A New Optimization Approach for Transmission Usage Allocation in Deregulated Power System

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Abstract: Deregulation of power system industry is a very large complex exercise based on respective national energy strategies and policies. A lot of matters and knowledge need to be studied before the idea of deregulation can be implemented. Theoretically, it is said that deregulation can make a large impact to increase efficiency and encourage the competitiveness among related parties. However, to implement the concept of deregulation to electric power supply is very tough challenge. In deregulation environment, regardless of market structure, to know the transmission usage allocation is vital and very a complex problem. Thus, a lot of algorithms have been proposed to overcome it. This paper intends to solve the transmission usage allocation problem using optimization approach. The optimization tool that will be utilized is Genetic Algorithm (GA). GA is probabilistic search technique that has its roots in the principle of genetics and strives for survival. In addition, GA is very robust. Since the nonlinear nature of power flow, it is expected that GA can give optimize results that equitable and acceptable. In this paper, 4-bus and Klos-Kerner 11-bus systems are used for analysis studies. Comparison with other method is also given in this paper.

Key words: Deregulation, genetic algorithm (GA), optimization, transmission usage allocation.

1. Introduction

Deregulation of electric supply industry offers a major change to the vertically integrated utility monopoly. The changes involving the main part of engineers’ and economists’ effort to reshape the three components of vertically integrated monopoly: generation, transmission and distribution. In a deregulated environment, the main tasks of these three components will remain the same as before. However, to comply with Federal Electric Regulatory Commission (FERC) orders, new types of unbundling, coordination and rules are to be established to guarantee competition and non-discriminatory open access to all users [1]. The aim of deregulation is to optimize the system welfare by introducing competitiveness among participants so this situation perhaps can be evolve to become an efficient industry.

Three major models that were actively discussed as alternatives to the current vertically integrated monopoly. They are pool model, bilateral contract model and hybrid model [1]. Regardless of the market structures and models, it is important to know the usage of the power network in order to obtained fair and transparent cost allocation to which parties involved. However, determining an accurate transmission usage could be difficult due to nonlinear nature of power flow. A few methods of power flow tracing are already proposed in Refs. [2-8]. These methods use the principle of proportionality assumption that is quite well known in the literature. Nevertheless, this principle is trying to adapt the Kirchoff’s First Law for power flow and this concept obviously neither provable nor disprovable. Even in Refs. [9, 10] a proving theory for proportionality concept has been
presented, but it still needed some unutterable assumption to justify the concept.

Teng [11] proposes a method that uses superposition theorem to trace the power flow and loss allocation. The method proposed an integration of Y-bus matrix with the equivalent impedance of load bus before the integration matrix is inversed into Z-bus. This information then will be used for power tracing purpose using superposition theorem. However, this method assumes that the current at each network injection point may flow through all line and all loads, which is can be argued. The method that introduces dominions contribution concept for power tracing has been proposed in Ref. [12]. It is a lower-level algorithm in which the concepts of source dominions and common branches are used in Ref. [3], as opposed to commons and links that used in Ref. [6]. Unfortunately, generators’ share to loss allocation is never considered. Lo and Alturki [13] propose a reactive power allocation method using current adjustment factor (CAF). CAF is a transformation of complex matrix for adjustment of nonlinearity of the network due to the interaction between loads and generators. In addition, the concept of voltage participation index (VPI) using modification of Y-bus is also proposed in this paper. However, the application of CAF for larger system which is predicted will become very complex.

Applications of Artificial Intelligence (AI) techniques in power system become embolden and can be used as an alternative option to solve many problems. Mustafa et al. [14] incorporated an Artificial Neural Network (ANN) to identify power source to sink relationship in deregulated power systems. Graph method is used as a teacher to train the neural network. The modified Y-bus method to allocate reactive power transfer is proposed in Ref. [15]. ANN incorporation again is used in this tracing algorithm. However, by using ANN, the requirement of a lot of training samples is necessary to obtain equitable and acceptable power tracing results. Thus the selections of samples need to be considered carefully.

