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OPTIMAL POWER FLOW WITH DIFFERENTIAL EVOLUTION CONSIDERING HVDC AND PEV VEHICULAR FLEET

Sai Kiran Panda
MTech Student
Department of Electrical Engineering
Andhra University College of Engineering(A)
Visakhapatnam, Andhra Pradesh, India.

Dr. K. Vaisakh
Professor
Department of Electrical Engineering,
Andhra University College of Engineering(A)Visakhapatnam,
Andhra Pradesh, India

Vangeti Sofia
MTech Student
Department of electrical Engineering
Andhra University College of Engineering(A)
Visakhapatnam, Andhra Pradesh, India.

ABSTRACT

The Optimal Power Flow (OPF) is an important criterion in today's power system operation and control due to scarcity of energy resources, increasing power generation cost and ever-growing demand for electric energy. As the size of the power system increases, load may be varying. The generators should share the total demand plus losses among themselves. The sharing should be based on the fuel cost of the total generation with respect to some security constraints. The security constraints are real and reactive power generation limits, tap changing transformers line flow limits. Since the dependence each generator fuel cost on the load it supplies, the objective of the OPF algorithm is to allocate the total electric power demand and losses among the available generators in such a manner, that it minimizes the electric utility's total fuel cost while satisfying the security constraints. But it is very difficult task considering all the constraints. many mathematical assumptions such as convex, analytic, and differential objective functions have to be given to simplify the problem.

However, the OPF problem is an optimization problem with, in general, nonconvex, no smooth, and nondifferentiable objective functions. These properties have become more evident and dominant if the effects of the valve point loading of thermal generators and the non-linear behaviour of electronic-based devices such as HVDC and PEV Vehicular Fleet are taking into consideration. Hence, it becomes essential to develop optimization techniques that are efficient to overcome these drawbacks and handle such difficulties. Differential evolution (DE) is an efficient and powerful population-based stochastic search technique for solving optimization problems over continuous space, which has been widely applied in many scientific and engineering fields. However, the success of DE in solving a specific problem crucially depends on appropriately choosing trial vector generation strategies and their associated control parameter values. Employing a trial-and-error scheme to search for the most suitable strategy and its associated parameter settings requires high computational costs. Moreover, at different stages of evolution, different strategies coupled with different parameter settings may be required in order to achieve the best performance.

Key words – OPF, DE, HVDC, PEV Vehicular Fleet

I INTRODUCTION

Advantages in High Voltage Direct Current (HVDC) technology, and engineers are now considering DC multi-terminal networks as a feasible option. Therefore, load flow analysis techniques have to be extended to deal with such mixed HVDC systems. Multiterminal DC networks integrated into an existing system can improve AC equipment, loading and stability, contribute to its load frequency control (LFC) and voltage regulation, increase interchange capacity, limit short circuit capacity, and contribute to the efficiency of electric power transmission. However, multi-terminal DC networks, as well as two-terminal DC links, require communication between converter terminals and control of DC system start-up and shut down. This communication is needed for the coordination of operating set points and for DC system structural changes, such as line or terminal outages. The integration of DC links or HVDC multi-terminal networks into AC systems is achievable and can be advantageous in certain applications such as bulk power transmission, AC network interconnections, and reinforcing AC networks

With the introduction of electric vehicles (EVs) in to the transport sector, the power sector mainly electric power system will suffer a drastic change due to vehicle charging. It is clear, however, that no matter what the percent penetration of the vehicle market, the electric utilities must be prepared to accept this load. Among the factors which must be considered are increased loads at the transmission level, increased loads at the sub transmission and distribution levels, and increased energy demands. Concerning the type of load which the EV presents, the relationship between EV deployment and load management plans should must be considered. So, there is a need to improve new models to make easier operation and control of new structure of power system. suitable power flow calculation methods, have become important research fields in power engineering to maintain stability and power quality.

