Transmission Network Expansion Planning Considering Unit Commitment Problem Simultaneously

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Abstract-- Transmission Network Expansion Planning (TNEP) is an important part of power system planning in new structured power market. Its goal is to minimize the network construction and operational cost while satisfying the demand increase, considering technical and economic conditions. Since change in Unit Commitment (UC), influences transmission lines, this paper presents an Integer Coded Genetic Algorithm (ICGA) to solve both problems together. Genetic algorithm can consider all generation and network constraints. Also random behavior of genetic algorithm can simulate real probabilities such as uncertainty in generation. Considering uncertainty for some units, in each iteration, it can find out the probability of congestion for each line. After all iterations it can highlight the transmission lines which need expansion, because of high congestion probability. Simulation results of the proposed idea are presented for IEEE30-bus network.

Keywords- transmission network expansion planning, integer coded genetic algorithm, unit commitment.

I. NOMINCLATURE

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DR_i</td>
<td>Ramp-down rate limit of unit i</td>
</tr>
<tr>
<td>F_{c(i)}</td>
<td>Production cost function of unit i</td>
</tr>
<tr>
<td>I_i</td>
<td>Commitment state of unit i at time t</td>
</tr>
<tr>
<td>NT</td>
<td>Number of periods under study (24 h)</td>
</tr>
<tr>
<td>N</td>
<td>Number of units</td>
</tr>
<tr>
<td>P_{it}</td>
<td>Generation of unit i at time t</td>
</tr>
<tr>
<td>P_{imin}</td>
<td>Lower limit of real power generation of unit i</td>
</tr>
<tr>
<td>P_{imax}</td>
<td>Upper limit of real power generation of unit i</td>
</tr>
<tr>
<td>P_{D,t}</td>
<td>System demand at time t</td>
</tr>
<tr>
<td>R_{S,it}</td>
<td>Spinning reserve of unit i at time t</td>
</tr>
<tr>
<td>R_{S,t}</td>
<td>System spinning reserve requirement at time t</td>
</tr>
<tr>
<td>SU_{it}</td>
<td>Start up cost of unit i at time t</td>
</tr>
<tr>
<td>SD_{it}</td>
<td>Shut down cost of unit i at time t</td>
</tr>
<tr>
<td>T_{off}</td>
<td>Minimum down time of unit i</td>
</tr>
<tr>
<td>T_{on}</td>
<td>Minimum up time of unit i</td>
</tr>
<tr>
<td>UR_i</td>
<td>Ramp-up rate limit of unit i</td>
</tr>
<tr>
<td>V(.)</td>
<td>Heavy side (unit step) function.</td>
</tr>
<tr>
<td>X_{off}</td>
<td>Off time of unit i at time t</td>
</tr>
<tr>
<td>X_{on}</td>
<td>On time of unit i at time t</td>
</tr>
<tr>
<td>P_{L,t}</td>
<td>Transmission capacity of line l at time t</td>
</tr>
<tr>
<td>P_{Lmin}</td>
<td>Minimum transmission capacity of line l at time t</td>
</tr>
<tr>
<td>Q_{imin}</td>
<td>Lower limit of reactive power generation of unit i</td>
</tr>
<tr>
<td>Q_{imax}</td>
<td>Upper limit of reactive power generation of unit i</td>
</tr>
<tr>
<td>V_{b,min}</td>
<td>Minimum voltage magnitude at bus b</td>
</tr>
<tr>
<td>V_{b,max}</td>
<td>Maximum voltage magnitude at bus b</td>
</tr>
<tr>
<td>γ_{min}</td>
<td>Lower limit vector of phase shifter angle</td>
</tr>
<tr>
<td>γ_{max}</td>
<td>Upper limit vector of phase shifter angle</td>
</tr>
<tr>
<td>T_{min}</td>
<td>Lower limit vector of transformer tap</td>
</tr>
<tr>
<td>T_{max}</td>
<td>Upper limit vector of transformer tap</td>
</tr>
</tbody>
</table>

II. INTRODUCTION

Transmission network expansion planning (TNEP) is a basic part of power system planning that determines where, when and how many new transmission lines should be added to the network. Its task is to minimize the network construction and operational cost, while meeting imposed technical, economic and reliability constraints. TNEP should be satisfied required adequacy of the lines for delivering safe and reliable electric power to load centers along the planning horizon [12-14]. TNEP is a hard, large-scale combinatorial optimization problem. It also depends on unit commitment problem.

