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Abstract - The introduction of flexible AC transmission system (FACTS) in a power system reduces the losses, reduces the cost of generation, and improves the stability also improves the load capability of the system. In this paper, a non-traditional optimization technique, genetic algorithm is used to optimize the various process parameters involved of FACTS devices in a power system The various parameter taken into the consideration were the location of the FACTS were their types and their rated value of the device. A genetic algorithm (GA) is simultaneously is used to minimize the total generation cost, and power loss/voltage deviation with in true and reactive power generation limits, Test results on the modified IEEE 30-bus system with various types of the FACTS controller The optimization results clearly indicates that the correct location of the FACTS devices will increase the loadability of the system and GA can be effectively used for this type of optimization.

Keywords - *Genetic Algorithm, FACTS, Optimal power flow, Optimization, Load flow.*

I. INTRODUCTION :

OPF [1] is a nonlinear programming problem, and is used to determine optimal outputs of the generators, bus voltage and transformer tap, setting in power system, with an objective to minimize total production cost. OPF was introduced in 1968 [2], several methods have been employed to solve this problem, *e.g*. Gradient base[2], Linear programming method [3] and Quadratic programming [4]. However all of these methods suffer from three main problems.

Firstly, they may not be able to provide optimal solution and usually getting stuck at a local optimal.

Secondly, all these methods are based on assumption of continuity and differentiability of objective function which is not actually allowed in the practical system.

Finally, all these methods cannot be applied with discrete variables, which are transformer taps. It seems that GA is an appropriate method to solve this problem, which eliminates the above drawbacks. GA, invented by Holland [5] in the early 1970s, is a stochastic global search method that mimics the metaphor of natural biological evaluation. Genetic Algorithms (GAs) operates on a population of candidate solutions encoded to finite bit string called chromosome. In order to obtain optimality, each chromosome exchanges the information using operators borrowed from the natural genetic to produce the better solution. GAs differs from other optimization and search procedures in four ways [6]:

(1) GAs work with a coding of the parameter set, not the parameters themselves. Therefore GAs can easily handle the integer or discrete variables.

(2) GAs search within a population of points, not a single point. Therefore GAs can provide a globally optimal solution.

(3) GAs use only objective function information, not derivatives or other auxiliary knowledge. Therefore GAs can deal with the non-smooth, non-continuous and no differentiable functions which are actually exist in a practical optimization problem.

(4) GAs use probabilistic transition rules, not deterministic rules, Although GAs seem to be a good method to solve optimization problem, sometimes the solution obtained from GAs is only a near global optimum solution

The use of flexible AC transmission system (FACTS) such as Thyristor controlled series compensation (TCSC), Thyristor controlled phase angle regulator (TCPAR), Unified power flow controllers (UPFC) and static Var compensators (SVC). These FACTS devices control the power flow in the network and also they to increase the system stability in the network and reduces the losses and reduce the cost of the production.

Therefore, it is necessary for any new installation of FACTS to be very well planned. This needs an off-line simulation of the power system with the different candidate FACTS devices location to assess the value added to the system in terms of system operation improvement. Among the different assessment tools used for this purpose, optimal power flow (OPF) [2]& [4] seems to be the best. By incorporating FACTS devices [9] in OPF with some modification, it can give scalar measures of its economic and technical benefits and so help in deciding for the optimal investment.OPF is a non-linear problem and can be non-convex in some cases. Moreover, incorporating FACTS devices complicates the problem further. Such complicated problem needs a well-efficient optimization technique for solving. Genetic algorithm is such efficient technique employed for this task in this paper.

Genetic algorithms (GAs) are parallel and global search techniques that emulate natural genetic operators. The GA is more likely to converge toward the global solution because it, simultaneously, evaluates many points in the parameter space. It does not need to assume that the search space is differentiable or continuous [6] In recent paper [7], the Genetic Algorithm Optimal Power Flow (GAOPF) problem is solved based on the use of a genetic algorithm load flow, and to accelerate the concepts it propose the use of gradient information by the use of the steepest decent method. The method is not sensitive to the starting points and capable to determining the global optimum solution to the OPF for range of constraints and objective functions. But GAOPF requires two load flow to be performed per individual, per iteration because all controllable variables are included in the fitness.

