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OPTIMAL POWER FLOW WITH DIFFERENTIAL EVOLUTION CONSIDERING PEV VEHICULAR FLEET AND FACTS DEVICE

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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 FACTS device 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, FACTS, PEV vehicular fleet, DE

I INTRODUCTION

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.

FACTS uses power electronic equipment to control and adjust operation and network parameters to optimize system operation and transmission capacity. HVDC could be seen as an example of FACTS according to the above definition. However, since it has been developed into a specific transmission technique, HVDC is not classified as FACTS equipment in present day terminology. For a conventional power system, without FACTS equipment, the network parameters are fixed. The possible adjustment and control during system operation relies primarily on the control of the real and reactive power of generators. This means that the power transport capabilities of existing power networks are not fully utilized. FACTS has emerged to implement fast and flexible control over transmission networks through power electronic devices. FACTS can increase the capacity of the transmission network in coordination with various fast control measures for generators.

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 & 1. This vector i.e., $X_{i,G} = \{x_{i,G}^i, .., x_{i,G}^D\}, i = 1,2, \ldots, NP$ 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.

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

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 INTRODUCTION TO FACTS

the introduction of the FACTS concept, many FACTS devices have been proposed. We can classify them into three groups based on the maturity of the technology. The first group has been applied in the power industry, such as static VAR compensators (SVR), thyristor-controlled series capacitor (TCSC), and static synchronous compensators (STATCOM). The second group has industrial sample machines and is still under investigation, such as unified power flow controller (UPFC). The third group has only a theoretical design without any industrial application, such as static synchronous series compensator (SSSC), thyristor-controlled phase shifting transformer (TCPST).

FACTS devices can be classified based on their connection types as series, shunt, and combined types. SVC and STATCOM are shunt type. TCSC and SSSC are series type. TCPST and UPFC are combined type. Designed by US Electrical Power Research Institute (EPRI), manufactured by Westinghouse, and installed at AEP power system in USA for industrial testing operation, UPFC is the most powerful FACTS device proposed as of today. Its control strategy is presently under further research [8].

Shunt Compensators

A common practice of system voltage adjustment is shunt reactive power compensation. The synchronous condenser was historically an important tool of shunt reactive power compensation. The static shunt reactive power compensation, as opposed to the rotating synchronous condenser, has wide industrial application due to its low cost and simple operation and maintenance. Conventional static shunt reactive power compensation is to install capacitors, reactors, or their combination, at the compensated buses to inject or extract reactive power from the system. Mechanical switches are used to put the shunt capacitor/reactors into or out of operation. Shunt compensators are widely applied in power systems due to their economic advantages and easy maintenance. Modern SVR with FACTS technology integrate power electronic elements into conventional static shunt reactive power compensation devices to achieve fast and continuously smooth adjustment. Ideal SVCs can maintain nearly constant voltages at the compensated buses. The good steady and dynamic characteristics render them widely applicable. Their basic elements are thyristor-controlled reactors (TCRs) and thyristor switched capacitors. To save cost, most SVCs connect to systems through step-down transformers. The valve control of the SVC produces harmonics. Filters are installed with SVCs to reduce harmonic contamination. They are capacitive as regards to fundamental frequency and inject reactive power into systems.

A STATCOM is also called an advanced static Var generator (ASVG). Its function is basically same as SVC with wider operation ranges and faster responses. As stated before, the control element of SVC is a thyristor, a semi-controllable element that can only be turned off when valve current crosses zero. STATCOM is made of fully controllable elements. A STATCOM can be represented as a shunt connected, controllable current source for power system stability and control analysis. The magnitude and phase angle are determined by the STATCOM controller [9]

Series Compensators

TCSC and SSSC are the series compensators. Series compensators are used to improve the system voltage by connecting a capacitor in series with the transmission line. In series compensation, reactive power is inserted in series with the transmission line for improving the impedance of the system. It improves the power transfer capability of the line. It is mostly used in extra and ultra-high voltage line.

TCSC can rapidly and continuously change the equivalent reactance of the compensated line, to maintain a constant power flow on the line within certain operating conditions. In system transients, the TCSC can increase system stability through its fast variation of line reactance. It is a series compensation device using semi controllable power electronic elements.

SSSC is a voltage-type inverters connected in series in a transmission line through transformer. Neglecting the line ground branches. It exactly works like the STATCOM except that it is serially connected instead of shunt. Its output is a series injected voltage which leads or lags the line current by 90°. the SSSC can be used to reduce or increase the equivalent line impedance and enhance the active power transfer capability of the line.

