# Real Power Allocation in Open Access Environment

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**Abstract— Tracing the flow of electricity becomes an important issue under transmission open access. In practice, power flow follows the physical laws of electricity and therefore it is not straight forward to map out how the participants make use of the system. This article focuses on presenting an analysis of the performance of major power tracing methods based on proportional sharing principle namely the Graph Theory. The power transmission costs, which are charged to the market participants, are a central issue of the new deregulated electricity markets. The article implements a methodology for transmission cost allocation based on the principle of proportional sharing states that any power flow leaving a bus is made up of the flows entering that bus in a proportional manner, thus satisfying Kirchhoff first law. To carry out the computer tests, IEEE 6 and 30 bus systems are taken to allocate real power as a part of transmission loss allocation. It also allows the assessment of contributions of individual generators (or load) to individual line flows.**

**Index Terms— Transmission loss allocation, Graph theory, deregulation, monopolistic.**

## I. INTRODUCTION

Transmission loss allocation is the process of assigning to each individual generation and load the responsibility of paying for a part of the system transmission losses. Although no power system variable is affected by this process, the revenue and payment reconciliation are dependent on the criterion adopted for this purpose Transmission loss allocation is not an easy task. Even in a simple two-node system with one generator supplying a single load, loss allocation between the generator and the load has to be agreed upon as there is no physical measurement or mathematical method that determines the loss shares in a unique manner. In a real system, matters obtain more complicated because of two facts. The first is that the determination of the line flows caused by each load through each transmission line has a good degree of arbitrariness. The second is that the transmission line loss is a nonlinear function of the line flow, and hence cannot be separated between partial flows through the same line in a unique convincing way [3]. Continuing trend towards deregulation and unbundling of transmission services has resulted in the need to assess what the impact of a particular generator or load is on the power system. A new method of tracing the flow of electricity in meshed electrical networks is proposed which may be applied to both real and reactive power flows. The method allows assessment of how much of the real and reactive power output from a particular station goes to a particular load. It also allows the assessment of contributions of individual generators (or load) to individual line flows [6].

In a competitive environment, usage allocation questions must be answered clearly and unequivocally. To help answer such questions, this article practices a proposed method for determining how much of the active and reactive power output of each generator is contributed by each load. This method takes as its starting point a solved power flow solution. Having determined where the power goes, one can compute how much power flows from a given generator to each load or from all generators to a particular load. It is also possible to determine how many MWs each load or generator contributes to the active flow in a branch. These physical "contributions" form a basis upon which the cost of building and maintaining each component of the network could be allocated among its users Computation of the contributions defined and used in is possible only if the quantities being allocated are linearly additive. This implies that active and reactive powers should be considered separately. Power flows of generators and loads are traced to determine the transmission system usage by each generator and load. Then, transmission losses caused by each generator or load are determined. Based on power flow tracing methodology, topological generation and load distribution factors are determined in through matrix inversion, with additional nodes added to represent line losses.

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## II. POWER TRACING

The monopolistic, vertically integrated power system has now become market driven. In this new operating environment, determining the impact of individual market players on the system has become very significant. To ensure fair competition among the players, all financial transactions should be transparent, and none of the costs should be allowed to be subsidized or cross-subsidized. In such a structure a transmission system is being used by multiple generation and load entities that do not own the transmission system. In view of market operation it becomes more important to know the role of individual generators and loads to transmission wires and power transfer between individual generators to loads. Transparency can be accomplished only when the power-flow path of a generator and its flow extent are known. This information, which can be determined by power-flow tracing, not only enables the independent system operators (ISOs) to pay proper revenue to the generators, but it also proves to be a very important tool for different analytical purposes [8].

Usage allocation refers to power contribution of each generator to each load. The advantage of knowing the usage allocation includes loss allocation associated to each path, cost assignment to transmission line pricing, congestion management, ancillary services and decision on scheduling of generators. To achieve the above mentioned advantages several schemes have been developed to solve the allocation problem. Methods based on dc load flow and sensitivity analysis cannot consider accurately, the reactive power transfer allocation and system non linearity. The bilateral transaction approach aims at assigning the transmission cost of any specific transaction between two nodes. Research has been carried out by unbundling the flow of electricity based on individual transactions taking place which is theoretically very difficult. Other commonly used approaches include application of superposition theorem and power tracing methods.