The main objective of this paper is to develop an algorithm to find and choose the optimal location of FACTS devices based on the Economic saving function, which obtained by energy loss reduction. Since there are different types of FACTS devices and their different location have different advantages. In realizing, for the proposed objective function, the suitable types of FACTS device, their location, and their rated value must be determined simultaneously. Thus this type of problem is solved by Genetic algorithm.

This paper is organized as follows: following the introduction, different FACTS devices mathematical models are described in section II. Then in section III, objective functions are described. In section IV, the genetic algorithms for optimal location of FACTS Devices are discussed in detail. The simulation results are given in section V.

2. MATHEMATICAL MODEL OF THE FACTS DEVICES

2.1. FACTS DEVICES

In the interconnected power system network power flows obey the Kirchoff's laws. The resistance of the transmission line is small compared to the reactance. Also the transverse conductance is close to zero. The active power transmitted by a line between the buses i and j may be approximated by following relationships:

$$P = \frac{V_i V_j}{X_{ij}} \sin(\delta_{ij}) \qquad (1)$$

Where Vi and Vj are voltages at buses i and j ;Xij: reactance of the line; δij: angle between the Vi and Vj. Under the normal operating condition for high voltage line the voltage Vi =Vj and θij is small. The active power flow coupled with θij and reactive power flow is linked with difference between the Vi-Vj. The control of Xij acts on both active and reactive power flows. The different types of FACTS devices have been choose and locate optimally in order to control the power flows in the power system network. The reactance of the line can be changed by TCSC.TCPAR varies the phase angle between the two terminal voltages and SVC can be used to control the reactive power. UPFC is most power full and versatile device, which control line reactance, terminal voltage, and the phase angle between the Buses. In this paper, four different typical FACTS devices have been selected: TCSC, TCPAR, SVC and UPFC. Their block diagrams are shown in Figure 1.

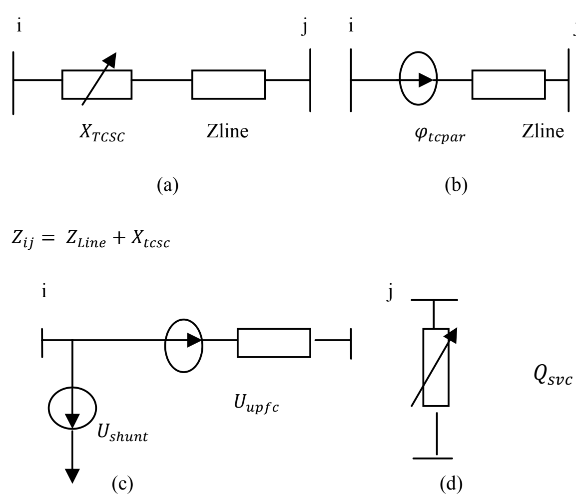

FIG. 1 : BLOCKS DIAGRAM OF THE CONSIDERED FACTS DEVICES- A) TCSC B) TCPST C) UPFC D) SVC

Thus the above FACTS devices can be applied to control the power flow by changing the parameters of the power system so that the power flow can be optimized.

2.2. MATHEMATICAL MODELS:

The power-injected model is a good model for FACTS devices because it will handle them well in load flow computation problem. Since, this method will not destroy the existing impedance matrix Z; it would be easy while implementing in load flow programs. In fact, the injected power model is convenient and enough for power system with FACTS devices. The Mathematical models of the FACTS devices are developed mainly to perform the Steady state research. The TCSC, TCPAR, SVC and UPFC are modeled using the power injection method [4,]-[5][8][13], Furthermore, the TCSC, TCPAR, SVC and UPFC mathematical model are integrated into the model of the Transmission line. Fig: 1 shows a simple transmission line, the parameter are connected between bus i and bus j.the voltages and angles at the buses i and j are Vi, δi and Vj, δj respectively. The real and reactive power flow between the buses i to bus j can be written as

$$P_{ij} = V_i^2 G_{ij} - V_i V_j [G_{ij}\cos(\delta_{ij}) + B_{ij}\sin(\delta_{ij})] \quad (2)$$

$$Q_{ij} = -V_i^2 (B_{ij} + B_{sh}) - V_i V_j [G_{ij}\sin(\delta_{ij}) - B_{ij}\cos(\delta_{ij})] \quad (3)$$

