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Optimal Location and Sizing of Hybrid Power Flow Controller Using Chaotic Evolutionary Algorithm to Enhance Power System Stability

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***Abstract*— In this paper, a new methodology based on optimal location and sizing of the Hybrid Power Flow Controller (HPFC) is proposed to improve voltage security and active power losses in the transmission system. Using this proposed method, the location of HPFC can be easily identified by using Chaotic evolutionary algorithm (CEA) instead of Genetic algorithm(GA) in existing method, it contain many iteration process but the presents of new GA based on chaotic systems to overcome this shortcoming. Employing the logistic map and tent map, the two chaotic systems to generate chaotic values instead of the random values in GA processes. The diversity of the Chaos Evolutionary Algorithm (CEA) avoids local convergence more often than the traditional GA. The numerical results show that the proposed method decreases the number of iterations in optimization problems and significantly improves the performance of the basic GA. The proposed approaches have been implemented on the bus test system and significant results show the effectiveness of it.**

***Index Terms*— HPFC,GA,CEA,Voltage Security**

I. INTRODUCTION

Economic and operational factors make power systems to utilize maximum percentage of their transmission capacity and consequently operate close to the stability limit with fewer margins. Existence of transmission system constraints dictates a finite amount of power that can be transferred between two points on the electric grid. In practice, it may not be possible to deliver the all bilateral and multilateral contracts in full and to supply all pool demand at low cost as it leads to violation of operating constraints such as voltage limits and line overloads [2]. In such stressful and tensional environment, power system congestion and voltage instability can be emerged as major threats that the system operators (SOs) may be faced with them. The SO should ensure the operation of transmission system within acceptable operating limits. Voltage security is a limiting factor in the planning and operation of many power systems. With increased system loading and a open transmission access pressures, power systems are more vulnerable to voltage instability. In a deregulated electricity market, it may always not have been possible to dispatch all of the contracted power transactions due to congestion of the transmission corridors. System operators try to manage congestion, which otherwise increases the cost of the electricity and threatens the system security and stability. Generation pattern is one of the major reasons which results in heavy flows tend to greater losses, and to threaten stability and security, ultimately making certain generation patterns economically undesirable.

These problems are avoided by installing the Flexible AC Transmission Systems (FACTS) devices [2] such as series and combined series-shunt controllers. Flexible AC Transmission System (FACTS) controllers are used increasingly to provide voltage and power flow control in many utilities. These devices used to control the power flows in the network, can help to reduce the flows in heavily loaded lines, the resulting in increased load ability, low system loss, improved stability of the network, reduced cost of production and fulfilled contractual requirement. A possibility of controlling power flow in the electric power system without generation rescheduling or topological changes can improve the performance considerably. It is important to ascertain the location for placement of these devices because of their considerable costs [3,4].

The proposed topology of HPFC consists of a shunt connected controllable source of reactive power, and two series connected voltage–sourced converters – one on each side of the shunt device. The two converters can exchange active power through a common DC circuit. By controlling the magnitudes and the angles of voltage vectors injected by the converters, the flow of active power through the line and the amounts of reactive power supplied to the sending and receiving segments of the line can be simultaneously and independently controlled. The control of the shunt device is coordinated with the control of the converters to provide the bulk of the total required reactive power. Since the converters are used along with the passive components the proposed topology can be considered “hybrid” and consequently, the proposed FACTS controller is named the “Hybrid Power Flow Controller” (HPFC).The main advantage of the HPFC is that it can utilize existing equipment, and hence substantial cost savings in the required converter ratings can be realized [1].

In this paper, a chaotic evolutionary algorithm based is proposed to determine the suitable number and size of HPFC and also its optimal location in power systems for improving the voltage security and active power loss reduction. Hence, a number of HPFC are allocated at particular buses and lines in order to improve the voltage security margin and active power loss reduction. The investment cost of this kind of FACTS devices is also

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considered in this paper study. The optimization is carried out on the basis of location, size and number of UPFC using CEA.

