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OVER CURRENT RELAYS PROTECTIVE COORDINATION IN DISTRIBUTION SYSTEMS IN PRESENCE OF DISTRIBUTED GENERATION

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Abstract- With the presence of DG units in distribution systems, its function would generally be changed. One of the most important effects of these units is on distribution systems protection. A way to decrease DG effects on distribution systems protection is re-coordination of protective devices. To prevent high cost, it should be made a change in system to decrease the effect of DG sources when a fault occurs. One of the suggested methods to do that is the use of fault current limiter (FCL). FCL makes no change on system operation in normal conditions and limit DG current at fault accordance conditions. In this paper, it is simulated sample ring network at DIgSILENT after reviewing protective devices and their protective coordination and using algorithm an optimal protective coordination would be created by the use of FCL in presence of DG.

Keywords: Distributed generation (DG), Fault Current Limiter (FCL), Protective Coordination, Distribution System.

I. INTRODUCTION

Distributed generation (DG) presence in power systems is one of attractive phenomena in power industry. With the presence of DG units in distribution systems, its function would generally be changed and it would variously be affected by these units. One of the most important effects of these units is on distribution systems protection. Since the number of DG units not only can be varied but also has a great deal of wide spread, Distribution systems protective devices manner is completely changed with the presence of distributed generation [1-4].

DG units are electrical energy souses which are connected to distribution systems and in comparison with the large scale power stations, have the lower generation capacity and also have a lower starting cost. There are some cases in which the use of DG should be paid attention such as: economical problems in power stations developing, high efficiency of these sources, decreasing of environmental pollution, increasing of power quality, decreasing of loss in distribution systems, improvement of voltage profile and so one. The most important distributed sources are fuel cells, micro turbines, batteries, wind and hydropower station, earth heating systems [1-3]. The fault current would increase in system when the distribution generation sources is installed so it is necessary to set some of the protective system points again after installation DG sources [1-3].

The problems of DG sources on distribution systems protection generally are: feeders misconception trip, misconception trip of generation units, increasing or decreasing of short circuit surface, unwanted islanding, prevention of automatic reclosing and unsynchronized reclosing [4]. One of the ways to decrease DG effects on distribution systems protection which needed high cost is re-coordination of protective devices and replacement of low power breakers and fuses instead of high power breakers and fuses.

To prevent this high cost, it should be made a change in system to decrease the effect of DG sources when a fault occurs. Of course it shouldn't make a change on system operation in normal conditions. One of the suggested methods to do that is the use of fault current limiter (FCL). FCL makes no change on system operation in normal conditions and limit DG current at fault accordance conditions. In this paper, it is simulated sample ring network at DIgSILENT after reviewing protective devices and their protective coordination and using algorithm an optimal protective coordination would be created by the use of FCL in presence of DG.

II. PROTECTIVE DEVICES CHARACTERISTIC

The protective devices such as: fuse, re-closer and breakers are used in the distribution systems. Breakers and re-closers are used in main feeders and fuses are used in lateral ones. In normal condition breakers and re-closers are equipped with reverse time over current relays. General characteristic of these relays is:

$$t(I) = TD\left(\frac{A}{M^{P}-1}+B\right) \quad (1)$$

where A, B and p are constants for particular curve characteristics; t is operating time of device; M is ratio of $\frac{I}{I_{pickup}}$ (I_{pickup} is the relay current set point) and TD is time dial setting.

The characteristic of fuses is similar to reverse time over current characteristic. General equation of fuses follows this relationship:

$$\log(t) = a\log(I) + b \tag{2}$$

where t and I are the associated operating time and current, and the coefficients and are calculated from curve fitting.

III. PROTECTIVE COORDINATION

The selection of over current protective devices with paying attention to their time-current setting in the distribution line length to remove of faults in lines and other equipment concerning the order of previous function is called protective devices coordination. The regulated device to operate at first is called main protection which is probable to fault and it operates quickly. The other device operates as the backup protection and it operates when main protective device doesn't operate.