Where $\delta_{ij} = \delta_i - \delta_j$ similarly the real and the reactive power flow between the bus j to bus i is given by-

$$P_{ji} = V_i^2 G_{ij} - V_i V_j [G_{ij}\cos(\delta_{ij}) - B_{ij}\sin(\delta_{ij})] \quad (4)$$

$$Q_{ij} = -V_i^2 (B_{ij} + B_{sh}) + V_i V_j [G_{ij}\sin(\delta_{ij}) + B_{ij}\cos(\delta_{ij})] \quad (5)$$

2.2.1 Modelling of TCSC: TCSC is a controllable series reactance with control variableX_s. The model of the TCSC is showed in the ***figure 1***

$$P_i(com) = V_i^2 \Delta G_{ij} - V_i V_j [\Delta G_{ij}\cos(\delta_{ij}) + \Delta B_{ij}\sin(\delta_{ij})] \quad (6)$$

$$P_j(com) = V_j^2 \Delta G_{ij} - V_i V_j [\Delta G_{ij}\cos(\delta_{ij}) - \Delta B_{ij}\sin(\delta_{ij})] \quad \text{…………… (7)}$$

Similarly the reactance power injected at bus i and j (Q_i(com)) can be expressed as-

$$Q_i(com) = -V_i^2 \Delta B_{ij} - V_i V_j [\Delta G_{ij}\sin(\delta_{ij}) - \Delta B_{ij}\cos(\delta_{ij})] \quad \text{……………… (8)}$$

$$Q_j(com) = -V_j^2 \Delta B_{ij} + V_i V_j [\Delta G_{ij}\sin(\delta_{ij}) + \Delta B_{ij}\cos(\delta_{ij})] \quad \text{……………… (9)}$$

Where

$$\Delta G_{ij} = \frac{X_c R_{ij}(X_{tcsc} - 2X_{ij})}{(R_{ij}^2 + X_{ij}^2)(R_{ij}^2 + (X_{ij} - X_{tcsc})^2)} \quad (10)$$

$$DB_{ij} = \frac{-X_{tcsc}(R_{ij}^2 - X_{ij}^2 + X_{tcsc}X_{ij}}{(R_{ij}^2 + X_{ij}^2)(R_{ij}^2 + (X_{ij} - X_{tcsc})^2)} \quad (11)$$

2.2.2 Modelling of TCPAR: The voltage angle between the buses i and j can be regulated by TCPAR.The model of a TCPAR with transmission line as shown in fig.1. The injected real and reactive power at buses i and j having the phase shifter are

$$P_i(com) = -V_i^2 S^2 G_{ij} - V_i V_j S [G_{ij}\sin(\delta_{ij}) - B_{ij}\cos(\delta_{ij})] \quad (12)$$

$$P_j(com) = -V_i V_j S [G_{ij}\sin(\delta_{ij}) + B_{ij}\cos(\delta_{ij})] \quad (13)$$

$$Q_i(com) = -V_i^2 S^2 B_{ij} + V_i V_j S [G_{ij}\cos(\delta_{ij}) + B_{ij}\sin(\delta_{ij})] \quad \text{…….. (14)}$$

$$Q_j(com) = -V_i V_j S [G_{ij}\sin(\delta_{ij}) - B_{ij}\cos(\delta_{ij})] \quad (15)$$

Where:

$$S = \tan(\varphi)_{tcpar} \quad (16)$$

2.2.3 Modelling of UPFC: A series inserted voltage and phase angel of inserted voltage can model the effect of UPFC on network. The inserted voltage has a maximum magnitude of Vt=0.1Vm, where the Vm is rated voltage of the transmission line, where the UPFC is connected. It is connected to the system through two coupling transformers [8,113].The real and reactive power injected at buses i and j can expressed as follows:

$$P_i(com) = -V_t^2 G_{ij} - 2V_i V_j G_{ij}\cos(\emptyset_{upfc} - \delta_{ij}) + V_i V_j [G_{ij}\cos(\emptyset_{upfc}) + B_{ij}\sin(\emptyset_{upfc})] \quad \text{…… (17)}$$

$$Q_i(com) = V_i V_j [G_{ij}\sin(\emptyset_{upfc} - \delta_{ij}) + B_{ij}\sin(\emptyset_{upfc})] \quad (18)$$

$$P_j(com) = V_j V_t [G_{ij}\cos(\emptyset_{upfc}) - B_{ij}\sin(\emptyset_{upfc})] \quad (19)$$

$$Q_j(com) = -V_j V_t [G_{ij}\sin(\emptyset_{upfc}) + B_{ij}\cos(\emptyset_{upfc})] \quad (20)$$

