Optimal Reactive Power Dispatch by Furnishing UPFC Using Multi-Objective Hybrid GAPSO Approach For Transmission Loss Minimisation and Voltage Stability

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Abstract: **The goal of optimal reactive power dispatch is to make the transmission loss minimal in addition to control of voltage profile such that the voltage deviations at the load buses for various loading conditions. By furnishing FACTS devices in the transmission system , the power control can be finely achieved. The paper describes ORPD for the power loss minimisation using optimal sizing of UPFC and its optimal location of UPFC for loss minimisation . The power flow is first solved by NR method without implementing or furnishing UPFC and then by furnishing UPFC randomly in the IEEE -30 bus system. The UPFC allows control of real and reactive power both in addition to voltage magnitude control at various buses. In this paper, OPRD is applied using the hybrid GA -PSO. Simulations are performed on IEEE-30 bus test system using MATLAB software package to ensure efficacy of the proposed algorithm. This paper aims at to find the optimum usage of UPFC which means the finding of the optimal location and size where their influence would be more useful as well as to determine their cost.**

Keywords: Unified Power flow controller UPFC, Genetic algorithm GA, Particle swarm optimisation PSO , Flexible AC transmission devices FACTs, Optimal Reactive Power Dispatch ORPD

I. INTRODUCTION

For security to be the best policy, the secured economic performance of power systems, OPRD plays a vital role. The reactive power is automatically generated with no cost .But; it affects the total generating cost by increasing the transmission loss. Concept that dispatches the reactive power to minimize the transmission loss will be consequent to the lowest production cost while satisfying constraints. Some uncertainties have developed due to tremendous growth of power systems .At the same time, electrical energy is in great demand due to urbanization of life style and industrialisation. With the tremendous advancement of technology, to increase the power delivery, transmission systems are being pushed to operate closer to their stability limits and at the same time reaching their thermal limits [9].

While matching supply and demand, main problems faced by power industry are stability problem and constraint associated with the thermal limit which affects the quality of power delivered [2]. One of the best methods for reducing these constraints and better utilisation of available capacity is FACTS devices which have made the present transmission and distribution of electricity more controllable and more efficient which help in controlling the flow in heavily loaded lines and enhance system stability.

In this paper, the ORPD problem is solved by furnishing the FACTS devices as an additional control parameter in. Power flow model of UPFC as an additional control parameter has been used in this study which finds first the power loss and then optimal location of UPFC and its cost. Earlier, the gradient–based optimization algorithm was used to solve ORPD problem [1,4]. But ORPD being a global optimization problem with several local minima that can lead the conventional optimization solutions to a local minimum [3]. Even, analytic and differential properties of the objective function have to be known in conventional methods to simplify the problem. In the near past , many stochastic algorithms such as simulated annealing, GA and EP were developed to solve the global optimization problem [5].

Recently, few algorithms including FACTS devices are proposed to solve the ORPD problem. However, these researches consider the problem as single-objective and it was solved using several methods, such as, iterative techniques [1], particle swarm optimization (PSO) [4-5], differential evolution [6] and (GA) [7].

This paper aims at hybrid GA-PSO approach for multi objective ORPD, to find UPFC optimum location, its cost a UPFC in a power system, with minimum transmission losses and voltage deviation at load buses. An existing NRLF algorithm is modified to include FACTS devices is presented in [10]. The proposed algorithm is tested on the IEEE-30 bus test system and using MATLAB software package.

II. PROBLEM FORMULATION OF ORPD

ORPD mainly related with minimization active power loss of power system, while satisfying the unit and system equality and inequality constraints such as generator voltage magnitude (V_{Gi}), reactive power generation of capacitor bank (Q_{Ci}) and transformer tap settings (t_K) [8].