After Garver’s paper that was published in 1970 [18], much research has been done on the field of TNEP problem. Some of them such as [12-14, 17& 19] are related to problem solution method. Some other researches, proposed different approaches for solution of this problem considering various parameters such as uncertainty in demand [16], reliability criteria [15, 26, 27], and economic factors [28]. Also, some of them investigated this problem and generation expansion planning together [29, 30]. Recently, different methods such as GRASP [14], Bender decomposition [17], HIPER [25], branch and bound algorithm [31], sensitivity analysis [23], genetic algorithm [12& 22], simulated annealing [24] and Tabu search [32] have been proposed for the solution of TNEP problem. In all of these methods, the problem has been solved regardless to the influences of uncertainty of generation and unit commitment on TNEP problem.

The principal objective of the unit commitment (UC) is to schedule the status of generation units in order to serve the load demand at minimum operating cost while meeting all plant and system constraints. UC is an important task in the daily operation planning of power systems.
In order to overcome complexity of UC problem, several methods have been used in recent years. Tabu search [8], simulated annealing [4], priority list based methods [3], Simplex method [4] Lagrangian relaxation [6], Dynamic Programming [10] and mixed-integer programming [9] are some techniques that have been used.

This paper presents an Integer Coded Genetic Algorithm (ICGA) to solve both problems together. Genetic algorithm can consider all generation and network constraints. Also random behavior of genetic algorithm can simulate real probabilities such as uncertainty in generation. Considering lack of some units, in each iteration, it can find out the probability of congestion for each line. After all iterations it can highlight the transmission lines which need expansion, because of high congestion probability. Simulation results of the proposed idea are presented for IEEE 30-bus network.

In this paper the goal is to solve both TNEP and UC problem with each other. Units are coded in the chromosome definition. Therefore it helps to minimize generation dispatches. In many of the genetic algorithm population, load flow cannot converge because of congested transmission lines. Therefore depends on the value of cost function, it have considered a weight factor for the importance of that population. This weight factor influences the results. It means that the congested lines in the population with higher objective function (1) have lower importance. Because related unit commitment is less probable.

In every iteration of genetic algorithm, good population with lower cost will be sort regardless of some few congested transmission lines. And depends on the objective function, the weight factor will be determined. The congested lines due to their weight factor will be influence the results. It leads to choose of lines for expansion in future.

III. PROBLEM FORMULATION

The objective is to minimize the cost of supplying the load as formulated below [5]:

\[
\text{Min} \left( \sum_{i=1}^{N_G} \sum_{t=1}^{N_T} \left[ F_i (P_{it}) \ast I_{it} + SU_{it} + SD_{it} \right] \right)
\]  

Function (1) is composed of fuel costs for producing electric power and startup and shutdown costs of individual units over the given period.

Generation constraints include the system power balance (2), system spinning reserve requirements (3), ramping up/down limits (4), minimum up/down time limits (5), and real power generation limits (6). [5]

The above mentioned constraints are the system power balance (2), system spinning reserve requirements (3), ramping up/down limits (4), minimum up/down time limits (5), real power generation limits (6) and fuel consumption limitations (7)

Other restrictions are Limitations on reactive power generation (8), constraints on power flow through transmission lines (9) and bus voltage limits (10). (11) and (12) are constraints on tap changing and phase shifting transformers. A power flow problem will be solved to check the system constraints.