In related work based on optimization techniques, several researches have been done. Abhyankar et al. [16] proposed an optimization approach to real power tracing. They proposed a tracing compliant that minimizes overall deviation from the postage stamp allocation. Nevertheless, this approach treats the power tracing problem as a linear constraint optimization problem. This approach is also used in Ref. [17] to trace the real power tracing problem that consists of circular flow.

As a tool of optimization, GA receives a lot of attention of many researchers to solve a number of power engineering problems. Yin and Germay [18] proposed a study on solving load flow problem using GA. This study is expanded by Wong et al. [19-22]. The concern of these authors is the Newton-Raphson technique will become diverged when the heavy loaded occurred in the system. Thus by implementing GA approach, the convergence of the load flow study could be solved. The incorporation of GA to the optimal power flow and economic dispatch has been proposed in Refs. [23-28]. Since GA has several methodologies of crossover operation, mutation approaches and evaluation techniques, these operations need to be used and studied differently and based on related problems that want to be solved.

From the extensive literature review, apparently it can be seen that the transmission usage allocation methodology using GA approach is unique and has not being applied. GA is a search algorithm based on mechanics of natural genetics, natural selection and uses population search method. Since GA has been done and developed for load flow study, it can be expected that GA will contribute significantly to the knowledge and application of transmission usage allocation for deregulated system.

This paper is organized as follows. General concept of GA is discussed in Section 2 followed by the application of GA into transmission usage allocation problem in Section 3. In Section 4, the computational
results of proposed method with the comparison with other power tracing method [11] including discussion are presented. Finally, conclusion is stated in Section 5.

2. Genetic Algorithm

In general, genetic algorithm (GA) is known as a subset of evolutionary algorithms that model biological processes that were influenced by the environmental factor to solve a various numerical optimization problems. GA allows a population composed of many individuals to evolve under specified selection rules to a state that maximizes the “fitness” (i.e., minimizes the cost) function. The method was developed by Holland [29] and popularized by Goldberg [30, 31]. Traditionally, GA is using a binary number as a representation, but lately, the using of floating and real numbers as representations are become popular [32, 33].

2.1 Representation

In this paper, floating numbers are used as representation of the chromosome. If the chromosome has $N_{\text{par}}$ parameters (an $N$-dimensional optimization problem) given by $p_1, p_2, \ldots, p_{N_{\text{par}}}$ then the single chromosome is written as an array with $1 \times N_{\text{par}}$ elements as follows:

$$\text{chromosome} = [p_1, p_2, \ldots, p_{N_{\text{par}}}]$$ (1)

2.2 Initialization

GA does not work with a single string but with a population of strings, which evolves iteratively by generating new individuals taking the place of their parents. Normally, the initial population is generated at random.

2.3 Evaluation Function

The performance of each string is evaluated according to its fitness. Fitness is used to provide a measure of how individuals have performed in the problem domain. The choice of objective and fitness function is proposed in the next section.

2.4 Genetic Operators

With an initial population of individuals and evaluated through its fitness, the operators of GA begin to generate a new and improved population from the old one. A simple GA consists of three basic operations: selection, crossover and mutation.

Selection determines which individuals are chosen for crossover and a process in which individual chromosomes are copied according to their fitness. Parents are selected according to their fitness performance and this can be done through several methods. For this paper, roulette wheel selection method is used. The novelty of this method and others can be seen deeply in Ref. [30].