II. STATIC MODEL OF HPFC

Let the circuit losses be neglected**:**

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$$R_S = R_R = 0$$

To generalize the discussion with respect to the point of equipment installation, let XL and k be defined as:

$$X_L = X_S + X_R \qquad 2$$

$$K = \frac{X_S}{X_L} \qquad 3$$

Next, let the following phasors be introduced:

$$V_S = V_S \angle \delta \qquad 4$$

$$V_R = V_R \angle 0 \qquad 5$$

$$V_X = V_X \angle \delta_X \qquad 6$$

$$V_Y = V_Y \angle \delta_Y \qquad 7$$

The steady state phasor equations of the AC portion of the circuitsare:

$$jkX_L I_S + \frac{1}{jB_M}(I_S - I_R) = V_S - V_X - \frac{1}{jB_M}(I_S - I_R) +$$

$$j(1-k)X_L I_R = -V_R + V_Y$$

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To maintain fixed charge on CDC, i.e., a steady state condition, the converters represented by voltage sources VX, and VY have to operate under the “constraint of power balance”:

$$Re[V_X I_S^*] = Re[V_Y I_R^*] \qquad 9$$

There are several limit conditions that should be imposed on the operation of the circuit.First, there are limits due to the practical converter sizes:

$$\sqrt{2}|V_X| \le V_{X_{max}} \qquad 10$$

$$\sqrt{2}|I_S| \le I_{X_{max}} \qquad 11$$

$$\sqrt{2}|V_Y| \le V_{Y_{max}} \qquad 12$$

$$\sqrt{2}|I_R| \le I_{Y_{max}} \qquad 13$$

Then, voltages at the equipment terminals are to be limited due to the insulation requirements:

$$\sqrt{2}|V_1| \le V_{1_{max}} \qquad 14$$

$$\sqrt{2}|V_2| \le V_{2_{max}} \qquad 15$$

Lower limits of terminal voltages may also be specified. These limits were not considered in the thesis, nevertheless, the analysis methodology used in the thesis can be easily adapted to include such additional requirements.

Finally the voltage ratings used for the shunt susceptance will stipulate that

$$\sqrt{2}|V_M| \le V_{M_{max}} \qquad 16$$

The phasor diagram representing one operating point of the line controlled by the HPFC is shown in Figure 1. The operating point represents a power flow lower than the “naturally occurring” power flow. Namely, if the two regions were directly interconnected, the “natural”power transfer between VS and VR

$$P_O = 3\frac{|V_S||V_R|}{X_L}\sin(\delta) \qquad 17$$

where δ represents the angle between the two voltages, as marked in Figure 1. The power flow controller changes this naturally occurring power transfer. In the case of the operating point shown in Figure 2 reduction of power flow is achieved by injecting voltages VX and VY to reduce the angular differences between VS and V1, and V2 and VR, respectively

The viable operating points could be obtained using iterative numerical techniques. A traditional approach is to express the desired output quantities (i.e., P2, Q1, and Q2) and variables subject to constraints (i.e., PX −PY, IS, IR, |V1|, |V2|, and |VM|) as functions of control variables (VX, δX, VY, δY, BM); and then, to use numerical iterations to achieve the desired solution. It can be observed that five control variables are at disposal to solve a system of four nonlinear equations, (i.e., P2 = P2ref, Q1 = Q1ref, Q2 = Q2ref, and PX −PY = 0). The existence of an additional degree of freedom gives rise to a notion of optimization, and qualifies the problem of selecting viable operating points into the class of problems of nonlinear constrained optimization.

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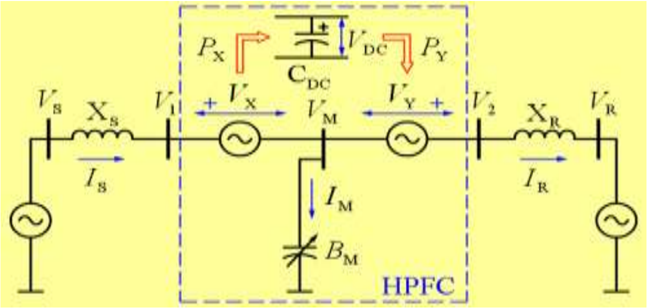

Figure 1.Equivalent circuit of HPFC

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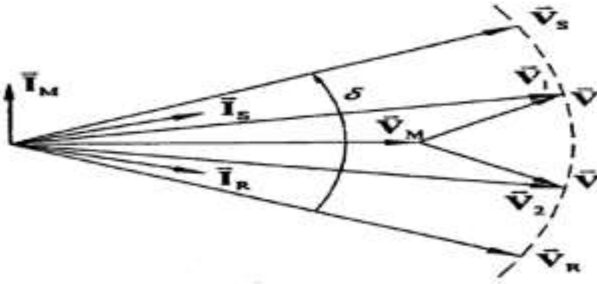

Figure 2. Phasor Diagram of HPFC

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III. PROBLEM FORMATION

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A. *ACTIVE POWER LOSS:*

The objective is to minimize the active power losses in the network. The transmission losses incur additional energy costs; thereby this is one of the objective of the system operator for achieving an optimal power flow. The active power losses can be calculated by,

$$f_1 = \sum_{k=1}^{nl} g_k \left[V_i^2 + V_j^2 - 2V_iV_j\cos(\theta_i - \theta_j)\right] \qquad 18$$

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Where nl is the total number of transmission lines, g ik is the conduct ance of the i-k line, whereas $V_i \angle \theta_i$ and $V_j \angle \theta_j$ represents the voltage of the ends of the line i-k.