Mathematically ORPD problem may be represented as an optimization problem as

$$Minnimise\ J(x,u) \quad (1)$$
$$subjected\ to\ g(x,u) = 0$$
$$and\ h(x,u) \leq 0$$

where, J is the objective function to be minimized, g(x,u) and h(x,u) represent equality and inequality constraints. Here , in this research, J is multi objective functions considering transmission loss, parameter selection for location of UPFC device, then real and reactive power transferred through UPFC leaving bus i to bus j through the dc link, voltage deviation .The equality and inequality constraints are selected as the transmission line constraints and security constraints[6]. Using all these $\bar{x}$ becomes the vector of dependent variables and can be given as follows:

$$x^T = [P_{gref}, V_{PQ}, L_{pij}, L_{qij},] \quad (2)$$

P_{gref} is real power of reference bus,V_{PQ} is voltage at the PQ busses and Q_g is the reactive power of generator.
The control vector $\bar{u}$ is given by is given by:

$$u^T = [P_{PV}, V_{PV}, P_{ijupfc}, Q_{ijupfc}] \quad (3)$$

P_{PV}, V_{PV} are the real power and voltage at the PV busses and T is transformer tap ratio and Q_{UPFC} the shunt and series compensated power of UPFC.

$$J(x,u) = r_a * P_{loss} + r_b(P_{g,ref} - P_{g,ref}^{lim})^2 + r_c \sum_{i=1}^{NPQ}(V_i - V_i^{lim})^2 + r_d \sum_{i=1}^{Ng}(Q_{ijupfci} - Q_{ijupfc}^{lim})^2 + r_e \sum_{i=1}^{Nl}(S_i - S_{li}^{lim})^2 \quad (4)$$

III. UPFC Model For ORPD :

The UPFC consists of the series inverter coupled to transmission line via a series transformer and the shunt inverter coupled to a local bus via a shunt connected transformer. The shunt inverter absorbs or generates controllable reactive power and provide active power exchange to the series inverter to satisfy operating control requirements. Fig. 1 shows the two voltage source model of UPFC.

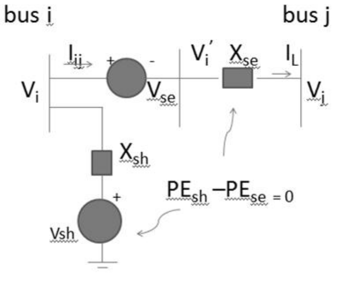

Fig. 1 Two voltage source model of UPFC

V_{se} and V_{sh} represent injected series and shunt voltage source voltages resp. X_{se} and X_{sh} are the UPFC series and shunt coupling transformer reactance resp. V_i and V'_i are voltages at buses i, i' and V_j is the voltage of bus j of the receiving end of transmission line. Ish is the shunt current through the UPFC shunt converter[11].

$$V_i = V_i\angle 0$$
$$V_i' = V_{se} + V_i \quad (5)$$
$$V_{se} = rV_i e^{j\gamma}$$
$$I_{se} = -jb_{se}V_{se} \quad (6)$$
$$S_{is} = V_i I_{se}^*$$
$$S_{js} = V_j I_{se}^* \quad (7)$$
$$P_{is} = -rb_{se}V_i^2 \sin\gamma$$
$$Q_{is} = -rb_{se}V_i^2 \cos\gamma \quad (8)$$
$$P_{js} = V_iV_jb_{se}r\sin(\theta_i - \theta_j + \gamma)$$
$$Q_{js} = V_iV_jb_{se}r\cos(\theta_i - \theta_j + \gamma) \quad (9)$$

$P_{shunt} = P_{se}$ for the lossless operation of UPFC
$P_{shunt} = -1.02\ P_{se}$ if losses have to be included.

P_{sh} and P_{se} are the active power exchange of converters with the DC link. P_{ij},Q_{ij} and P_{ji},Q_{ji} are the real and reactive power flows leaving bus i and bus j respectively.

$$P_{sh} = V_i^2 * g_{sh} - V_iV_{sh}(g_{sh}\cos(\theta_i - \theta_{sh}) + b_{sh}\sin(\theta_i - \theta_{sh})) \quad (10)$$
$$Q_{sh} = -V_i^2 * b_{sh} - V_iV_{sh}(g_{sh}\sin(\theta_i - \theta_{sh}) - b_{sh}\cos(\theta_i - \theta_{sh})) \quad (11)$$

The active and the reactive power supplied by the series converter of UPFC is given by

$$P_{series} = rV_iV_jb_{se}r\sin(\theta_i - \theta_j + \gamma) - rb_{se}V_i^2\sin\gamma \quad (12)$$

$$Q_{series} = -rV_iV_jb_{se}r\cos(\theta_i - \theta_j + \gamma) + rb_{se}V_i^2\sin\gamma + r^2b_{se}V_i^2 \quad (13)$$