II DIFFERENTIAL EVOLUTION

In general, most of the classical optimization techniques mentioned applies sensitivity analysis and gradient-based optimization algorithms by linearizing the objective function and the system constraints around an operating point. Unfortunately, the OPF problem is a highly non-linear and a multimodal optimization problem. More recently, OPF has enjoyed renewed interest in a variety of formulations through use of evolutionary optimization techniques to overcome the limitations of classical optimization techniques. A wide variety of advance optimization techniques have been applied in solving the OPF problems such as genetic algorithm (GA), simulated annealing, Tabu Search, and particle swarm optimization (PSO). Recently, a new evolutionary computation technique, called differential evolution (DE) algorithm, has been proposed and introduced. The algorithm is inspired by biological and sociological motivations and can take care of optimality on rough, discontinuous and multi-modal surfaces. The algorithm mainly has three advantages: finding the true global minimum regardless of the initial parameter values, fast convergence, and using a few control parameters. Being simple, fast, easy to use, very easily adaptable for integer and discrete optimization, quite effective in non-linear constraint optimization including penalty functions and useful for optimizing multi-modal search spaces are the other important features of DE.

The differential evolution algorithm was proposed by the storn and price, it is simple yet powerful population based stochastic search technique, which is an efficient and effective global optimizer in the continues search domain. DE has been successfully applied in diverse fields. Differential evolution algorithm is a population-based algorithm such as genetic algorithms using similar operators; crossover, mutation and selection. The main difference between the genetic algorithm and DE is the mutation scheme that makes DE self-adaptive and the selection process. In DE, all the solutions have the same chance of being selected as parents. DE employs a greedy selection process: the better one of new solution and its parent wins the competition providing significant advantage of converging performance over genetic algorithms [Adel A. Abou El-Ela] [5].

In DE, there exist many trial vector generation strategies out of which a few may be suitable for solving a particular problem. Moreover, three crucial control parameters involved in DE, i.e., population size, scaling factor, and crossover rate, may significantly influence the optimization performance of the DE. Therefore, to successfully solve a specific optimization problem at hand, it is generally required to perform a time-consuming trial-and-error search for the most appropriate strategy and to tune its associated parameter values.

Differential Evolution Algorithm

1. Differential evolution is same as the evolutionary algorithm, it is also starts with a population of NP D- dimensional search variable vectors.
2. The following generations in differential evolution (DE) will be represented by discrete time steps like t = 0, 1, 2, ……t, t+1, etc.
3. Since the vectors are likely to be changed over different generations, the following notation may be adopted for representing the i[th] vector of the population at the current generation (i.e., at time t =t) as
   $X_i(t) = [x_{i,1}(t), x_{i,2}(t), \ldots\ldots, x_i(t)]$
   These vectors are referred to as 'genomes' or 'chromosomes.'
4. Several optimization parameters must be tuned. All the parameter which are needed for the DE will called as control parameters in the algorithm they are,
   a) Mutation (or differentiation) constant *F*.
   b) Cross over constant CR, and
   c) Size of population NP.

The rest of the parameters are

a. Dimension of problem *D* that scales the difficulty of the optimization task.
b. Maximum number of generations (or iterations) *GEN*, which says the stopping condition.
c. Lower and higher boundary constraints, respectively which limits the feasible area.

DE works in a simple cycle of stages

Initialization

At the very beginning of a DE run either at t=0, problem parameters or independent variables are initialized somewhere in their feasible numerical range. Therefore, the j[th] parameter of given problem has its lower and upper boundary limits as x_j^L *and* x_j^U, respectively then the j[th] component of the i[th] population members may be initialized as,

$$x_{i,j}(0) = x_j^L + rand(0,1)(x_j^U - x_j^L) \quad (1)$$

Where, rand (0,1) is a uniformly distributed random number lying between 0 and 1. This vector i.e., $X_{i,G} = \{x_{i,G}^i, \ldots\ldots, x_{i,G}^D\}, i = 1,2, \ldots, NP$ is called as target vector.

Mutation,

After the initialization, DE employs the mutation operation to produce a donor (or mutation) vector $V_{i,G}$ with respect to each individual $X_{i,G}$ in the target vector. This method of creating donor vector distinguishes between the various DE schemes. For each target vector $X_{i,G}$ at the generation G, its associates the mutant vector $V_{i,G} = \{v_{i,G}^1, v_{i,G}^2, \ldots\ldots, v_{i,G}^D\}$ can be generated through specific mutation strategy. To create the donor vector $V_i(t)$ for each i^{th} member:

1. Select three other parametric vectors say r_1, r_2, and r_3 vectors are randomly chosen from the current population.
2. Next, a scalar number F scales the difference between the any two of the three random vectors and the calculated difference is added to the third one where the donor vector $V_i(t)$ is obtained.
3. The process for the j^{th} component of each vector can be expressed as,

$$v_{i,j}(t+1) = x_{r1,j}(t) + F(X_{r2,j}(t) - x_{r3,j}(t)) \quad (2)$$

Where x_{r1}, x_{r2} and x_{r3} are three distinct points taken randomly from the current population and not coinciding with the current x_i. The usual choice for F is a number between 0.4 and 1.0.