B. *LOCATION OFUPFCFOR ENHANCING VOLTAGE SECURITY*

The static voltage stability L-index is used to identify the weakest buses in electric power systems. Those buses are recognized critical which have the most amount of L-index. The following equations are utilized for identifying the critical buses [5].

$$L_{n1} = \sum_{K=1}^{N_C} L_{n1}^{K^2} \qquad 19$$

$$L_{n1}^{k} = \left|\frac{V_{0_{n1}}}{V_{n1}}\right| \qquad 20$$

$$V_{0j} = -\sum_{i\in G} F_{ij} V_i \qquad 21$$

$$F_{LG} = -[Y_{LL}]^{-1}[Y_{LG}] \qquad 22$$

where,

FLG: is complex matrix which gives the relation between load bus voltages and source bus voltages and also information about the location of load nodes with respect to generator nodes.

Fij: are the complex elements of [FLG] matrix. [YLd and [YLG]: are corresponding partitioned portions of network Y -bus matrix. nl : is the number of load bus.

Vonl: is the voltage of equivalent generator from the viewpoint of bus nl.

L:I : is the L-index of bus nl in condition of outage of elementk.

Lnl : is the L-index of bus nl for total single contingencies. For stability, bound on the index Lnl must not be violated (maximum limit = 1) for any of the nodes nl. The global indicator L describing the stability of the complete subsystem is given by L = maximum of Lnl for all n1 (load buses). A L index value away from I and close to zero indicates an improved system security. The weakest and most critical buses were chosen as candidates for installing the HPFC.

C. Definition of Objective Function

After recognizing the most critical lis and the buses as candidate places for installing HPFC, in orneder to determine the appropriate and optimal location, number and size of one, the optimization problem is solved by using CEA technique. The objective function and also fitness function are defined as follows:

$$obj = minimize\{f(SLI, C_{hpfc}, L)\} \qquad 23$$

$$FF = (\alpha_1 \times SLI) + (\alpha_2 \times L) + (\alpha_3 \times C_{hpfc}) \qquad 24$$

$$SLI = \sum_{k=1}^{N_{line}} a_k \left(\frac{p_k}{p_k^{max}}\right)^4 \qquad 25$$

$$L = \sum_{n1=1}^{N_L} L_{n1}^2 \qquad 26$$

where, FF: is the fitness function.

SLI: represents the severity ofloading of all branches.

L: represents the L-index for whole network.

a_k : is the weight factor of branch k which is assumed to be equal to 1 for all lines.

Nline: is the total number of network lines.

NL: is the total number of network loads.

Pk : is the real power flow on line k.

Pk max : is the maximum real power flow on line k.

Chpfc: is the cost function of HPFC in kVar .

S: is the operating range of HPFC in MVar.

In this optimization process, the best location, size and number of HPFC are determined when the total cost of installed HPFC and severity of loading and voltage stability indices for whole network are in their minimum amount

IV. OVERVIEW OF CEA AND ITS IMPLEMENATION FOR OPTIMAL SOLUTION OF PROBLEM

Chaos is a bounded dynamic behavior that it occurs in deterministic nonlinear system. Although, it appears to be stochastic, it occur in a deterministic nonlinear system under deterministic conditions. It is highly sensitive to changes of initial condition than a small change to initial condition can lead to a big change in the behavior of the system. Chaos theory is typically described the so-called 'butterfly effect'. There are three main properties of the chaotic map, i.e.