Combined type Compensators

The combination could be separated series and shunt controllers or a unified power flow controller. In principle, combined shunt and series Controllers inject current into the system with the shunt part of the Controller and voltage in series in the line with the series part of the Controller. The TCPST and UPFC were called as combined type compensators.

UPFC is a combination of static synchronous compensator (STATCOM) and a static series compensator (SSSC) which are coupled via a common dc link, to allow bidirectional flow of real power between the series output terminals of the SSSC and the shunt output terminals of the STATCOM, and are controlled to provide concurrent real and reactive series line compensation without an external electric energy source. In this thesis modelling of STATCOM and load flow analysis with STATCOM will be discussed in the next section.

IV MODELLING OF FACTS DEVICE

The STATCOM consists of one VSC and its associated shunt-connected transformer. It is the static counterpart of the rotating synchronous condenser but it generates or absorbs reactive power at a faster rate because no moving parts are involved. In principle, it performs the same voltage regulation function as the SVC but in a more robust manner because, unlike the SVC, its operation is not impaired by the presence of low voltages.

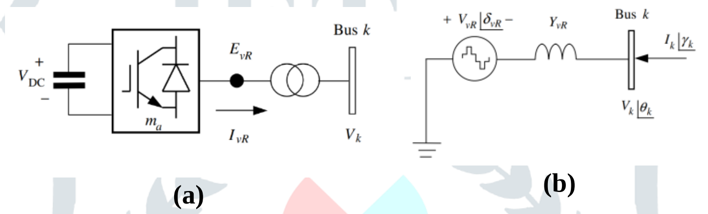

Fig 1 Static compensator (STATCOM) system: (a) schematic representation of STATCOM (b) Equivalent circuit of STATCOM

the shunt voltage source of three phase STATCOM can represented as

$$E_{vR}^{\rho} = V_{vR}^{\rho}(\cos\delta_{vR}^{\rho} + j\sin\delta_{vR}^{\rho}) \quad (5)$$

where, ρ indicates phase quantities of a, b, c. The transfer admittance can be written as

$$[I_k] = [Y_{vr} - Y_{vr}]\begin{bmatrix} V_k \\ E_{vr} \end{bmatrix}$$

$$\left.\begin{aligned} I_k &= [I_k^a\angle\gamma_k^a \quad I_k^b\angle\gamma_k^b \quad I_k^c\angle\gamma_k^c]^T \\ V_k &= [V_k^a\angle\theta_k^a \quad V_k^b\angle\theta_k^b \quad V_k^c\angle\theta_k^c]^T \\ E_{vR} &= [V_{vR\,k}^a\angle\delta_{vR\,k}^a \quad V_{vR\,k}^b\angle\delta_{vR\,k}^b \quad V_{vR\,k}^c\angle\delta_{vR\,k}^c]^T \\ Y_{vR} &= diag[Y_{vR\,k}^a \quad Y_{vR\,k}^b \quad Y_{vR\,k}^c] \\ E_{vR} &= V_{vR}(\cos\delta_{vR} + j\sin\delta_{vR}) \end{aligned}\right\} \quad (6)$$

Based on the shunt connection in fig 3.2 the following equations can be written

$$S_{vR} = V_{vR}I_{vR}^* = V_{vR}Y_{vR}^*(V_{vR}^* - V_k^*)$$

where,

$$\left.\begin{aligned} S_{vR} &= P_{vR} + jQ_{vR} \\ V_{vR} &= V_{vR}\angle\delta_{vR};\ V_k = V_k\angle\delta_k \\ Y_{vR} &= Y_{vR}\angle\theta_{vR}\ \text{(Polar form)};\ Y_{vR} = G_{vR} + jB_{vR}\ \text{(Rectangular Form))} \end{aligned}\right\} \quad (7)$$

The following active and reactive power equations are obtained for the converter and bus k, respectively

$$P_{vR} = V_{vR}^2G_{vR} + V_{vR}V_k[G_{vR}\cos(\delta_{vR} - \theta_k) + B_{vR}\sin(\delta_{vR} - \theta_k)] \quad (8)$$

$$Q_{vR} = -V_{vR}^2B_{vR} + V_{vR}V_k[G_{vR}\sin(\delta_{vR} - \theta_k) - B_{vR}\cos(\delta_{vR} - \theta_k)] \quad (9)$$

V PEV VEHICULAR FLEET

Due to the scarcity of fossil fuels and environmental pollution automobile industry developing electric vehicles has a great influence on the transport sector which reduces air pollution and transport costs 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. The charging station of electric vehicles has a great influence on the power system. A charging station of an electric vehicle can charge over 300 batteries at a time. The participation of the electric vehicle fleet in 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 chapter 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 2.2 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.