The proportional sharing principle basically amounts to assuming that the network node is a perfect ‘mixer’ of incoming flows so that it is impossible to tell which particular inflowing electron goes into which particular outgoing line. This seems to agree with common sense and with the generally accepted view that electricity is indistinguishable. The concept of “power flow tracing” between generators and transmission has been discussed for determining wheeling rates of new users under deregulated environments [6].

## III. FUNDAMENTALS OF LOAD FLOW TRACING

In order to simplify the problem, we first make the following basic assumptions:

a) An ac load flow solution is available from on-line
state estimation or off-line system analysis. The studied system has finite number of buses. It is operated properly and there is no loop flow in the system.

b) Real power and reactive power required by
Transmission line resistance, reactance and charging capacitance have been moved to the line terminal buses (see Section III for details) and modelled as “equivalent loads” according to ac load flow solution. Therefore the line active and reactive power flows keep constant along the line, each edge has a definite direction and the network is “lossless.”

c) A generator has the priority to provide power to the
load on the same bus. The remaining power will enter the network to supply other loads in the network to avoid unnecessary losses. It is true even according to a transaction contract a generator does not sell electricity to the local load. This is because electricity has no label and system operators have the authority to dispatch the power flow. Therefore the buses of a network can be classified as generator buses, load buses and network buses based on their net injection to the system. This concept can be applied to both active and reactive power flows.

d) The flows of electricity obey the proportional-sharing
Rule.

The above assumption leads to the following lemmas-

*Lemma 1:* A lossless, finite-nodes power system without loop flow has at least one pure source, i.e. a generator bus with all incident lines carrying outflows. This lemma will be proved below. It guarantees to start and continue a downstream tracing from an existing pure source.

*Lemma 2:* A lossless, finite-nodes power system without loop flow has at least one pure sink, i.e. a load bus with all incident lines carrying inflows [8].

## IV. PROPORTIONAL SHARING PRINCIPLE

The proportional sharing principle is based on Kirchhoff’s current law. It deals with a general transportation problem and assumes that the network node is a perfect mixer of incoming flows. Practically the only requirement for the input data is that Kirchhoff’s current law must be satisfied for all the nodes in the network. In this respect the method is equally applicable to ac as well as dc power flow. As electricity 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, it may be assumed that each MW leaving the node contains the same proportion of the inflows as the total nodal flow P [6]. The nodal sum i.e. total incoming and total outgoing power at node is equal. The main principle used to trace the flow of electricity will be that of proportional sharing is shown in Fig 1(a). In this, four lines are connected to node **a,** with two inflows and with two with outflows. The total power flow through the node is Pa = 40 + 60 = l00MW of which 40% is supplied by line j-a and 60% by line k-a.

According to proportional sharing principle-

The 70MW outflowing in line a-m consists of

70*40/100=28 MW. supplied by line j-a and

70*60/100=42MW supplied by line k-a**.**

Similarly the 30MW outflowing in line a-n consists of

30*40/100=12MW supplied by line j-a and

30*60/100=18 MW supplied by line k-a.

The proportional sharing principle basically amounts to assuming that the network node is a perfect ‘mixer’ of incoming flows so that it is impossible to tell which particular in flowing electron goes into which particular outgoing line. The principle is fair as it treats all the incoming and out-flowing flows in the same way.

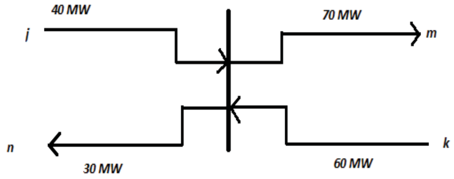


*Fig 1(a): Representation of Proportional Sharing Principle*

## V. DOWNSTREAM LOOKING ALGORITHM

Now consider the dual, downstream-looking, problem when the nodal through-flow *P*, is expressed as the sum of outflows

$$P_i = \sum | P_{i-l} | + P_{Li}$$

$$P_i = \sum C_{li} P_i + P_{Li}$$

where alpha(i)$^d$ is, as before, the set of nodes supplied directly from node i and

$$C_{li} = | P_{i-l} | / P_l$$

This equation can be rewritten as

$$P_i - \sum C_{li} P_i = P_{Li}$$

$$A_D P = P_L$$

Where A$_d$ is the *(n* x *n)* downstream distribution matrix and P, is the vector of nodal demands. The (i.l) element of A$_d$ is equal to

$$[A_d]_{il} = \begin{cases} 1 \\ -C_{li} = -| P_{i-l} | / P_l \\ 0 \end{cases}$$

