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A novel Optimal Power Flow study with TCPS

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***Abstract*— One of the really significant utility algorithms available in an energy system to meet transmission and operational constraints to produce lower cost generation patterns is optimal power flow (OPF). In order to achieve a solution, a large range of traditional techniques are available. The predicted loads used in classical OPF algorithms are increasing over time in everyday life and are also not fully error-free. By varying the load requirements, the transmission lines are overloaded and expected errors result in optimum system failure. Hence, in this modern context, power flow analysis techniques could not be able to include appropriate solution. To address the dynamic optimization issue for the 30bus scheme, this paper presents a simple dynamic programming analysis. Our aim is to reduce fuel costs and maintain at their safe limits the tap-setting of power requirements of alternators, line voltage magnitude, line synchronous condensers / reactors and transformers.**

Keywords-FACTS; Genetic algorithm; Power flow optimum

I. INTRODUCTION

In 1962, Carpentier introduced the Optimal Power Flow (OPF) problem as a Provider-constrained problem of economic dispatch. The OPF formulation is intended to reduce operating costs while meeting limitations such as voltage limits, capacity for generation, etc. It determines the optimal setting of the operating units for generation. This problem needs to be solved as rapidly and efficiently as possible[1].

There are a variety of traditional approaches, such as the method of Lambda iteration, the method of Gradient, the method of Newton, etc. These methods, however, suffer from some shortcomings such as enormous computational efforts and time consumption, starting point sensitivity, periodic convergence to optimum local solution, non-applicable with discrete variables, etc.[3].

It is well established that FACTS instruments can enhance both the steady and transient output of electrical systems. With the addition of FACTS devices on the network, the degree of non-convexity on OPF issues is further increased and the normal traditional methods will not yield optimal results. Therefore, a new, effective and modern approach needs to be employed. OPF must therefore be solved using one of the new techniques, the Genetic Algorithm.

Invented in the early 1980s by Holland[4], GA is a probabilistic search space approach that imitates the analogy of normal evolutionary assessment. As they overcome the limitations of traditional methods and are stable, GAs are an appealing alternative to other optimization methods[5].

II . OPTIMAL POWER FLOW PROBLEM FORMULATION

A well known optimization question is the mathematical formulation of the OPF problems. It is possible to represent the basic formulation of any optimization as minimising a given objective function subject to any physical or operational limitations of the method. Therefore, an optimization problem consists of An optimization problem which is susceptible to constrains. The key objective is to increase the total water energy available in all of the reservoirs. The terminology should understand that the water collected in one reservoir is used in all of its downwind reservoirs, so that the reservoir pressure is more significant in the upstream reservoir than the storage tank in the downstream reservoir[1]:

2-1. Function objective:

$$\max \sum_{i=1}^{n} E_P(x_i^{k_f}) + \sum_{k=a}^{k_f} E_p(u_{mi}^k)$$

Where:

k_f : The last planning horizon time.

$E_p(x_i^{k_f})$: Potential water energy deposited in the tank i at the edge of the planned period k_f . The quantity of moisture is dependent on just this power. $x_i^{k_f}$ collected in the tank i , on its viable head of water and on the viable of water of the down reservoirs.

$\sum E_p^k(u_{mi}^k)$: Absolute potential energy of the water that is released u_{mi}^k from reservoir m, which it could meet the downwind tank i then, the last period of the intending horizon k_f .

$a = k_f - S_{mi}$

m : The reservoir that precedes the reservoir immediately i .

S_{mi} : The length of the water released from the reservoir m to reach its direct downstream reservoir i , in hours.

2-2. Operational limitations:

The system's key operating constraints are the following [1-2, 5-8]:

- Constriction in hydraulic continuity:

The following restriction defines the water balance function for every tank at each period of time:

$$x_i^k = x_i^{k-1} + y_i^k - u_i^k - v_i^k$$

Where:

x_i^k : The Reservoir Material i at period k , in Mm^3.

u_i^k : Turbine release of hydroelectric plant i in period k , in Mm^3.

v_i^k : Hydroelectric power spillage i in time k , in Mm^3.

y_i^k : Total reservoir inflows i in period k , in Mm^3.

The cumulative stream to reservoirs is calculated as follows, taking account of hydraulic coupling.:

$$y_i^k = q_i^k + u_{mi}^{k-S_{mi}}$$

q_i^k : Normal reservoir inflows i in period k , in Mm^3.

$u_{mi}^{k-S_{mi}}$: Discharge of turbines from a hydroelectric project m , Later on, the downstream reservoir would hit i at period $k-S_{mi}$.

