Generation Output Routing and Shares in the Iraqi 400kV Power Gird

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ABSTRACT

With the power systems deregulation and the introduction of competition in the electricity supply industry, it has become important to answer many questions such questions are; How much power of a certain generator is received by a particular load? What pattern of flow these powers are following and how they are traversing the transmission network? How to charge the system loads for the system losses? Is it required to charge the generation for the system losses too? This work describes a method to answer such questions. It starts by conventional load flow solution at a particular generation and load profiles. Then, the generated active powers are traced from generators to loads via the transmission system in directions and values using the proportionality principles. A matlab programs are developed for calculating the power generation shares in loads and links flows. The programs are verified using a literature documented IEEE 30-bus test system. The programs are then applied on the Iraqi 400kV power grid and results appeared of relevance to planning and economic studies.

Keywords: Proportionality sharing, Transmission allocation, Generator participations, Power management.

سريان حصص مخرجات التوليد في شبكة ال400kV العراقية

الخلاصة:

تزايد التنافس و التجزئة في صناعة تجهيز الطاقة الكهربائية ادى الى الحاجة الى الاجابة على العديد من الاسئلة. منها، ما حصة حمل معين من توليد مولد معين؟ ما شكل انسياب القدرات في شبكة النقل وما تشكله قدرات مولدات او احمال معينة من انسياب الكلي للخطوط؟ كيف تقسم و تستحصل كلف المفاقيد في المنظومة؟ وهل يتوجب على التوليد المشاركة في كلف مفاقيد المنظومة؟ يعرض هذا البحث طريقة للاجابةعلى بعض من هذه الاسئلة. بدءا" من حسابات انسياب الاحمال لحالة حمل و توليد معينة، يتم تتبع القدرات الفعالة من مواقع التوليد الى مواقع الاحمال اتجاها و مقادير استنادا الى اساسيات المشاركة النسبية. تم بناء برمجيات matlab لتنفيذ خوارزميات الطريقة و تم التحقق من ادائها بمقارنة النتائج مع تلك لمنظومة اختبار قياسية (IEEE-30 bus) موثقة في المراجع. نفذت

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البرمجيات المتحققة على شبكة النقل العراقية ذات الضغط الفائق (400kV) ووجدت النتائج ذات اهمية لدراسات التخطيط و الدراسات الاقتصادية.

List of Symbols

C_{ij} Contribution of generator i to the load and outflow of common j
C_{ik} Contribution of generator i to the load and outflow of common k
EHV Extra high voltage
F_{ijk} Flow on the link between commons j and k due to generator i
F_{jk} Flow in the link between commons j and k
I_k Inflow of common k

INTRODUCTION

Inmany countries, the power supply industry is undergoing rapid changes in structure and operation. For years, the regulated monopoly structure of power supply industry allowed very little option to customers in choosing their electricity supplier. They have to buy their power from the local utility. The new electricity market has some common features with other markets: product (electricity), sellers (generators), buyers (loads), and transportation system (transmission system). While the market is decomposed into components, many forms of charges in each component have been introduced. To charge effectively, it has become very important to determine which generators are supplying a particular load, how much use each generator is making of a transmission line and what is each generator contribution to the system losses. Network structure of the transmission grid provides a number of alternative routes through which power can flow from a generator to a load. Transmission loss in a line depends on power flow through it, and power flow in any line is the sum of the power supplied from different generators connected to the system. Portion of the transmission loss is caused by a generator depends on the way its power flow shares the lines in the network with the supply from other generators [1].

Several methods have been proposed for determining the contribution of generators to branch flows, loads, and losses of the transmission lines. References [2,3, and 4] propose a topological approach for allocating a particular generator or a load in every branch flow based on an electricity tracing method. Reference [4] proposed a technique based on the proportionality principles to determine the generators share in loads. In this technique, buses identification is performed first based on generator power and its flow direction in the system lines. Finally, the buses supplied by the same set of generators are identified [5]. In this work the approach of ref.[5] is modified and presented. The approach introduces some new concepts such as domain, common, link and state graph and is suitable for large-scale power system applications, and will be discussed in the following sections.

