A NEW APPROACH FOR DETERMINATION OF BREAK POINTS FOR PROTECTION CO-ORDINATION

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Abstract Interconnected power system networks are multi loop structured. Settings determination of all overcurrent and distance relays in such networks can be in different forms and complicated. The main problem is the determination of starting points i.e. the location of starting relays in the procedure for settings, which is referred to as break points. In this paper, a new approach based on graph theory is introduced in which the relevant matrices dimensions are much reduced. The method is flexible and achievement of the desired solution can be obtained in a relatively short time.

Key Words Break Point Set, Protection System, Relay Co-Ordination

چکیده شبکه های سیستم قدرت بهم پیوسته دارای ساختار چند حلقه ای هستند. تعیین تنظیمات تمامی رله های جریان زیاد و دیستانس در چنین شبکه هایی شکل‌های گوناگون و پیچیده است. مشکل اصلی برای هماهنگی تعیین نقاط شروع هماهنگی، یعنی مکان رله های شروع در روند هماهنگی است که نقاط شکست نامیده می شود. در این مقاله، یک روش جدید بر مبنای تئوری گراف معرفی می‌شود که بعد ماتریسهای مربوطه را کاهش می دهد. روش ارائه شده قابل انعطاف است و نایل شدن به جوابهای مورد نظر در زمان کوتاه تری حاصل می شود.

1. INTRODUCTION

Many attempts have been made in the past for the co-ordination of overcurrent and distance relays settings both for interconnected and industrial power system networks [1]-[4]. The selection of appropriate settings by the co-ordination procedures leads to disconnection of minimum parts of the network under consideration [5,6]. The complexity of the problem increases with the number of loops presented in the system. A basic difficulty in setting relays results when one sets the last relay in a sequence, which closes a loop, it must coordinate with the one set initially in that loop. If it does not, one must proceed around the loop again. Of course, a given relay usually participates in more than one loop, so this procedure needs some organization. Indeed, for a given network we require 1) a minimum set of relays to begin the process with the break points 2) an efficient sequence for setting

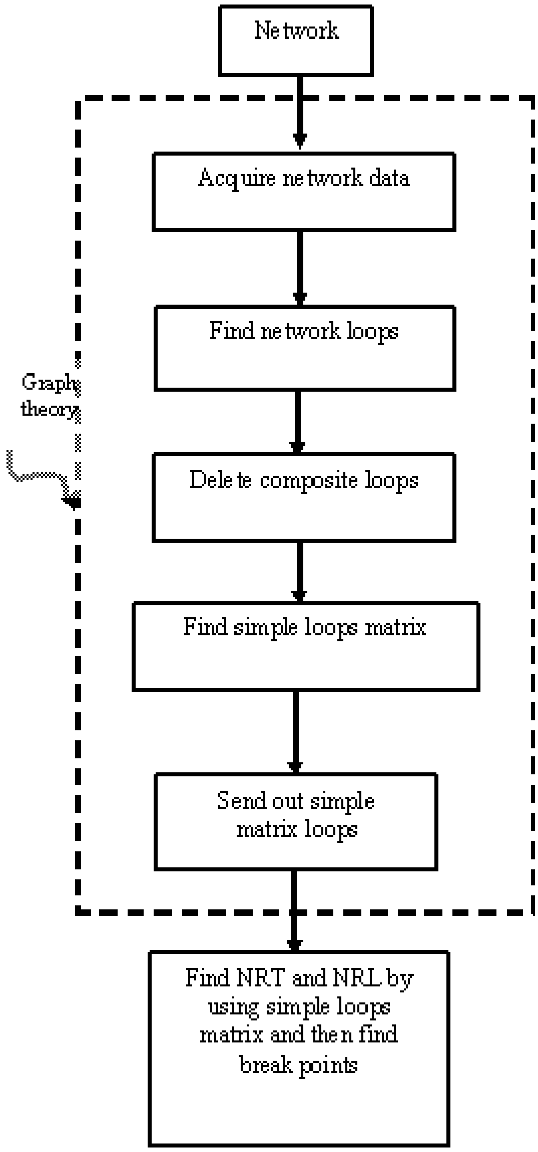

Figure 1. Ordinary graph theory algorithm for break points determination.