- Limits on minimum and maximum storage:

$$\underline{x}_i \le x_i^k \le \overline{x}_i$$

$\underline{x}_i, \overline{x}_i$: Lower and higher levels for stream processing power for reservoirs, and, i , in Mm^3.

- Limits of minimal and full release:

$$\underline{u}_i \le u_i^k \le \overline{u}_i$$

$\underline{u}_i, \overline{u}_i$: Initial and gross storm drainage levels, accordingly,, of hydroelectric plant i .

- Demand-generation balance:

The cumulative electricity produced by all hydroelectric power generation should fulfill the needs for power system at each point of the projection period. This has the general structure, numerically speaking:

$$\sum_{i=1}^{n} P_i^k = D^k$$

Where:

D^k : For each time, the demand for electrical power k , in Mw.

P_i^k : Electricity generated by hydropower plants i at period k , in Mw.

n : The number of the system's reservoirs.

3. Method of Solution

In scientific equations, we summarize the shorter - term planning problems of a hydropower plant system as follows[1]:

$$\max \sum_{i=1}^{n} E_P(x_i^{k_f}) + \sum_{k=a}^{k_f} E_p(u_{mi}^k) \quad (1)$$

Subject to these limitations:

$$x_i^k = x_i^{k-1} + y_i^k - u_i^k - v_i^k \quad (2)$$

$$\sum_{i=1}^{n} P_i^k = D^k \quad (3)$$

$$0 \le x_i^k \le \overline{x}_i \quad (4)$$

$$0 \le u_i^k \le \overline{u}_i \quad (5)$$

$$v_i^k \ge 0 \quad (6)$$

By applying the discrete limit principle as follows[1, 9-10], this problem can be solved:

Identify the restriction (2) to the dual parameter with the parameter (1) λ_i^k . We combine the constraints to fulfill the equilibrium between requirement for electric energy and generation (3) along with kernel function, to attribute (1) β^k , and then we define the purpose H^k , called the Lagrangian feature, and also has the accompanying shape:

$$H^k = \sum_{i=1}^{n} [\lambda_i^k (x_i^k + y_i - u_i^k + u \sum_m u_{mi}^{k-s_{mi}})] + \beta^k (\sum P_i^k - D^k)$$

The problem (1)-(6) becomes:

$$\max H^k \quad (7)$$

Subject to constraints (4)-(6), with the associate variable conversion equation [9]:

$$\lambda_i^{k-1} = \frac{\partial H^k}{\partial x_i^{k-1}} \quad (8)$$

The ideal trajectory when constraints (4), (5) and (6) are inactive u_i^k will be reached when the following optimality conditions for each hydroelectric plant and at each period are satisfied:

$$\frac{\partial H^k}{\partial u_i^k} = 0 \quad (9)$$

We need to know the operating limits in order to solve these equations, which are:-

The is the early condition that is established, i.e., at the early time , the initial substance among all reservoirs is known, so:

$$x_i^0 = b_i \quad (10)$$

- For the ad joint equation, the second one is the terminal condition:

$$\lambda_i^{k_f} = \frac{\partial E_p(x_i^{k_f})}{\partial x_i^{k_f}} \quad (11)$$

As a result, equations (2) and (8)-(11) constitute a problem with a 2-point state line rate whose approach specifies the best possible variables of state and power. By using the gradient approach, this issue is solved iteratively.

In order to take into account potential breaches of limitations (4) and (5), we proceed as follows:

- If the value of some u_i^k which satisfies the optimality condition (8) violates the constraint (5), we will patch them to the limits of their borders, and the others will be left alone. Then a new analysis is performed, but with just the free variables, for the optimum.

The enhanced one we have Lagrange method [1,3,11], which consists of adding a function, to deal with potential restriction violations (4), $R_i^{\,k}$ to the Hamiltonian H^k, which penalizes the violation of constraints (5). Then the Hamiltonian H^k becomes:

$$H^k = \sum_{i=1}^{n} [\lambda_i^{\,k}(x_i^{\,k} + y_i - u_i^{\,k})] + \beta^k\left(\sum P_i^k - D^k\right) + R_i^k \tag{12}$$

The purpose $R_i^{\,k}$ is,

$$R_i^{\,k} = \rho_i^{\,k}\Psi_i^{\,k} + r(\Psi_i^{\,k})^2 \tag{13}$$

Where:

r : fine weight.