The operating constraints of the UPFC (active power exchange between two inveters via the DC link) is :

$$\Delta P_{\Sigma} = PE_{sh} - PE_{se} = 0 \quad (14)$$

Where,$PE_{sh} = Re(V_{sh}I_{sh}^*)$ $and\ PE_{se} = Re(V_{se}I_{ij}^*)$

There are in all 13 modes of operation of UPFC in power flow control [11]. The control equation of any mode can be generally written as:

$$\Delta F(x, f^{spec}) = 0$$
$$\Delta G(x, g^{spec}) = 0 \quad (15)$$

Where $x = [\theta_i, V_i, \theta_j, V_j, \theta_{se}, V_{se}]^T$;
f^{spec} and g^{spec} are the control references.

For the analysis purpose, the steady state model of UPFC is described by following equations and is as shown in Fig. 2

$$P_{iUPFC} = -1.02rV_iV_jb_{se}\sin(\theta_i - \theta_j + \gamma) + 0.02rb_{se}V_i^2\sin\gamma$$
$$P_{jUPFC} = rV_iV_jb_{se}\sin(\theta_i - \theta_j + \gamma) \quad (16)$$
$$Q_{iUPFC} = -rb_{se}V_i^2\cos\gamma$$
$$Q_{jUPFC} = rV_iV_jb_{se}r\cos(\theta_i - \theta_j + \gamma) \quad (17)$$

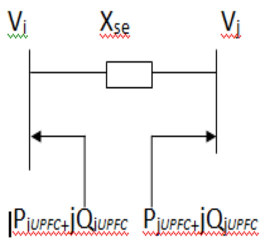

Fig. 2 Steady state model of UPFC

IV. HYBRID PARTICLE SWARM OPTIMIZATION (PSO)

The hybrid approach consists of two stages.

1. Implementation of GA
2. Implementation of PSO

IV.1 IMPLEMENTATION OF GA

The common terms used while solving problem using GA are:

- **Search space:** The space of all feasible solutions which all desired solutions resides is called search space. Each point in the search space represents one possible solution which can be marked by its fitness value for the problem.
- **Population:** it is the number of individuals present with the same length of solutions.
- **Fitness:** it is the value assigned to an individual present with the same length of solution it contains.
- **Fitness function:** it is a function that assigns fitness value to the individual . It is problem specific.
- **Selection :** Selecting individual for creating the next generation .
- **Crossover:** The main objective of crossover is to recognize the information of two different individuals and produce a new one.
- **Mutation:** It is nothing but randomly changing the values in a solution. It is used to introduce some part of artificial diversification in the population to avoid premature convergence to local optimum.

In stage-1, GA has been applied. Firstly to generate the chromosome generation based on random voltages values on the load busses. Using this , the values of P_i and Q_i at various busses have been found out for the system . The Jacobean matrix elements of NRLF have been calculated .Then crossover has been applied using these load values . All these give the children solutions. Then using these random load values , mutation has been done and fitness function selects the best line with power output has been calculated to give maximum loss in the transmission lines for the proper concoction of UPFC.

For optimum location of UPFC following function has been used

$$\Phi = Max\left\{ |V_i||V_j||Y_{ij}|\sum_{n=1}^{N}\cos(\theta_{ij}-\delta_i-\delta_j) \right\} \qquad (18)$$

IV.2 IMPLEMENTATION OF PSO

PSO is a swarm intelligence population based evolutionary algorithm for global optimization. PSO is basically developed through simulation of bird flocking in two-dimension space. The position of each agent is represented by XY axis position and also the velocity is expressed by V_x and V_y (the velocity along X-Y axes). Each agent knows its best value so far (p_{best}) and its XY position and in the group (g_{best}). This information is analogy of personal experiences of each agent. Namely, each agent tries to modify its position using the following information: - the current positions (x, y); the current velocities (vx, vy); the distance between the current position and pbest; the distance between the current position and gbest. Various terminologies used in PSO are

- Particle definition
- PSO Parameters
- Number of particles
- Inertia weight (w)
- Acceleration constants
- Number of iterations
- Values of velocity which is given as follows

$$V_i^{m+1} = wV_i^m + a_1 rand1(P_{best} - X_i^m) + a_2 rand2(g_{best} - X_i^m) \qquad (19)$$

