Selecting Bilateral Transactions for Minimum Losses in Deregulated Power System  
– An Assignment Model Approach

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Abstract—The optimal power flow issue is one of the most important problems faced by dispatching Engineers regarding large scale power systems. It is a mathematical approach of the global power system optimization problem that aims at determining the least control movements to keep power system at most desired state. Thus, it represents flexible and powerful tool, which can address a wide range of planning and operation studies. However, the complexity of optimal power flow increases dramatically with large scale networks, which often discourages the utilization of this powerful tool in many applications. In the deregulated environment it allows bilateral transactions in which it becomes necessary to select the transactions which are suitable for consumer end to specified generator. The Optimal Power Flow (OPF) problem with transmission loss as an objective function is formulated as an Assignment problem and is solved by using Hungarian technique. The test cases used in this paper are the standard IEEE-6 bus. Results obtained by using assignment problem by Hungarian technique.

Keywords—Optimal power flow; Hungarian technique; Independent system operator.

I. INTRODUCTION

Interconnected systems are being used worldwide for the transmission of electric power. Generation of electric power and its utilization can be thousands of kilometers apart with transmission line spanning the vast extend. There will be resistive power losses in the form of heat energy along the transmission line because the lines are not perfectly conductor. The total power transmission loss is about 10% of generated power. The power loss can be decreased using optimal power flow with power losses as an objective function. This will in turn increase the profitability of generating companies.

In restructured power systems, the energy trades can be done in two ways: 1. energy auction or pools and 2. bilateral contracts. Bilateral contracts are becoming more popular among the Independent System Operator (ISO) and market participants (i.e., the sellers and buyers of electric energy). Bilateral contracts are financially safer for the market participants, because they can hedge against high price volatilities of real-time markets [3].

A bilateral transaction between a supplier and a buyer involves the injection of power at one location in the network and the extraction of the same amount of power, at the same time, at another location. Each bilateral transaction should, therefore, be represented by a source (positive injection) connected to the point of injection and a sink (negative injection) connected to the point of extraction. The source and sink are assumed to have same size (transaction rate in MW). The power injections associated with different bilateral transactions can influence the loading on transmission interfaces can increase or decrease depending on the system operating conditions, transaction size, and the direction of power transfer and the number of transactions considered [2].

An important problem that arises during the operation of power system is optimizing the power flow. There can be various objective functions in OPF. Some of these are reduction in power generation cost, reduction in power transmission system losses, minimization of fuel emission during power generation which is related to environmental pollution, etc. Different techniques have been used for solving the optimal power flow problem [1]. An optimal power flow with cost minimization using Newton’s method is described. This is an analytical method in which we take derivative of gradient to speed up the convergence. This method has limitations in handling the constraints.

The difficulty arises in the fact that near the limit the penalty is small, so that optimal solution will tend to allow the variable, for example, voltage to float over its limit. Another analytical method is the interior point method for the solution of constrained optimal power flow. This method is faster as compared to other conventional analytical methods. In [3], the authors describe loss reduction method using alterations in the hardware installations as well as software based constrained optimization. This shows the need of some good optimization technique with OPF which is the main aim of research work.

One of the optimization techniques to solve Assignment Problem is to apply Hungarian method. Hungarian mathematician Konig (1931) developed the
Hungarian method of assignment which provides an efficient method of finding the optimal solution without having to make a direct comparison of every solution. It works on the principle of reducing the given cost matrix to a opportunity costs. If we can reduce the cost matrix to the extent of having at least one zero in each row and column, it will be possible to make optimal assignments [3].

II. OPTIMAL POWER FLOW (OPF)

A. Formulation as a Linear Programming Problem

The assignment problem is a special case of the transportation problem, in which:

(i) supply=1
(ii) demand=1

It is due to this fact that assignments are made on a one-to-one basis. Because the assignment problem is a special case of the transportation problem, a linear programming formulation can be developed.