Crossover is a process after the parents chromosomes are selected from roulette wheel method. It is a process that each individual will exchange information to create new structure of chromosome called offspring. In this paper, two points crossover is used by adapting the novelty of the combination of an extrapolation and crossover methods that has been discussed in Ref. [32]. It begins by randomly selecting a parameter in the first pair of parents to be crossover at point:

$$\alpha = \text{round}\{\text{random} \times N_{\text{par}}\}$$ (2)

Let $\text{parent}_1 = [p_{m1}, \ldots, p_{ma}, \ldots, p_{mad}, \ldots, p_{md}, \ldots, p_{m_{N_{\text{par}}}}]$ (3)

$\text{parent}_2 = [p_{d1}, \ldots, p_{da}, \ldots, p_{d_{N_{\text{par}}}}]$ (4)

Where $m$ and $d$ subscripts discriminate between the mom and dad parent. Then the selected parameters are combined to form new parameters that will appear in the offspring, as follow:

$$p_{\text{new1}} = p_{ma} - \beta(p_{ma} - p_{da})$$ (5)

$$p_{\text{new2}} = p_{da} + \beta(p_{ma} - p_{da})$$ (6)

Where $\beta$ is also a random value between 0 and 1. The final step is to complete the crossover with the rest of the chromosome, as follow:

$$\text{offspring}_1 = [p_{m1}, \ldots, p_{\text{new1}}, \ldots, p_{m_{N_{\text{par}}}}]$$ (7)

$$\text{offspring}_2 = [p_{d1}, \ldots, p_{\text{new2}}, \ldots, p_{d_{N_{\text{par}}}}]$$ (8)

Although selection and crossover are applied to chromosome in each generation to obtain a new set for
better solutions, occasionally they may become overzealous and lose some useful information. To protect these irrecoverable loss or premature convergence occur, mutation is applied. Mutation is random alteration of parameters with small probability called probability of mutation (0-50%). Multiplying the mutation rate by the total number of parameters gives the number of parameters that should mutated. Next, random numbers are chosen to select of the row and columns of the parameters to be mutated. A mutated parameter is replaced by a new random parameter.

3. GA for Transmission Usage Allocation

In deregulated power system, transmission usage allocation is important due to transmission congestion management. Knowing the capacity usage of power flow will help in alleviating the congestion in the system. From the literature review, it can be said that most of the methods that have been proposed are using approximate models and transform the system into linear. In fact, power flow nature is nonlinear. Thus, this paper proposes a nonlinear method, i.e., GA to trace the transmission usage allocation. As stated above, GA is a very robust approach that shows its capability in nonlinear environment.

The prerequisite of this method is power flow solution or load flow study must be conducted before applying GA to transmission usage allocation problem. All information including bus voltage, voltage angle, real and reactive power generated, load demand and transmission loss in the network system can be obtained by running power flow solution tool. For this paper, Newton-Raphson technique is used in power flow solution tool that has been developed in Ref. [34].

For a power system with \(N\) buses, it is assumed that the system consists of \(N_G\) generator buses (slack bus and voltage controlled, PV bus) and \(N_L\) load buses (PQ bus). However, for voltage controlled bus that has load, it is assumed that it will give the priority to its own load before supply the power to the other busses. In the interconnected power system, the power at each bus, \(n\) can be obtained by using the following equations:

\[
S_n = (P_n + jQ_n) \quad (9)
\]

\[
P_n = P_{G,n} - P_{D,n} \quad (10)
\]

\[
Q_n = Q_{P,n} - Q_{D,n} + Q_{sh,n} \quad (11)
\]

Where \(S_n\) is apparent power, \(P_{G,n}\) is real generation, \(P_{D,n}\) is real demand, \(Q_{G,n}\) is reactive generation, \(Q_{D,n}\) is reactive demand and \(Q_{sh,n}\) is injected MVAR at bus \(n\). The load current, \(I_{L,n}\) of load bus can be obtained as follow:

\[
I_{L,n} = \left( \frac{P_{L,n} + jQ_{L,n}}{V_{L,n}} \right)^* \quad (12)
\]

Where \(V_{L,n}\) is the voltage of load bus \(n\) obtained from power flow solution and * is conjugate. Line current at each transmission line can be obtained from power flow solution.