Crossover Operation

After the mutation operation, crossover operation is applied to each pair of the target vector $X_{i,G}$ and its corresponding mutant vector $V_{i,G}$ to generate a trail vector. $U_{I,G} = (u_{i,G}^1, u_{i,G}^2, \ldots\ldots, u_{i,G}^D)$. Crossover operation is applied to increase the potential diversity of the population.

There are two kinds of crossover schemes namely: 'Exponential' and 'Binomial' can be used by DE. In this thesis binomial crossover scheme is used which can be performed as follows:

Crossover is performed on each of the D variable and may be outlined as,

$$u_{i,j}(t) = \begin{cases} v_{i,j}(t) & if\ rand\ (0,1) < CR \\ x_{i,j}(t) & else \end{cases} \quad (3)$$

In equation (4), the crossover rate CR is specified by user with in the range [1, D]. The binomial crossover operator copies the j^{th} parameter of the mutant vector $V_{i,G}$ to the corresponding element in the trail vector $U_{i,G}$ if the corresponding element in the trail vector $U_{i,G}$ if $rand_j$ [0,1] ≤ CR or $j=j_{rand.}$ Otherwise, it is copied from the corresponding target vector $X_{i,G.}$ There exists another exponential crossover operator, in which the parameters of trial vector $U_{i,G}$ are inherited from the corresponding mutant vector $V_{i,G}$ starting from a randomly chosen parameter index till the first time $rand_j$ [0,1] > CR. The remaining parameters of the trial vector $U_{i,G}$ are copied from the corresponding target vector $X_{i,G.}$ The condition $j=j_{rand}$ is introduced to ensure that the trial vector $U_{i,G}$ will differ from its corresponding target vector $X_{i,G}$ by at least one parameter. DE's exponential crossover operator is functionally equivalent to the circular two-point crossover operator.

Selection Operation

Before performing the selection process check whether the values of some parameters of a current trail trial vector exceeds or not. If it is exceeded reinitialize them with in the prespecified range. Then the objective function values of all trail vectors are evaluated. After that, the selection operation is performed. Selection operation is performed to determine which one of the target vector or the trial vector will survive in the next generation i.e. at time t = t + 1.

$$X_i(t+1) = \begin{cases} U_i(t)\ if\ f(U_i(t)) \leq f(X_i(t)) \\ X_i(t)\ if\ f(X_i(t)) > f(U_i(t)) \end{cases} \quad (4)$$

where, f( ) is the function to be minimized. So, if the new trial vector provides a better value of the fitness function, it replaces its target in the next generation; otherwise, the target vector is retained in the population. Hence, the population either gets better (w.r.t. the fitness function) or remains constant but never worsen.

III HVDC Load Flow

High voltage DC transmission is now an acceptable alternative to AC and is proving an economical solution not only for long distance transmission but also for underground and submarine transmission. It also serves as a means to interconnect systems of different frequencies or to deal with problems of stability or fault levels [8].

High Voltage Direct Current (HVDC) transmission is important for long distance, underground, and submarine transmission. Due to the increasing strains on existing systems, it is necessary to develop a better method for performing the load flow analysis of an integrated HVDC power system. However, the power flow has to be substantially enhanced to be capable of modelling the operating state of the combined AC and DC systems, and this must be done fast and efficiently under the specified conditions of load generation and DC system control strategies.

The development of an enhanced HVDC-load flow system based on the Newton - Raphson method is in two methods they are Simultaneous and sequential load flow; Simultaneous load flow is the focus of this paper. The variation of the DC link chosen for the problem formulation are:

(1) the converter, terminal DC voltage;
(2) the real and imaginary components of the transformer secondary current;
(3) converting transformer tap ratios;
(4) the firing angle of the rectifier; and
(5) the current in the DC link.