In order not to enter in both main and backup relays operation in fault occurrence, there should be a time interval between main and backup relays operation time. In a protective system, relay operation time should make the nearest breaker trip when a fault occurs. In order to prevent of serious damage on system, it also shouldn't be so longer that whether inaction of main protection occurs or backup relay trips. The time interval depends on following factors:

1) Required time to fault current trip by breaker.
2) Time of backup flay over shoot.
3) Error (fault) of equipments as relays and current transformers (CT) and short circuit currents calculation.
4) Safe margin to be sure backup relay inaction.

To obtain coordination time interval (CTI) of two relays, mention times should be added. Both in past and at the present time, in many cases relays are coordinated by choosing a constant time. In the past this time was 0.5 second, but nowadays because of being breakers faster and decreasing of time related to relay overshoot it is 0.4 second. However it should be less than 0.3 second in best possible conditions. The characteristics of relays (R_1 & R_2 & R_3) which are main and backup relays are noticed in Figure 1, respectively. CTI is time interval between main and backup relays.

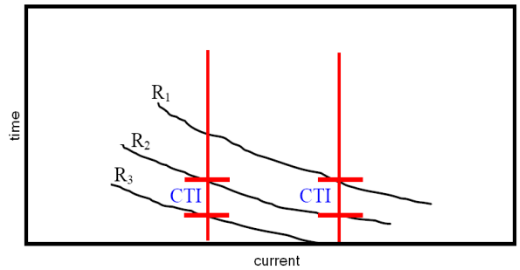

Figure 1. Relays coordination time interval

IV. OBJECTIVE FUNCTION & OPTIMUM COORDINATION CONSTRAINTS OF PROTECTIVE RELAYS

One of the most important issues in power systems protection is protective relays coordination. Because of the importance of the issue and quick protection basis, it is a long time that it is brought forth minimizing of operation time of protective design and several formulations are presented as well.

Objective function which is used in optimum coordination of relays is:

$$\min F = \min \sum W_i T_{ik} \tag{3}$$

where W_i is vector with positive coefficient for relay "i" and T_{ik} is vector of indicator of main (i) and backup (k) over current relays operation times.

One of the above constraints function is coordination constrain:

$$T_{nk} - T_{ik} \geq \Delta T \tag{4}$$

where T_{nk} is first backup relay (R_n) operation time for relay R_i for a supposed fault in k protective zone. ΔT is coordination time interval and its amount is between 0.2 to 0.5 second. In this paper, selected ΔT equal to 0.3 second.

Borders constraints on relay setting and relays operation times are:

$$TDS_{i\min} \leq TDS_i \leq TDS_{i\max} \tag{5}$$

$$Ip_{i\min} \leq Ip_i \leq Ip_{i\max} \tag{6}$$

where TDS_i and I_{pi} in relay R_i are time during setting and pickup current, respectively. In this paper, normal reversed over current relays are used with following characteristic:

$$T_{ik} = \frac{0.14 \times TDS_i}{[(I_{ik} / Ip_i)^{0.02} - 1]} \tag{7}$$

where I_{ik} is short circuit current of relay R_i. Equation (7) is normal reversed characteristic of "SPCS2D26" relay made in ABB Company.

V. SIMULATION OF SAMPLE SYSTEM

A. Introducing of Simulated System

Nowadays, distribution systems are constantly complicated. As 30 buses IEEE tested network has appropriate number and complicated bus, it is used in this paper. Although, distribution level is the main end of this paper only the distribution level (33kV) portions are studied. Reformed network of 30 buses system has 22 buses and 43 relays that shown in Figure 2. Connection to 132kV substations are designed by infinite bus with 200 MVA short circuit power. It can be found the data lines and loads and also the data of main and backup relays system in the appendix.

All of the process using MATLAB (for algorithm execution and math equations) and DIgSILENT (network simulation and short circuit and load flow calculations) softwares is simulated and they are executed on illustrated distribution network.