Before applying GA, it is necessary to point out that the very important data among the information that obtained from power flow solution are the voltage and its angle at each bus. The method that will be proposed in this paper is to trace the voltage contribution from generator buses at every bus except for the slack bus. The voltage contribution will be treated as optimization problem and GA is applied to find the optimize results of voltage contribution from the respective individual generator bus.

To solve the transmission usage allocation problem, the following GA components are designed:

3.1 Chromosome

The real and imaginary parts of the voltages of the buses in the power system are encoded using floating-point numbers and arranged as elements in the chromosomes. These elements are depending on the number of variables of the test system. The number of variable can be expressed in general as \((nbus-slack-PV isolated) \times N_G\), where \(nbus\) is number of bus, slack is slack bus, \(PV isolated\) is the voltage-controlled bus that does not has any incoming power from any other bus and this bus is solely supply power into the system and \(N_G\) is the number of generation bus. Fig. 1 shows the...
chromosome when \( n_{bus} = 4, N_G = 2, N_L = 2 \) and PV isolated = 1.

### 3.2 Evaluation

For each chromosome, the process of evaluation will be done. The floating numbers will be decoded by multiplying each element with the respective bus voltage. At any bus \( i \) (except slack and PV isolated), the sum of the voltage that contributed from individual generator can be expressed as:

\[
V_i = \sum_{n=1}^{\text{ngen}} v_i^{G,n} \tag{13}
\]

The mismatch in voltage magnitude at bus \( i \) can be defined as:

\[
\Delta V_i = |V_i^{sp} - V_i| \tag{14}
\]

Where \( V_i^{sp} \) is the bus voltage at bus \( i \) that obtained from load flow study.

Then, each voltage (contributed by individual generator) is used to obtain the contribution of individual generator to each load in the system, as follows:

\[
S_{L,j}^{G,n} = v_i^{G,n} (i_{L,j})' \tag{15}
\]

Where \( i_{L,j} \) is obtained using Eq. (4). The components of real and reactive power in Eq. (15) then are separated as follow:

\[
P_{L,j}^{G,n} = \text{real}(S_{L,j}^{G,n}) \tag{16}
\]

\[
Q_{L,j}^{G,n} = \text{imag}(S_{L,j}^{G,n}) \tag{17}
\]

The sum of real and reactive power that contributed by individual generator can be defined as:

\[
P_{L,i} = \sum_{n=1}^{\text{ngen}} P_{L,j}^{G,n} \tag{18}
\]

\[
Q_{L,i} = \sum_{n=1}^{\text{ngen}} Q_{L,j}^{G,n} \tag{19}
\]

The mismatch in load bus \( i \) can be defined as:

\[
\Delta P_{L,i} = |P_{L,i}^{sp} - P_{L,i}| \tag{20}
\]

\[
\Delta Q_{L,i} = |Q_{L,i}^{sp} - Q_{L,i}| \tag{21}
\]

Where \( P_{L,i}^{sp} \) and \( Q_{L,i}^{sp} \) are real and reactive power of the demand that were obtained from load flow study.

Again, the voltage, \( v_i^{G,n} \) is used to obtain the loss at each transmission line. The loss can be obtained by using equations below:

\[
P_{i-j}^{G,n} = \text{real}(v_i^{G,n} (I_{i-j})') \tag{22}
\]

\[
Q_{i-j}^{G,n} = \text{imag}(v_i^{G,n} (I_{i-j})') \tag{23}
\]

\[
\text{Loss}_{i-j}^{G,n} = P_{i-j}^{G,n} + Q_{i-j}^{G,n} \tag{24}
\]