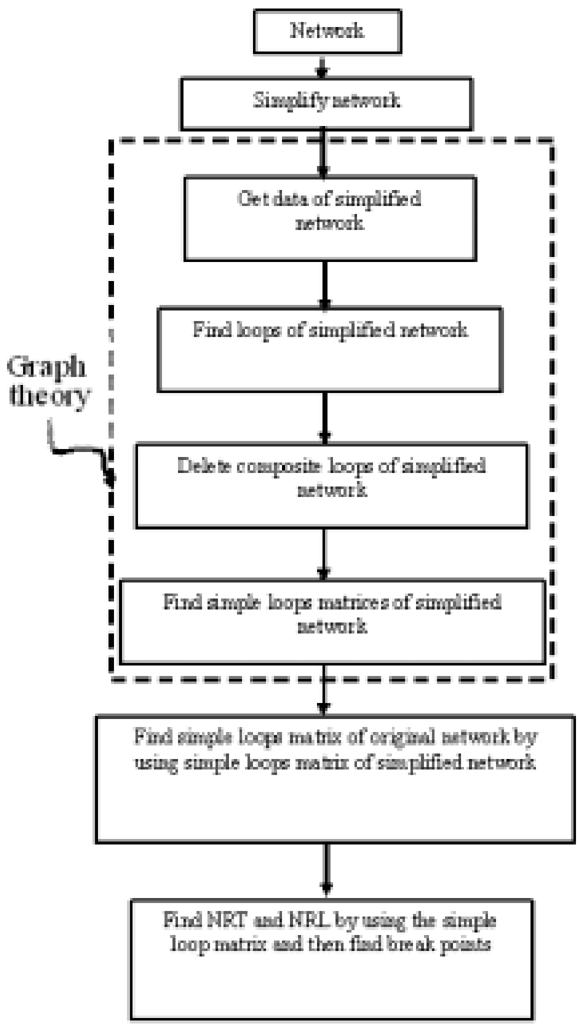

Figure 2. New method algorithm.

the remaining relays, i.e., determination of efficient primary and back up relay sets [1].

Therefore, finding the starting points, which are called break points, is basic requirement. Dwarakanath and Nowiz developed a method based on graph theory for determination of break points, directed loop matrix and relative sequence matrix [4]. Damburg and Ramaswawi et al, followed the previous work and obtained a method for all simple loops of network determination [1,2]. In these methods, all the loops including simple and non simple are found using the whole network. Although the methods are flexible, but because of creating extra large size matrices, solving the problem for real interconnected networks is difficult.

The break points chosen following the above procedure may not be the minimum set. Their procedure generates a minimal set, but not the minimum set. A minimal set is a set whose subset does not satisfy the minimal set with least cardinality [7].

Bapeswara Rao and Sanhara Rao [8] proposed a

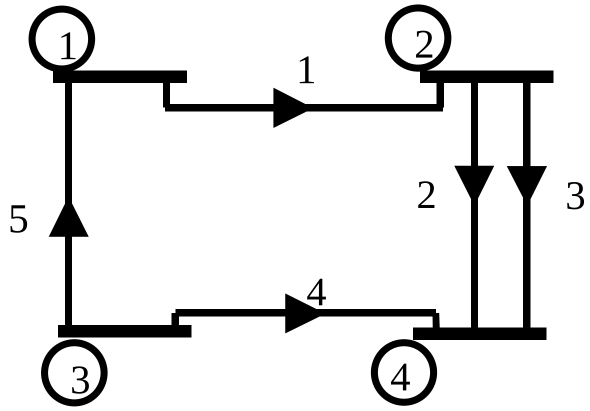

Figure 3. Simple network with two parallel lines.

method for determining the minimum break points set of a power system network and manipulation of matrix L'. However, determination of the complete loop matrix L' can be time consuming for large power networks.

Prasad et al suggested a faster method for break point set (BPS) determination based on simple loop matrix. Although, this method has a good advantage compared to the previous ones, but there is a need for consideration of the whole system at the beginning stage to compose a simple loop matrix [9].

Recently, Madani and Rijanto have presented a new graph-theoretical approach for composition of minimum or near to minimum BPS [10]. In this representation, each break point (BP) relay is replaced by a diode. Some efforts such as network reduction, network splitting etc for networks having specific configuration are made [10]. This is an efficient and quick method for power system networks having specific configuration. In other words, the method cannot be applied to power systems that do not have the specific features and therefore it has some limitations. In this method, removal of one or more parallel lines can be made, if the parallel lines only connect a sub-network to the rest of the network under consideration. Network splitting can be done if there is a bus of the network such that its removal causes the network to be divided into two or more subnetworks [10]. Therefore if a network does not have any of the above conditions, the relevant reduction cannot be done. Some of the interconnected networks do not have such configuration.