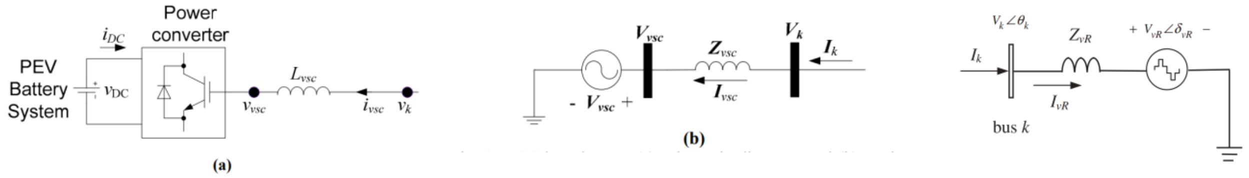

Fig 2 VSC-based PEV: (a) schematic diagram, and (b) equivalent circuit

The schematic diagram and equivalent circuit of the VSC based PEV for reactive power control in power flow studies are presented in Fig. 2 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 The reactive power flow is determined by the amplitude of the source voltage V_k and the VSC output voltage V_{vsc}. Furthermore, the active power supplied by the PEV battery system equals the active power exchange with the grid by assuming a lossless VSCg. Therefore, an additional constraint is defined as,

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

$$V_{vsc} = |V_{vsc}|\angle\delta_{vsc};\ Y_{ik} = |Y_{ik}|\angle\theta_{ik} \qquad (10)$$

The nodal power flow equations at node *k* are,

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

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

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,

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

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

VI Power flow equations with FACTS Device and PEV Vehicular Fleet

The power flow equations for both PEV Vehicular fleet and FACTS Device were

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

$$P_{vsc} = |V_{pev}||V_k||Y_{pev}|\sin(\delta_k - \delta_{pev} + \theta_{pev}) \qquad (16)$$

$$P_{vR} = V_{vR}^2 G_{vR} + V_{vR}V_k[G_{vR}\cos(\delta_{vR} - \theta_k) + B_{vR}\sin(\delta_{vR} - \theta_k)] \qquad (17)$$

$$Q_{vR} = -V_{vR}^2 B_{vR} + V_{vR}V_k[G_{vR}\sin(\delta_{vR} - \theta_k) - B_{vR}\cos(\delta_{vR} - \theta_k)] \qquad (18)$$

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

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

$$\left.\begin{array}{l} \Delta P_k = (P_k^{sp}) - (P_k^{cal} + P_k) \\ \Delta P_{PEV} = (P_{EV-s}) - (P_{PEV}) \\ \Delta P_{vR} = P_{vR}^{sp} - P_{vR}^{cal} \\ \Delta Q_k = (Q_k^{sp}) - (Q_k^{cal} + Q_k) \\ \Delta Q_{pev} = (Q_{pev}^{sp}) - (Q_{pev}^{cal} + Q_{pev}) \\ \Delta Q_{vR} = Q_{vR}^{sp} - Q_{vR}^{cal} \end{array}\right\} \qquad (21)$$