\[
\sum_{i=1}^{N_G} P_{it} \ast I_{it} = P_{D,t} + P_{L,t}
\]  

\[
\sum_{i=1}^{N_G} R_{it} \ast I_{it} \geq R_{S,t} (t=1, \ldots, N_T)
\]

\[
P_{it} - P_{(t-1)i} \leq [1 - I(t-1)_{it}] \ast UR_i + L(t-1)_{it} P_{\text{min}} (i=1, \ldots, N_G)
\]

\[
P_{(t+1)i} - P_{it} \leq [1 - I(t-1)_{it}](1 - L_{it}) \ast DR_i + L(t-1)_{it} P_{\text{min}} (i=1, \ldots, N_G)
\]

\[
[X_{\text{it}}^{\text{con}}]_{t=1}^{N_T} [I_{\text{it}}^{\text{con}}]_{t=1}^{N_T} \geq 0
\]

\[
[X_{\text{it}}^{\text{eff}}]_{t=1}^{N_T} [I_{\text{it}}^{\text{eff}}]_{t=1}^{N_T} \geq 0 \text{ (t=1, \ldots, N_T)}
\]

\[
P_{it} \leq P_{i,\text{max}} I_{it} (t=1, \ldots, N_T) (i=1, \ldots, N_G)
\]

\[
F_{\text{FP}}^{\text{min}} \leq \sum_{t=1}^{N_T} \sum_{i \in \text{FT}} \left[ F_{it} (P_{it}) \ast I_{it} + SU_{it} + SD_{it} \right] \leq F_{\text{FP}}^{\text{max}}
\]  

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\[
Q_{\text{it}} \leq Q_{\text{it},\text{max}} (t=1, \ldots, N_T) (i=1, \ldots, N_G)
\]

\[
P_L \leq P_{L,\text{max}} (t=1, \ldots, N_T) (i=1, \ldots, N_G)
\]

\[
V_{\text{hmin}} \leq V^{\text{h}} \leq V_{\text{hmax}} (t=1, \ldots, N_T) (b=1, \ldots, N_B)
\]

\[
T_{\text{itmin}} \leq T^{\text{t}} \leq T_{\text{itmax}} (t=1, \ldots, N_T)
\]

\[
\gamma_{\text{imin}} \leq \gamma^{\text{t}} \leq \gamma_{\text{imax}} (t=1, \ldots, N_T)
\]
IV. INTEGER-CODED GENETIC ALGORITHM

A. Chromosome Definition

Thermal inertia of steam and gas turbines doesn’t allow operators to turn units on/off over and over. Then we can consider the number of turning a unit on and off is less than a given number $N_s$. Let $N_s = 5$ then the schedule of each unit can be demonstrated by a 5 digit string so that each digit shows the period of time that the unit remains in up or down state. Positive numbers indicate up state period and negative digits indicate down state.

Each chromosome consists of $NG$ genes correspond to $NG$ units. It is evident that two adjacent digits of each gene are with opposite sign or zero. Fig. 2 shows the concept clearly.

$$\sum_{i=1}^{5} T_i^{c} = 24 \quad i \in \{\text{Gen. units}\}$$  \hspace{1cm} (13)

B. Fitness Function

The fitness function used for evaluating chromosomes contains total thermal system operating cost over the scheduling horizon, calculated as follows.

Start up/shot down cost should be considered for units (if any).

$$SU_{it} = \sum_{i=1}^{NG} \sum_{c=2}^{5} V(T_i^{c})SU_i(-T_i^{c-1})$$  \hspace{1cm} (14)

$$SD_{it} = \sum_{i=1}^{NG} \sum_{c=2}^{5} [1 - V(T_i^{c})]SD_i$$  \hspace{1cm} (15)

To calculate total production cost economic dispatch (ED) should be run. Quadratic program is used to solve ED problem.

$$F_{it}(P_i) = a_i + b_i P_i(t) + c_i (P_i(t))^2$$  \hspace{1cm} (16)

$$T.P.C. = \sum_{i=1}^{NT} \sum_{c=1}^{NG} F_{ci}(P_{it})*I_{it}$$  \hspace{1cm} (17)

The fitness function is one of the key elements of GAs as it determines whether a given potential solution will contribute its elements to future generation through the selection process or not. Since the objective of GAs is to maximize the fitness, while the objective function of transmission planning model is to minimize the objective function (OF) as given by Eq. (1), therefore it is necessary to map the objective function onto the fitness function. The fitness function (Fit) adopted in this study is:

$$F_{it} = \frac{A}{OF}$$  \hspace{1cm} (18)

$A$ is considered $10^{12}$ as a system-dependent constant.