In this paper, a simple and flexible approach for determination of BPS is presented. The method is based on graph theory and network reduction. The main difference between the new approach and the previous graph theory based one is that, in this approach, network reduction is made first, then the appropriate loops are composed, whilst in the traditional graph theory approach composition of the matrices loops are made on the original network.

The reduction network rules in the new approach are such that, they can be applied to different power system networks.

2. PROBLEM STATEMENT

Ordinary graph theory and the new algorithms for BPS determination are illustrated in Figure 1 and Figure 2 respectively.

As mentioned in the previous section, the main complexity in Figure 1 is using whole system network configuration and determination of simple loops via whole loops or direct [1-4]. From Figure 1 can be understood that after manipulating of information of the whole network, all loops are composed. Then the composite loops, i.e., the loops consisting of two or more simple loops that do not affect the procedure for break points finding, are deleted. Therefore, the remaining loops, being simple loops, are identified. From the loops, matrices NRT and NRL, the elements of which represent the number of relays in the total simple loops containing relevant relay and the number of relays in a loop are found. Finally the break points set are obtained [3,4].

For example applying the existing method for a 400kV/230kV transmission networks with about 120 buses and 500 transmission lines, about 500,000 loops are obtained, in other word the matrix dimension will be 500*500,000, for it is difficult to carry out mathematical calculations even with advanced computers.

The solution of this problem requires simplification of the power system network before loops composition, which is presented in this paper. The algorithm of the procedure illustrated in Fig.2 demonstrated this.

TABLE 1. C_{Sd} Matrix OF Figure 3.

C_{Sd}		1	2	3	4	5
Directional Simple Loops	1	1	1	0	-1	1
	2	-1	-1	0	1	-1
	3	1	0	1	-1	1
	4	-1	0	-1	1	-1
	5	0	1	-1	0	0
	6	0	-1	1	0	0

TABLE 2. C_{Sd} Matrix OF Simplified Network.

C_{Sd}		1	2	4	5
Directional Simple Loops	1	1	1	-1	1
	2	-1	-1	1	-1

TABLE 3. The Composed Matrix.

C_{Sd}		1	2	3	4	5
Directional Simple Loops	1	1	1	0	-1	1
	2	-1	-1	0	1	-1
	3	1	0	1	-1	1
	4	-1	0	-1	1	-1

TABLE 4. The Loop Matrix of Reduced Network.

C_{Sd}		1	2	3
Directional Simple Loops	1	1	1	-1
	2	-1	-1	1

As can be seen from the figure, simplification is made first, then the same graph theory procedure as in Figure 1 is made for simplified network. After that, simple loops matrix elements for original network using simple loops matrix of simplified network are found. The NRT and NRL matrices are composed from which the break points set are found. This is an efficient and quick method for power system networks and relays Co-ordination procedure.

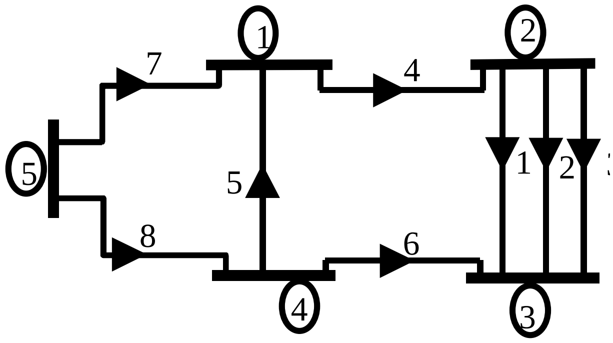

Figure 4. A typical network with three parallel lines.

The simplification rules for the new method will be given in the next section.

3. SIMPLIFICATION RULES

A. Network with Parallel Lines Let a typical simple network shown in Figure 3, which has two parallel lines 2 and 3.

Table 1 shows the simple loops matrix with the direction of the loops of the network.