Now, the mismatch vector can be written as,

$$\begin{bmatrix} \Delta P_k \\ \Delta Q_k \\ --- \\ \Delta P_{pev} \\ --- \\ \Delta P_{vR} \\ \Delta Q_{vR} \end{bmatrix} = \begin{bmatrix} \frac{\partial P_k}{\partial \delta_k} & \frac{\partial P_k}{\partial V_k}|V_k| & \frac{\partial P_k}{\partial \delta_{pev}} & \frac{\partial P_k}{\partial \delta_{vR}} & \frac{\partial P_k}{\partial V_{vR}}|V_{vR}| \\ \frac{\partial Q_k}{\partial \delta_k} & \frac{\partial Q_k}{\partial V_k}|V_k| & \frac{\partial Q_k}{\partial \delta_{pev}} & \frac{\partial Q_k}{\partial \delta_{vR}} & \frac{\partial Q_k}{\partial V_{vR}}|V_{vR}| \\ \hline \frac{\partial P_{pev}}{\partial \delta_k} & \frac{\partial P_{pev}}{\partial V_k}|V_k| & \frac{\partial P_{pev}}{\partial \delta_{pev}} & \frac{\partial P_{pev}}{\partial \delta_{vR}} & \frac{\partial P_{pev}}{\partial V_{vR}}|V_{vR}| \\ \hline \frac{\partial P_{vR}}{\partial \delta_k} & \frac{\partial P_{vR}}{\partial V_k}|V_k| & \frac{\partial P_{vR}}{\partial \delta_{pev}} & \frac{\partial P_{vR}}{\partial \delta_{vR}} & \frac{\partial P_{vR}}{\partial V_{vR}}|V_{vR}| \\ \frac{\partial Q_{vR}}{\partial \delta_k} & \frac{\partial Q_{vR}}{\partial V_k}|V_k| & \frac{\partial Q_{vR}}{\partial \delta_{pev}} & \frac{\partial Q_{vR}}{\partial \delta_{vR}} & \frac{\partial Q_{vR}}{\partial V_{vR}}|V_{vR}| \end{bmatrix} \begin{bmatrix} \Delta\delta_k \\ \frac{\Delta V_k}{V_k} \\ --- \\ \Delta\delta_{pev} \\ --- \\ \Delta\delta_{vR} \\ \frac{\Delta V_{vR}}{V_{vR}} \end{bmatrix} \qquad (22)$$

The state variables in the correction vector can be increased by

$$\left.\begin{array}{l} \delta_i^{n+1} = \delta_i^n + \Delta\delta_i^n \\ \delta_{vR}^{n+1} = \delta_{vR}^n + \Delta\delta_{vR}^n \\ \delta_{pev}^{n+1} = \delta_{pev}^n + \Delta\delta_{pev}^n \\ |V_i|^{n+1} = |V_i|^n(1 + \frac{\Delta|V_i|^n}{|V_i|^n}) \\ |V_{vR}|^{n+1} = |V_{vR}|^n(1 + \frac{\Delta|V_{vR}|^n}{|V_{vR}|^n}) \end{array}\right] \quad (23)$$

Where n is an iteration count.

VII Optimal power flow with Differential Evolution considering FACTS and PEV Vehicular Fleet

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

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

VIII 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 FACTS 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 FACTS 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 FACTS multi terminal system it consists of 2 control variables. The basic differential evolution method is applied for 5 iterations. The best results for DE combined with FACTS 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 two terminal FACTS device with PEV vehicular fleet as a load.

DIFFERENTIAL EVOLUTION COST MINIMIZATION			
Control Variables	Min	Max	DE-NRLF
P1	0.10	5.00	2.3832
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	1.0130
V8	0.95	1.06	1.0173
COST($/h)			771.9362
Ploss			0.1932

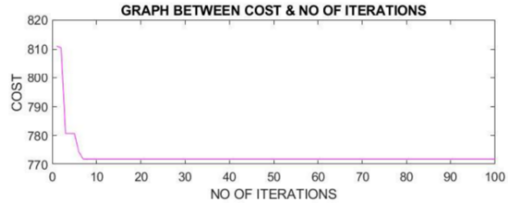

Fig 3(a) Cost variation (DE-NR) for IEEE 14 bus system with two terminal FACTS device with PEV vehicular fleet as a load

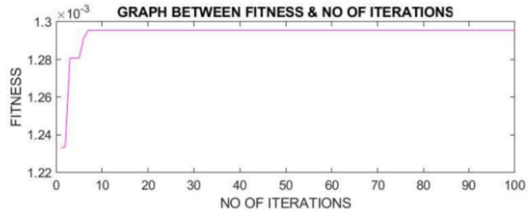

fig 3(b)fitness variation (DE-NR) IEEE 14 bus system with FACTS Device and PEV vehicular fleet as a load

Table 2 Results of DE based cost minimization problem for IEEE 14 bus system with two terminal FACTS device with PEV vehicular fleet as active power injection

DIFFERENTIAL EVOLUTION COST MINIMIZATION			
Control Variables	Min	Max	DE-NRLF
P1	0.10	5.00	2.2684
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	1.0149
V8	0.95	1.06	1.0191
COST($/h)			746.3098
Ploss			0.0784

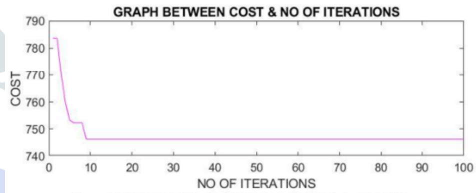

Fig 4(a) cost variation IEEE 14 bus with FACTS Device and PEV vehicular fleet as a active power injection