C. GA Evolution

When two parents are selected, their symbol strings are combined to produce “offspring” solution using genetic-like operators. The common operators are crossover and mutation.

This paper uses perturbation in addition to common operators to achieve a lower operating cost. Test results show benefits of this new operator [11]. It should be notified that in all GA Evolution stages, ineq. (13) should be met.

1) Initial Population

Since initial population will be generated randomly, many chromosomes can not support system load for some hours so two new constraint (19), (20) introduced to check chromosomes and generate a better initial population.

2) Crossover

The common way in crossover is to select one or more crossing points in the parent chromosomes and swaps the resulting pieces. There is one extra important restriction here for choosing cross point. We ought not to break one units schedule in half. It’s only authorizing to swaps one or more whole unit schedules. Fig. 3 shows the crossover operator.

3) Mutation

While crossover operator exchanges the whole schedule of units between two parents, mutation operator influences the up/down schedule for one random unit in a portion of population. For each selected chromosome one random point and its related digit is chosen. If the integer is positive/negative it will be replaced with another random integer between its value and minimum up/down time of the unit. Eq (13) should be met by changing one another integer.

4) Perturbation

This operator is applied to the best chromosomes with a suitable rate. It is a special case of proposed mutation. While in mutation, any digit can be replaced by any other acceptable digit; in perturbation, random selected digit will be added with $+1$ or $-1$. It means we decide to increase or decrease the previous on or off time. To meet (1) one another digit (e.g. adjacent integers) should be changed.

5) Excessive-Power elimination operator

The existence of some units operating at minimum power during certain time intervals in a daily schedule may indicate commitment of excessive expensive units during these time intervals. Such a commitment schedule may be improved if some of the units operating at minimum are turned off while certain conditions are met. The excessive power elimination operator checks whether the rest of the online units satisfy demand requirements during the time interval that the unit is turned off. If the above requirements are satisfied, then the operator turns the unit off for this specific time interval and the new schedule is evaluated. If it is superior to the original, the new solution is encoded back to the chromosome. This operator can increase the rate of convergence.

$$\sum_{i=1}^{NG} P_{i_{\max}}*I_{it} \geq P_{D_{t}}+P_{L_{t}}$$  \hspace{1cm} (19)

$$\sum_{i=1}^{NG} P_{i_{\min}}*I_{it} \leq P_{D_{t}}+P_{L_{t}}$$  \hspace{1cm} (20)
The proposed GA algorithm was implemented in “MATLAB” program. The program is tested on IEEE 30 bus network. Test results have been obtained considering population size of 50 for 300 generations with crossover and mutation rate of 0.8 and 0.2, respectively. Load & units growth rate are assumed 10%.

As shown in figure 4, the lines number 35, 10, 29, 30 have priority for expansion in future. Because in many of unit commitments with lower cost, congested take care in this lines. The lines which have not shown in the figure had no considerable congestion in any iteration.

V. TEST RESULTS

VI. CONCLUSION

The genetic algorithm can solve both UC and TNEP problem with each other. In every iteration of genetic algorithm, good population with lower cost sort regardless of some few congested transmission lines. And depends on the objective function, the weight factor will be determined. The congested lines due to their weigh factor will be influence the results. It leads to choose of lines for expansion in future. Employing ICGA with some new operators leads to many advantages. Minimum up/down time can be checked directly in chromosome. Hence causes elimination of many penalty functions usually distort the search space. The proposed ICGA reduce chromosome size significantly as compared to the usual binary coding. ICGA is able to find a solution with lower cost than other techniques. It also ensures having at least one feasible solution during every stage of the GA simulation. Large search space in GA also prevents entrapping in local minimum.

VII. REFERENCES

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