As it is shown in the table, the network includes six directional simple loops. Each row represents a simple loop. When the direction of a loop is the same as the direction shown on the line, the value of 1 is included in the table. Obviously, the value of a cell of the table, which is –1 represents the loop direction is opposite to the relevant line direction. For example in loop No. 1, which includes four lines 1, 2, 4 and 5, the direction of the loop is the same as direction of the lines 1, 2, and 5 whereas line 4 has opposite direction. The values of first row of Table 1 show this.

To find C_{sd}, a simpler method is suggested. Namely, one of the parallel lines, let us say line 3, is removed and for the simplified network, the relevant C_{Sd} are found (Table 2).

Now from the C_{Sd} matrix, the simple loop of the

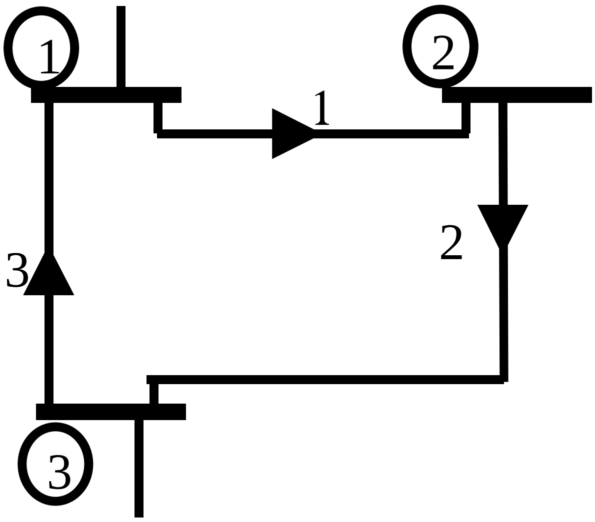

Figure 5. Sample network with one series bus.

TABLE 5. The Loop Matrix of Figure 5.

C_{Sd}		1	3
Directional Simple Loops	1	1	-1
	2	-1	1

original network is found as follows:

First, a column called column 3 is added to Table 3 and the values of the matrix elements of this column are set to zero. Then the rows of the new matrix which posses non zero elements in column 2 (because column two represents line No. 2, which is parallel to line 3) is added to the matrix. After that, the none zero elements of column 2 of the added rows are set to zero, instead, the zero elements of column 3 of the rows are replaced with relevant column 2 elements. Table 4 shows the new composed matrix.

Finally, two new rows regarding the loops of two parallel lines 2 and 3 are added. The final table will be exactly Table 1, i.e., the table of the original network.

The simplified approach is a flexible one and can be applied to any parallel lines. For example, if there are three parallel lines connecting two buses of a network as shown in the Figure 4, first two

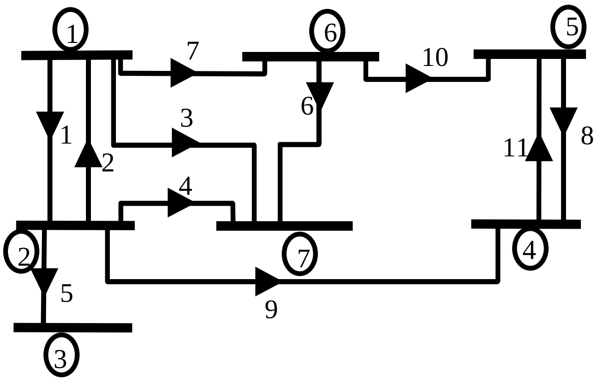

Figure 6. Sampled network.

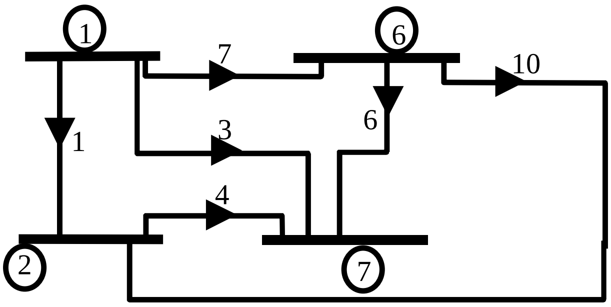

Figure 7. Simplified network.

TABLE 6. Final C_{Sd} Matrix.