Concepts and Algorithm

Based on the active or reactive branch flows from a solved power flow or state estimation output, the method organizes the busses and branches of the network into homogeneous groups according to few concepts which will be introduced later. Once this organization is complete, it is possible to answer questions such as ”how far does the power produced by a certain generating station go?” or “which generators are supplying a certain load?". It is also possible to represent the state of the system by a directed acyclic graph.

Proportionality Sharing Principle

The Proportional Sharing Principle (PSP) is important in tracking the flow of electricity. In this concept, the electricity tracking is considered topological in nature that deals with a general transportation problem of how the flows are distributed in a meshed network. The network is assumed to be connected and described by a set of i nodes, j directed links (transmission lines or transformers), 2j flows (at both ends of each link) and a number of sources (generators) and sinks (loads) connected to the nodes. Practically the only requirement for the input data is that Kirchhoff's current law must be satisfied for all the nodes in the network.

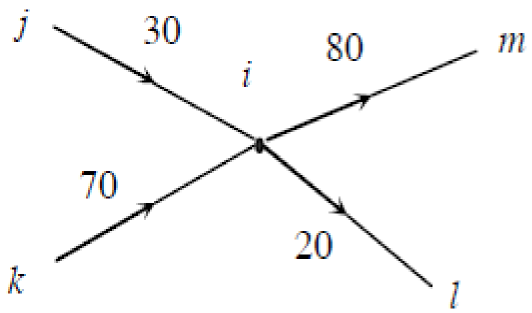
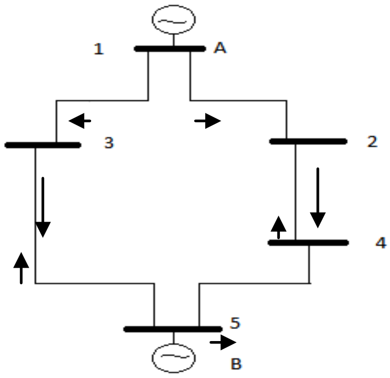


Figure (1) Proportionality sharing principle example

The main principle used to track the flow of electricity will be that of proportional sharing. This is illustrated in Figure (1) where four lines are connected to node *i*, two with MW's inflows and two with MW's outflows. The total power flow through the node is P_i = 70 + 30 = l00MW of which 30% is supplied by line *j-i* and 70% by line *k-i*. As electricity is indistinguishable and each of the outflows down the lines 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_i. Hence the 80MW outflowing in line *i-m* consists of 80(30/100) = 24MW supplied by line *j-i* and 80(70/100) = 56MW supplied by line *k-i*. Similarly the 20MW outflowing in line *i-l* consists of 20(30/100) = 6MW supplied by line *j-i* and 20(70/100) = 14MW supplied by line *k-i*. The proportional sharing principle basically amounts to assuming that the network node is a "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 [3].

The domain of a generator: It is defined as the set of buses which are reached by power produced by this generator [5]. Power from a generator reaches a particular bus if it is possible to find a path through the network from the generator to the bus for which the direction of travel is always consistent with the direction of the flow as computed by a power flow program.



Figure(2) A sample five-bus system

In the system of Figure (2), there are 2 generating units (A, B), and of power rating of 60MW, and 50MW respectively. The domain of each generator is the set of buses where the generator power is reached to, hence; The domain of Gen. (A) is buses (1, 2, 3) The domain of Gen (B) is buses (2,3,4,5).

Commons: the common is the set of buses that are supplied from the same set of generating units. The set of the connected buses supplied from the same generators are treated as a common, but buses which are supplied from the same set of generation units that are supplying a particular common, and these buses are not connected to the buses of that common is treated as separate common [5]. For the common construction for the system of Figure(2) the following applies:-

Buses (1) are supplied from generator A only so this is common 1.