The equations relating these five variables and their solution strategy are discussed. As the model developed is independent of a particular control mode of the DC link, the AC and DC link equations are solved separately and thus the integration into a standard load flow program is possible without significant modifications of the AC load flow algorithm. In the AC system iterations, each converter is designed as a complex power load at the AC terminal bus bar, and the DC link equations are solved using the most recent value of the AC bus bar voltage. The AC and DC system equations are solved simultaneously, taking outt the inter-connectedness of both equations [Arrillaga and Arnold1990] [8]

IV MODELLING OF HVDC

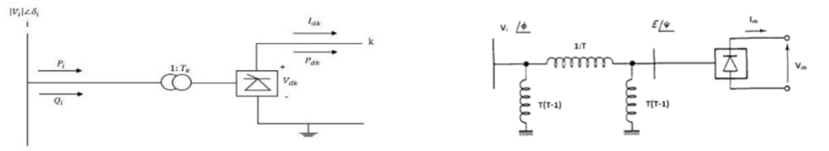

Fig 1(a) Modelling of DC Converter Station 1(b) Single phase equivalent circuit for basic converters

$V_{dk} = (K_1 T_k |V_i| \cos\theta_k - \frac{3}{k} X_{ck} I_{dk})(sgn)_k$ (5)

where,

$|V_i|$ = AC terminal voltage

T_k = Converter transformer taps ratio

X_{ck} = commutating reactance

I_{dk} = DC current

$K_1 = {3\sqrt{2}}/{\pi}$

$(sgn)_k$ = 1 if the converter at the AC bus bar 'i' is a rectifier

= -1 if the converter at the AC bus bar 'i' is an inverter

θ_k = converter control angle

The active and reactive power flow from the bus to i to all converter stations connected to it 'k' is

$P_i(dc) = k_1|V_i| \sum_{k=1}^{n} (sgn)_k T_k I_{dk} \cos\phi_k$ (6)

$Q_i(dc) = k_1|V_i| \sum_{k=1}^{n} T_k I_{dk} \sin\phi_k$ (7)

These equations with new injected power P_d and Q_d can be written as

$P_{sch} - P_{cal}(AC) - P_{cal}(DC) = 0$ (8)

$Q_{sch} - Q_{cal}(AC) - Q_{cal}(DC) = 0$ (9)

V PEV VEHICULAR FLEET

Due to the scarcity of the fossil fuels and environmental pollution automobile industry developing the electric vehicles has a great influence in the transport sector which it reduces the air pollution and transport cost the main characteristic of these vehicles is the use of batteries as a source to supply all or a part of driving force. An electric vehicle is any motor with rechargeable battery packs that can be charged from the electric grid. Charging station of electric vehicles has a great influence on the power system. A charging station of a electric vehicle can charge over 300 batteries at a time. The participation of the electrical vehicle fleet to the grid has created the need of developing new models aimed at facilitating their inclusion into the electric networks.

With the introduction of electric vehicles (EVs) in to the transport sector, the power sector mainly electric power system will suffer a drastic change due to vehicle charging. It is clear, however, that no matter what the percent penetration of the vehicle market, the electric utilities must be prepared to accept this load. Among the factors which must be considered are increased loads at the transmission level, increased loads at the sub transmission and distribution levels, and increased energy demands. Concerning the type of load which the EV presents, the relationship between EV deployment and load management plans should must be considered. So, there is a need to improve new models to make easier operation and control of new structure of power system. This paper covers the specific and simple model for PEV fleet suitable for load flow studies.

VI MODELLING OF PEV VEHICULAR FLEET

The schematic diagram of PEV is shown in fig 2 where the batter pack forms the storage unit. This drive includes the three-phase power inverter and an AC machine. A power electronic converter, namely VSC, interfaces the on-board storage units with the power grid not only to exchange active power, but also reactive power.

The schematic diagram and equivalent circuit of the VSC based PEV for reactive power control in power flow studies are presented in Fig. 3.3 The VSC-based PEV schematic diagram comprises a battery system, a power converter and a coupling inductance. It can be appreciated that the VSC-based PEV equivalent circuit for power flow studies can be represented as a complex voltage source V_{vsc} behind the transformer impedance Z_{vsc} [7]. The instantaneous charging status of a PEV batter power equations are given below

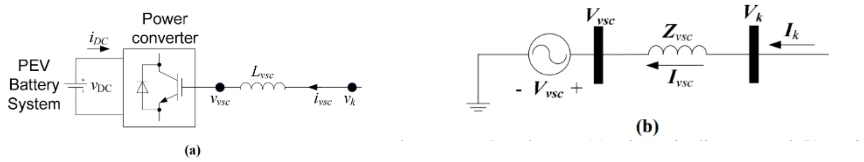

Fig 2 VSC-based PEV: (a) schematic diagram, and (b) equivalent circuit

PEV Vehicular fleet is connected to the 14 bus the power flow equations can be written as,

$$\left.\begin{aligned} V_{pev} &= |V_{pev}| \angle\delta_{pev} \\ Y_{PEV} &= Y_{PEV}\angle\theta_{PEV} \\ V_k &= V_k\angle\delta_k \end{aligned}\right\} \quad (10)$$