C_{sd}		1	3	4	6	7	10
Directional Simple Loops	1	1	-1	1	0	0	0
	2	0	-1	0	1	1	0
	3	0	0	1	-1	0	1
	4	0	-1	1	0	1	1
	5	-1	1	0	-1	0	1
	6	-1	0	-1	1	1	0
	7	-1	0	0	0	1	1

lines 2 and 3 are removed and the above method is applied. After completing the above procedure, the parallel 1 and 3 lines are removed and the procedure is repeated. This procedure continues

TABLE 7. The Final Loop Matrix For The Original Network.

C_{sd}		1	2	3	4	6	7	8	9	10	11
Directional Simple Loops	1	1	0	-1	1	0	0	0	0	0	0
	2	0	0	-1	0	1	1	0	0	0	0
	3	0	0	0	1	-1	0	1	-1	1	0
	4	0	0	-1	1	0	1	1	-1	1	0
	5	-1	0	1	0	-1	0	1	-1	1	0
	6	-1	0	0	-1	1	1	0	0	0	0
	7	-1	0	0	0	0	1	1	-1	1	0
	8	0	0	0	1	-1	0	0	-1	1	-1
	9	0	0	-1	1	0	1	0	-1	1	-1
	10	-1	0	1	0	-1	0	0	-1	1	-1
	11	-1	0	0	0	0	1	0	-1	1	-1
	12	0	0	0	0	0	0	1	0	0	1
	13	0	-1	-1	1	0	0	0	0	0	0
	14	0	1	1	0	-1	0	1	-1	1	0
	15	0	1	0	-1	1	1	0	0	0	0
	16	0	1	0	0	0	1	1	-1	1	0
	17	0	1	1	0	-1	0	0	-1	1	-1
	18	0	1	0	0	0	1	0	-1	1	-1
	19	1	1	0	0	0	0	0	0	0	0

until all the two parallel lines have been taken into account.

For Figure 4, when parallel lines 2 and 3 are removed, the remaining network consists six directional simple loops where, four of which include line no. 1. For the two other lines, i.e. lines 2 and 3, the same procedure is applied. Therefore, the total simple loops consisting separate parallel lines is (3*4=12). Two simple loops do not include any parallel line.

In addition, three parallel lines themselves compose six loops. Therefore, the total simple loops are: (3*4)+2+6=20

In other words, for n parallel lines connected to two buses we have:

TABLE 8. NRT Matrix.

Relay Number	1	2	3	4	6	7	8	9	10	11
NRT	31	31	45	36	45	43	35	66	66	35
Relay Number	1`	2`	3`	4`	6`	7`	8`	9`	10`	11`
NRT	31	31	45	36	45	43	35	66	66	35

No. of simple loops = n*No. of simple loops consisting one parallel line + No. of simple loops which do not include parallel lines + No. of loops, having parallel lines [n*(n-1)]

The main advantage of this method is that, any parallel lines can be considered regardless of whether the parallel lines split the network into subnetworks or not, whereas some previous approaches do have such limitation [10].

B. Joining a Bus to Adjacent Bus

1). Joining a serial bus to adjacent bus If a bus of a power system network has only two nonparallel lines, the bus can be joined to one of its adjacent buses and simple loop matrix is composed for the reduced network. As an example, in Figure 5 the relevant matrix is given in Table 4.

According to this procedure, bus 2 is joined with 3 and instead of both lines 1 and 2 only line 1 remains. The relevant matrix for the new network is shown in Table 5.

The procedure for composing the original matrix, i.e., Table 5 from Table 4 is as follows:

- A column is added to Table 5. This is because of bus No. 2, which has been removed.
- The line connected to bus No.2, which has not removed is found (line No. 1)
- The matrix elements relative to the added column are allocated as the line No.1 if the direction of the omitted line is the same as line No.1. If not, the elements are multiplied by –1.

2). Joining a Bus at the End of Radial Feeder to Adjacent Bus If a bus in a network is connected