Buses (2,3) are supplied from generator A and B so this is common 2.

Bus (4,5) is supplied from generator (B) only and it is common 3.

Links: The buses are divided into commons, each branch is either internal to a common (i.e. it connects two busses which are within the same common) or external (i.e. it connects two buses which are part of different commons). One or more external branches connecting the same commons form what will be called a link. It is very important to note that the actual flows in all the branches of a link are all in the same direction [5]. Furthermore, this flow in a link is always from a common of rank N to a common of rank M, where M is always strictly greater than N. Now, to find the links of the system in Figure (2) we divide the lines into two types: exterior (between the commons) such as :-

Links between commons 1 and 2 are the lines (1-2) and (1-3).

Links between commons 2 and 3 are the lines (3-5) and (2-4)

And internal such as : the line (4-5) inside common 3

State Graph

Given the direction of the flows in all the branches of the network, the concepts described earlier produce unique sets of commons and links. If the commons are represented as nodes and the links as branches, the state of the system can be represented by a directed, acyclic graph [5]. This graph is directed because the direction of the flow in a link is specified. It is acyclic because links can only go from a common supplied by fewer generators to a common supplied by more generators., the root nodes of such a graph correspond to a common of rank one while the leaves consists of the highest ranked commons. The state graph of the system of Figure(2) is shown in Figure(3).

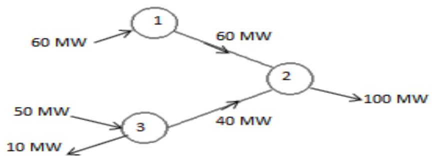


Figure (3) State graph with a load flow of the system of Figure(2)

The results obtained so far provide a qualitative view of the system. To obtain quantitative information, a few more definitions and a fundamental assumption are to be defined. The inflow of a common is defined as the sum of the power injected by sources connected to busses located in this common and of the powers imported to this common from other common.

The assumption provides the basis of a recursive method algorithm for determining the contribution of each generator to the load in each common. Translating the above mentioned definitions into mathematical relations, the following equations, equations(1-3), yield the generators contributions to loads and flows:

$$F_{ijk}=C_{ij}*F_{jk} \quad \ldots(1)$$

$$I_k=\sum_j F_{jk} \quad \ldots(2)$$

$$C_{ik}=\frac{\sum_j F_{ijk}}{I_k} \quad \ldots(3)$$

To find the contributions of generators in the graph in Figure(2):
First compute the inflows of each common:
Common 1: 60 MW
Common 2: 40 + 60 = 100 MW
Common 3: 50 MW
Then, compute the contributions starting from the root node of the state graph:
Relative contributions to the load and outflow of common 1:
Generator A: 60 / 60 = 1.0 p.u.
Absolute contributions to the inflow of common 2:
Generator A: 60 x 1.0 = 60 MW
Generator B: 40 x 1.0= 40 MW
Relative contributions to the load and outflow of common 2:
Generator A: 60 / 100 = 0.6 p.u.
Generator B: 40 / 100 = 0.4 p.u.
Absolute contributions to the inflow of common 3:
Generator B: 50 MW
Relative contributions to the load of common 3 (and to its outflow):
Generator B: 50 / 50 = 1 p u

A Matlab programs were developed to mimic the detailed above mentioned systematic calculations for a general n-bus, b-branches system. The developed Matlab

programs where tested on the IEEE-30 bus test system and the results obtained were almost in perfect match to those reported in reference [5].
The above mentioned topographical oriented follow up of the power flow process is further refined and upgraded compared to that presented in Ref.[5]. The upgrade proposed and performed to a realistically resemble what happen in the actual operative system. The simple upgrade criterion is, “A load connected to a generating bus is fully supplied by the bus generation if its capacity fulfill the load”.

