0458	$^{T}4-12$	
11	1.0979				1.0118
		Qc21	0.0380		
13	1.0619	Qc23	0.0531	$^{T}28-27$	
		Qc24	0.0258		
		Qc29	0.0309		

Case 1; Basic case

In this case the system is optimized with optimal reactive power dispatch method under base load condition for 100% load level. The real power readings of the generators are selected from [1], To obtain the optimal values of the controlled variables the differential evolution based algorithm was run. The optimal values of the control variables and power loss obtained are shown in table IV. The minimum transmission loss is 49500MW which is smaller than result received in [1] for the same IEEE 30-bus system.

Case-2: Contingency case-Again same case is considered of same values of load condition and generator setting but network contingency will considered. The restriction of maximum values of L-index under contingency condition from reaching high values. For the network contingency, say that (3-12) with including voltage stability constraints the differential evolution based algorithms will applied to find the optimal values of the control variables under normal condition these result will show in table V.

TABLE V

CONTROL VARIABLES FOR THE 30-BUS SYSTEM

I. Generator voltages		II. Shunt Compensation		III. Transformer taps	
bus No.	Value	SVC	Value	Tran. Tap	Value
1	1.0700	Qc10	0.0140	$^{T}6-9$	1.0284
2	1.0625	Qc12	0.0554		0.9000
		Qc15	0.0421	T	
5	1.0387			$6-10$	
		Qc17	0.0260		1.0137
8	1.0403	Qc20	0.0484	$^{T}4-12$	
					0.9850
11	1.0863	Qc21	0.0159		
13	1.0646	Qc23	0.0194	$^{T}28-27$	
		Qc24	0.0497		
		Qc29	0.0288		

TABLE VI

PERFORMANCE PARAMETERS

Parameter	Values	
	Case 1	Case 2
P_{g1} (pu)(slack bus)	0.9989	1.0236
^{L}max	0.1310	0.1800
P_{loss} (pu)	0.0489	0.0507

For such types of optimal values of control variables when line (3-12) was removed ,it will found the maximum values of L-index of system is 0.1800 only. This is the improvement of voltage stability will found due to restriction has maximum L-index value.

Table VI shows the performance parameters of the reactive power dispatch using differential evolution based reactive power dispatch.

Simulation Results

The details of the simulation study carried out on IEEE 30-bus system using the proposed DE-based method are presented here. It is chosen as it is a benchmark system, has more control variables and provides results for comparison of the proposed method. The approach can be generalized and easily extended to large-scale systems. IEEE 30-bus system consists of 6 generator buses, 24 load buses and 41 transmission lines of which 4 branches (6-9), (6-10), (4-12) and (28-27) are with the tap-setting transformer. Generator parameters are given in the Appendix. The transmission line parameters of this system and the base loads are given in [1].

VI. Conclusion

In this paper, an efficient DE solution to the ORPF problem has been presented for determination of the global or near-global optimum solution for optimal reactive power dispatch with and without voltage deviation in PQ buses. The main advantages of the DE to the ORPD problem are optimization of different type of objective function, real coded of both continuous and discrete control variables, and easily handling nonlinear constraints. The proposed algorithm has been tested on the IEEE 30-bus system to minimize the active power loss. The optimal setting of control variables are obtained in both continuous and discrete value.

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