Minimal Path Technique for Congestion Management in Electrical Market

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Abstract: Restructuring of electric power system was mainly introduced in order to create a competition through an electricity market, in such a way to dispatch generators with the lowest bidding prices. However, limitations on the power carrying capability of transmission lines created the problem of congestion. This paper presents a developed technique based on the minimal path concept for managing the congestion problem. The main achievement of this technique, in comparison with other developed methods, is that it does not have to evaluate the contribution of each generator (i.e. distribution factors) in the power flow through each line in the given system, which results in the formulation of a large number of equations to be solved. Instead, it identifies the generators connected to the receiving and sending ends of the congested line, classify these generators into three types (increasing, decreasing and critical) and according to this classification their outputs are decreased and/or increased by specified increments until congestion is solved. Hence, one does not need to formulate equations and then solve it.

Keywords: Minimal paths, Congestion, Electricity Market.

1. INTRODUCTION

Congestion in transmission lines occur when the required power flow in the lines exceed the Capacity of lines. Hence, congestion management can be considered as one of the procedures and methods taken to avoid or solve congestion [1]. A major cause for congestion is the growths in peak demand far exceed the enhancement in transmission capacity. Congestion is also important from economic point of view because in order to satisfy a certain demand at a given location, the system operator is forced to buy from more expensive generators, resulting in congestion cost. Consequently, the main task of congestion management is how to maintain the competition of electrical generators for supplying loads constrained by the capacity of transmission systems.

Various works have been carried out on congestion management. A review about methods for this management has classified them into methods based on power market, optimization and artificial intelligence [2-5]. Methods based on

the combination of demand response, thyristor controlled series capacitors [6], and on generators and loads, real and reactive power flow contribution factors [7,8] were developed. Also, [9,10] show methods for finding the impact of renewable energy on congestion management and on low voltage distribution networks respectively.

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This paper presents a method for congestion management based on the minimal path concept [11].The method identifies the generators which are connected to the sending and receiving ends of the congested lines, where their loadings are decreased and increased, respectively, in one MW steps by taking their bidding prices in to account. The method was applied to a 30-bus system.

2. MINIMAL PATH TECHNIQUE

The technique developed for solving the power congestion at a transmission line consist of the following steps:

1. Evaluation of the minimal path matrix of the given system. A minimal path is a path between a generator and a load bus in such a way that it does not contain a loop. The matrix includes all possible paths between all generators and each load bus in the system.
2. Dispatch the generators according to their bids.
3. Perform load flow analysis to see if there is any congested transmission line.
4. Identify the congested transmission line, Lcon.
5. Find the sending and receiving end buses of Lcon and let them be Bs and Br, respectively.
6. Determine the generators which feed Lcon.
7. Consider Bs as the bus from which the power is injected into Lcon.

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8. By using the path Matrix, locate Bs in this matrix and then go back towards the generator column, which is the first column in the matrix and in the same row. If the power flow direction at this row is not from the generator To the Bs, ignore this generator. Otherwise, this generator is assigned a decreasing generator (G-dec) and its dispatch will be reduced. Then check all the rows which contain Bs, as explained before.

9. Consider Br as the bus in which the power is injected, to it. Locate Br in the path matrix and by going Backwards, towards the generator column in the same Row, to identify the corresponding generator. This generator is assigned as increasing generator (G-inc) ,that is, its dispatch Is to be increased regardless to the direction of the power flow from the generator to the Br. Then repeat the same procedure for all rows which contain the Br.

10. At some connections, the generator that feeds the Bs and Br may be considered as increasing or decreasing generator, so that the technique will consider this generator as a critical generator (G-crt) and will not make any changes on it because any changes on it will affect the load in the system and congestion cannot be solved.

11. Consequently, there will be possible types and combinations of generators as follows:

    11.1. If there are both G-dec and G-inc and no G-crt then:

    a. arrange G-inc in ascending order according to their bidding price and the technique chooses the cheapest one to be increased by one MW.

    b. arrange G-dec in descending order according to their bidding price and the technique chooses the most expensive one to be reduced by one MW.