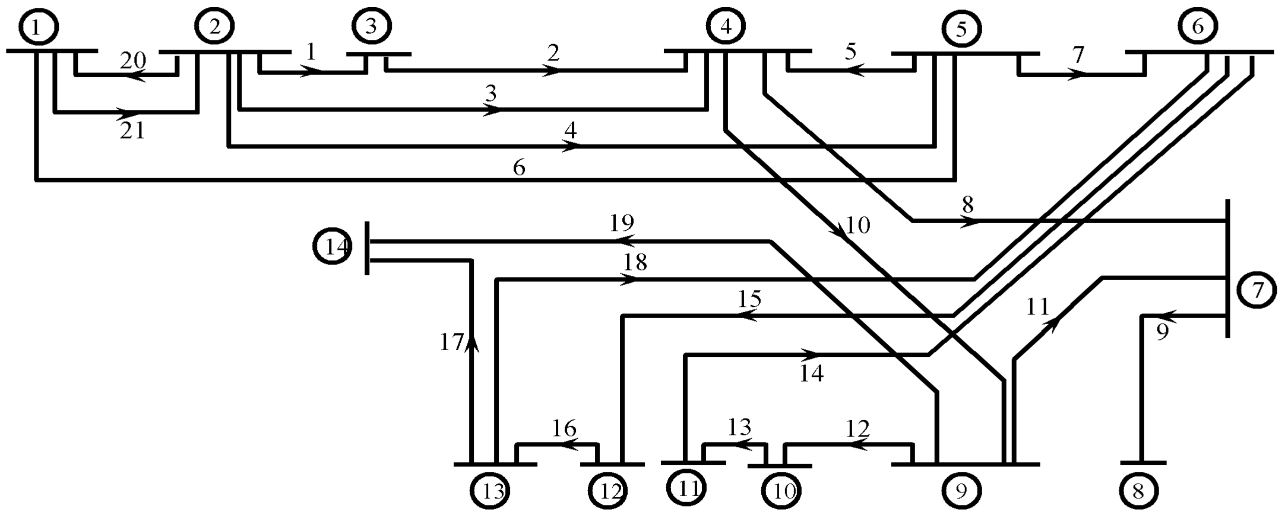

Figure 8. IEEE 14 BUSES interconnected network.

to a radial feeder and the next bus at the remote end of the feeder is also connected to an another radial feeder and this continued until the last feeder is connected to load, all buses belonging to the radial feeders can be joined to each other and become one bus. This cannot affect any Break Point Sets (BPS). In other words, if we compose the matrix, the relative columns consist of zero values.

4. COMPUTATIONAL IMPLEMENTATION OF THE PROCEDURE

Example A. 7 BUS Network Consider Figure 6 consisting of 11 lines, 7 buses and includes all features described in section 3. Each line consists of two relays installed at two its ends. For example, relays No. 1 and 1' are installed at the two ends of line 1.

The implementation of the procedure on the network of Figure 6 is given below:

Line No. 5 consists only one radial line. Therefore, this line number and consequently bus No. 3 are omitted first. Then one of the each parallel lines 1 and 2 and 8 and 11, let's say lines No. 2 and 11 are removed. After these removals, buses 4 and 5 become serial buses and each consists of two non-parallel feeders, therefore by removing the two buses the reduced network is shown in Figure 7.

The simplified loop matrix is given as Table 6. It should be noted that although the procedure of the previous section has been implemented on the network of Figure 8, however one direction of the directional simple loops are represented in Tables 6 and 7 for matrices dimensions reduction.

Now, from Table VI, the loop matrix elements for the original matrix are calculated as follows:

a). Two columns are added to Table 6. The first one is related to line 8 whose matrix column elements are the same as line 10, and the second one belongs to line 9 whose matrix column elements are the matrix elements of line 10 multiplied by –1.

b). Two other columns which are related the removed lines, i.e., line 2 and 11 are also added. The matrix elements of the two columns 2 and 11 are the same as columns 1 and 8 with opposite sign respectively. Of course, the relative loops are added to the matrix.

c). Obviously, line No. 5 is not included in any loop, therefore it is not necessary to be added.

By applying the above procedure, the final loop matrix for the original network is given in Table 7. Then NRT is obtained by calculating L_D [8], as shown Table 8.

TABLE 9. NRL Matrix.

Loop	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
NRL	3	3	5	6	6	4	5	5	6	6
Loop	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}	C_{18}	C_{19}	
NRL	5	2	3	6	4	5	6	5	2	
Loop	$-C_1$	$-C_2$	$-C_3$	$-C_4$	$-C_5$	$-C_6$	$-C_7$	$-C_8$	$-C_9$	$-C_{10}$
NRL	3	3	5	6	6	4	5	5	6	6
Loop	$-C_{11}$	$-C_{12}$	$-C_{13}$	$-C_{14}$	$-C_{15}$	$-C_{16}$	$-C_{17}$	$-C_{18}$	$-C_{19}$	
NRL	5	2	3	6	4	5	6	5	2	

TABLE 10. NRT Matrix.