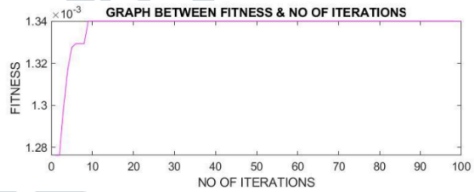

Fig 4(b) fitness variation (DE-NR) IEEE 30 bus with FACTS Device and PEV vehicular fleet as active power injection

Table 3 Results of DE based cost minimization problem for IEEE 30 bus system with FACTS Device and PEV vehicular fleet as a load

DIFFERENTIAL EVOLUTION COST MINIMIZATION			
Control Variables	Min	Max	DE-NRLF
P_1	0.50	2.00	1.6975
P_2	0.20	0.80	1.6618
P_5	0.10	0.35	0.2208
P_8	0.10	0.30	0.1408
P_{11}	0.15	0.50	0.2196
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	1.0163
V_{11}	0.95	1.05	1.0080
V_{13}	0.95	1.05	1.0061
COST($/h)			840.0626
Ploss			0.2565

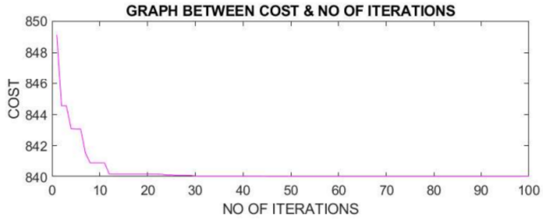

Fig 5(a) Cost variation (DE-NR) IEEE 30 bus system with FACTS Device and PEV vehicular fleet as a load

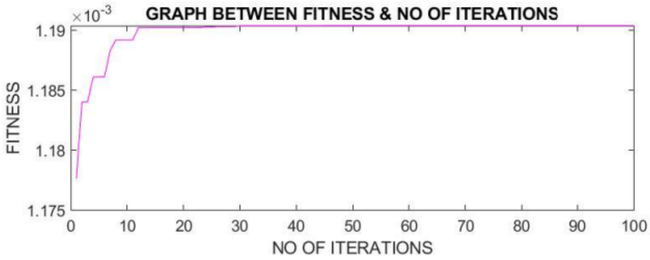

Fig 5(b) Fitness variation (DE-NR) IEEE 30 bus system with FACTS and PEV Vehicular fleet as a load

Table 4.6 Results of DE based cost minimization problem for IEEE 30 bus system with FACTS Device and PEV vehicular fleet as a active power injection

DIFFERENTIAL EVOLUTION COST MINIMIZATION			
Control Variables	Min	Max	DE-NRLF
P_1	0.50	2.00	1.7472
P_2	0.20	0.80	0.6788
P_5	0.10	0.35	0.2573
P_8	0.10	0.30	0.1529
P_{11}	0.15	0.50	0.2237
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	1.0153
V_{11}	0.95	1.05	1.0068
V_{13}	0.95	1.05	1.0047
COST($/h)			881.2454
Ploss			0.3760

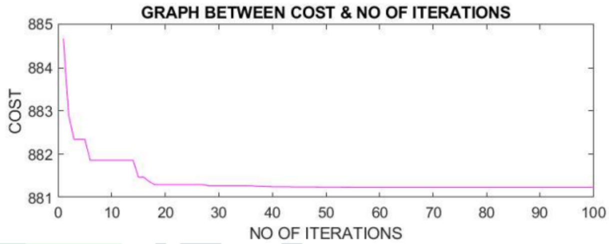

Fig 6(a) Cost variation (DE-NR) IEEE 30 bus with FACTS Device and PEV vehicular fleet as a active power injection

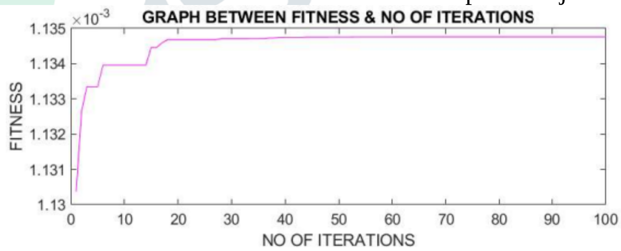

Fig 6(b) Fitness variation (DE-NR) IEEE 30 bus with FACTS Device and PEV vehicular fleet as a active power injection

IX 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 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 FACTS 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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