A Non Proportional Sharing Power Flow Tracing Based on Bus Power Balance Equations

Roozbeh Morsali [1] and Abdolreza sheikholeslami[2]

[1] Noushitrvani Instute of Technology, University of Mazandaran

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Abstract

Index terms—

1 A Non Proportional Sharing Power Flow Tracing Based on Bus Power Balance Equations

Roozbeh Morsali 1 , Abdolreza Sheikholeslami 2

Abstract–Using proportional sharing assumption in power flow tracing has always been a controversial issue because there is no proof to accept or deny such an assumption. In this paper, we propose tow new method one based on proportional sharing and the other based on bus power equations and network's impedance matrix to solve power flow tracing problems. And we use these solutions to find generation units and consumer loads shares in transmitting power of each line of the network. Both methods are able to handle loop flow and can be applied for both active and reactive power flow tracing. The case study on IEEE 24 bus reliability test system (RTS) shows that the proposed tracing methods are effective and accurate in transmission cost allocation and other tracing problems. Also a comparison between these methods has been made to illustrate the efficiency of proportional sharing assumption.

2 INTRODUCTION

arious changes in the socio-economic structure of power systems lead to the drastic changes in the technical aspects of power system control and management, after the era of restructuring. Nowadays, power systems are totally market driven in most of countries all around the world. In a vertically integrated system the answer of this question: "what is the share of a certain unit in the power flow of a particular line or in the demand power of a particular load" is of a little importance. This always referred as power flow tracing (PFT) problem, which is one of the challenging issues in restructured power systems and has been received a great attention during these years.

In order to find a practicable method to allocate the cost of transmission between different market participants, different methods have been applied, each with particular criteria or assumptions. Reviewing the literatures, one can deduce that these methods can be classified into two major categories. The methods of the first category do not really follow the power flow from generating units into the loads. Following a market clearing process, these methods always find the share of different participants in cost of a certain transmission line using sensitivity factors. These methods always solve the problem very fast without engaging in time and memory consuming processes like matrix inversion, so they are suitable for bulky power systems. The methods which use different form of generation shift factors (GSF) belong to this category. [1] use GSFs to solve the tracing problem. The main question about the effectiveness of such methods is: "which one is more interesting to us when we are about to solve the tracing problem? The "impact of change in generation of a unit on the flow of a certain line or its share?" Answering this question logically, some new approaches were proposed in literatures [1]- [5] based on GSFs. Another defectiveness of such methods is due to their dependence on slack bus.

The methods of the second category use different tricks and some times, simplifying assumptions to trace the real share of different participants in power flow of different lines. This category contains the topological [6], [7] and the upstream and down-stream looking algorithms, which all assume proportional contribution factors. The method of up-/down-stream tracing for example was used in [1], [8]. A topological-based method was presented in [9], which uses extended incidence matrix (EIM). Though the authors pointed out that the method does not assume proportional sharing, the method does not consider any difference between different sources of power injection to a bus, when analyzing their shares in bus outflows. This is the main assumption in proportional sharing methods instead of considering physical relations between different in-/outflows.

In [10], the authors used network Zbus and applied the circuit laws to draw a relation between the flow of a line and the injected current from different network buses. Though the method is categorized in first category, application of the circuit law instead of proportional sharing assumption is a very interesting aspect of this work.

In this paper two different methods of power flow tracing are proposed and compared. The first method uses the proportional sharing assumption to draw the relations between power in-and out-flows of network buses from power balance equation of the network buses. The second method uses the idea of power balance equation of the first method, but uses the circuit laws to draw the mentioned relations. Both methods can trace the active and reactive power flows from generating units to loads, even in the case of networks with loop flows. The main advantage of proposed methods is the fact that they both trace the actual share of different participants in power flow of network lines rather than their impact on these flows. Another virtue of the presented methods is the way they handle the loss issues in tracing process. The problem appears since the power which is extracted in receiving end of a line is not the same as injected one due to line losses. [9] For example, added the half value of active and reactive losses of each line to the load value of two end of the line. This is a good approximation, but it slightly changes the results of tracing algorithm.

The rest of the paper is organized as follows. Section III gives an overview of proposed methods as well as the problem formulation for both methods. IEEE reliability test system (RTS) is presented as an illustrative example in section IV and the results of proposed methods are compared and in detail discussed. Conclusions are drawn in section V.