$\rho_i^{\,k}$: Lagrange multipliers, updated as follows:

$$\rho_i^{\,k} = \rho_i^{\,k} + 2r\max(x_i^{\,k} - \bar{x}_i, -\frac{\rho_i^{\,k}}{2r}) \tag{14}$$

The operating function $\Psi_i^{\,k}$ is determined as follows:

$$\Psi_i^{\,k} = \max(x_i^{\,k} - \bar{x}_i, -\frac{\rho_i^{\,k}}{2r}) \tag{15}$$

II. MODEL OF TCPS

The schematic diagram of a TCPS is shown in figure 1. A impedance is pumped in sequence mostly with instrument. From the shunt linked transformer, the actual and defined performance exerted by the transmission line is divided. The limitations are ignored here in both the transformers and the generator. Therefore, the exchange of aggregate upper part between all the TCPS and the system (real and reactive) is nil. The complicated energy injected from the transmission line is influenced by specific assistance system and the current of the line.

In Figure 2, the corresponding system is shown in figure 1, where $\boldsymbol{V}_s$ and $\boldsymbol{V}_{sh}$ Described either by inductor and capacitor transformer voltage, accordingly,. X_s and X_{sh} The sequence and simultaneous transmission lines leakage reaction is described by, respectively. X_s' represent the vulnerability reactive power to see from the load winding with the transmission system[7] is given by the contamination reactance.

$$X_s' = X_s + n2\, X_{sh} \tag{16}$$

where n is the ratio of reactive power transformer uprisings

The origins of the charge controller and the corresponding displacement reactivity X_{sh} a shunt extracted source of current can be interpreted ($\boldsymbol{I}_{sh}$) as shown in Figure 3. There are two main components to the shunt extracted current: in phase part (I_p) and quaternion factor (I_q) which relates voltage slag $\boldsymbol{V}_m$. Hence, I_{sh} can be phrased as

$$I_{Sh} = \left(I_p - jI_q\right)e^{j\delta_m} \tag{17}$$

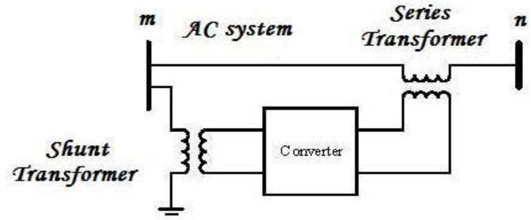

Fig.1.TCPS schematic diagram

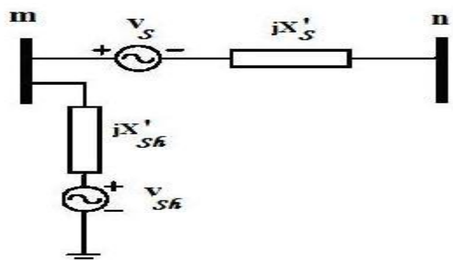

Fig.2.TCPS equivalent circuit

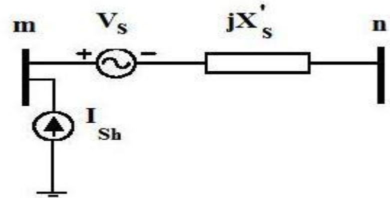

Fig.3.TCPS current injection model

III. SEVERITY INDEX

Here, this actually carried in different illumination Situations can be represented by an actual power line flow efficiency and cost effectiveness as being

$$PI = \sum_{m=1}^{N_i} \frac{w_m}{2n}\left(\frac{P_{lm}}{P_{lm}^{\max}}\right)^{2n} \tag{18}$$

where P_{lm} is The true flow of power and $P_{lm}^{\max}$ is the classified line ability-m, n is the exponent and w_m A true coefficient of nonnegative grading that can be used to represent the value of the method associated with the graph. In this operating PI, if these paths are all within their ranges, while operating loads are at high levels, they will be tiny and reach a high value. Thus, For a definite sequence of the electricity network, it offers a good indicator of the magnitude of line overloads.

The optimization algorithm must decide two types of variables to solve the OPF problemPgi effective energy production system and Vgi transit transformer voltages, which become statistically independent, and tk tap changer configuration, which are discrete variables. Thanks to the discrete existence of the transformer tap locations, the discrete variables are in the formulation. In handling problems with discrete variables, traditional methods are not successful. In this article, the OPF issue is fixed by the Genetic Algorithm.