    11.2. If there are G-dec and G-crt and no G-inc, then:

    a. for G-dec, the procedure is the same as 11.1.b

    b. arrange G-crt into ascending order and then increase by one MW.

    11.3. If there are G-inc and G-crt and no G-dec, then:

    a. For G-inc, the procedure is the same as 11.1.a.

    b. arrange G-crt into descending order and the technique choses the most expensive one to be reduced by one MW.

    11.4. If there is only G-dec then congestion cannot be solved.

    11.5. If there is only G-crt then congestion cannot be solved.

12. For each of the steps 11.1, 11.2 and 11.3, find the new dispatch of generators and evaluate the corresponding costs of generation and congestion.

3. ILLUSTRATION

3.1. Classification of Generators

The steps of the developed technique, regarding the classification of generators into G-inc, G-dec and G-crt, are illustrated by means of the system shown in Figure **1**, which shows a system having three generators numbered 1, 2 and 3 and having loads at buses 4, 5, 6, 7, 8 and 9.

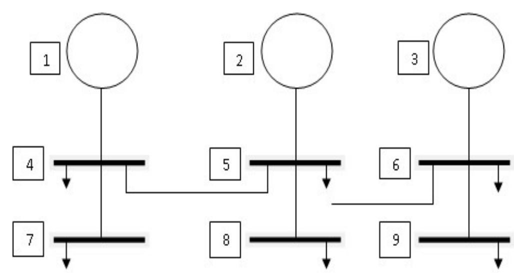

Figure 1: A system used for illustration.

3.1.1. The Minimal Path Matrix

This matrix is shown in Table **1** and consist of 18 paths. Each path starts at a generator and terminate at a load bus.

3.1.2. Assume that the line between buses 4 and 5, L_{45}, is congested and the direction of power flow is from 5 to 4. Hence, B_S=5 and B_r=4.

3.1.3. From the path matrix, it can be deduced that generators 2 and 3 supply B_S by means of the paths (7, 8, 9, 10, 11, 12, 16, 17 and 18). Hence, G_2 and G3 are assigned as G-dec. In addition, it can be found that The generators G_1, G_2 and G_3 are connected to The B_r by means of the paths (1, 2, 3, 4, 5 and 6). Hence, these generators are assigned G-inc.

Table 1. Minima Path Matrix

Path No.	Elements of the Path
1	1,4
2	1,4,7
3	1,4,5
4	1,4,5,8
5	1,4,5,8,6
5	1,4,5,8,6,9
6	1,4,5,8,6,9
7	2,5
8	2,5,8
9	2,5,8,6
10	2,5,8,6,9
11	2,5,4
12	2,5,4,7
13	3,6
14	3,6,9
15	3,6,8
16	3,6,8,5,4
17	3,6,8,5,4
18	3,6,8,5,4,7

3.1.4. Since G_2 and G_3 are considered as G-dec. and as G-inc. then these generators are assigned G-crt. Hence, for the assumed congested Line, there are only two types of generators, G-inc (i.e. G_1) and G-crt. (i.e. G_2 and G_3).

3.1.5. The congestion can be solved by increasing the output of G1 and decreasing the output of the most expensive of G2 and G3 in steps of 1 MW until congestion is solved.

3.2. Cost of Generation and Congestion

The sequence of calculating such costs is as follows and illustrated by means of the system shown in Figure **2**, which shows a system having 30 buses, 40 transmission lines and 6 generators.

3.2.1. The developed program asks for the following data:

a. Bus, load and line data of the given system as shown in Tables **2** and **3**, respectively.

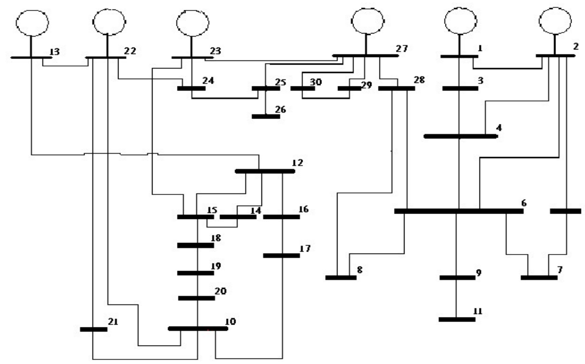

Figure 2: A test system of 30 buses.