Loop	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
NRL	3	3	0	0	0	4	0	5	6	6
Loop	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}	C_{18}	C_{19}	
NRL	5	0	3	0	4	0	6	5	2	
Loop	$-C_1$	$-C_2$	$-C_3$	$-C_4$	$-C_5$	$-C_6$	$-C_7$	$-C_8$	$-C_9$	$-C_{10}$
NRL	3	3	5	6	6	4	5	5	6	6
Loop r	$-C_{11}$	$-C_{12}$	$-C_{13}$	$-C_{14}$	$-C_{15}$	$-C_{16}$	$-C_{17}$	$-C_{18}$	$-C_{19}$	
NRL	5	2	3	6	4	5	6	5	2	

After that, matrix NRL is obtained as Table 9. The elements of the table represent the number of relays in each loop. According to the procedure [4], first the loops with least relays are found, which are C_{12}, C_{19},$-C_{12}$,$-C_{19}$. For example for loop C_{12} the relevant relays are 8 and 11. Among the relays of the loops, relay No. 8 is the first break point, because this relay posses highest value in matrix NRL. Then all rows of matrix elements of L_D having relay No.8 are set to zero and by calculating L_D, the new NRT is obtained as Table 10.

Consequently, NRL matrix is found and shown in Table 11.

By repeating the algorithm, relay No. 1 will be the next break point. Finally, by continuing the procedure the break points set are as follows: {8,1,11', 2', 3,6}

Example B. IEEE 14 BUS Network Figure 7 being IEEE 14 Buses interconnected network consisting 21 lines, 14 buses is considered to show

TABLE 11. Final NRL Matrix.

Relay Number	1	2	3	4	6	7	8	9	10	11
NRT	31	20	33	25	45	27	0	66	33	33
Relay Number	1`	2`	3`	4`	6`	7`	8`	9`	10`	11`
NRT	20	31	39	36	28	43	35	33	66	35

TABLE 12. 16 Elements Of NRT Matrix.

Relay Number	1	2	3	4	5	6	7	8
NRT	188	188	167	113	66	248	365	196
Relay Number	10	11	12	13	14	15	16	17
NRT	175	196	130	130	130	141	141	261

the flexibility of the program.

Due to many steps of computational procedure and pages limitation, the implementation of some steps on the network of Figure 7 is given below. It should be noted that the following steps are carried out one after the other.

Step 1) Buse 8, which is connected to a radial feeder, is removed.

Step 2) One of the parallel lines 20 & 21, let's say lines no. 21 is removed.

Step 3) After applying two steps 1 and 2, buses 1, 3, 7, 10, 11, 12 and 14 become serial buses and each consists of two non-parallel feeders, therefore, they are omitted and joined to one of their adjacent buses.

The relevant rules described in section 3 are applied one after the other until all possible simplification has been done. The total steps for the network have become 20.

The interesting feature of the network are that after the last step has been applied no network remains. In other word all buses and lines are removed and no loop exists in the simplified network. Therefore, the reverse procedure should be applied to obtain the basic loops.

Now, the loop matrix elements for the original matrix are calculated according to the final parts of A, B1 and B2 of the previous section. By applying the above procedure for this network, the final loop matrix for the original network is obtained. The loop matrix of original network includes 114 loops. Then the same as previous example, NRT is obtained next. NRT has 40 elements. Due to large dimension, only 16 element of NRT were represented in Table 12. After that, matrix NRL is obtained. First the loops with least relays are found. Among the relays of the loops, relay No. 18 is the first break point, because this relay posses highest value in matrix NRL. Then all rows of matrix elements of L_D having this relay are set to zero and by calculating L_D , the new NRT is obtained.

By repeating the algorithm, relay No.20 will be the next break point. Finally, by continuing the procedure the break points set are as follows: {18, 20, 21', 10, 4, 1, 15', 8,5', 3, 12}.

5. CONCLUSION

The paper demonstrated that in the new method for calculation of break points using graph theory, matrices dimensions are much smaller than the conventional graph theory method. The new method is very flexible and can incorporate easily different network configurations including parallel lines, series buses, radial, ring and interconnected systems and the combination of these. The developed approach has been applied to a 7 bus and IEEE 14 bus networks results indicate that the new approach is flexible and successful.

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