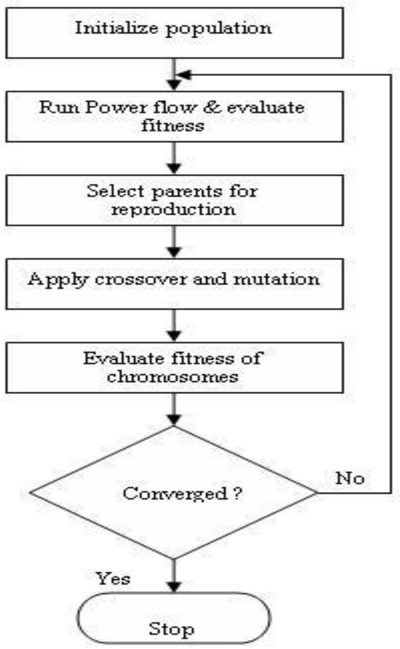

Fig.4.Flowchart of GA-OPF Algorithm

To resolve the OPF difficulty, when applying genetic algorithm, it can either be used Leaving the conventional approach to look for the continuous variables to reach the required quantities of all the fixed effects or to look for the separate variables alone. The individuals in the GA population consist of binary strings corresponding to all variables in the first approach, and the fitness value of each individual is calculated Utilizing parameters of the regulation described by the individual by running the power flow algorithm. The genetic operators are then added to the population of GA. This approach continues until the convergence criterion is met. In Figure 4, this is depicted pictorially.

In the second method, only the transformer tap environment, which alone is a distinct quantity, is coded as the GA population entity. In this case, using the transformer tap setting represented by the individual, each individual is Assessed by executing the optimum software for power flow. Therefore, the traditional LP-based algorithm searches for continuous variables in this method and GA searches for discrete variables.

Population representation and initialization It is important to address fitness assessment and application of genetic operators while applying GA to the OPF problem.

A GA acts on chromosomes, which are sets of zeros and ones. The specification of an issue in a GA starts from the parameter representation (i.e., the description of the issue). To use the power of the GA to efficiently transmit information through chromos strings and the problem's objective function, the encryption must be carefully designed. A candidate OPF solution represents each person in the population. All the Factors of power in the method consist of the Strategy components. For the OPF issue under consideration, the Efficient electricity generating parameters are dependent variables Pgi and module Device operating voltage for Reactor V and Tap changer Configuration.

1000011110 111001110…..1000111111

P_2 P_3 P_n

100001 101111……....111111

V_1 V_2 V_n

101 100…………..111

T_1 T_2 T_n

The goal of the OPF issue under consideration is to minimise the overall cost of fuel that satisfies the constraints. For each person, the equality limitations are met by operating the Newton Raphson real power algorithm and the restrictions on the parameters of the model are taken into account by assigning a binomial scheduling algorithm to the problem of optimization. The new objective function is, with the introduction of the penalty function,

$$Min\ \ f = F_T + SP + \sum_{j=1}^{N_l} VP_j + \sum_{i=1}^{N_g} QP_j + \sum_{j=1}^{N_l} LP_j \qquad (19)$$

There, violation of the violation terms for the relevant bus transformer real power operating cap, load bus voltage limit offence are SP, VPj, QPj and LPj; respectively, this Agressive energy production cap infringement and transmission flow restricts the violating device. The following equations describe these quantities:

$$SP = \begin{cases} K_s\left(P_s - P_s^{\max}\right)^2 \text{ if } P_s > P_s^{\max} \\ K_s\left(P_s - P_s^{\min}\right)^2 \text{ if } P_s > P_s^{\min} \\ 0 \quad \text{otherwise} \end{cases} \qquad (20)$$

$$VP_j = \begin{cases} K_v\left(V_j - V_j^{\max}\right)^2 \text{ if } V_j > V_j^{\max} \\ K_v\left(V_j - V_j^{\min}\right)^2 \text{ if } V_j > V_j^{\min} \\ 0 \quad \text{otherwise} \end{cases} \qquad (21)$$

$$QP_j = \begin{cases} K_q\left(Q_j - Q_j^{\max}\right)^2 \text{ if } Q_j > Q_j^{\max} \\ K_q\left(Q_j - Q_j^{\min}\right)^2 \text{ if } Q_j > Q_j^{\min} \\ 0 \quad \text{otherwise} \end{cases} \qquad (22)$$

$$LP_j = \begin{cases} K_l\left(S_l - S_l^{\max}\right)^2 \text{ if } S_l > S_l^{\max} \\ 0 \quad \text{otherwise} \end{cases} \qquad (23)$$

When the penalty factors are Ks, Kv, Kq and Kl. The effectiveness of the method lies in selecting these penalty parameters properly. An accurate definition of penalities variables has to be found. Ks, Kv, Kq and Kl using the above penalty function method. Nevertheless, to decrease the number of violation variables, the restrictions are also standardized and only one R penalty factor is used.