Note that **A,** is also sparse and non symmetric. Adding and gives a symmetric matrix which has the same structure as the nodal. Admittance matrix. If $A_d^{-1}$ exists then $P= A_d^{-1} P_L$ and its ith element is equal to

$$P_i = \sum [A_l{}^{-1}]_{ik} P_{ik} \qquad \text{for i=1,2…..n}$$

This equation shows how the nodal power P, distributed between all the loads in the system. On the other hand, the same $P_i$ is equal to the sum of the generation at node ***i*** and all the inflows in lines entering the node. Hence the inflow to node ***i*** from line **i-j** can be calculated using the proportional sharing principle as

$$| P_{i-l} | = (| P_{i-l} / P_i ) P_i = (| P_{i-l} | / P_i ) \sum [A_l{}^{-1}]_{ik} P_{ik}$$
$$= \sum D_{i=j}, k^L P_{LK}$$

Where $\sum D_{i=j}, k^L P_{LK}$ is the topological load distribution factor that is the portion of kth load demand that flows in line i-j.

This definition is again similar to that of the generalized load distribution factor based on DC load-flow sensitivity analysis. However, the topological factor represents the share (which is always positive) of the load in a line flow while the generalized factor determines the impact of the load on a line flow and may be negative. The generation at a node is also an inflow and can be calculated using the proportional sharing principle as

$$P_{Gi} = (P_{Gi} / P_i ) P_i = (P_{Gi} / P_i ) \sum [A_d{}^{-1}]_{ik} P_{ik}$$

This equation shows that the share of the output of the ith generator used to supply the kth load demand is equal to $P_{Gi} P_{LK} [A_d^{-1}]_{ik} / P_i$ and can be used to trace where the power of a particular generator goes to[6].

## VI. RESULTS AND DISCUSSIONS

### (A) An application with IEEE 6 bus system

To make the applied method easy to understand, a small test system was selected to explain the steps involved. The one-line diagram of the system is shown in Figure 7(a), and the system data can be found. From the power-flow results, the direction of power flows through the lines can be determined. The real power-flow direction is indicated by the arrows placed under the branches.

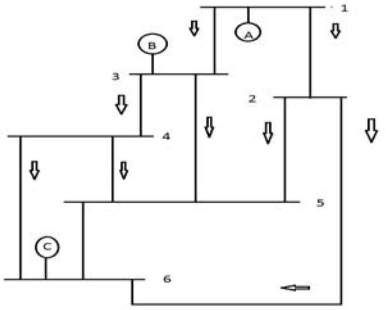
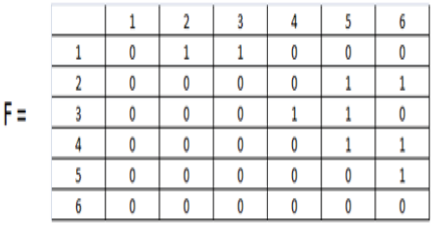


Fig2 (a): Single line diagram of 6 bus system

Three generators are connected to buses 1, 3, 6. From the power-flow directions shown in the figure, it can be seen that only bus 1 is the start buses, as the bus has all the outgoing power. All other generator buses, namely buses 3 and 6, do not get power only from the generators connected to that bus through the transmission lines. For instance, bus 3 gets power from bus 1, while. Again, bus 6 is only the bus where all of the connecting lines carry incoming power, and no line carries power out of this bus. So, bus 6 is the only end bus in this system. This process of selecting start and end buses should be repeated for reactive power flow also, as this might result into a different set of start and end buses. In this case, there will be a single start bus for reactive power flow at bus 1.Once the start and end buses are selected, the flow direction matrix (F ) is formed. Matrix F for active power allocation of the test system is shown below:

Table 1(a): Flow Incidence Matrix of 6 bus system



F =

|   | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 0 | 1 | 1 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 | 0 | 1 | 1 |
| 3 | 0 | 0 | 0 | 1 | 1 | 0 |
| 4 | 0 | 0 | 0 | 0 | 1 | 1 |
| 5 | 0 | 0 | 0 | 0 | 0 | 1 |
| 6 | 0 | 0 | 0 | 0 | 0 | 0 |

The elements of F having value 1 indicate a direct connection between the corresponding buses. As bus 1 is directly connected to bus 2 and 3 only, and the direction of the power flow is from bus 1 to bus 2, so the first row of F has a double 1 value in column 2 and 3. In bus 6, although there are three lines connected, power flow in all of these buses is toward this bus, so all of the elements in the last row of F are 0.

The total inflow for each of the buses is calculated, followed by the calculation of the contribution for each of the generator buses on itself. This is taken as 1 if the generator is a start generator. So, for the six-bus system, the contribution of generators 1 toward itself will be 1. For all other generators at buses 3 and 6, their contributions on the bus where they are connected will be calculated as

$$C_{33}= P_{G3} / P_3$$

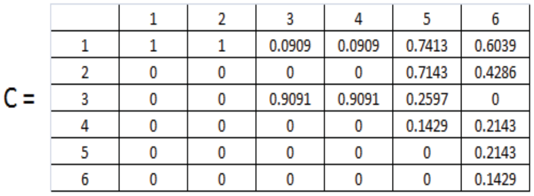
where PG3 is the output of the generator at bus 3, and P3 is the total inflow at bus 3.

Once the contribution of generators toward their own buses are over, any of the start buses is selected (1, here), and the contribution of this bus is calculated for all the buses (j) having a non-zero element of F corresponding to this new bus. From the flow-direction matrix shown above, it is seen that, corresponding to bus 1, only bus 2 has a non-zero element. So, the contribution of bus 1 on bus 2 will be

$$C_{12}= P_{12} / P_2$$

where P12 is the power flow from bus 1 to bus 2, and P2 is the total inflow at bus 2. Bus 2 will now be considered as the start bus, and the process will be repeated for all other buses until it reaches any one of the end buses. These steps are repeated for all generators. The resulting contribution matrix, which gives the contribution of each bus

Table 1 (b): Contribution matrix

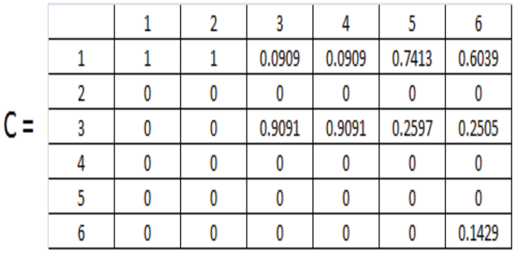


C =

|   | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 0.0909 | 0.0909 | 0.7413 | 0.6039 |
| 2 | 0 | 0 | 0 | 0 | 0.7143 | 0.4286 |
| 3 | 0 | 0 | 0.9091 | 0.9091 | 0.2597 | 0 |
| 4 | 0 | 0 | 0 | 0 | 0.1429 | 0.2143 |
| 5 | 0 | 0 | 0 | 0 | 0 | 0.2143 |
| 6 | 0 | 0 | 0 | 0 | 0 | 0.1429 |

If any bus has a contribution value of less than 1 toward itself (here buses 2, 3, 4, and 6), then its contribution for all other buses gets modified by multiplying each of the contribution value for that bus by its self-contribution, which is less than 1 (as per Step 11 of the algorithm). The final contribution matrix of the generators toward the active load for the test system is

Table1 (c): Final contribution Matrix



C =

|  | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 0.0909 | 0.0909 | 0.7413 | 0.6039 |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0.9091 | 0.9091 | 0.2597 | 0.2505 |
| 4 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 0 | 0 | 0 | 0 | 0 | 0.1429 |