3 III.

4 PROPOSED NETHODS

In this section both methods are explained and their formulations are presented. In both methods we assume that the generation of different units and the load values are given.

Considering generating units, lines and transformers which are connected to bus i, one can write a simple equation for active power balance at this bus (1).

Based on the proportional sharing assumption, there is no difference between different terms in left hand of equation (**??**). This equation combined with proportional sharing assumption leads to (2) for each line:

Where u l, g is share of unit g in power flow of line l, When this unit is connected to the sending bus of line l.

Where w l, l' is the share of line l' in power flow of line l. There is out Nl out i equations of form of (2) for bus i, so we have Nl equations each for a certain line of the network. (3) and (**??**) are written based on proportional sharing assumption and determine the share of bus i in flows in power flow of the lines which transmit active power from this bus to others.

We now can express the power flow of each line in two different ways. Let us show them in two tables. Table **??** shows the share of each unit in power flow of each line (the variables we are about to find in tracing problem). Table **??**I contains the shares which are mentioned earlier in (3) and (4).Table I Share of Each Unit in Power Flow of Line L in out i i i i g l d l g Sg d Sd l Sl l Sl PG PL PD PL ? ? ? ? + = + ? ? ? ? ? (1) , , 1 1 1 Ng Nl l g l l g l u w ? ? = = + = ? ?**(2)**

, , 0 other wisein i i g out i i g li l g g Sg li Sl PG g Sg l Sl PG PL u ? ? ? ? ? ? ? ? + = ? ? ? ? ? ? ?**(3)**

' , , 0 otherwise Comparing these two tables, an equation can be written for the share of each generating unit in power flow of each line (5) (Ng X Nl equations). In order to understand (5), one can separate two terms of the right hand of this equation. U l, g is the direct share of unit g in power flow of line l, when they both connected to a same bus. The second term (summation) is the indirect share (of other units), carrying by the other lines to line l.in i i in out l i i i g li l l g Sg li Sl PL l Sl l Sl PG PL w ? ? ? ? ? ? ? ? ? ? + = ? ? ? ? ? ? ? (4) Gen. 1 Gen. 2 ? Gen. Ng Line 1 x1,1 x1,2 ? x1,Ng Line 2 x2,1 x2,2 ? x2,Ng ? ? ? ? ? Line Nl xNl,1 xNl,2 ? xNl,Ng

The main advantage of (5) is that it can handle loop flows in the network.

For a certain unit there are Nl equations in form of (5), while this unit has Nl different shares in the flow of different lines. Let us write these equations for unit g: (**??**) is a set of Nl equations with Nl unknown variables. These equations can be solved easily using (7). In this equation X g is a Nl X1 vector and g th column of the matrix X (Nl X Ng).

It should be noticed that only one matrix inversion is necessary, since this matrix does not change for different units. One can also solve (6) with a faster method, since matrix Z is a very sparse matrix. This leads to a lower solution time for a bulky power system. To allocate the share of each load in power flow of each line we can begin from (1) as starting point. Then we should rewrite (2), (3) and (**??**) in order to calculate share of bus utflows (consisting of loads and lines with outgoing power flow) in power flow of lines, which inject power into bus i . Let us show these shares in matrix Y (Nl XNd) .

Reactive power tracing formulation in this method is exact the same as active power case, so this part of formulation is excluded, but the results of reactive power tracing are also shown in section IV.

5 2) Method of non proportional sharing

The only change in this sub-section with respect to the previous one is replacing the proportional sharing assumption with Kirchhoff's circuit laws. As a result, (3) and (**??**) are not valid anymore. To calculate the share of inflows of bus i in power flow of the lines which transmit active power from this bus to the others, one can replace all the lines which carry power to this bus, with generating units (pseudo units) of the same value of active and reactive generation as the regarding lines active and reactive power inflows. Reminding network has a new Z bus (Fig. 1). Let us call it Z new bus . It is not necessary to recalculate all the elements of this matrix. There is a simple modification method presented in power system analysis text books, like [11], that can be used to modify Z bus. Besides, all the matrix entries are not necessary in the formulation. Considering all of the units and loads as current sources, voltage of different network buses is given as (8). ? = + ? (6) 1 (

) .g Nl Nl g X eye W U ? × = ? (7) , 1 . new Nb new Z = Substituting (8) in (9) ( ) / . / 2 ij i j ij i ij I V V z V y = ? +**(9) , , , 1 .** [

].2 new new new new Nb i k j k i k ij ij k ij k Z Z Z y I I z = ? = + ?**(10)**

A Non Proportional Sharing Power Flow Tracing Based on Bus Power Balance EQ uations In (10) the term which is written between brackets depends on network parameters and is therefore a constant value (a ij), so

Let us separate positive and negative effects of loads and generations on power flow of line ij. In (14) Si+ is total apparent power injected to bus i by the units which have positive effect on the flow of line ij.