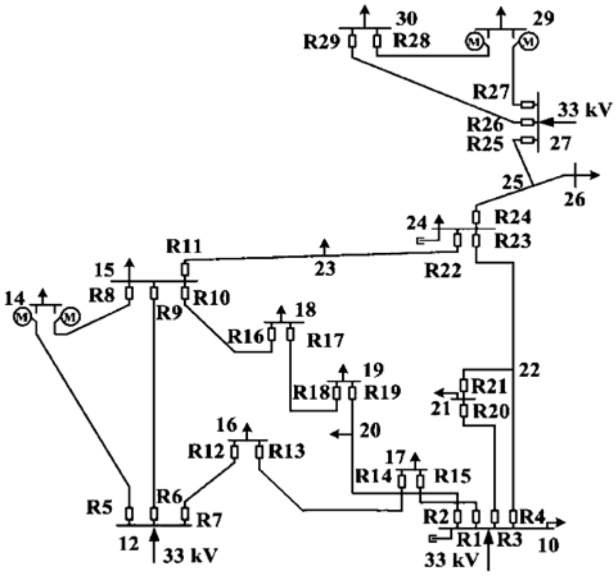

Figure 2. Reformed network of IEEE 30 buses system

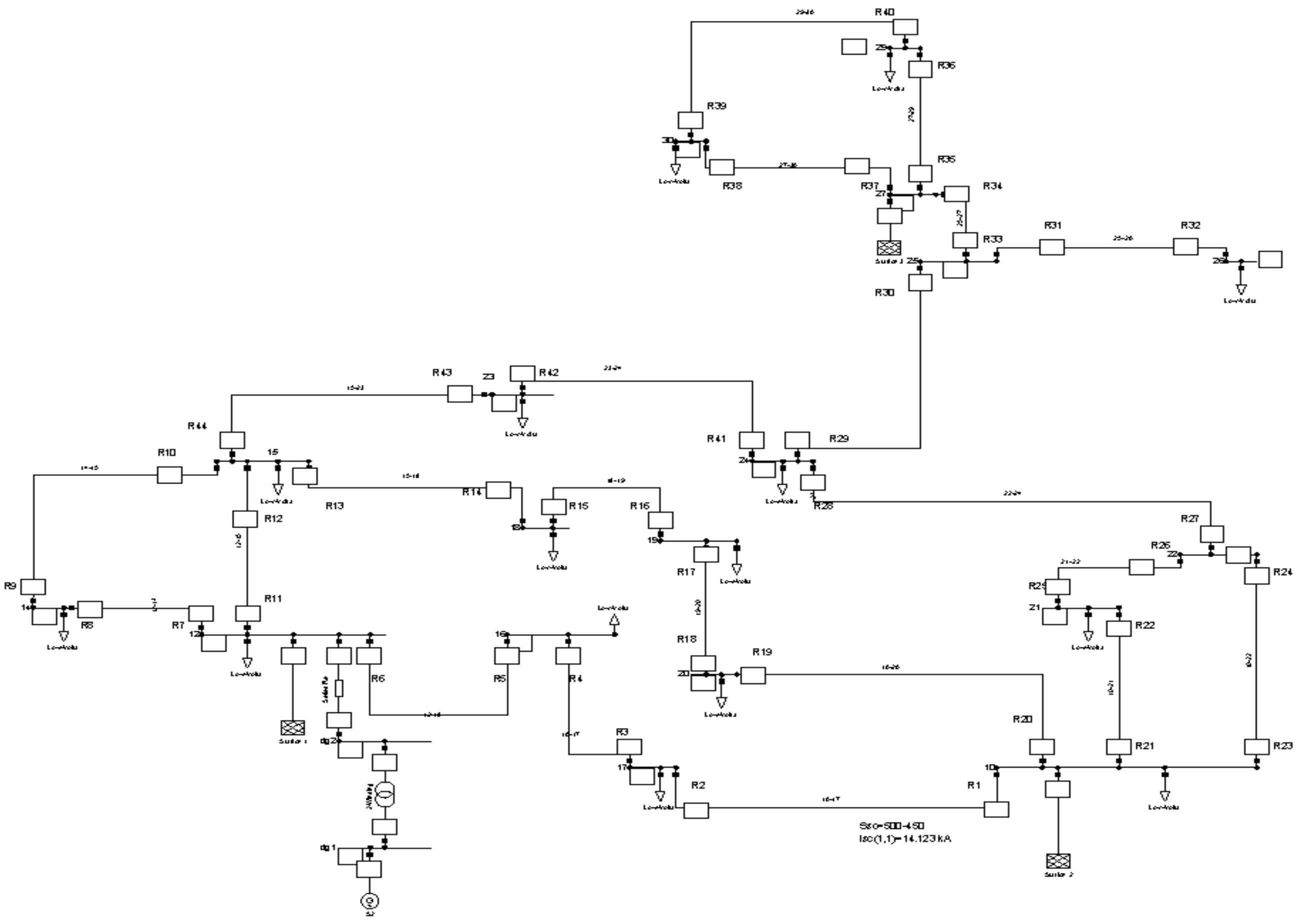

Figure 3. Reformed network of IEEE 30 buses system in DIgSILENT software

B. Optimum Coordination Results

In order to execution of optimum coordination program in MATLAB, it is used genetic algorithm. Since suitable tools in MATLAB, exist for genetic algorithm execution, it is not needed to direct programming of genetic algorithm and it is just needed constraints and optimization function definition. For example coordination constraints between main relay (1) and backup relay (19) are presented with following expression:

c(1,[1 2 3])=[1 19 *t_op*(*x*(1),*Ip*(1),*Isc*(1,1),*mp*)-*t_op*(*x*(19),*Ip*(19),*Isc*(19,1),*mp*)+**0.3**];

Above expression is indicated the following constraint:

$$T_{nk} - T_{ik} \geq \Delta T \quad (8)$$

where

t_op: relays operation time calculation function;

$x(1)$ and $x(19)$: TDS of relays 1 and 19, respectively;

$Isc(1,1)$: Short circuit current in backup relay (19) for a fault in main relay (1) location.;

$Ip(1)$ and $Ip(19)$: pickup currents of relays 1 and 19, respectively.

Obtained time based on genetic optimization is 35/03 seconds. Important parameters of genetic optimization are shown in Table 1. Paying attention to system complication, this time is seemed reasonable. Obtained minimum of CTI amount is presented in Table 2. This time is approximately 0.27 second.

Table 1. Important parameters of genetic optimization

Parameter	Amount
Cross-Over coefficient	0.9