The nodal power flow equations at node k are,

$P_k = |V_k||V_{pev}||Y_{pev}| \cos(\delta_{pev} - \delta_k + \theta_{pev})$ (11)

$Q_k = |V_k||V_{pev}||Y_{pev}| \sin(\delta_{pev} - \delta_k + \theta_{pev})$ (12)

The complex voltage source generated at the AC side of the VSC is defined as,
Similarly, the equations that describe the power flow equations at node *vsc* are,

$$P_{pev} = |V_{pev}||V_k||Y_{pev}|\cos(\delta_k - \delta_{pev} + \theta_{pev}) \quad (13)$$

$$Q_{pev} = |V_{pev}||V_k||Y_{pev}|\sin(\delta_k - \delta_{pev} + \theta_{pev}) \quad (14)$$

VII Power flow equations with HVDC and PEV Vehicular Fleet

The power flow equations for both HVDC and PEV Vehicular fleet

$$P_{pev} = |V_{pev}||V_k||Y_{pev}|\cos(\delta_k - \delta_{pev} + \theta_{pev}) \quad (15)$$

$$Q_{pev} = |V_{pev}||V_k||Y_{pev}|\sin(\delta_k - \delta_{pev} + \theta_{pev}) \quad (16)$$

$$P_{i,DC} = K_1|V_i|\sum_{k=1}^{n}(sgn)_k T_k I_{dk}\cos\phi_k \quad (17)$$

$$Q_{i,DC} = K_1|V_i|\sum_{k=1}^{n} T_k I_{dk}\sin\phi_k \quad (18)$$

$$P_k^{cal} = |V_k|\sum_{i=1}^{n}|V_i||Y_{ik}|\cos(\delta_i - \delta_k + \theta_{ik}) \quad (19)$$

$$Q_k^{cal} = |V_k|\sum_{i=1}^{n}|V_i||Y_{ik}|\sin(\delta_i - \delta_k + \theta_{ik}) \quad (20)$$

$$\left.\begin{aligned}
\Delta P_k &= (P_k^{sp}) - (P_k^{cal} + P_k)\\
\Delta P_{PEV} &= (P_{EV-s}) - (P_{PEV})\\
\Delta P(|V|,\delta,U_{dc}) &= (P_{Gi} - P_{Di}) - P_{i,cal}(|V|,\delta) - P_{i,cal}(|V|,U_{dc})\\
\Delta Q_k &= (Q_k^{sp}) - (Q_k^{cal} + Q_k)\\
\Delta Q_{pev} &= (Q_{pev}^{sp}) - (Q_{pev}^{cal} + Q_{pev})\\
\Delta Q(|V|,\delta,U_{dc}) &= (Q_{Gi} - Q_{Di}) - Q_{i,cal}(|V|,\delta) - Q_{i,cal}(|V|,U_{dc})
\end{aligned}\right\} \quad (21)$$