Let us separate the share of each unit (or pseudo unit) and each line in this flow Now the share of all units and lines which inject power into bus i in each outflow of this bus, are determined, and the share of other units which are not connected to this bus should be found. This problem is solved earlier in subsection III. A. Again, the share of each load in power flow of each line should be calculated too. To do this, one can consider the network with all the power from this bus to the others, replaced with loads (pseudo loads) of the same value of active and reactive consumption as the regarding lines active and reactive power outflows. A new Z bus should be defined and this time the share of load and outflows in inflows of bus i can be found. Reactive power can be traced using this method either. It is sufficient to replace Â operator with Im and rewrite the equations.

As can be seen in this method and method which discussed earlier in sub-section III.A, two different equations are written for each line. One of them, which is used to find the units' shares in flow of each line, is written considering the line flow at sending end of the line, while the other one which is useful to find the loads' shares, considers flow of the receiving end of the line. It helps us divide the cost of line losses equally between units and loads without any simplifying assumption (like the method which was used in **??**18] to model line losses with two load at two end of the line) while solves the tracing problem precisely (see section II).

6 3) Cost allocation among participants

The power which transfers through a line comes from different units and finally feeds different loads, so it is sensible to divide the transmission cost of this line into two equal shares between these units and these loads. The share of unit g and load d in transmission cost of line l can be found using (**??**8) and (**??**9) respectively.

7 4) Share of each unit in consumption of each load

Considering the share of each unit in flow of each line (X), one can find the share of each generating unit in consumption of each load (21).

IV.

8 CASE STUDY

The case studies are tested on the IEEE Reliability Test System (RTS1) which consists of 24 buses, 26 generators, and 17 loads (Fig. 2). System information has been extracted from [12]- [14]. The load profile corresponds to 6 PM of a Monday of a winter* * * 1 . . . new Nb ij i k i ij k k S V I V a I = = = ? (11) * * 1 (. .) new Nb ij i ij k k P V a I = = ? ? (**12**)g d g d ij ij ij ij ij P P P P P + + ? ? = + + +**(13)**

* * * (. .) (.)g ij ij i i ij i P a V I a S + + + = ? = ?**(14)**

* * (.) (.) in i i g ij ij g ij l g Sg l Sl P a S a S + ? ? ?? = ? + ? ? ?**(15)**? + ? ? ? ? ? ? ? ? = ? ? ? ? (17) , , * , 2 l g l g l X Cost Cost g Sg l Sl = ? ? ? (18) , , * , 2 l d l d l X Cost Cost d Sd l Sl = ? ? ? (19) , , , * * in out i i i l g l l g l l Sl l Sl d g i d d Sd X PL X PL d Sd PD ? ? ? ?? ? ?? ? = ? ? ? ? ? (20) , , , 0 0 otherwise i g i g i g GSL ? ? ? ? ? = ? ? ? (21)

weekday. The capacities of lines 11-13 and 15-24 have been reduced from 500 MVA in [12] to 175 MVA. A onehour time horizon is considered. The results of unit commitment algorithm considering DC and AC load flows are shown in Table III. Proposing a good method for transmission pricing is beyond the scope of this paper. Besides all the results cannot be included here, so for sake of comparison, a fixed cost of 10 $ is considered for each MW flow of each line in each hour and the results of transmission cost allocation are presented in different examples. Reactive power flow tracing results are excluded due to simplicity in concluding from results. The method presented in sub-section III.A is used here to find the share of all of the units and loads in active power flow of each line. The results of active power transmission cost allocation are presented in Tables IV and V for generating units and loads respectively. As can be seen in Table III, the results of DC and AC optimal power flow sub-routines differ in many respects, so to make the comparison easier, a transmission price is defined, for each unit/load as the ratio of its share in $ to its generation/consumption in MW-h. In order to validate the results, the problem is solved using method of [9] for this case (but the results are not included here) and the results were completely same for DC load flow. In the case of using AC load flow, there are some little differences in the results due to different ways of dealing with the loss issue.