The number of population	20
The number of generation	50

Table 2. Obtained minimum of CTI

Relay Unit	Relay Current (Amp)	Numerical Relays	
		Operating Time (sec)	CTI (sec)
R1	7093	0.9116	---------
R24,1	608	1.1808	0.2691

C. The Study of DG Effects on Protective Coordination of Sample Distribution System

DG influence can be considered by following ways:

a) DG different locations consideration:

DG is placed on different buses to study the effects of DG replacement in different places in sample network. The recorded results as released coordination amount based on low CTI and miss-coordination are illustrated in various states of DG in Table 3.

Most of the times, putting DG in a bus often makes coordination of margin decrease that it is shown as low CTI in table 3. However DG effects sometimes effects so much that coordination between pairs of main and backup relays are completely missed. It is illustrated as miss-coordination in Table 3.

Table 3. Type of CTI deviation (DG=20MVA)

DG @ bus	Number of low CTI	DG @ bus	Number of miss-coordination
10	9	10	0
12	12	12	0
15	13	15	0
16	12	16	0
17	8	17	2
18	16	18	0
19	14	19	0
21	9	21	5
24	8	24	3
27	6	27	0
30	4	30	0

b) DG different capacities consideration:

In order to effective study of DG on relays coordination, a DG unit is placed on the network and DG capacity amount gradually is increased. The result of DG capacity increasing effects is shown on CTI of distribution system in Figure 4. As it can be seen through increasing DG capacity, relays CTI margin is less than its ideal, i.e. 0.3 second.

