Transmission Usage Allocation Based on Power Factor Using Distribution Factor Method for Deregulated Electricity Supply

by Syarifuddin Nojeng

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Abstract **-- In a deregulated electricity supply required method of determining the actual power flow on each line of the generator to load. This paper is a study to solved the problem of the utilization of transmission by using the distribution factor method. The main purpose of this paper is to provide a new scheme for determining the utilization of the transmission line. The proposed method was verified on the IEEE14-bus system and the results shows that the proposed method has successfully allocate the transmission usage with considerate of the of power factor of the user. The proposed method could encourage the user to transmission charge and can provide a good tool for allocating the use of transmission line for all individual users that fairly.**

Keywords – Transmission usage allocation, power factor, distribution factor.

I. Introduction

Today, the electric supply industry has been changing rapidly throughout the world as a consequence of the implementation of deregulation. In deregulation, the transmission user in the interconnection network has to pay the cost of transmission service and this cost is determined based on the utilization of transmission line [1].

There are some method to determine of transmission usage for instance; Proportional sharing method, Distribution factor etc. However, these method do not to consider the power factor problems on the load whereas it is one of the factors associated with the transmission transfer capability [1]. Therefore, it needs improvement in determining the transmission usage allocation method that reflects the transmission load characteristic power factor.

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In fact, the load power factor below standard will be cause the decrease in electrical power delivery capability because it can lead to the increase of the voltage drop in the line. Some of the factor that contributes to the decrease of the power factor was the use of reactive loads such as induction motors and lamp typed discharge which was widely used in industries. Almost electricity companies in USA charge a penalty (additional cost) to users who have a low power factor below of 0.95, and Taiwan Power Company based on power factor of 0.8.

While, the reference for power factor of the State Electricity Company in Indonesia (PLN) established of 0.9. So, an additional fee will be charged to the user who has the power factor less than the reference power factor [4]. In Australia, The National Electricity Market Management Company (NEMCO) mandates that generators should provide the power factor in range of 0.9 lagging to 0.93 leading. In Norway, Sweden and Denmark provide a power factor range of 0.92 lagging to 0.98 leading [5].

II. Transmission Usage Allocation

The allocation of transmission usage method is presented is the distribution factors by Hugh Rudnick,et.al [6]. This method is can be to implementing for purpose of allocating payments to users of the transmission network with define; Generalized Shift Distribution Factors (GSDFs) or A Factors, Generalized Generation Distribution Factors (GGDFs) or D Factors, and Generalized Load Distribution Factors (GLDFs) or C Factors are the three factors associated with this approach. An approach for tracing power flow based on proportional sharing principle using Bialek Method [7-8]. Based on electricity theorema, is indistinguishable and each of the outflows down the line from node i is dependent only on the voltage gradient and impedance of the line, so it may be assumed that each MW leaving the node contains the same proportion of the inflows is the total nodal flow i P . Bialek Tracing Algorithm Method has two algortithm which are; upstream and downstream algorithm. The upstream algorithm allocated contribute individual generator in each line transmission. While, the downstream algorithm is using to determine in each transmission usage/supplement charge for individual load. This method most common but its main drawback is that the shares are always positive; i.e., no counterflows are encountered and all the charges to the network participant are positive.

Then, Kirschen proposed an approach based on proportional sharing principle using Graph method [9]. According with the active power flows obtained from the results of power flow study, the method introduce new concepts of domain-domain generator, common, and link. The domain of a generator is defined as the set of buses which are reached by the power produced by same generator. A common is defined as a set of neighboring buses supplied by the same generators and the rank of a common is defined as the number of generators supplying power to the buses with compare this common. Having divided the buses into commons, each branch is either internal to a common (i.e., it connects two buses which are part of the same common) or external (i.e., it connects two buses which are part of different commons).

The approach the state of the system that can be represented by a directed, a cyclic graph if the commons are represented as nodes and the links as branches. This graph is directed because the direction of the flow in a link is specified. It is a cyclic because links can only go from a common supplied by fewer generators to a common supplied by more generators [10]. The disadvantage of this method is that the contribution of each generator for each 'common' (i.e., the set of buses supplied from the same set of generators) is assumed to be the same as well as it ignores the counterflow within the network.

Gubina [11] introduce The Nodal Generation Distribution Factors (NGDF) method for determining the contributions of generators in a customer load. This method without use the system matrices for determining the share of each generator in the particular line power flow. Based on a search algorithm for power flow directions and the matrix calculations are not required. This method is based on the proportional sharing, it only allocates the share in the positive direction and this seems to be unfair to the network users.