- Ergodicity. 21
- Randomness.
- Sensitivity to initial condition

The ergodicity property of chaos can ensure chaotic variables to traverse all state non-repeatedly within a certain range according to its own laws . So, this can be used as an optimization mechanism which avoids falling into local minimum solution . The sensibility to the initial state, one of the most important characters of chaotic systems, can ensure that there are not two identical new populations even if the two best fit solutions obtained by sequential evolving procedures are very close. So, such population not only reserves the best fit chromosome, but also maintains population diversity. By using these properties, an effective approach was proposed for maintaining the population diversity and avoids the search being trapped in local optimum. In this paper, uses logistic and tent maps to generate the chaotic sequence. Chaotic sequences have been proven easy and fast to generate and store, there is no need for storage of long sequences . In addition, an enormous number of different sequences can be generated simply by changing its initial condition. Moreover, these sequences are deterministic and reproducible. Outline the two chaotic mappings as follows: Logistic map, Tent map

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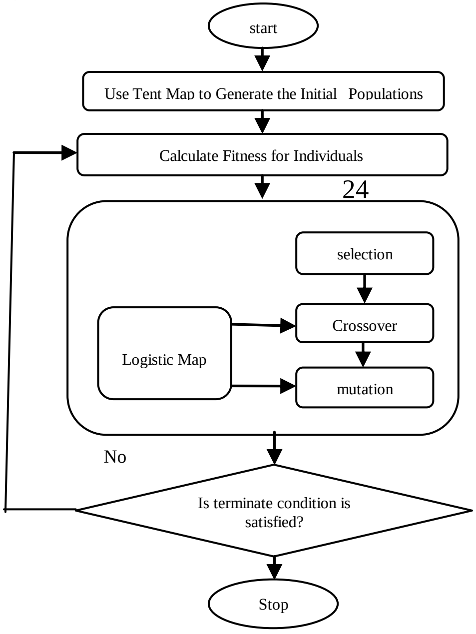

Fig 3.Flow Chart of CEA

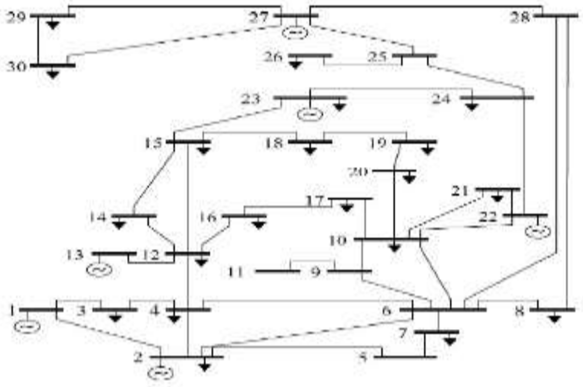

Fig 4.IEEE 30 bus system

Hybrid method based on GA and chaotic function for image encryption; their results show that the hybrid method can perform a high level of resistance against statistical invasions. In random-based optimization algorithms, are used chaotic variables instead of the random variables. GA had aroused intense interest, due to the flexibility, versatility and robustness in solving a optimization problems, which conventional optimization methods find difficult [6]. One of the major disadvantages of the GA is its premature convergence, especially while a optimization problems had been more local optima. In this situation, the solving procedure is trapped in the local optimum and most of the operators can't produce offspring surpassing their parents any more . In this paper, CGA is proposed that combine the concept of chaos with a GA.

V. SIMULATION STUDIES

In order to show the effectiveness of proposed approach, it is demonstrated on the IEEE 30-bus system.

By using the chaotic evolutionary algorithm the following solutions have been obtained

No	From bus	To bus	CSI
1	4	5	4.719225
2	3	8	6.999022
3	14	15	5.226812
4	15	16	5.427832
5	16	17	6.239277
6	16	24	3.161515
7	22	23	2.969456

TABLE 1. CONTINGENCY SEVERITY INDEX FOR EACH OF CRITICAL LINES

Bus no	L-inedex
4	1.340164
7	1.127306
8	1.189626
15	1.434161
16	1.511056
17	1.244686
18	1.291253

TABLE II-LINDEX FOR EACH OF CRITICAL BUSES

HPFC No.	Location of HPFC		Rated Apparent Power (MVA)	Investment Cost of HPFC	Fitness Function
	Line No	Bus No			
1	16 17	16	300	1.8203E+06	1.1 1 42E+09
2	4 5	4	150	1.8203E+06	1.1142E+09

TABLE III. TIIE RESULTS OF OPTIMIZATION PROBLEM BY CEA

VI. CONCLUSION

This paper focuses on a technique of optimal location and sizing of HPFC to reduce the active power losses and improve voltage security and additionally the application of CEA . In this the congested transmission lines and weak buses are identified based on maximum amount of contingency severity index and L-index respectively as the candidate locations for installing HPFC. The optimal location problem of HPFC based on active power losses and voltage security enhancement have been modeled as an optimization problem and solved by CEA algorithm. The proposed method is effective for the choice and allocation of HPFC in electrical power systems.

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