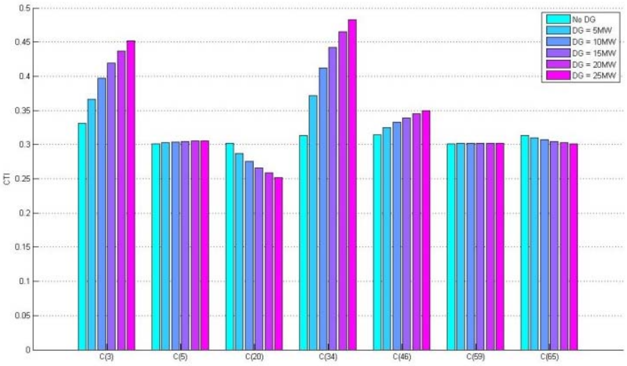

Figure 4. CTI of distribution system relays with DG capacity increasing

The negative effects of increased DG capacity on decreasing of CTI margin and also coordination margin in C(34) index which is related to main relay 21and backup relay 19,are shown in Table 4 which is maximum deviation of CTI according to DG capacity amounts.

Table 4. Maximum deviation of CTI according to DG capacity

DG Size (MW)	Max (CTI-0.3)
0	0.0309
5	0.0715
10	0.1124
15	0.1421

D. Coordination Return between Relays by FCL Application

D.1. FCL

FCL is a device that it is set it is set in network series form and it limited fault current in considered level and make a few losses in normal conditions of operations [5-6]. In using FCL some cases as losses in normal conditions, reliability and economical problems should be considered. Some of the advantages of FCL are fault current limiting and system stability improvement and voltage say decrease.

It is necessary to study the location of installation of FCL, because it should be selected so that because of economical problems, low number of FCL is used. After various studying on these fields, researchers have found out that FCL should be installed near to DG so that the effect of FCL on DG is maximized.

D.2. Coordination Return by FCL

The share of DG in fault current can be reduced by use of FCL. In this paper, we are going to compensate the effects of DG on CTI by changing the amount of FCL. For the first step, a FCL is located on the bus 12 which is connected to DG unit. Impedance of FCL is increased 0-

80 ohms. The results are shown at Figure 5. As it can be noticed with increasing of FCL capacity, CTI amount gets closer to the ideal amount. The considered subject is obviously distinguished by the comparison with maximum deviation of CTI corresponding with different amount of FCL. It is shown in Table 5 in index C(34).