The contribution of a generator toward a bus is considered to be same as the generator's contribution to all branches connected to that bus and having an outward power flow direction from the bus into the branch. So, determining the bus from which power is sent into the branch will lead to the contribution of generators on the branch loss as well as branch flow. Similarly, the contribution of any load on branch loss will be the same as the contribution of the load on the bus that is connected to the branch and carries power in an outward direction from the branch toward the load. The contribution of individual generators on the load is represented by the following graph-

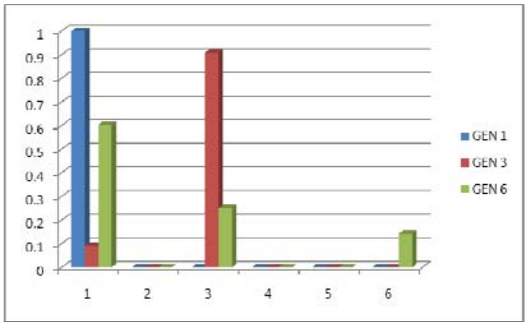


Fig 1(c): Graphical Representation of generator contribution to loa

From the figure, it is clear that

(i) Generator 1 is supplying 100% power to Bus 1.
(ii) Generator 3 is supplying 9.09% power to Bus 1 and 90.9% power to Bus3
(iii) Generator 6 is supplying 60.3% power to Bus 1, 25.05% power to Bus 3 and 14.29% power to Bus 6.

(B) An application with IEEE 30 bus system

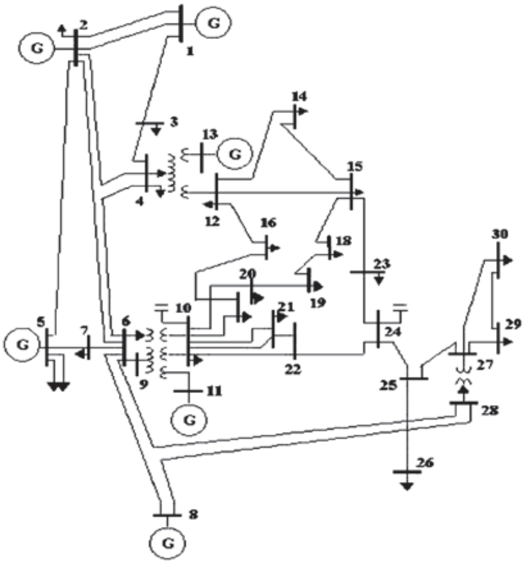


Fig 3(a): Single line diagram of 30 bus system

Considering bus 1 as the start bus, reactive power is traced in the above system. Starting with the flow-incidence matrix, the connections are checked between each lines are contribution is analyzed by proportional sharing principle.

Following the similar steps of Downstream Looking Algorithm, the above system is traced for reactive power and the updated contribution matrix is shown in Table 5

The contribution of individual generators on load buses can be represented as-

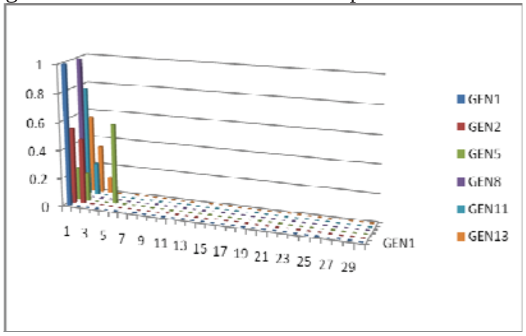
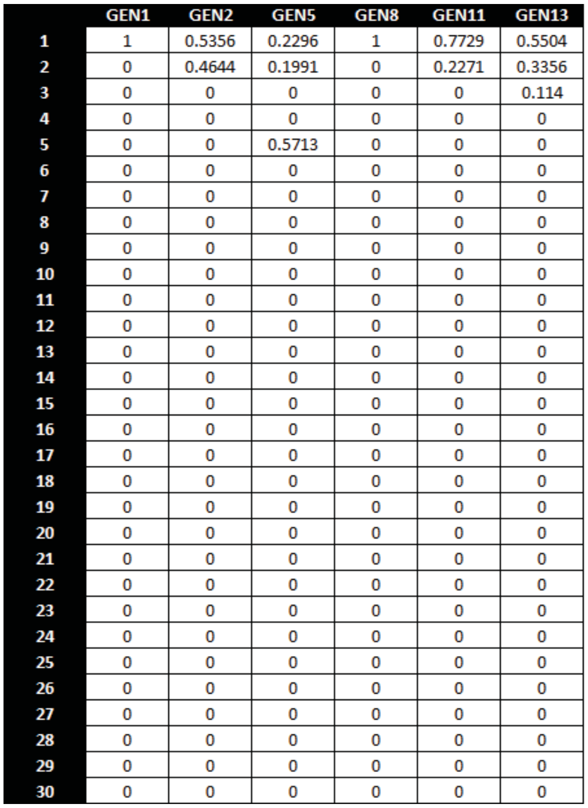