There are some interesting points in the results of these two tables. Transmission cost is split into two same shares between units and loads. The share of load at bus 1 is zero even though the consumption is not zero, because there is no line connected to this bus which delivers active power.

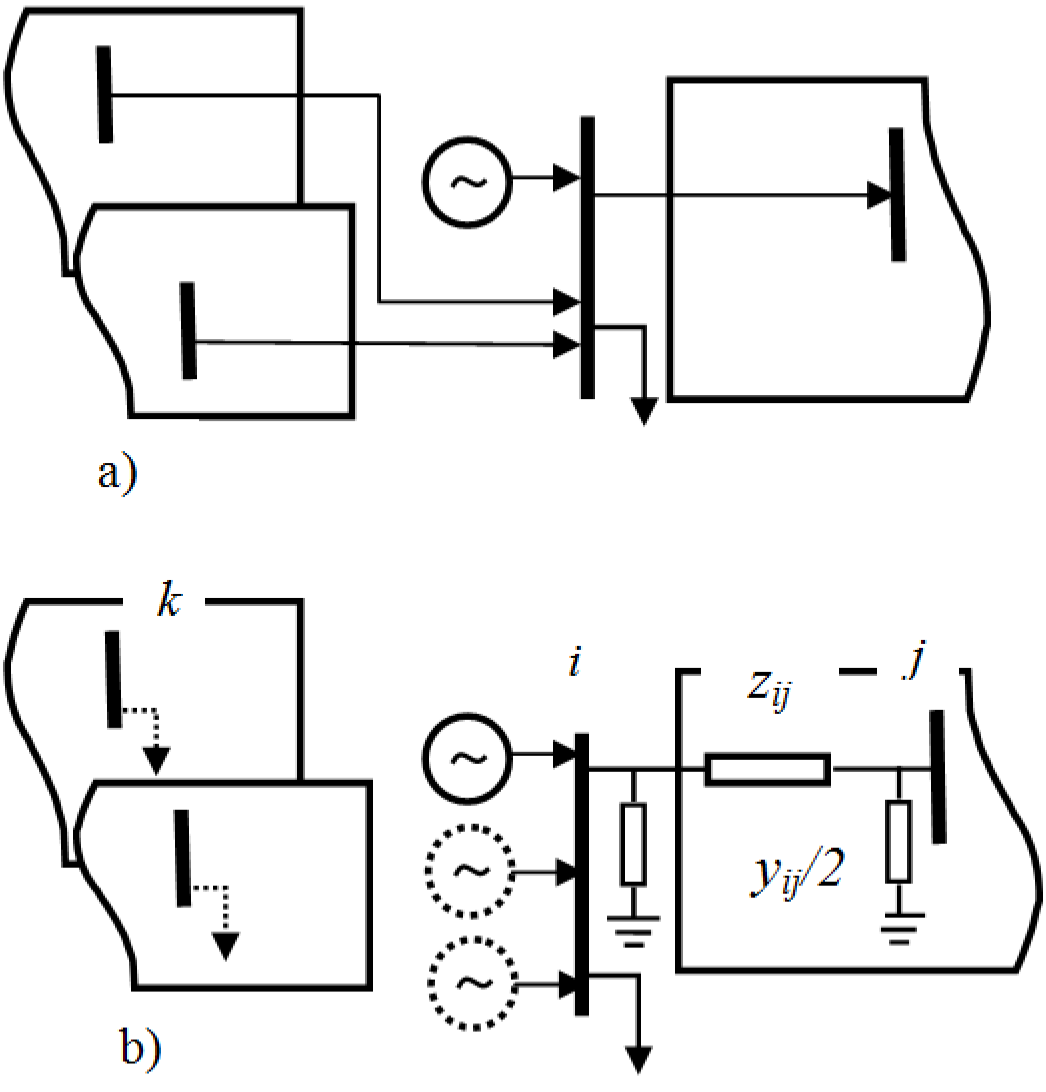
9 2) Peak load, second method

As mentioned earlier in sub-section III. B circuit lows and active and reactive bus power balance equations can be used to solve the power flow tracing problem. This method is applied here and the results of active power transmission cost allocation are presented in Tables VI and VII for generating units and loads respectively. Comparing the results with those of Tables IV and V, one can deduce that though proportional sharing has some advantages (e.g. modeling simplicity and being explainable), it is not fair enough especially for a deregulated system where the payoffs should be calculated based on the real usage of participants. The results of this method are near to the results of the first method but there are some differences that cannot be neglected. Tables VI and VII in contrast with IV and V show that the value of reactive power which a unit generates or a load consumes affects the share of this unit/load in flow of each line. It is noticeable that the price of transmission is no longer equal for units 2 and 3, due to replacing proportional sharing assumption with circuit lows.

10 CONCLUSION

The results of case studies show both methods can effectively solve the active and reactive power flow tracing problems. The first method which assume proportional sharing to find the participants' shares in power flow of each line gives same results as previous methods in this category for DC power flow modeling, but the its results are slightly different when an AC power flow is used to model the network operation, because of different method of handling the loss issues. The results of second method which uses circuit lows are different from the results of first method to show that the reactive power flow affects the share of each unit and each load in power flow of each line, especially in a system with highly inductive loads. [1]