Let \( X_{ij} \) denote the assignment of facility \( i \) to job \( j \) such that

\[
X_{ij} = \begin{cases} 
1 & \text{if facility } i \text{ is assigned to job } j \\
0 & \text{otherwise}
\end{cases}
\]

B. Objective Function

One of the important objective functions is minimization of active power loss or transmission loss. In the deregulated environment it allows bilateral transactions in which it becomes necessary to select the transactions which are suitable for consumer end to specified generator. So the assignment model is used to solve the problem for selecting the transactions which are having minimum number of losses. There are two procedures to tackle the minimization of active power loss [8]. One of the ways is to calculate the slack bus active power and then try to minimize it. Second way is to compute the active power loss occurring on the individual lines and then minimize the summation of all line losses. Both procedures have advantages and disadvantages. In slack bus approach computation is much easy but it can only minimize the whole system transmission loss. Sometimes it is needed to minimize the active power loss in some specific portion of transmission line. In summation approach, computation is relatively complicated but we have the option to minimize the active power loss only in some specific portion of transmission line [5].

The mathematical model of the assignment problem can be stated as:

The objective function is to,

Minimize \( Z = \sum_{j=1}^{n} \sum_{i=1}^{m} C_{ij} X_{ij} \)

Subject to the constraints

\( \sum_{j=1}^{n} X_{ij} = 1 \) for all \( i \) (resource availability)

\( \sum_{i=1}^{m} X_{ij} = 1 \) for all \( j \) (activity requirement)

Where, \( X_{ij} = 0 \) or 1 and \( C_{ij} \) represents the cost of resource \( i \) to activity \( j \).

From the above, it is clear that the assignment problem is a variation of the transportation problem with two characteristics: (i) the cost matrix is a square matrix, and (ii) the optimal solution for the problem would be always such that there would be only one assignment in a given row or column of the cost matrix.

C. The Constraints

Consider worker \( i \). The total work done by the worker is the sum. In summation notation, this is written as-

\( \sum_{j=1}^{n} x_{ij} \). Since the total work done by the worker \( i \) is \( a_i \), the total work done cannot exceed \( a_i \). That is, we must require

\( \sum_{j=1}^{n} x_{ij} \leq a_i \), \hspace{1cm} \text{for } i=1, 2, \ldots, m.

Consider job \( j \). The total job available is the sum \( x_{1j} + x_{2j} + \cdots + x_{nj} \). In summation notation, this is written as-

\( \sum_{i=1}^{m} x_{ij} \). Since the demand at job \( j \) is \( b_j \), the total work should not be less than \( b_j \), that is, we must require

\( \sum_{i=1}^{m} x_{ij} \geq b_j \), \hspace{1cm} \text{for } j=1, 2, \ldots, n.

This results in a set of \( m+n \) functional constraints.

III. PROPOSED TECHNIQUE

Assignment problems can be formulated with techniques of linear programming and transportation problems. As it has special structure, it is solved by the special method called Hungarian method. This method was developed by D. Konig (1931), a Hungarian mathematician and is therefore known as the Hungarian method of assignment problem. This method provides an efficient method of finding the optimal solution without having to make a direct comparison of every solution. It works on the principle of reducing the given cost matrix to a matrix opportunity costs [3]. In order to use this method, one needs to know only the cost of making all possible assignments. Each assignment problem has a matrix (table) associated with it. Normally, the objects (people) one wishes to assign are in rows, whereas the column represent the tasks (or things) assigned to them. The number in table would then be the costs associated with each particular assignment [6].

There are few steps for solving the assignment problem using Hungarian method which are given in flow chart-

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Hungarian method is based on the principle that if a constant is added to the elements of cost matrix, the optimum solution of the assignment problem is the same as the original problem. Original cost matrix is reduced to another cost matrix by adding a constant value to the elements of rows and columns of cost matrix where the total completion time or total cost of an assignment is zero.