Where

$$w = w_{max} - \frac{w_{max} - w_{min}}{iter_{max}} \times iter \qquad (20)$$

$$X_i^{m+1} = X_i^m + V_i^{m+1} \qquad (21)$$

In stage 2, PSO has been applied. Firstly the lines are arranged in the descending order of the power loss and using this data, the velocity function has been written to give the based on the voltages at various busses .Here, GA has been employed to obtain the optimal region quickly and in stage-2, the PSO with systematic reduction of the size of the search region [16] is used to find the local optimum. Here, function used for optimum capacity of UPFC calculation is

$$\Psi = Min\sum_{i=1}^{N_B}(V_{Normal} - V_i) \qquad (22)$$

Where, V_{normal} is the normal voltage and V_i is the voltage at i^{th} bus .

V. THE OPERATIONAL INDICES

Various operational indices considered in the algorithm are as follows:

i)Voltage Profile Index(VPI): Basically this index will measure the variations in voltages at all the busses with respect to V_{ref} .For accuracy flat voltage profile is always preferred. VPI is calculated as

$$VPI = \sum_{i=1}^{N} \left| V_{normal} - V_{iupfc} \right| \quad (23)$$

The per unit value of this VPI is given by

$$PUVPI = \frac{VPI_{with\,upfc}}{VPI_{w/tupfc}} \quad (24)$$

ii)Voltage Stability Index(VSI):Basically this index is calculated for all busses except slack bus from bus no.2 to all other busses as follows:

$$VSI_i = \left| 1 + \frac{V_{normal,i}}{V_i} \right|^2 \quad (25)$$

iii)Power loss sensitivity Index(PLSI):The variation in power loss has inverse relation with the voltage profile at various busses. Power loss sensitivity index at each bus is given by

$$PLSI_i = \frac{\partial P_L}{\partial V_i} \times \Delta V_i \quad (26)$$

The transmission loss minimises as the $PLSI_i$ becomes more and more negative. The variations To ensure validity of the proposed hybrid method, it is tested on standard IEEE- 30 bus test system having non-linear characteristics. The results of the proposed hybrid approach prove the effectiveness of the proposed approach in terms of solution quality and computation time.

VI. SIMULATION RESULTS AND DISCUSSIONS

The IEEE -30 BUS system is used as the test system to prove the effectiveness of the proposed algorithm for ORPD. Firstly, it is simulated for normal load flow using NRLF analysis .The total power losses have been found to be 10.8095pu. Then the load on the load bus is randomly increased. Fig.3 shows the plot for variations in the voltages at various busses without increasing the load , with increasing the load. It has been observed that the losses have increased to 11.461pu. Here, now by randomly concocting UPFC, IEEE 30 bus system is simulated for the load variations and again the power losses have been found to be10.9983pu. The proposed approach is proved to be efficient from the results of hybrid GAPSO to be 9.4652pu. Fig.4 Depicts the power losses in all lines of IEEE 30 bus system for the normal load flow , with increase in load and with proposed approach. Fig. 5 gives the Comparison of Power loss in a line and randomly three transmission lines are chosen for which the comparative results of power loss have been drawn in Fig. 6 for normal load condition, for increased load and optimised values using the proposed algorithm. Fig. 7 shows the error function calculation for the placement of UPFC in the transmission line between bus no. 6 and bus no.7 . Fig.8 shows the variation of power loss sensitivity index with the variation of voltage profile for the placement of UPFC in transmission line between bus no. 6 and bus no.7 .