2.2.4 Modelling of SVC:the main purpose of SVC is to control the voltage at weak points in a network. Thus this SVC should be installed at the centre of the transmission line. The reactive power of an SVC can be defined as

$$Q_{SVC} = \frac{V_i(V_i - V_r)}{X_s 1} \quad (21)$$

Where, $X_s 1$ is the equivalent slope reactance in P.U equal to the slope of the voltage control characterstics and V_r are reference voltage magnitude. The exact loss formula of the system having N number of buses is [1]

$$P_{1t}^{c} = \sum_{j=1}^{N}\sum_{K=1}^{N} \alpha jk(PjPk+QjQk)+\beta jk(QjPk\text{-}PjQk) \quad \ldots.. (22)$$

Where PjPk and QjQk respectively are real and reactive power at bus-j and αjk,βjk are the loss coefficient defined by

Where

$$\alpha jk = \frac{Rjk}{ViVk}\cos(\delta j - \delta k) \quad (23)$$

$$\beta jk = \frac{Rjk}{ViVk}\sin(\delta j - \delta k) \quad (24)$$

Where Rjk is the real part of the j-K^{th} element of [Z-bus] matrix. The total loss if the FACTS device one at a time is used can be written as follows [12]

$$P1k = (P_{1k}^{c} - [P_i(com) - P_j(com)]) \quad (25)$$

More than ine device used at the time can be expressed as

$$\text{P1k} = (P_{ik}^{c} - \sum_{d=1}^{Nd}[(P_i(com) + P_j(com)] \quad (26)$$

Where Nd is the number of devices to be located at various lines.

3. OBJECTIVE FUNCTION:

The aim is that to utilize the FACTS device for optimal amount of power in a system is to supply without overloaded line and with an acceptable voltage level. The optimal location of FACTS device problem is to increases as much as possible capacity of the network.i.e loadability. In this work, the FACTS devices have been considered to Economic saving function, which obtained by energy loss, it requires calculation of total real power losses at the day and light load levels.

Objective function is give by-

Min F(u) is

$$P_L(V,d,s) = \sum_{i=1}^{N} P_{Lt} * E_{loss} * \Delta t - C_{in} \quad (27)$$

Subject to

F(b,v) = 0

F1(S)<M1

F2(V)<M2

Where u set of parameters that indicates the location, device and the rated value. F (b, v): conventional power flow equations, and ΔT –time duration. E_{loss} is energy loss cost. C_{in} is investment cost of FACTS device. F_1(s) <M_1, and F_2 (v) <M_2 are inequality constraints for FACTS devices, and conventional power flows. The FACTS devices can be used to change the power system parameters. These parameters derive different results on the objective function (1). Also various FACTS device locations, rated value and types have also influences on the objective function. The above-mentioned parameters are very difficult to optimize simultaneously by conventional optimization methods. To solve this type of combinatorial problem, the genetic algorithm is employed. The genetic algorithms are well developed and utilized effectively for this work. The C computer coding are developed and for simulated.

4. GENETIC ALGORITHM

Heuristic methods may be used to solve the complex optimization problems. Thus, they are able to give a good solution of a certain problem in a reasonable computation time, but they do not assure to reach the global optimum [3]-[4]- [5]. In case of GAs (Genetic Algorithm) are global search technique, based on the mechanisms of natural selection and genetics; they can search several possible solutions simultaneously. The GAs start with random generation of initial population and than the selection, crossover and mutation are produced until the best population is found

ENCODING:

The main objective of the optimization is to find the best locations for the given number of FACTS devices within the defined constrains. The configuration of FACTS devices is obtained by three parameters: the location of the devices, their types and their rated values. [4,5]. Each individuals is represented by n-facts number of strings, i.e. number of FACTS devices to be used this optimization problem. The first values of the each string indicate the location information. Only one device in a transmission line, the second value of the string is represent the type of the devices: TCSC for 1, TCPAR for 2, SVC for 3, UPFC for 4 and zero for no device is connected. The last value stands for rated value of the each device. According to the model of the FACTS devices, the rated values (RV) of each FACTS device is converted into the real compensation as follows:

TCSC: The TCSC has a working range between -0.8 Xij and 0.2 Xij, where Xij is the reactance of the transmission line, where the TCSC installed.

$$X_{tcsc} = RV * 0.45 - 0.25$$

TCPAR: the working rage of TCPAR is in between the -5 degrees to +5 degrees

$$\varphi_{tcpar} = RV * 5 degrees$$

SVC: The working range of the SVC is between –100Mvar and +100Mvar. The SVC has been considered as a reactive power sources with the above limit.

$$V_{SVC} = RV * 100(MVAr)$$

UPFC: The working range of the UPFC is between -180 degrees to +180 degrees.

$$\varphi_{UPFC} = RV * 180\ degree$$

5. INVESTMENT COST:

Since different FACTS devices cost function are developed on the base of the Siemens AG Database [15]. The cost function of SVC, TCSC and UPFC are related to operating ranges but, in case of TCPAR it depends on the operating voltage and current of the circuits, it is fixed, where it is located, the cost function can expressed as

C_{in}= T_{limit} + installation cost, where T_{limit} is thermal limit of the line.

The cost function for SVC, TCSC and UPFC is:

C_{insvc}=0.0003S^2–0.3051S+127.38(US$/Kvar) (28)

C_{intcsc} =0.0015S^2 –0.7130S+153.75(US$/Kvar). (29)

C_{inupfc} =0.0003S^2 –0.2691S+188.22(US$/Kvar) (30).

Where S is the operating rating of the FACTS devices in MVAr .and$C_{insvc,}C_{intcsc}$ are in US$/Kvar

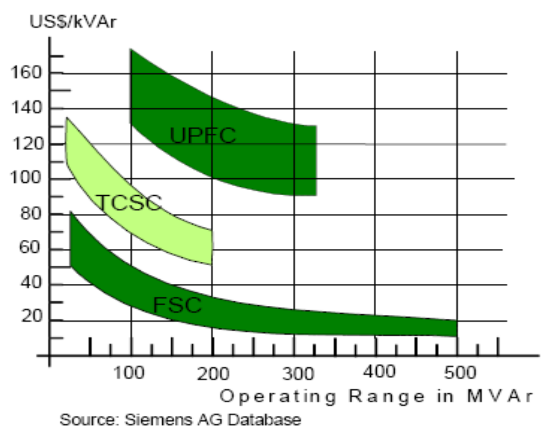

FIG. 2 : INVESTMENT COST CURVE

6. INITIAL POPULATION:

The initial population is generated from the following parameters [4]-[5], N_{FACTS} is the number of the FACTS devices to be located, the possible location of the devices i.e $N_{location}$, types of the device i.e N_{types}, and N_{ind} is the number of individual of the population The first, a set of NFACTS numbers of strings are produced. For each string, the first value is randomly chosen from drawing numbers among the selected devices. The third value of each string, which contains the rated values of the FACTS devices, is randomly selected between the -1 and +1. To obtain the entire initial population and the above process is repeatedN_{ind} times.

The objective function is computed for each individual of the population. In this case the objective function is define in order to determine the impact of the FACTS devices on the state of the power system. The inverse of the objective function is used to calculate the fitness of each individual in the population

Fitness = 1/ Objective function +1

Reproduction:

This technique is based on the roulette wheel selection [3, 4, 5] is used in this paper for reproduction, According to their fitness value the fitness is selected to move to a new generation.

Crossover:

A crossover is a technique which is used to rearrange the information between the two different types of the individual and produce the new one. In this paper a two point crossover is employed and the probality P_c of the crossover is 0.75.

Mutation:

The probality of the mutation is less than 0.05. Mutation is used to random alteration of bits of the string position. The bits will be changed from$\pm$0.5. the above process can be explained by the use of flowchart.

Start

Read the line data's N_{FACTS},N_{TYPES}

Generate the Initial

Calculate the fitness value of each individual

Crossover, Mutation

Best individual is found

Output of the best individual is selected

Print result

Stop

FIG. 3 : FLOWCHART OF GENETIC ALGORITHM

7. SIMULATION TOOL:

Power flows are solved with the help of AU power software package. Simulation was carried out on IEEE 30 bus test system, it consist of 30 bus, 41 lines, generator are modelled as PV-node, load are modeled as PQ-node, the line is modeled using the classical π scheme.