Although the performance index is greatly increased by GA, the factual reduction component is transformed to an optimization problem to be greatly increased as,

$$Fitness = \frac{k}{f} \tag{24}$$

IV. Results and discussions

The first part deals with solving the The Genetic Algorithm dilemma of optimization for a 30-bus test system without FACTS devices..

TABLE I. PARAMETER CONTROL SETTINGS FOR OPF FOR A 30 BUS SYSTEM

No. of generations	Population size	Crossover rate	Mutation rate
60	50	0.6	0.05

Real bus voltage power, voltage magnitude for the bus voltage, power for the load bus, and power flow through the branches are considered as constraints. In Fig., the chart showing generation versus fitness is shown. 5. A minimum cost of $803,489 / hr is obtained with the following values for actual power and voltage in Table 1.

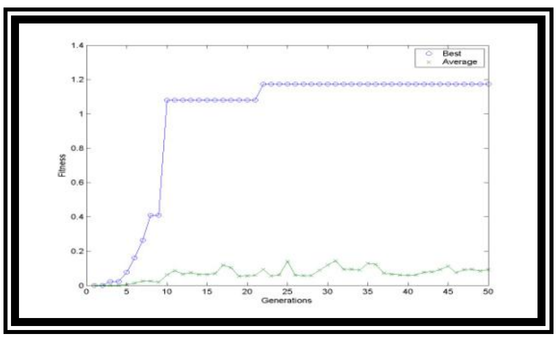

Fig.5. Generation versus fitness for a system of 30 buses

TABLE I. REAL POWER AND VOLTAGE FOR GENERATOR BUSES

P_1	194.353
P_2	26.86
P_3	3.22
P_4	50.76
P_5	5.16
P_6	2.66
V_1	0.9764
V_2	1.0702
V_3	0.9728
V_4	0.9626
V_5	1.0095
V_6	1.0694

TABLE II. CONTROL PARAMETER SETTINGS INCLUDING TCPS

Line outages	No. of generations	Capacity of community	Fusion value	Level of Transformation
1-2	60	50	0.2	0.06
1-3	60	50	0.4	0.02
3-4	60	50	0.1	0.05

It is shown that the power flow through the branches is violated when some of the branches are out of service. We consider the outage of 1-2, 1-3 and 3-4 divisions. We place one of the FACTS devices, TCPS, in suitable locations, which are determined by sensitivity analysis, to relieve these lines from overloading. There will then be an additional constraint in the problem representation, which is the phase shifting transformer constraint. The control variables would then be the true generator power and the TCPS step angle[9]. The GA coding involves the number of control variables, their range that determines the minimum limit and maximum limit, number of bits, etc.

TABLE III. SIMULATION RESULT ON INCLUDING TCPS FOR VARIOUS LINE OUTAGES

Line outage	1-2	1-3	3-4
P_1	139.6825	142.8571	161.9048
P_2	38.0952	38.0952	22.8571
P_3	15.000	32.2222	32.7778
P_4	39.6825	40.4762	48.4127
P_5	18.0952	3.3333	8.0952
P_6	32.3810	26.0317	8.8889
X_{TCPS1}	-5.2381	9.3651	-9.6825
X_{TCPS2}	-2.0635	2.6984	7.778
X_{TCPS3}	-2.6984	-3.0159	0.1587
X_{TCPS4}	0.1587	-2.3810	-6.5079
SI	0	0	0

Matpower addresses power flow and provides true slack bus power, generator bus reactive power, load bus voltage, and branch power flow. Table 2 gives the setting of control parameters for different line outages, like TCPS.

The value of real power, phase angle of TCPS and cost are given in Table 3. It is seen that the line overloads were relieved through the adjustment of phase angle of TCPS.

V. Conclusion

The minimum cost achieved without the inclusion of FACTS equipment was similar to the cost of using the Gradient method[10]. The proposed work, we can conclude, has offered a better global solution. Furthermore, it saves both processing time and machine memory and delivers the most optimal performance.

The next part deals with improving security. In the simple case, We see that the actual power of the slack bus, the power factor of the bus voltage, the stream voltage magnitude and the power from the branches are within the boundaries.However, some of the lines get overwhelmed when there are line outages. FACTS devices are included to alleviate the overloading of lines. The lines are rescued from overloading by proper placement of TCPS and hence the severity index is obtained to be zero.

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