Realistic system study

The developed programs were implemented on the EHV, 400kV, Iraqi power grid. The system contain : 24 buses, 12 of which are generating buses, and 39 transmission lines. The system single line diagram and sample bus and line data are given in the appendix. A system total generation of 5835 MW and loading of 5800 MW were considered for the state Newton-Raphson load flow analysis.
Table(1) show the domain configuration of the Iraqi 400kV power grid. The domain sets of buses varies from a minimum of two buses for generation site at bus(10) and eleven buses for generation site at bus(1). That of course is very much dependent on the generation capacity, the number of line connections and the power flow direction. Table(2) shows the bus constituents of each of the 16 commons forming the power grid. Most of the commons contain only one bus and only two of three buses. Figure(4) shows the grid state graph. It is of 16 commons (vertices) and 20 links joining them to form the acyclic system graph.

Table (1) The domain of generators

Gen.(buses)	Domain(buses)
1	(1 , 2, 3, 13, 14, 15, 17, 21, 22, 23, 24)
2	(2, 3, 13, 14, 15, 17, 22, 23, 24)
1	(3, 17, 23, 24)
4	(4, 5, 22, 23, 24)
6	(5, 6, 23)
8	(7, 8, 15, 19, 20)
9	(7, 8, 9, 11, 15, 17, 18, 19, 20
10	(10, 19)
11	(11, 17, 18)
12	(12, 15, 16, 17)

Table (2) Commons construction

Commons		2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Buses	1 21	2 13 14	3	4	5	6	7 8 20	9	10 19	11 18	12 16	15	17	22	23	24

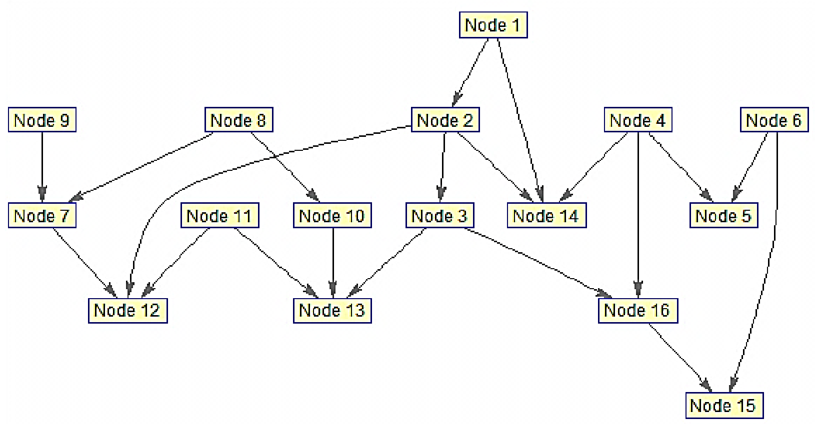


Figure (4) State graph showing the commons connection

Using the information from the load flow results, it is then possible to compute the load and the inflow of each common as well as the flows on the links. Starting from the root nodes of the state graph (commons 1,4,6,8 and 9) and moving towards the leave nodes (commons 5,12,13,14 and 15), it is possible to compute the contributions of the generators to each of the commons. These contributions are illustrated in Table(3). The sparsity of this matrix is an indication of how much "power mixing' takes place in the system at a particular time. It is also interesting to note that for the commons where power mixing does take place, the contributions vary from almost 100% to almost nothing.

Table (3) Per-unit contribution from generation sites to commons

Common / Bus	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	1	0.57	0.52	0	0	0	0	0	0	0	0	0.116	0.137	0.714	0.333	0.457
2	0	0.43	0.392	0	0	0	0	0	0	0	0	0.087	0.103	0.177	0.251	0.344
3	0	0	0.088	0	0	0	0	0	0	0	0	0	0.023	0	0.057	0.078
4	0	0	0	1	0.745	0	0	0	0	0	0	0	0	0.109	0.088	0.121
6	0	0	0	0	0.255	1	0	0	0	0	0	0	0	0	0.271	0
8	0	0	0	0	0	0	0.471	0	0	0	0	0.351	0	0	0	0
9	0	0	0	0	0	0	0.467	1	0	0.739	0	0.348	0.291	0	0	0
10	0	0	0	0	0	0	0.063	0	1	0	0	0.047	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0.261	0	0	0.103	0	0	0
12	0	0	0	0	0	0	0	0	0	0	1	0.051	0.343	0	0	0