Table 2. Bus Data

Bus #	Type	P_d	Q_d	V_m	V_a
1	1	0	0	1	0
2	1	0	0	1	0
3	2	2.4	1.2	1	0
4	2	7.6	1.6	1	0
5	2	0	0	1	0
6	2	0	0	1	0
7	2	22.8	10.9	1	0
8	2	30	30	1	0
9	2	0	0	1	0
10	2	5.8	2	1	0
11	2	0	0	1	0
12	2	11.2	7.5	1	0
13	1	0	0	1	0
14	2	6.2	1.6	1	0
15	2	8.2	2.5	1	0
16	2	3.5	1.8	1	0
17	2	9	5.8	1	0
18	2	3.2	0.9	1	0
19	2	9.5	3.4	1	0
20	2	2.2	0.7	1	0
21	2	17.5	11.2	1	0
22	1	0	0	1	0
23	1	0	0	1	0
24	2	8.7	6.7	1	0
25	2	0	0	1	0
26	2	3.5	2.3	1	0
27	1	0	0	1	0
28	2	0	0	1	0
29	2	2.4	0.9	1	0
30	2	10.6	1.9	1	0

Table 3. Line Data

From bus	To bus	R	X	B	Line Capacity (MW)
1	2	0.02	0.06	0.03	8
1	3	0.05	0.19	0.02	8
2	4	0.06	0.17	0.02	12
2	5	0.05	0.2	0.02	11
2	6	0.06	0.18	0.02	13
3	4	0.01	0.04	0	6
4	6	0.01	0.04	0	9
5	7	0.05	0.12	0.01	11
6	7	0.03	0.08	0.01	13
6	8	0.01	0.04	0	22
6	9	0	0.21	0	6
6	28	0.02	0.06	0.01	15
8	28	0.06	0.2	0.02	10
9	11	0	0.21	0	8
10	17	0.03	0.08	0	10
10	20	0.09	0.21	0	9
10	21	0.03	0.07	0	15
10	22	0.07	0.15	0	11
12	13	0	0.14	0	18
12	14	0.12	0.26	0	5
12	15	0.07	0.13	0	3
12	16	0.09	0.2	0	4
13	22	0	0.26	0	5
14	15	0.22	0.2	0	5
15	18	0.11	0.22	0	8
15	23	0.1	0.2	0	19
16	17	0.08	0.19	0	2
18	19	0.06	0.13	0	4
19	20	0.03	0.07	0	7
21	22	0.01	0.02	0	4
22	24	0.12	0.18	0	4
23	24	0.13	0.27	0	9
23	27	0	0.56	0	6
24	25	0.19	0.33	0	2
25	26	0.25	0.38	0	5
25	27	0.11	0.21	0	4
27	28	0	0.4	0	4
27	29	0.22	0.42	0	8
27	30	0.32	0.6	0	9
29	30	0.24	0.45	0	5

In these Tables, P_d, Q_d, V_m and V_a represent active load, reactive load, voltage magnitude and voltage angle at each Bus, respectively. R, X and B represent the resistance, reactance and susceptance of each Line, respectively.

b. Bidding prices Are offered by generators as shown in Table **4**.

Table 4. Bidding Prices

Gen. #	Bid ($/MW)	Capacity (MW)
1	9	40
2	3	40
13	8	40
22	3	40
23	5	30
27	4	35

3.2.2. Having inserted the input data, the program dispatches the generators according to their bids, starting by the cheapest bid and going to the next one until the total demand is satisfied. The results are shown in Table **5**. The abbreviations in the table are as follows:

RBOB=Revenue Based on Bid; this is the cost of generation for each generator based on its bid.

AR=Actual Revenue; this is the revenue based on the market clearing price.

AP=Additional Profit; this is the difference between AR and RBOB.

In this Case, the market clearing price was that of Gen #13 and equal to 8 $/MW.

3.2.3. Run the developed load flow Program, which is based on Newton-Raphson Method, to see if there is any congested line. In this case, the program found a congestion on the line connecting the load buses 4 and 6. Consequently, the program applies the minimal path technique to solve this congestion by using the 1 MW step redispatch and the results are shown in Table **6**.