Now, the mismatch vector can be written as,

$$\begin{bmatrix} \Delta P(V,\delta) \\ \Delta P(V,\delta,U_{dc}) \\ \hline \Delta Q(V,\delta) \\ \Delta Q(V,\delta,U_{dc}) \\ \hline \Delta R(V,U_{dc}) \\ \hline \Delta P_{pev} \end{bmatrix} = \begin{bmatrix} \frac{\partial P_i}{\partial \delta_i} & \frac{\partial P_i}{\partial \delta_j} & |V_i|\frac{\partial P_i}{\partial |V_i|} & |V_j|\frac{\partial P_i}{\partial |V_j|} & \frac{\partial P_i}{\partial U_{dc}} & \frac{\partial P_i}{\partial \delta_{pev}} \\ \frac{\partial P_j}{\partial \delta_i} & \frac{\partial P_j}{\partial \delta_j} & |V_i|\frac{\partial P_j}{\partial |V_i|} & |V_j|\frac{\partial P_j}{\partial |V_j|} & \frac{\partial P_j}{\partial U_{dc}} & \frac{\partial P_j}{\partial \delta_{pev}} \\ \hline \frac{\partial Q_i}{\partial \delta_i} & \frac{\partial Q_i}{\partial \delta_j} & |V_i|\frac{\partial Q_i}{\partial |V_i|} & |V_j|\frac{\partial Q_i}{\partial |V_j|} & \frac{\partial Q_i}{\partial U_{dc}} & \frac{\partial Q_i}{\partial \delta_{pev}} \\ \frac{\partial Q_j}{\partial \delta_i} & \frac{\partial Q_j}{\partial \delta_j} & |V_i|\frac{\partial Q_j}{\partial |V_i|} & |V_j|\frac{\partial Q_j}{\partial |V_j|} & \frac{\partial Q_j}{\partial U_{dc}} & \frac{\partial Q_j}{\partial \delta_{pev}} \\ \hline \frac{\partial R}{\partial \delta_i} & \frac{\partial R}{\partial \delta_j} & |V_i|\frac{\partial R}{\partial |V_i|} & |V_j|\frac{\partial R}{\partial |V_j|} & \frac{\partial R}{\partial U_{dc}} & \frac{\partial R}{\partial \delta_{pev}} \\ \hline \frac{\partial P_{pev}}{\partial \delta_i} & \frac{\partial P_{pev}}{\partial \delta_j} & |V_i|\frac{\partial P_{pev}}{\partial |V_i|} & |V_j|\frac{\partial P_{pev}}{\partial |V_j|} & \frac{\partial P_{pev}}{\partial U_{dc}} & \frac{\partial P_{pev}}{\partial \delta_{pev}} \end{bmatrix} \begin{bmatrix} \Delta \delta_i \\ \Delta \delta_j \\ \hline \Delta |V_i| / |V_i| \\ \Delta |V_j| / |V_j| \\ \hline \Delta U_{dc} \\ \hline \Delta \delta_{pev} \end{bmatrix} \quad (22)$$

$$\left.\begin{aligned}
\delta_i^{n+1} &= \delta_i^n + \Delta\delta_i^n\\
\delta_{pev}^{n+1} &= \delta_{pev}^n + \Delta\delta_{pev}^n\\
|V_i|^{n+1} &= |V_i|^n\left(1 + \frac{\Delta|V_i|^n}{|V_i|^n}\right)\\
U_{dc}^{(n+1)} &= U_{dc}^{(n)} + \Delta U_{dc}^{(n)}
\end{aligned}\right\} \quad (23)$$

Where n is an iteration count.

VIII Optimal power flow with Differential Evolution considering PEV Vehicular Fleet and HVDC

Step 1 Set the generation number G = 0, and randomly initialize a population of NP individuals $P_G = \{X_{i,G},, X_{NP,G}\}$ with $X_{i,G} = \{x_{i,G}^1, \dots, x_{i,G}^D\}$, i=1, 2, …, NP uniformly distributes in the range $[X_{min}, X_{max}]$, where $X_{min} = \{x_{min}^1, \dots, x_{min}^D\}$ and $X_{max} = \{x_{max}^1, \dots, x_{max}^D\}$

Step 2 Run load flow with Multi terminal HVDC and PEV Vehicular Fleet by the current population $P_G = \{X_{i,G},, X_{NP,G}\}$ after update power generation P_G values by checking the generating limits

Step 3 WHILE stopping criterion not satisfied

DO

Step 3.1 Mutation

Generate a muted vector $V_{i,G} = \{v_{i,G}^1, \dots, v_{i,G}^D\}$ for each target vector $X_{i,G}$

FOR i = 1to NP

Generate a muted vector $V_{i,G} = \{v_{i,G}^1, \dots, v_{i,G}^D\}$ corresponding to the target vector $X_{i,G}$ via one of the equations

Step 3.2 Crossover

Generate a trail vector $U_{i,G} = \{u_{i,G}^1, \dots, u_{i,G}^D\}$ for each target vector $X_{i,G}$

Binomial crossover

For i= 1 to NP

$j_{rand} = [rand(0,1) * D]$

FOR j= 1to D

$$u_{i,j}(t) = \begin{cases} v_{i,j}(t) & if\ rand\ (0,1) < CR \\ x_{i,j}(t) & else \end{cases}$$

END FOR
END FOR

Step 4

Before completing the selection process run load flow with Multi terminal HVDC and PEV Vehicular Fleet then updated trail vector $U_{i,G}$.