Fig 3 (b): Graphical representaion of contribution of individual generators to load

The final contribution matrix which shows the contribution of the 6 generators on the 30 individual buses is as follows-

Table 2(a): Final contribution matrix of 30 bus system on the 6 generators



| | GEN1 | GEN2 | GEN5 | GEN8 | GEN11 | GEN13 |
|---|---|---|---|---|---|---|
| **1** | 1 | 0.5356 | 0.2296 | 1 | 0.7729 | 0.5504 |
| **2** | 0 | 0.4644 | 0.1991 | 0 | 0.2271 | 0.3356 |
| **3** | 0 | 0 | 0 | 0 | 0 | 0.114 |
| **4** | 0 | 0 | 0 | 0 | 0 | 0 |
| **5** | 0 | 0 | 0.5713 | 0 | 0 | 0 |
| **6** | 0 | 0 | 0 | 0 | 0 | 0 |
| **7** | 0 | 0 | 0 | 0 | 0 | 0 |
| **8** | 0 | 0 | 0 | 0 | 0 | 0 |
| **9** | 0 | 0 | 0 | 0 | 0 | 0 |
| **10** | 0 | 0 | 0 | 0 | 0 | 0 |
| **11** | 0 | 0 | 0 | 0 | 0 | 0 |
| **12** | 0 | 0 | 0 | 0 | 0 | 0 |
| **13** | 0 | 0 | 0 | 0 | 0 | 0 |
| **14** | 0 | 0 | 0 | 0 | 0 | 0 |
| **15** | 0 | 0 | 0 | 0 | 0 | 0 |
| **16** | 0 | 0 | 0 | 0 | 0 | 0 |
| **17** | 0 | 0 | 0 | 0 | 0 | 0 |
| **18** | 0 | 0 | 0 | 0 | 0 | 0 |
| **19** | 0 | 0 | 0 | 0 | 0 | 0 |
| **20** | 0 | 0 | 0 | 0 | 0 | 0 |
| **21** | 0 | 0 | 0 | 0 | 0 | 0 |
| **22** | 0 | 0 | 0 | 0 | 0 | 0 |
| **23** | 0 | 0 | 0 | 0 | 0 | 0 |
| **24** | 0 | 0 | 0 | 0 | 0 | 0 |
| **25** | 0 | 0 | 0 | 0 | 0 | 0 |
| **26** | 0 | 0 | 0 | 0 | 0 | 0 |
| **27** | 0 | 0 | 0 | 0 | 0 | 0 |
| **28** | 0 | 0 | 0 | 0 | 0 | 0 |
| **29** | 0 | 0 | 0 | 0 | 0 | 0 |
| **30** | 0 | 0 | 0 | 0 | 0 | 0 |

## VII. CONCLUSION

This Article uses a method for power-flow tracing and allocation of transmission losses based on the power-flow results. It employs the graph theoretic methods directly to determine the contribution of the generators to individual loads or line flows. Unlike other graph theory based approaches, the method does not require sub-grouping of the system buses. This makes the method very simple to implement, and also it significantly decreases the computation time. The method allocates loads and losses to the generators avoiding any possibility of cross-subsidy. So, increased accuracy and improved speed with the very simple approach of the method are its main advantages over the other similar methods, considering the premium value of the power and energy losses.

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