CONCLUSION

In this paper, a reported power tracking concepts has been augmented and used after developing in a Matlab algorithm. The algorithm is implemented on the Iraqi EHV power grid. The results lead to the participation of the generation sites in loads, line flows and, with further extension, line losses. The importance of the aforementioned results is gross when dealing with planning, economic, and deregulation issues.

Acknowledgments

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Appendix

In this appendix, the Iraqi 400kV, EHV power grid sample data are presented. Fig(A.1) shows the system single-line diagram. Tables(A.1) and (A.2) gives a sample data lines for the bus and line information respectively.

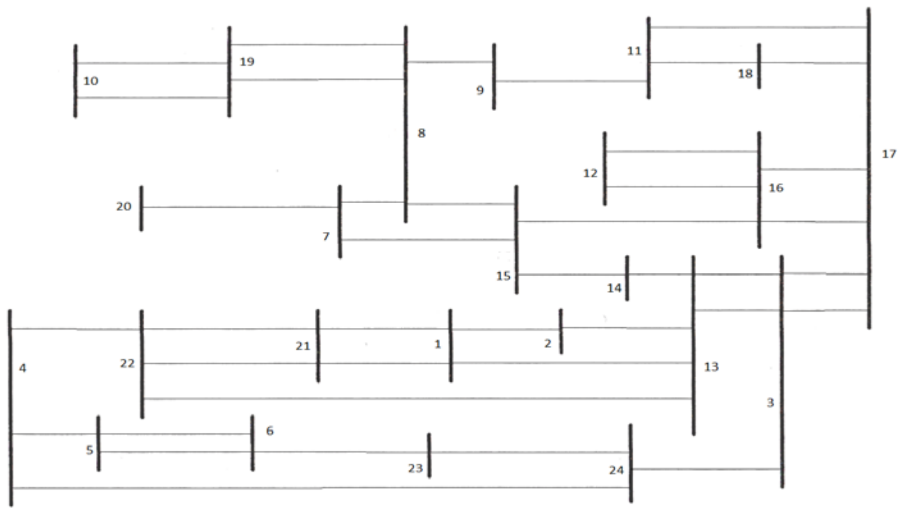

Figure (A.1) Single line diagram of the 400kV grid

Table (A.1) Sample of the 400kV power grid bus data

Bus No.	Voltage Mag.(pu)	Angle Degree	------Load------		---Generation---		Injected Mvar
			MW	Mvar	MW	Mvar	
1	1.04	0	199.780	116.633	1102.520	241.326	0
2	1.04	-0.045	0.000	0.000	369.036	176.010	0
3	1.009	-3.335	126.560	56.001	184.518	-78.003	0
4	1.02	-3.057	422.866	198.322	774.976	48.096	0
. . .							
22	1.022	-3.524	213.098	151.446	0.000	0.000	0
23	0.995	-9.949	311.022	160.371	0.000	0.000	0
24	1.008	-4.296	259.713	108.176	0.000	0.000	0

Table (A.2) Sample of the Iraqi 400kV power grid per-unit line data

From bus	To bus	R	X	½ B	Tap setting
1	2	0.000125	0.001043	0.0163955	1
1	13	0.00122	0.01015	0.159485	1
1	21	0.0015169	0.01379	0.81718	1
2	13	0.001094	0.009106	0.143088	1
. . .					
16	17	0.00029	0.00262	0.038815	1
17	18	0.00087	0.00788	0.11674	1
21	22	0.001165	0.009675	0.60812	1
24	23	0.00479	0.04354	0.64499	1