Step 3.3 Selection

FOR i=1 to NP

Evaluate the trail vector $U_{i,G}$

IF $f(U_{i,G}) \leq f(X_{i,G}), THEN\ X_{i,G+1} = U_{i,G},\ f(X_{i,G+1}) = f(U_{i,G})$

IF $f(U_{i,G}) < f(X_{best,G}), THEN\ X_{bext,G} = U_{i,G},\ f(X_{best,G}) = f(U_{i,G})$

END IF

END IF

END FOR

Step 3.4 increment the generation count G = G+1

Step 5 END WHILE

IX RESULTS

The simulation results of the differential evolution method for fuel cost objective function have been applied to IEEE 30 Bus system with NR -load flow, it is chosen a benchmark system have more control variables and provide results for comparison of different terminal connections of HVDC and PEV vehicular fleet this approach can be generalised and applied for to large scale systems. For the test cases IEEE 30 bus and IEEE 14 bus multiterminal HVDC and PEV vehicular fleet load flow is applied for IEEE 30 bus system consists of six generators, four transformers and 36 lines and total 25 control variable, for IEEE 14 bus system consists of five generators and 17 lines total 21 control variables. For HVDC multi terminal system it consists of 5 control variable 3 dc busses. The basic differential evolution method is applied for 5 iterations. The best results for DE combined with HVDC load flow multi terminal and two terminal and PEV vehicular fleet with two different test cases for IEEE 30, 14 bus compared below and results are tabulated in tables.

Table 1 Results of DE based cost minimization problem for IEEE 14 bus system with HVDC multi terminal and PEV Vehicular as a load.

DIFFERENTIAL EVOLUTION COST MINIMIZATION			
Control Variables	Min	Max	DE-NRLF
P1	0.10	5.00	2.2731
P2	0.20	0.80	0.2000
P3	0.20	0.50	0.2000
P6	0.20	0.35	0.2000
P8	0.20	0.30	0.2000
V1	0.95	1.06	1.0600
V2	0.95	1.06	1.0450
V3	0.95	1.06	1.0100
V6	0.95	1.06	1.0111
V8	0.95	1.06	1.0165
COST($/h)			744.1450
Ploss			0.0831

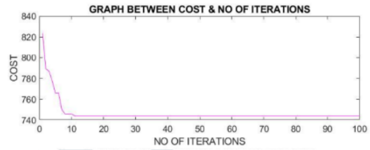

Fig 3(a) cost variation (DE-NR) IEEE 14 bus with HVDC multi terminal and PEV vehicular fleet as a load

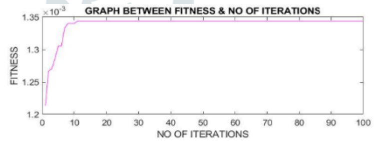

Fig 3(b) fitness variation (DE-NR) IEEE 14 bus with HVDC multi terminal and PEV Vehicular as a Load\

Table 2 Results of DE based cost minimization problem for IEEE 14 bus system with HVDC multi terminal and PEV Vehicular Fleet as active power injection.

DIFFERENTIAL EVOLUTION COST MINIMIZATION			
Control Variables	Min	Max	DE-NRLF
P1	0.10	5.00	2.3883
P2	0.20	0.80	0.2000
P3	0.20	0.50	0.2000
P6	0.20	0.35	0.2000
P8	0.20	0.30	0.2000
V1	0.95	1.06	1.0600
V2	0.95	1.06	1.0450
V3	0.95	1.06	1.0100
V6	0.95	1.06	1.0092
V8	0.95	1.06	1.0147
COST($/h)			773.0875
Ploss			0.1984

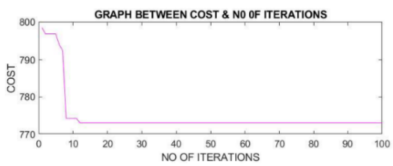

Fig 4(a) cost variation IEEE 14 bus with HVDC multi terminal and PEV Vehicular Fleet as active power injection.

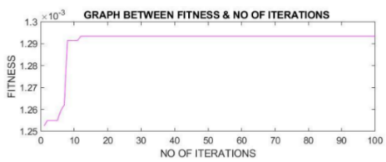

Fig 4(b) fitness variation IEEE 14 bus with HVDC multi terminal and PEV Vehicular Fleet as active power injection.

Table 3 Results of DE based cost minimization problem for IEEE 30 bus system with HVDC multi terminal and PEV Vehicular as a load.

