A Novel Method for Calculating Demand Not Served for Transmission Expansion Planning

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Abstract—Restructuring of the power market introduced demand uncertainty in transmission expansion planning (TEP), which in turn also requires an accurate estimation of demand not served (DNS). Unfortunately, the graph theory based minimum-cut maximum-flow (MCMF) approach does not ensure that electrical laws are followed. Nor can it be used for calculating DNS at individual buses. In this letter, we propose a generalized load flow based methodology for calculating DNS. This procedure is able to calculate simultaneously generation not served (GNS) and wheeling loss (WL). Importantly, the procedure is able to incorporate the effect of FR losses, excluded in MCMF approach. Case study on a 5-bus IEEE system shows the effectiveness of the proposed approach over existing method.

Index Terms—Graph theory, load flow analysis, power system reliability, planning, transmission lines.

I. INTRODUCTION

Restructuring of the power market introduced demand uncertainty in transmission expansion planning [1]. Here, new lines are identified based on the minimization of the sum of the cost of the expected demand not served (EDNS) and capital cost for setting up additional transmission capacities [2], [3]. Consequently an accurate estimation of DNS is required. Unfortunately, the graph theory based MCMF approach does not ensure that electrical laws are followed [2] - [5]. Nor can it be used for calculating DNS at individual buses, referred to as DNSi, an important input for “local” planning. In this article, we propose a generalized load flow based methodology to overcome the shortcomings of the MCMF approach. In fact, this methodology can also be used to simultaneously calculate GNS and WL. Here GNS/DNS can be calculated even while considering FR losses, hereafter referred to as network losses (NL). The MCMF approach cannot incorporate the effect of network losses. In addition to minimizing DNS, the planner can minimize WL to improve the economics of the power systems.

II. DNS

A. Minimum-cut Maximum-flow Methodology

Using graph theory the DNS for the system is calculated according to the formula [2]:

\[
DNS = \sum_{s=1}^{b} D_{s} - \max \left( f_{S-L} \right) \tag{1}
\]

\[
\max \left( f_{S-L} \right) = \min \left[ c(q_{S-L}) \right] \tag{2}
\]

Here, \( D_{s} \) represents the demand at bus ‘s’, and \( f_{S-L} \) is the flow from node \( S \) to node \( L \). In equation (2), \( Q \) refers to the set of all such \( q_{S-L} \) cuts, where \( q_{S-L} \) is a set of elements whose removal from the graph breaks all directed paths from node \( S \) to node \( L \). \( c(q_{S-L}) \) is the sum of the capacities of all the elements defining the \( q_{S-L} \) cut. A graph theory representation of the network is given in section III.

B. Proposed Methodology

Fig. 1 is a schematic diagram of a bus “s” in an electrical network with “m” incoming and “n” outgoing transmission lines. As a first step, an economic load dispatch using DC-load flow is run – without considering transmission capacity constraints -- with the specified demand and generation at each node. DNS and GNS are then calculated at each bus “s” using the following relationships:

\[
\text{DIFF}_{s} = D_{s} - \min \left( \sum_{i=1}^{m} T_{f,i,s} c_{i,s} \right) + \min \left( \sum_{j=1}^{n} T_{f,j,s} c_{j,s} \right) - G_{s} \tag{3}
\]

\[
DNS_{s} = \text{DIFF}_{s} : \text{if DIFF}_{s} > 0 \tag{4}
\]

\[
GNS_{s} = \text{abs}(\text{DIFF}_{s}) : \text{if DIFF}_{s} < 0 \tag{5}
\]

\[
DNS = \sum_{s=1}^{b} DNS_{s} \quad : \quad GNS = \sum_{s=1}^{b} GNS_{s} \tag{6}
\]

In fact, DNS/ GNS calculations should only be made on buses that have at least one congested line, thereby reducing the computational time. It may be pointed out that DNS ≠ GNS.

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in a network with network losses. WL can be calculated according to:

$$WL = \sum_{k=1}^{i} (T_{f,k,s} - T_{c,k,s})$$  

(7)

$G_i$ is generation at bus ‘s’; $T_{f,k,s}$ and $T_{c,k,s}$ refer to the actual power flow and transmission capacity of the $i^{th}$ incoming line to bus ‘s’ respectively. Similarly (i) $T_{f,k,s}$ and $T_{c,k,s}$ and (ii) $T_{f,k,s}$ and $T_{c,k,s}$ have analogous meaning for the $j^{th}$ outgoing line from bus ‘s’ and the $k^{th}$ congested line respectively.

### III. Case Study

The base network used for the case study is shown in Fig. 2 [2]. Two additional cases have been generated by first changing the capacity of (i) T1 from 100 MW to 25 MW (case-2) and (ii) T2 from 75 MW to 25 MW (case-3). The graph theory representation of the power system with three cases is shown in Fig. 3 [2]. S-I and S-2 branches represent the generation capacity at buses 1 and 2 respectively. Branches 2-L, 3-L, 4-L and 5-L represent the respective loads at buses 2 to 5.

![Fig. 2. Network for case study with specified generation, load and transmission capacities, generator at bus-1 is slack generator.](image)

![Fig. 3. Graph theory representation of Fig. 2 with given capacity of the branches.](image)

Table-I shows (i) DNS, in all five buses and (ii) a comparison of DNS calculated by the proposed methodology (PM) and MCMF approach for a “lossless” network (LLN). Here the negative and positive values refer to GNS and DNS respectively. The shortcoming of the MCMF approach is illustrated by the results of cases 1 and 3. In case-1, the MCMF approach suggests that the network is reliable and does not require any transmission expansion. On the other hand, MCMF underestimates the DNS by a factor of 2.4. Table-II compares the power flow in each transmission line using the proposed method and MCMF and shows the wheeling losses for the three cases.

A comparison of Tables-I and III shows that the presence of network losses changes the values of (i) DNS and GNS and (ii) DNS/ GNS. According to Table-III, it can be seen that the difference between DNS and GNS in cases 1, 2 and 3 are 4.5 MW, 12.1 and 6 MW respectively, indicating more realistic situation. The MCMF approach cannot incorporate the effect of network losses.

### IV. Conclusion

In this letter, we have quantitatively shown that the proposed methodology, which follows electrical laws, indeed yields DNS/ GNS which are different from those calculated using the MCMF approach. This approach is especially useful for TEP in countries such as India that do not follow the nodal pricing mechanism. The calculation of DNS, allows planners to prioritize the setting up of transmission lines based on the consumer mix (residential, commercial, industrial, agricultural etc.) in a particular bus. Moreover, calculation of DNS/GNS can be used for locating and boosting or adding generation capacities.

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