This paper is organized as follows. Section I describes the problem of load power factor. In section II will describes about transmission usage allocation method existing. Section III formulates the proposed method based on the of a load power factor to application on a the IEEE 14 bus system and results are presented in Section IV. Section V concludes the results.

III. PROBLEM STATEMENT

A. Power factor of load

When the load L has power factor equal to the reference, the load L will pay the transmission cost based on normal cost [Fig.1]. But when the load#L is added with a reactive power , transmission owner does not obtain any additional utilization fee because P is constant. In this situation, the transmission decreases due to the increase of the losses. Conversely, if the load L improves its power factor (for example, with the installation of capacitor banks, the user does not obtain load L cost reduction, since P is constant. While, the transmission owner gets the benefit because it reduces the apparent power, S. Reduction in S would effect to the current flow in line which reduces the line loss. Hence, consequently the line capacity will increase.

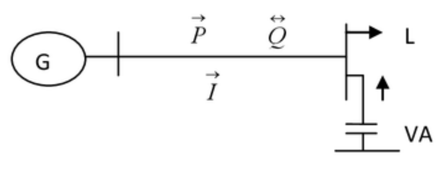

Fig.1 The Single line diagram with capacitor bank

The reactive power, active power and apparent power according to the IEEE std. 1459-2000 can be expressed as follows:

$$S = P + jQ \tag{1}$$

The line current due to reactive power changes in load by #Q is follows:

$$I'_L = \frac{P + jQ_L}{V} \tag{2}$$

B. *Distribution Factor method*

Concept theory:

By define the Factor A as a sensitivity factor that show related of change power injection ΔP_{ik} in bus, and the change of ΔF_{i-j} on line i-j.

Define admittance matrix B is:

$$B_{ij} = -x_{ij}^{-1} \tag{3}$$

and

$$B_{ii} = \sum x_{ij}^{-1} \tag{4}$$

Then, define matrix elements A by formula:

$$A_{i-j,k} = \frac{(z_{ik} - z_{jk})}{x_{ij}} \tag{5}$$

and;

$$F_{i-j} = \sum_{k \neq R} A_{i-j,k} . \Delta PI_k \tag{6}$$

where:

$$\sum_{k \neq R} \Delta PI_k + \Delta PI_R = 0 \tag{7}$$

Let, one bus as reference (reference R), we can formulate for generator contribute as follows:

$$F_{i-j} = \sum_g D_{i-j,g} . G_g \tag{8}$$

And power flow the load contribute in line as follows:

$$F_{i-j} = \sum_g C_{i-j,k} . L_k \tag{9}$$

IV. PROPOSED METHOD

The Power factor $(\cos\phi)$ is defined as a ratio of active power and apparent power which is expressed in the following equation:

$$P = VI \times \cos\phi_1 = VI' \times \cos\phi_2 = VI'' \times \cos\phi_3 \tag{10}$$

For simplicity, voltage V in eq. (10), is assumed as a constant, and we can define:

$$\cos\phi_1 = \cos\phi_{ref} \tag{11}$$

where ΔI is the current changes due to changes of lagging power factor, thus the relationship is obtained as following;

$$I \cos\phi_{ref} = I' \cos\phi_2 \tag{12}$$

These equations can be further written as follows ;

$$I \cos\phi_{ref} = (I + \Delta I') \cos\phi_2 \tag{13}$$

Therefore:

$$I \cos\phi_{ref} - I \cos\phi_2 = \Delta I' \cos\phi_2 \tag{14}$$

Power flow changes in line for lagging power factor, can be expressed as follows:

$$\frac{\Delta I'}{I} = \frac{\cos\phi_{ref} - \cos\phi_2}{\cos\phi_2} = \frac{\Delta P'}{P} = \frac{\cos\phi_{ref} - \cos\phi_2}{\cos\phi_2} \tag{15}$$

And :

$$\Delta P' = P \left[\frac{\cos\phi_{ref} - \cos\phi_2}{\cos\phi_2} \right] \tag{16}$$

Where: $\Delta P'$ defined as additional power flow due power factor > reference.

Similarly, for leading power factor :

$$\Delta P'' = P \left[\frac{\cos\phi_{ref} - \cos\phi_3}{\cos\phi_3} \right] \tag{17}$$

Where P is power flow in ecah line.