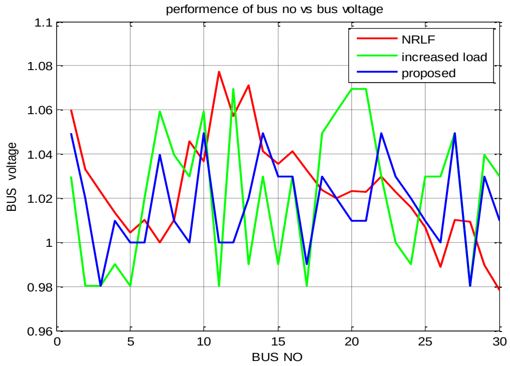

Fig.3 Plot of bus voltages at various busses

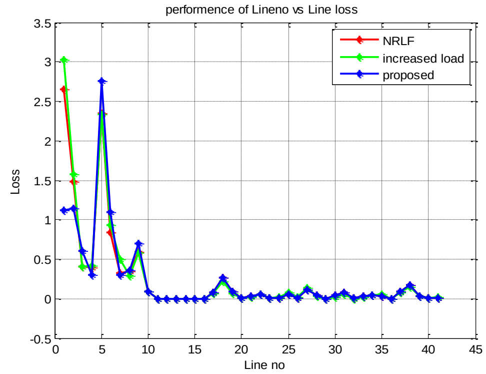

Fig. 4 Plot of power loss in all the transmission lines of IEEE -30 bus system

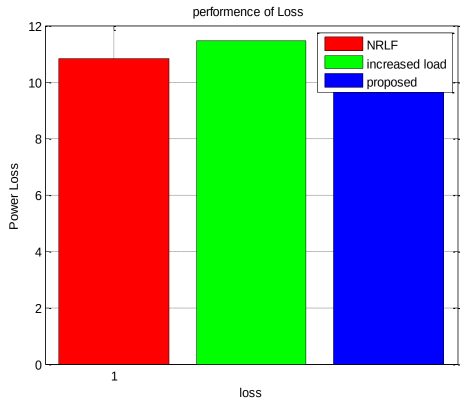

Fig. 5 Comparison of Power loss in the line at normal , increased load and optimised loss

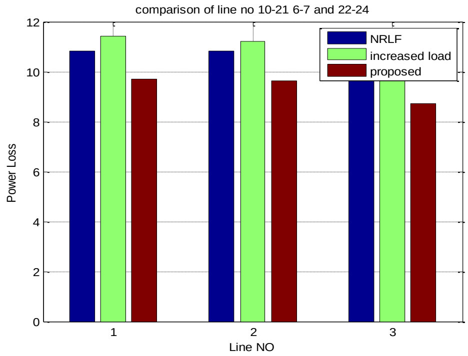

Fig. 6 Comparison of Power Loss of three lines

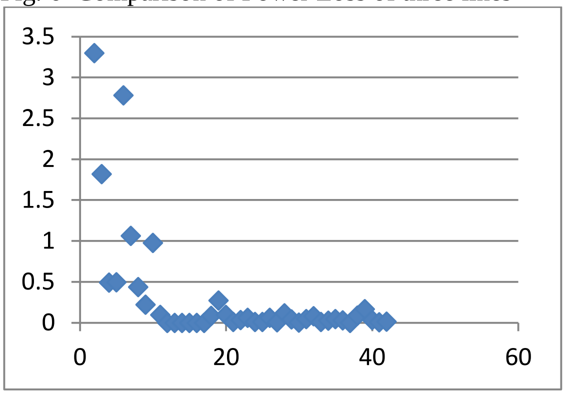

Fig.7 Error function for UPFC placement in line6-7

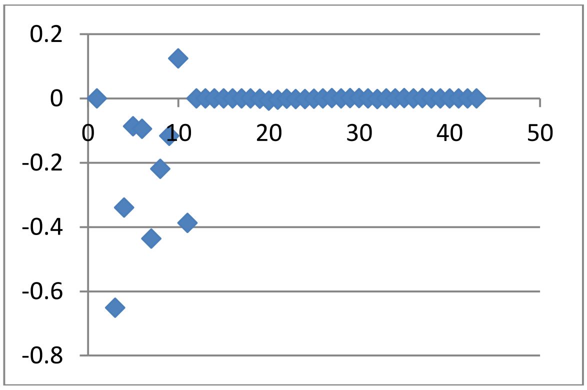

Fig.8 Power loss sensitivity for UPFC placement in line 6-7

VII. CONCLUSION

A mathematical model for ORPD and simultaneously optimising concoction and cost of UPFCs is presented in this paper. It includes two important aspects: to minimise power loss and maximise the system load ability via optimising location and parameters of the given number of UPFCs and voltage constraints at various busses must be satisfied during optimisation. A multi objective hybrid computational intelligence approach i.e. GA-PSO is used to solve this multi objective nonlinear programming problem. The computation schemes are discussed in detail, such as the construction of chromosome, handling of equality and inequality constraints, consideration of network losses, voltages at various buses the location of UPFC to be implemented , its cost and the power flow computation etc. The case studies of the IEEE- 30 system has confirmed that the this method is very effective and exact for solving the ORPD .

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