DIFFERENTIAL EVOLUTION COST MINIMIZATION			
Control Variables	Min	Max	DE-NRLF
P_1	0.50	2.00	1.6363
P_2	0.20	0.80	0.5738
P_5	0.10	0.35	0.1723
P_8	0.10	0.30	0.1274
P_{11}	0.15	0.50	0.2149
P_{13}	0.15	0.40	0.1500
V_1	0.95	1.05	1.0500
V_2	0.95	1.05	1.0450
V_5	0.95	1.05	1.0100
V_8	0.95	1.05	1.0179
V_{11}	0.95	1.05	1.0099
V_{13}	0.95	1.05	1.0079
COST($/h)			772.5612
Ploss			0.0405

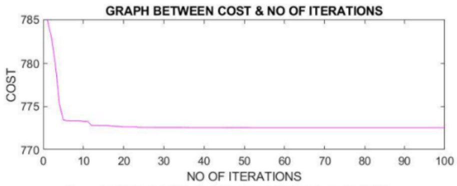

Fig 5(a) cost variation (DE-NR) IEEE 30 bus with HVDC multi terminal and PEV Vehicular as a load.

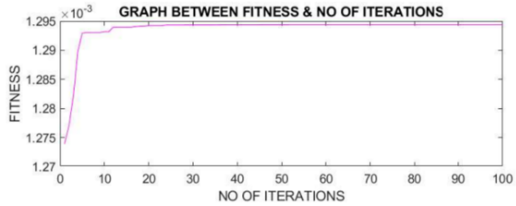

Fig 5(b) fitness variation (DE-NR) IEEE 14 bus with HVDC multi terminal and PEV Vehicular as a load.

Table 4 Results of DE based cost minimization problem for IEEE 30 bus system with HVDC multi terminal and PEV Vehicular Fleet as active power injection.

DIFFERENTIAL EVOLUTION COST MINIMIZATION			
Control Variables	Min	Max	DE-NRLF
P_1	0.50	2.00	1.6532
P_2	0.20	0.80	0.6468
P_5	0.10	0.35	0.1899
P_8	0.10	0.30	0.1298
P_{11}	0.15	0.50	0.2161
P_{13}	0.15	0.40	0.1500
V_1	0.95	1.05	1.0500
V_2	0.95	1.05	1.0450
V_5	0.95	1.05	1.0100
V_8	0.95	1.05	1.0171
V_{11}	0.95	1.05	1.0089
V_{13}	0.95	1.05	1.0059
COST($/h)			804.4385
Ploss			0.1519

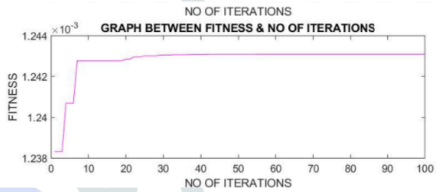

Fig 6(a) cost variation (DE-NR) IEEE 30 bus with HVDC multi terminal and PEV Vehicular Fleet as active power injection

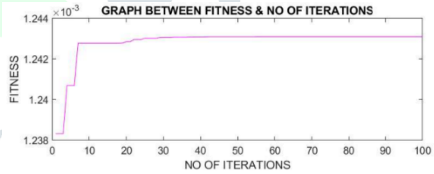

Fig 6(b) fitness variation (DE-NR) IEEE 14 bus with HVDC multi terminal and PEV Vehicular Fleet as active power injection.

X CONCLUSIONS

The DE optimization problem which is an optimization problem with, in general, non-convex, non-smooth, and non-differentiable objective functions has been considered in the The properties of the non-convex, non-smooth, and non-differentiable objective functions have become more evident and dominant if the effects of the valve-point loading of thermal generators and the non-linear behavior of electronic-based devices such as HVDC and PEV vehicular fleet are taken into consideration. Hence, essential optimization techniques that are efficient to overcome these drawbacks and handle such difficulties have been developed and presented.

In this thesis work, the differential evolution algorithm was proposed by the storn and price has been presented in detail and applied to solve optimization problems. DE have been applied for different objective functions such as fuel cost minimization and applied for IEEE 14, 30 bus. From the simulation results obtained on IEEE 30 bus and IEEE 14 bus system, it has been observed that TCPS gives better results for DE method for cost objective functions The results have confirmed the potential of the proposed approach and showed it effectiveness, robustness, and superiority over the classical techniques and other heuristic methods.

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