This assignment is also referred as the optimum solution since the optimum solution remains unchanged after the reduction [4].

IV. SIMULATION RESULTS

The assignment model is tasted on IEEE 6-bus system. In the deregulated environment it becomes very necessary to select the transactions which are having minimum losses. So the assignment model is used to solve the problem for selecting the transactions which are having minimum number of losses. The algorithm is programmed in MATLAB from MathWork and the simulation is done in Power World Simulator. Fig. shows the 6-bus system.

Consider 6-bus system, there are 3 loads and 3 generators in the system with constant base loads. Suppose the constant base load is 200MW, the transmission lines having certain transmission losses. The following cost matrix shows transmission losses in table-I.

<table>
<thead>
<tr>
<th>Loads</th>
<th>Generators</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>G1</td>
</tr>
<tr>
<td>L1</td>
<td>11</td>
</tr>
<tr>
<td>L2</td>
<td>9</td>
</tr>
<tr>
<td>L3</td>
<td>7</td>
</tr>
</tbody>
</table>

After applying Hungarian technique as describe in flow chart, the matrix becomes-

<table>
<thead>
<tr>
<th>Loads</th>
<th>Generators</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>G1</td>
</tr>
<tr>
<td>L1</td>
<td>5</td>
</tr>
<tr>
<td>L2</td>
<td>0</td>
</tr>
<tr>
<td>L3</td>
<td>0</td>
</tr>
</tbody>
</table>
Therefore, the suitable generator-load pair and system MW loss is shown in table III-

<table>
<thead>
<tr>
<th>Suitable Transactions (Generator-Load pair)</th>
<th>System MW loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2,2-1,3-3</td>
<td>22</td>
</tr>
</tbody>
</table>

From the table III, it is shown that 22MW is the minimum total loss in the system.

Similarly, by taking 10MW load over and above of 200 MW, the transmission losses are shown in table IV-

<table>
<thead>
<tr>
<th>Loads</th>
<th>Generators</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>G1</td>
</tr>
<tr>
<td>L1</td>
<td>0.03</td>
</tr>
<tr>
<td>L2</td>
<td>0.02</td>
</tr>
<tr>
<td>L3</td>
<td>0.02</td>
</tr>
</tbody>
</table>

After applying Hungarian technique as described in flow chart, the matrix becomes-

| Loads | Generators | | |
|-------|------------|----------------|
|       | G1  | G2  | G3  |
| L1    | 0.01 | 0   | 0.02|
| L2    | 0   | 0   | 0.01|
| L3    | 0   | 0.01| 0   |

Therefore, the suitable generator-load pair and system MW loss is shown in table VI-

<table>
<thead>
<tr>
<th>Suitable Transactions (Generator-Load pair)</th>
<th>System MW loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2,2-1,3-3</td>
<td>0.05</td>
</tr>
</tbody>
</table>

From the table VI, it is shown that 0.05MW is the minimum total loss in the system.

The loads which are directly connected to generators the line resistance is more and other line resistances kept smaller. So, system loss is 22MW when base load is kept at 200MW. The transactions (Generator-load pair) for 10MW load and 200MW load are similar. Therefore, these are the best transactions in the total system on which the losses are minimum. This method is suitable for ‘n’ number of load with same number of generator. If number of generator/load are not equal then add the dummy as per the requirement of the problem. And the results are validated with the MATABL coding. The results are coming out to be similar as that are get by forming the model in power world simulator.

V. CONCLUSION

In this paper, Assignment model is given which is used to solve the optimal power flow problem with transmission loss as an objective function. This is very efficient method used to find optimal solution without making direct comparison of every solution.

The complexity of this method is less because it does not have to perform the number of iterations as which have to perform in another techniques, so this method is very faster than other techniques. Therefore, it is shown that selection of bilateral transaction could be possible using Hungarian technique.

REFERENCES