The eq. (16-17) shows that power changes due to power factor depend on actual power factor and reference power factor, can be written as follow;

$$\Delta P_{i,\cos\phi} = P_i^k \left[\frac{\cos\phi_{ref} - \cos\phi_3}{\cos\phi_3} \right] \tag{18}$$

Therefore a new transmission usage equation can be written as follow;

$$P_{i,\cos\phi}^k = P_i^k + \Delta P_{\cos\phi} \tag{19}$$

where:

$P_{i,\cos\phi}^k$ = Power flow in circuit i by user k (MW) depend on power factor

P_i^k = Power flow in circuit i by user k (MW)

According to Eq. (19), we can demonstrate the variation of the cost of the transmission line utilization. The C_{PF} variable can be defined as a price parameter due the actual power factor change to reference power factor.

Figure 3 shows that when the value C_{PF} value is unity, hence the load has a power factor equal with the reference. The higher of the difference between the reference to the actual power factor at the load, the greater will be value of the C_{PF}. The C_{PF} are in the range of 0.95 to 1.3 for the reference power factor of 0.9 and actual load power factor of 1 to 0.7. While, when the reference power factor is 0.95 and the actual power factor reduces to 0.7, the loads are potentially charge the transmission price until to 1.37 times.

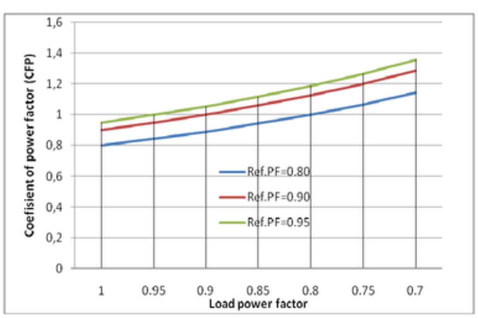

Fig. 3 The relationship between actual power factor (lagging) and the power factor correlation coefficient, C_{PF}

V. CASE STUDY AND DISCUSS

The proposed method was tested on a IEEE14-bus system.

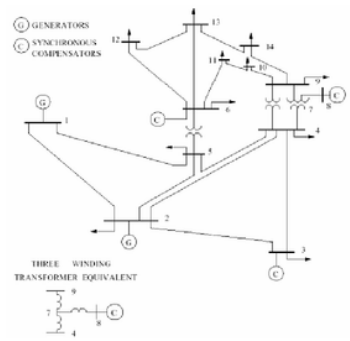

Fig. 2. The IEEE 14 bus test systems

The transaction is assumed to involve only real power and the contributions of reactive power flows are also neglected. In this case study, the proposed method is tested on the IEEE 14-bus system as shown in Fig. 2. This system includes 2 generators at buses 1and 2 while 11 loads are located at buses 2, 3, 4, 5, 6, 9, 10, 11, 12, 13 and 14. The generators serve a total system load of 259 MW. The reference power factor used in this case study is 0.8 and 0.9 respectively. The Generalized Generation Distribution Factors and Generalized Load Distribution Factors is used to determine the contribution of generation and load to the line flows respectively.

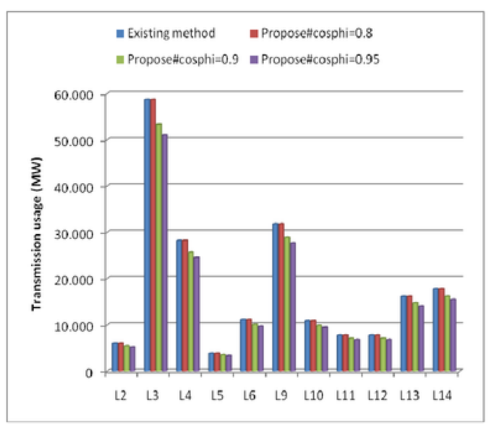

Fig. 4 Transmission usage on each load based on distribution method and proposed method.

In figure 4 shows the transmission usage allocated to the load based on distribution factor method (existing) and proposed method. The reference power factor in set by 0.9 while the load power factor is varies from 0.8 to 0.95. It can be seen that with the Distribution method, the load at bus 2 will pay the same amount of transmission cost although the reference power factor is different. Contrast, with the proposed method the transmission cost for the load is increased as the load power factor below the reference power factor and started to reduce when it passes the power factor that has been set as a reference.

VI. CONCLUSION

The proposed method which is based on the distribution factor by considering of the power factor has shown significant results in allocating the transmission usage to the user. The results found from the IEEE-14 bus system show that there are differences in the transmission utilization which depend on the level of the power factor of the user.

The advantages of the proposed methodis more favorable because it can give dis-incentive or incentive to all users of the transmission based on load characteristic. Further, the proposed will be encourage the user to improve the load which in turn reduce the generation cost. This proposed method can be further be extended by considering of the transmission pricing.

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