Figure 1: Fig1



1

Figure 2: Fig. 1 (

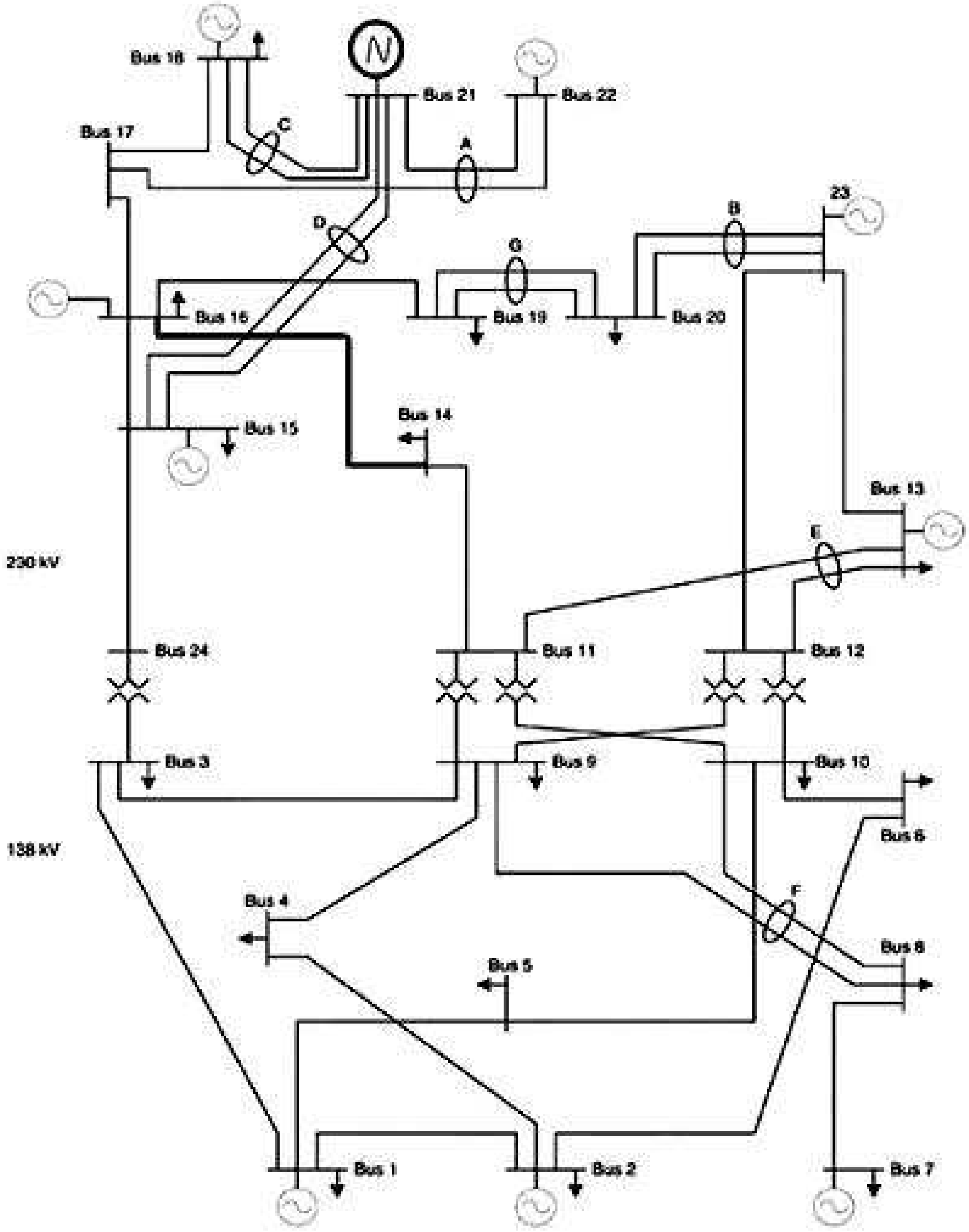


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Figure 3: Fig. 2 .

III

[Note: Results of AC and DC Unit Commitment 1) Peak load, first method]

Figure 4: Table III

16	U155	On	155.00	155.00	80.00
18	U400	On	400.00	400.00	178.98
21	U400	On	400.00	400.00	-17.26
23	U155	On	155.00	155.00	63.88
23	U155	On	155.00	155.00	63.88
23	U350	On	350.00	350.00	87.92

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Bus No	Unit type	US ($) DC	US ($) AC	UTP($/MW-h) DC	UTP ($/MW-h) AC
1	U20	0.00	0.00	-	-
1	U20	37.33	30.74	1.92	1.81
1	U76	146.34	137.64	1.93	1.81
1	U76	146.34	137.64	1.93	1.81
2	U20	42.70	35.84	2.25	2.14
2	U20	0.00	0.00	-	-
2	U76	171.41	162.32	2.26	2.14
2	U76	171.41	162.32	2.26	2.14
7	U100	314.87	302.69	3.15	3.06
7	U100	314.87	302.69	3.15	3.06
7	U100	314.87	302.68	3.15	3.06
13	U197	749.77	848.68	5.88	6.07
13	U197	749.77	848.69	5.88	6.07
13	U197	749.77	848.68	5.88	6.07
15	U12	41.47	45.24	3.76	3.77
15	U12	41.47	45.24	3.76	3.77
15	U12	41.47	45.24	3.76	3.77
15	U12	41.47	45.24	3.76	3.77
15	U12	41.47	45.24	3.76	3.77