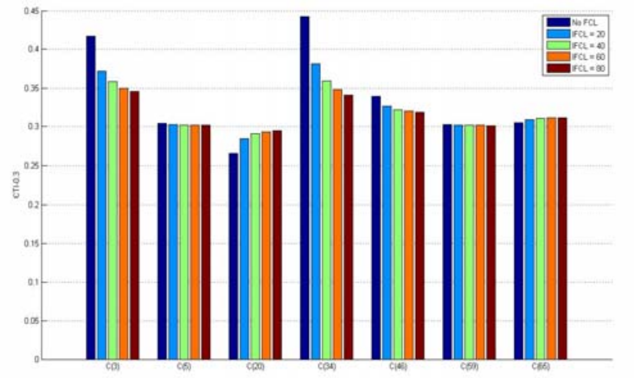

Figure 5. CTI of distribution system with different amount of FCL

Table 5. Maximum deviation of CTI corresponding with different amount of FCL

FCL Size (ohm)	Max (c)
0	0.1422
20	0.0814
40	0.0591
60	0.0499
80	0.0457

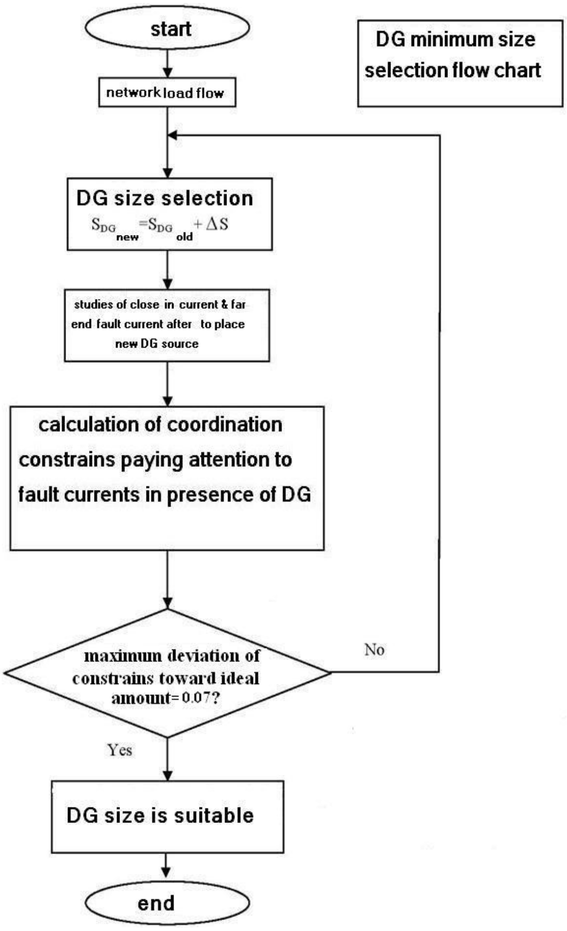

Figure 6. DG minimum size selection flow chart

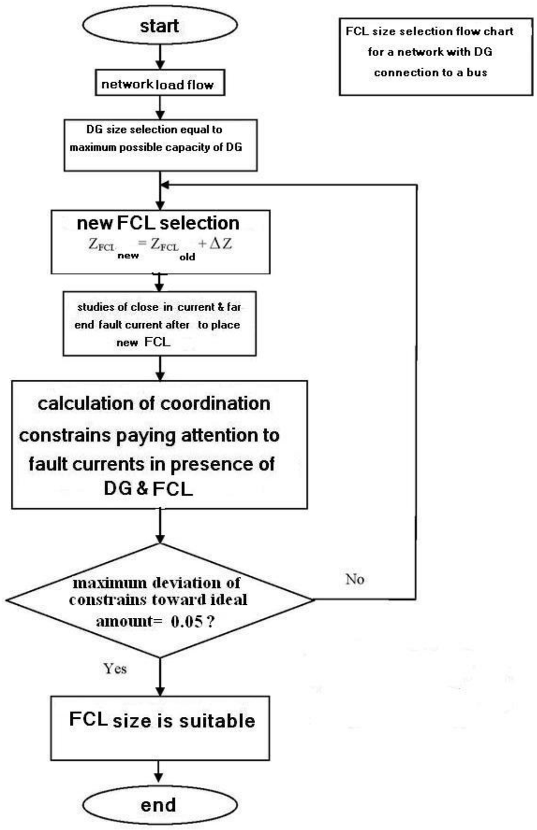

Figure 7. FCL size selection flow chart

Considering the Table 5, the positive effect of FCL for decreasing CTI and returning of coordination is distinguished. Considering the effects of DG on maximum deviation of coordination margin and also paying attention to flowchart Figure 6, it could make a decision to used or not to used FCL application for a DG (in a specific bus). According to Table 5, if 0.07 is selected as minimum CTI, it would be distinguished that there is no need to FCL for DG units having 0-5 MW in bus 12. It is necessary to apply an appropriate FCL if the DG capacity would be more than mentioned amount in future develops of distribution system. So considering economical and technical points, the amount of FCL is determined for maximum DG capacity in bus 12 (15MW).

According to simulation results and paying attention to table 6 and flowchart of Figure 7, it can set CTI to 0.05 by 60 ohms FCL, that it is technically suitable. Through repetitive optimum, the best obtained result for coordination margin would be 0.02.