Where \( P_{i-j}^{G,n} \) is real power flow from bus \( i \) to bus \( j \), \( P_{j-i}^{G,n} \) is real power flow from bus \( j \) to bus \( i \), and \( \text{Loss}_{i-j}^{G,n} \) is the loss of line \( i-j \) contributed by generator bus \( n \). \( I_{i-j} \) and \( I_{j-i} \) are obtained from load flow study. The sum of each generator’s contribution for line loss can be defined as:

\[
\text{Loss}_{i-j} = \sum_{n=1}^{\text{ngen}} \text{Loss}_{i-j}^{G,n} \tag{25}
\]

The mismatch in loss can be expressed as:

\[
\Delta \text{Loss}_{i-j} = |\text{Loss}_{i-j}^{sp} - \text{Loss}_{i-j}| \tag{26}
\]

Finally, the total real power from any generator is equal to the power delivered to the all system. It can be described as follows:
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\[ P_{G,n} = \sum_{i=1}^{\text{line}} \text{Loss}_{G,n} + \sum_{k=1}^{\text{nbus-sack-PVisolated}} P_{G,k} \quad (27) \]

Where \text{line} is the number of transmission line in the system. The mismatch in total real power can be obtained using the following equation:

\[ \Delta P_{G,n} = |P_{G,n(sp)} - P_{G,n}| \quad (28) \]

Where \( P_{G,n(sp)} \) is the real power generation of bus \( n \) that was obtained from load flow study.

3.3 Objective and Fitness Functions

The objective function can be defined as the sum of the square of the elements’ evaluation mismatches. It can be expressed as:

\[ \min(H) = \sum_{i=\text{bus}} |\Delta V_i|^2 + \sum_{i=\text{bus}} |\Delta P_i|^2 + \sum_{i=\text{bus}} |\Delta Q_i|^2 + \sum_{i=\text{bus}} |\Delta P_{G,i}|^2 \quad (29) \]

The value of \( H \) approaches zero towards convergence. After evaluation each chromosome, the objective function in Eq. (29) is transformed and normalized to fitness function scheme that to be maximized as follows:

\[ f = \frac{1}{1 + H + K |P_{G,n(sp)} - P_{G,n}|} \quad (30) \]

Where \( K = 0 \) if the contribution of generator \( n \) to load \( k \) is lower than the value of total generation \( n \). \( K = 1000 \) if opposite situation occurred. This is due to GA sometimes gives multiple optimization results that make the contribution of a particular generation to loads higher than the generation itself even the value of \( H \) is approaches to zero. So if the non logical results occurred, the penalty is given so that the particular chromosome will not be chosen for the next GA operations and iteration.

3.4 Crossover Operation

In the present work, the 2-point crossover method is adopted and the functions in Eqs. (2)-(8) are used. This is due to find the optimize results for the real and imaginary part of the voltage contribution.

3.5 Mutation Operation

An element of a chromosome is selected randomly. The value of the element is replaced by a value that arbitrarily chosen within a range of 0 to 1. The process of an application of GA to transmission usage allocation problem is shown in Fig. 2.

4. Computational Result and Discussion

Basically, the simulation program of GA has been developed using MATLAB. Two case systems are used to test the feasibility and the effectiveness of the method proposed. Load flow studies have been conducted using the tool that has been developed in Ref. [34].

4.1 Simple 4-Bus Test System

This system is illustrated in Fig. 3. There are two

\[ \text{Fig. 2 Flow of transmission usage allocation using GA.} \]
A New Optimization Approach for Transmission Usage Allocation in Deregulated Power System

Fig. 3  Simple 4-bus system.

Table 1  Converged bus solution of 4-bus system.

<table>
<thead>
<tr>
<th>Bus No.</th>
<th>Mag. (MW)</th>
<th>Deg. (MVar)</th>
<th>Load (MW)</th>
<th>Generation (MVar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.05</td>
<td>0</td>
<td>0</td>
<td>36.282</td>
</tr>
<tr>
<td>2</td>
<td>1.07</td>
<td>1.015</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>3</td>
<td>1.019</td>
<td>-3.09</td>
<td>30.001</td>
<td>18.008</td>
</tr>
<tr>
<td>4</td>
<td>1.007</td>
<td>-4.86</td>
<td>54.995</td>
<td>12.99</td>
</tr>
</tbody>
</table>

Table 2  Converged line solution of 4-bus system.