8. SIMULATION RESULT

The modified IEEE 30 bus test system is shown in figure 4 is used to check the effectiveness of the proposed algorithm. Whose line and data can be found out from [14]. Also in this paper the used and the location of the FACTS devices are considered for the economic saving function which is obtained by the energy loss reduction also there are different operating condition are simulated for the optimal location FACTS devices problem; reducing the transmission real power loss changes the transmission line capacity. In case of single device optimization the simulation result are shown in the table 1 since TCSC and SVC provides relatively less reduction in total active power loss while the use of TCPAR provides 7% more reduction in losses and also it reduces the total real power loss in MW and increases the revenue saving per day the details are shown in table 4 The FACTS device which not only reduces the real power loss but also improves the loadability, stability of the system and improves the voltage. The Table2 shows the results of voltage increases due to location of FACTS devices in a network. Figure 3 shows the number of devices required to reduce the total real power loss of the system. From the results declared that, the UPFC effectively reduces the losses up to 89-90% of the total loss, and in case of, TCSC, TCPAR, and SVC reduces the losses up to 75%, 70-73% and 55% of total power loss reduction respectively. Less number of devices used is to obtain 89-90% of loss reduction by UPFC, but for other cases the number of devices will be increased. From the results it is clear that UPFC is the most powerful FACTS device while comparing other devices. Since the initial investment cost of UPFC is very high. Other devices like: TCSC, TCPAR, and SVC

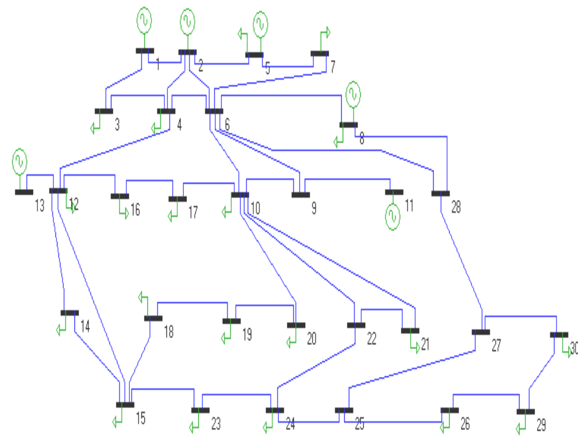

FIG. 4 : IEEE 30 BUS SYSTEM

TABLE 1. ENERGY LOSS COST

Load Level	Cost [$/KWh]
Day Load	0.60
Night Load	0.44

TABLE 2. ECONOMIC SAVING COST

Device	Economic Saving / Day (Day- Load)	Economic Saving / Day (Light-Load)
1. TCSC	$0.3365	$0.3104
2. SVC	$0.3203	$0.2817
3. TCPAR	$0.5182	$0.4844
4. UPFC Vt=0.03	$0.5324	$0.4892

TABLE 3. SHOWS THE VOLTAGE DIFFERENCE AFTER AND BEFORE THE LOCATION OF FACTS DEVICES

Before		After	
Bus 1	1.060	Bus 1	1.060
Bus 25	0.94865	Bus 25	0.98864
Bus 26	0.92964	Bus 26	0.949646
Bus 29	0.92992	Bus 29	0.9304
Bus 30	0.91749	Bus 30	0.91741

TABLE 4. SIMULATION RESULT

From Line	To Line	Device Type	Rated Value	Total Power loss	% Power loss Reduction
2	5	TCSC	18.2 % reactance Line	0.32699	14.33%
24	25	SVC	9.9 MVAR	0.3269	13.66%
9	6	TCPAR	3.12^0 degree	0.3269	22.045%

CONCLUSION:

In this paper the the proposed algorithm is used to determine the location of the given number of the FACTS devices in a power system. Since their types and the rated value are simultaneously optimized. Four different types of the FACTS devices are simulated like TCSC, TCPAR, SVC, and UPFC. The system real power loss reduction, significantly improves the system performance. Thus the simulation result certify the efficiency that the efficiency of the proposed algorithm also simultaneously optimize the location, type and the rated value of the device. Further this algorithm is practical and easy to implement into the power system.

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