VI. CONCLUSIONS

DG is placed on different buses to study the effects of DG replacement in different places in sample network. Most of the times, putting DG in a bus often makes coordination of margin decrease (low CTI) and DG effects sometimes effects so much that coordination between pairs of main and backup relays are completely missed (miss-coordination). In order to effective study of DG on relays coordination, a DG unit is placed on the network and it can be seen through increasing DG capacity, relays CTI margin is less than its ideal, i.e. 0.3

second. In this paper, we compensated the effects of DG on CTI by changing the amount of FCL. It can be noticed with increasing of FCL capacity, CTI amount gets closer to the ideal amount.

APPENDIX

Table A. Lines information

From Bus	To Bus	*R* (pu)	*X* (pu)	*B* (pu)	*V* line
1	2	0.0192	0.0575	0.0528	132
1	3	0.0452	0.1652	0.0408	132
2	4	0.057	0.1737	0.0368	132
3	4	0.0132	0.0379	0.0084	132
2	5	0.0472	0.1983	0.0418	132
2	6	0.0581	0.1763	0.0374	132
4	6	0.0119	0.0414	0.009	132
5	7	0.046	0.116	0.0204	132
6	7	0.0267	0.082	0.017	132
6	8	0.012	0.042	0.009	132
6	9	0	0.208	0	132
6	10	0	0.556	0	132
9	11	0	0.208	0	132
9	10	0	0.11	0	132
4	12	0	0.256	0	132
12	13	0	0.14	0	33
12	14	0.1231	0.2559	0	33
12	15	0.0662	0.1304	0	33
12	16	0.0945	0.1987	0	33
14	15	0.221	0.1997	0	33
16	17	0.0524	0.1923	0	33
15	18	0.1073	0.2185	0	33
18	19	0.0639	0.1292	0	33
19	20	0.034	0.068	0	33
10	20	0.0936	0.209	0	33
10	17	0.0324	0.0845	0	33
10	21	0.0348	0.0749	0	33
10	22	0.0727	0.1499	0	33
21	22	0.0116	0.0236	0	33
15	23	0.1	0.202	0	33
22	24	0.115	0.179	0	33
23	24	0.132	0.27	0	33
24	25	0.1885	0.3292	0	33
25	26	0.2544	0.38	0	33
25	27	0.1093	0.2087	0	33
28	27	0	0.396	0	33
27	29	0.2198	0.4153	0	33
27	30	0.3202	0.6027	0	33
29	30	0.2399	0.4533	0	33
8	28	0.0636	0.2	0.0428	132
6	28	0.0169	0.0599	0.013	132

Table B. Loads information

Bus	Base kV	Load (MW)	Load (MVAr)
10	33	5.8	2
12	33	11.2	7.5
14	33	6.2	1.6
15	33	8.2	2.5
16	33	3.5	1.8
17	33	9	5.8
18	33	3.2	0.9
19	33	9.5	3.4
20	33	2.2	0.7
21	33	17.5	11.2
22	33	0	0
23	33	3.2	1.6
24	33	8.7	6.7
25	33	0	0
26	33	3.5	2.3
27	33	0	0
29	33	2.4	0.9
30	33	10.6	1.9

Table C. Main/backup relays of network

Primary Relay	Secondary Relay	Primary Relay	Secondary Relay
1	19	23	2
1	22	23	19
1	24	23	22
2	4	24	25
3	1	24	28
4	6	25	21
5	3	26	23
6	8	26	28
6	12	27	23
7	5	27	25
7	12	28	30
8	10	28	41
9	7	29	27
10	11	29	41
10	14	30	33
10	42	30	31
11	5	31	29
11	8	31	33
12	9	32	29
12	14	32	31
12	43	33	37
13	9	33	35
13	11	34	37
13	42	34	32
14	16	35	38
15	13	36	35
16	18	36	32
17	15	37	39
18	20	38	36
19	17	39	34
20	2	40	30
20	22	40	27
20	24	41	43
21	2	42	40
21	19	43	9
21	24	43	14
22	26	43	11

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BIOGRAPHIES

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