<table>
<thead>
<tr>
<th>From Bus</th>
<th>To Bus</th>
<th>Line Loss (MW MVar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-4</td>
<td></td>
<td>0.45+2.27</td>
</tr>
<tr>
<td>1-3</td>
<td></td>
<td>0.18+0.76</td>
</tr>
<tr>
<td>2-4</td>
<td></td>
<td>0.59+2.94</td>
</tr>
<tr>
<td>2-3</td>
<td></td>
<td>0+2.71</td>
</tr>
<tr>
<td>3-4</td>
<td></td>
<td>0.13+0.16</td>
</tr>
</tbody>
</table>

Table 3  Contribution of individual generators to line losses and loads for 4-bus system.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2</td>
<td>0.45+2.27</td>
<td>0</td>
<td>0.43+1.97</td>
</tr>
<tr>
<td>1-3</td>
<td>0.18+0.76</td>
<td>0</td>
<td>0.2+0.96</td>
</tr>
<tr>
<td>2-4</td>
<td>0.59+2.94</td>
<td>0.1+0.06</td>
<td>0.48+2.87</td>
</tr>
<tr>
<td>2-3</td>
<td>0+2.71</td>
<td>-0.08+0.04</td>
<td>0.08+2.76</td>
</tr>
<tr>
<td>3-4</td>
<td>0.13+0.16</td>
<td>-0.07+0.09</td>
<td>0.06+0.03</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Load Bus</th>
<th>12.75+7.19</th>
<th>17.28+10.8</th>
<th>12.72+5.78</th>
<th>17.27+12.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>22.51+4.38</td>
<td>32.5+8.66</td>
<td>22.84+2.42</td>
<td>32.14+10.6</td>
</tr>
<tr>
<td>Total</td>
<td>36.02+14.8</td>
<td>50.5+25.2</td>
<td>36.3+11.2</td>
<td>49.98+28.8</td>
</tr>
</tbody>
</table>

that bus 2 is a PV isolated bus because this bus does not have any incoming power from any other buses and solely supply the power to the system. This test system can be obtained from [11]. The chromosome of this test system is encoded same as in Fig. 1.

For this system, roulette wheel technique is used to determine the selection of mum and dad chromosomes, probability of crossover $p_c$ is set to 0.9 and probability of mutation $p_m$ is set to 0.5. By applying GA, effects of population and iteration number give the different results. If the population and iteration number are too large, it will take a longer time computation for convergence, while if the population and iteration number are small, the system will become immature and converge via experimental approach.

Contribution of individual generators to line losses and loads for real (MW) and reactive power (MVar) for this system using GA is tabulated in Table 3. After performing few cycles of simulations, the population for GA is set to 100. The mismatch versus iteration is shown in Fig. 4. The method that proposed in [11] is the same as in this table. It can be seen that for line 1-4 and line 1-3, only generator G1 contribute to the line losses. This situation is similar for line 2-4 and line 2-3, where the contributor for these line losses are from generator G2 only. These results are away from the method proposed in [11], where in each line, both generators give contributions to the line losses. This is...
due to the effect of superposition theorem that applied in this method. However, the correctness of this approach still can be debated.

From Table 3, it can be seen that the total real and reactive power are quite closed to the result that obtained in load flow study (Table 1). From this test system, it shows that the application of GA for transmission usage allocation can give optimize and acceptable results.

4.2 Klos-Kerner 11-Bus Test System

This system is illustrated in Fig. 5. This system consists of 11 buses (1 slack bus, 2 PV buses and 8 PQ buses) and 15 transmission lines. Power flow solution is tabulated in Tables 4 and 5. This system can be obtained in Ref. [20].