By comparing Tables **5** and **6**, it can be observed that the dispatch of G_2, whose bidding price is 3 $/MW, has been reduced from 40 MW to 36 MW (i.e. by 4 MW) and the dispatch Of G_{13}, whose Bidding price is 8 $/MW, has been increased from 21.3799 MW to 25.3103 MW (i.e. by 3.9304).

Table 5. Results of Dispatch and Cost Analysis

Gen. #	Gen (MW)	RBOB ($)	AR ($)	AP ($)
1.0000	0.0000	0.0000	0.0000	-0.0000
2.0000	40.0000	120.0000	320.0000	200.0000
13.0000	21.3799	171.0394	171.0394	0
22.0000	40.0000	120.0000	320.0000	200.0000
23.0000	30.0000	150.0000	240.0000	90.0000
27.0000	35.0000	140.0000	280.0000	140.0000

Table 6. Cost Analysis after Solving Congestion

Gen#	Gen. (MW)	RBOB ($)	AR ($)	AP ($)
1.0000	-0.0000	-0.0000	-0.0000	0.0000
2.0000	36.0000	108.0000	288.0000	180.0000
13.0000	25.3103	202.4827	202.4827	0
22.0000	40.0000	120.0000	320.0000	200.0000
23.0000	30.0000	150.0000	240.0000	90.0000
27.0000	35.0000	140.0000	280.0000	140.0000

Consequently, the cost of congestion= (8*3.904) - (3*4)=19.4432 $

4. RESULTS AND DISCUSSION

The above analysis of a System, which had 30 buses, 40 transmission lines and 6 Generators, has shown that the system had 18 minimal paths. According to the bidding prices ($/MW) of the Generators, which were (3,3, 4, 5, 8, 9), their merit order of dispatch was 2, 22, 27, 23, 13 and 1, respectively.

Consequently, their dispatches of real power in MW were 40, 40, 35, 30 and 21.3799 hence giving The total cost of generation $ 701.0392. However, when the load flow program was run for this system with the above dispatches assigned to its generators, it was found that the power flow in the line between buses 4 and 6 was greater than its rated power of 9 MW (i.e. the line was congested). The generated minimal paths were used to identify the generators connected to the sending and receiving ends of the line and incremented/decremented their outputs in one MW steps until congestion was solved. As a result, the output of generator 2, with price of 3 $/MW, reduced by 4 MW and the output of generator 13, with price of 8 $/MW, was increased by 3.9304 MW. The total new cost was $ 720.4824, and cost of congestion was $ 19.4432.

It can be stated here that the main contribution of this paper, in comparison with other works, is that for e.g. in [7] one must formulate equations for the power flow contributing factors in order to solve the problem of congestion. However, the developed minimal path identifies the generators which effect the flow in the congested line and then increase/decrease their output by a certain defined increment until congestion is solved.

5. CONCLUSIONS

A congestion management technique based on the minimal path technique was developed. The developed code for this management includes load flow analysis and congestion cost evaluation. It identifies the generators which affect the power flow in a congested line and their outputs are adjusted according to their classification without the need for formulating and solving large number of equations. Since the concept of minimal path is also used in the reliability evaluation of power system by finding cut sets or failure modes of a given system, the developed code, although it was mainly produced for congestion management, it can be enhanced to be a single package for congestion management, load flow and reliability analysis.

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NOMENCLATURE

Acronyms

AP Additional Profit

AR Actual Revenue

B_S Sending end Bus

B_r Receiving end BUS

G_1 Generator number 1

G_{-crt} Critical Generator

G_{-dec} Decreasing Generator

G_{-inc} Increasing Generator

L_{con} Congested transmission line

L_{45} Transmission line between buses 4 and 5

PU Per Unit

MW Mega Watt

MVAR Mega Volt Ampere Reactive

RBOB Revenue Based On Revenue

Parameters

B shunt susceptance in PU

P_d active load in MW

Q_d reactive load in MVAR

R transmission line resistance in PU

V_a voltage angle in degrees

V_m voltage magnitude in PU

X transmission line inductive reactance in PU

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