15	U155	582.89	584.34	3.76	3.77
16	U155	763.37	897.15	4.92	5.79
18	U400	1857.6	1976.37	4.64	4.94
21	U400	3783.8	3825.80	9.46	9.56
23	U155	1500.3	1541.02	9.68	9.94
23	U155	150.33	1541.02	9.68	9.94
23	U350	3387.8	3479.72	9.68	9.94
Total	-	18192	18192	-	-

Bus No	Unit type	State On	Pg (MW) DC	Pg (MW) AC	Qg (MW) AC
1	U20	On	0.00	0.00	0.00
1	U20		19.38	16.97	4.10
1	U76	On	76.00	76.00	-3.14
1	U76	On	76.00	76.00	-3.14
2	U20	Off	18.93	16.78	10.00
2	U20	Off	0.00	0.00	0.00
2	U76	On	76.00	76.00	30.00
2	U76	On	76.00	76.00	30.00
7	U100	On	100.00	99.08	18.68
7	U100	On	100.00	99.08	18.68
7	U100	On	100.00	99.07	18.68
13	U197	On	127.52	139.75	0.00

Bus No	Bus demand	LS ($) DC	LS ($) AC	, ($/MW-h) LTP DC	LTP ($/MW-h) AC
1	108.00	0.00	0.00	-	-
2	97.01	15.86	1.69	0.16	0.02
3	180.01	2312.8	2277.7	12.85	12.65
4	74.01	835.56	925.99	11.29	12.51
5	71.01	544.79	634.81	7.67	8.94
6	136.01	1746.4	1870.3	12.84	13.75
7	125.01	0.00	0.00	-	-
8	171.01	928.15	1007.8	5.43	5.89
9	175.01	2038.4	2139.3	11.65	12.22
10	195.01	2274.2	2391.5	11.66	12.26

Figure 6:

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