For this system, the selection, probability of crossover and probability of mutation are same with 4-bus system. Since the system consists of three generator buses, it is expected that large population and iteration are needed to obtain fair results. After several cycles simulations, the population is set to 200 and the maximum iteration is set to 500. Fig. 6 shows the result of mismatch versus iteration for the selected population and maximum iteration.

Fig. 7 shows the result of optimize magnitude voltage of generator buses 1, 2 and 3 to each load bus for this system using GA. It can be seen that the voltage contribution of bus 1, bus 2 and bus 3 are 100% for their respective buses and the rests are tabulated as shown in this figure. The sum of the contribution of these voltages at each bus is equal to the bus voltage obtained from Table 4.

The contribution of individual generators to loads is tabulated in Table 6. The result shows that the sums of each generator’s contribution give the close result to load flow study in Table 4. This shows that GA gives the acceptable results for transmission usage allocation problem. In addition, by using this approach, real and reactive power of transmission loss and load can be traced simultaneously and this gives significant advantage to reduce power tracing problem in deregulated environment.

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**Table 4** Converged bus solution of 11-bus system.

<table>
<thead>
<tr>
<th>Bus No.</th>
<th>Voltage</th>
<th>Angle</th>
<th>Load Generation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mag.</td>
<td>Deg.</td>
<td>MW</td>
</tr>
<tr>
<td>1</td>
<td>1.05</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>1.05</td>
<td>-0.25</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>1.048</td>
<td>-0.28</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>1.046</td>
<td>-0.46</td>
<td>20</td>
</tr>
<tr>
<td>5</td>
<td>1.047</td>
<td>-0.29</td>
<td>10</td>
</tr>
<tr>
<td>6</td>
<td>1.046</td>
<td>-0.44</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>1.045</td>
<td>-0.42</td>
<td>12</td>
</tr>
<tr>
<td>8</td>
<td>1.045</td>
<td>-0.38</td>
<td>5</td>
</tr>
<tr>
<td>9</td>
<td>1.046</td>
<td>-0.41</td>
<td>15</td>
</tr>
<tr>
<td>10</td>
<td>1.047</td>
<td>-0.33</td>
<td>20</td>
</tr>
<tr>
<td>11</td>
<td>1.046</td>
<td>-0.43</td>
<td>8</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>90</td>
</tr>
</tbody>
</table>

**Table 5** Converged line solution of 11-bus system.

<table>
<thead>
<tr>
<th>Line</th>
<th>From Bus</th>
<th>To Bus</th>
<th>Line Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MW</td>
<td>MVar</td>
<td>MW</td>
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The drawback of using GA for transmission usage allocation application is GA will require large computation time for a larger system. However, it can be conclude that the computational time is acceptable since this is tested for off line operation.

The other problem is GA will give multiple optimization solutions for each simulation. This means that every running simulation produces different acceptable results. Since the transmission usage allocation solution is not unique, the result of GA tool can be accepted as long as the result obtained is logic and produce the required load demand and losses occurred. Thus GA needs to be guided carefully so that the result is acceptable for deregulated power system environment. In this paper, the acceptable results were obtained after performing several simulations.

5. Conclusions

In this paper, a new method has been proposed for transmission usage allocation in deregulated power system using optimization technique, i.e. Genetic Algorithm. The transmission usage allocation problem can be traced by tracing the voltage contribution from individual generators at each bus. The voltage contribution is treated as optimization problem. Then, GA will compute an optimized result of voltage contribution so that the power flow and loss in the power network can be allocated. In this method, the continuous floating numbers are used as representation of the parameters in each chromosome. Even GA works as a black box problem, the results that have been presented in this paper are acceptable and promising. In addition, by using this method, the real and reactive power for transmission loss and load can be traced simultaneously.

Acknowledgments

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References
