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Reliability Analysis of Radial Distribution Networks with Cost Considerations

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Abstract: Reliability of a distribution system plays a vital role in every electrical system and improving it to meet customer satisfaction is a major task at present. In this paper, a multi objective optimizing method called Weighted Mixed Integer Non Linear Programming is developed based on Pareto front technique. This is used for optimal placement of ties in a radial network and compared the performance before and after reconfiguration. Comparison is done in terms of reliability indices (SAIFI, SAIDI, CAIDI, ASAI, ASUI and AENS) and future investment which is to be done for improving reliability. Future investment consists of finding the components and respective actions, where to invest with minimum amount which helps to improve the reliability of the system. The proposed work considers an IEEE 33 bus system and developed in MATLAB Software.

Keywords: Reliability Indices; Pareto Front Technique; Radial Distribution Networks.

NOMENCLATURE

SAIFI – System Average Interruption Frequency Index.

SAIDI – System Average Interruption Duration Index.

CAIDI – Customer Average Interruption Duration Index.

ASAI – Average System Availability Index.

ASUI – Average System Unavailability Index.

AENS – Average Energy Not Supplied.

WMINLP – Weighted Mixed Integer Non Linear Programming.

ENS – Energy Not Supplied.

1. INTRODUCTION

Customer satisfaction is an important factor in any electrical distribution system. In order to achieve that, the distribution companies have to supply the power with minimum possible number of interruptions to customers. The distribution systems were neglected in the past when compared to generation systems and transmission systems in terms of reliability. However, the situation has changed now in such a way that most of the reliability studies are focused on the distribution systems. This is because of the fact that individual unavailability of distribution system in total electrical system has the highest contribution in the customer's supply.

Most of the distribution systems are of radial type as they are easy to build and expand in future. One of the disadvantages in radial feeders is that, if one component fails then it will affect many customers. So, in this paper the focus is on radial distribution networks in the proposed methodology. Reliability Optimization in distribution systems using a binary programming with nonlinear model is used in [4].

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The demand of electrical energy is increasing day by day, which can be partly compared by reducing the losses in the distribution system. Reconfiguration of network and inclusion of capacitors in the network are the possible solutions to reduce the losses. The capacitors inclusion is done for supplying the reactive load which in turn reduces the losses. The methodology presented is considered to develop optimal locations of ties as well as capacitors to be placed in the network [7].

The methodology for reducing the failure rate and repair time so as to increase reliability and upgrading of communication, system automation, reinforcing lines, placing parallel lines, redesign of layout, can be performed and are explained in [8]. A methodology on how to increase probability in delivering power with identification of new investments in distribution components is depicted in [6]. Moreover, in reference [3] an algorithm is developed to determine optimal interval for maintenance actions to be performed in distribution networks [9, 10].

Estimation of outage parameters and investment actions that are to be performed at each load point in the network can be found by using a fuzzy set method explained in [5] and used in the present methodology. In this paper, it is proposed to perform optimal ties placement with capacitor banks installation for loss reduction in the network and find the investment actions to improve reliability of network. The whole procedure is performed for before reconfiguration, after reconfiguration and finally both are compared. The proposed work is tested on an IEEE 33 bus system.

Organization of the work is as follows: In section II, presented the idea and explained about the methodology proposed to improve reliability. In section III, presented about the case study. In section IV, provided the results obtained for the sample power systems. In section V, discussed the conclusions.

2. METHODOLOGY

The methodology here is defined based on a multi objective optimization technique, which can be used for finding optimal location of ties, minimum investment costs, optimal location for capacitors and their sizes, and also reliability indices of a radial distribution network. A function with single objective can be defined as;

$$\min g(a) \; ... \; a \in \text{N} \tag{1}$$

Similarly, a function with multiple objectives can be defined as;

$$\min [g_1(a), g_2(a), ... \; g_n(a)] \; ... \; a \in \text{N} \tag{2}$$

where, $n > 1$ (number of objectives)

$g(a)$ is an objective function

N is the set of constraints.

The minimum loss for network reconfiguration can be mathematically formed as

Minimize $\sum_{a=0}^{n} \text{P}_{\text{I}a}$ subject to

(a) Real power constraints

$$\text{P}_{\text{I}a} = \sum_{b \in \text{N}(a)} \alpha_{ab} \, (\text{g}_{ab}\text{V}_a^2 - \text{V}_a\text{V}_b[g_{ab} \cos \theta_{ab} + b_{ab} \sin \theta_{\text{ab}}] \tag{3}$$

(b) Reactive power constraints

$$\text{Q}_{\text{I}a} = \sum_{b \in \text{N}(a)} \alpha_{ab} \, [-(b_{ab} + \text{b}_{\text{shab}}/2) \, \text{V}_a^2 + \text{V}_a\text{V}_b(b_{ab} \cos \theta_{ab} - g_{ab} \sin \theta_{ab})] \tag{4}$$

(c) Voltage magnitude limits

$$V_{a\,\min} \leq V_a < V_{a\,\max},\ a = 1, 2, ..., n \tag{5}$$

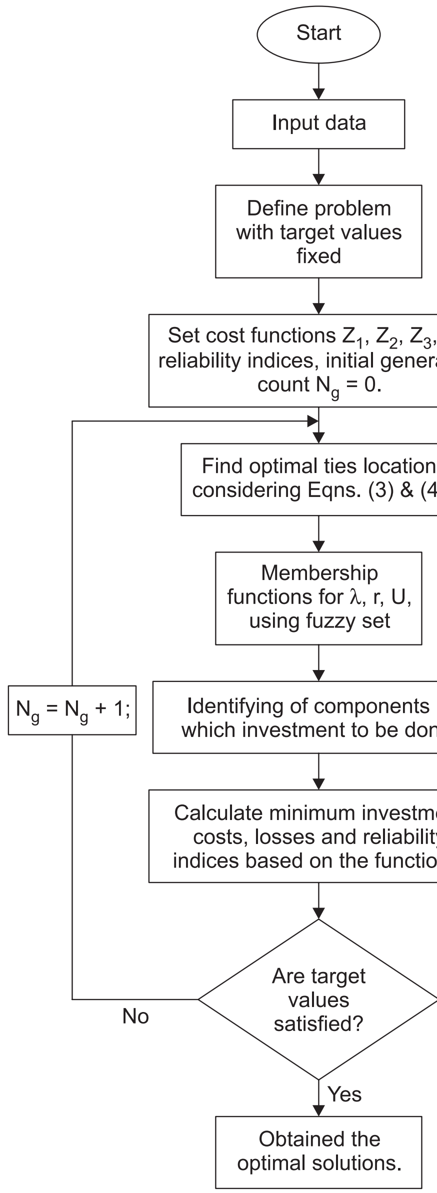

Figure 1: Flow chart of the methodology proposed

where,

P_{Ia} = Real power injected at node a

Q_{Ia} = Reactive power injected at node a

$N(a)$ = Set of nodes connected to node a

α_{ab} = 1; if node a is parent of node b
0; otherwise

g_{ab} = Series conductance of line ab

b_{ab} = Series susceptance of line ab

b_{shab} = Shunt susceptance of line ab

V_a = Voltage magnitude at node a

Previous studies on membership functions of failure rate, repair time and unavailability by using fuzzy set to obtain the outage data is explained in [5]. Moreover, in this reference the methodology also provides the identification of components where to invest and the minimizing functions for respective costs (cost of investment, energy not supplied cost, losses cost, capacitors installation cost), by which failure rate and repair time can be reduced. This is developed as a multi objective optimization problem based on WMINLP. The proposed methodology also considers the technical constraints such as active and reactive power balance, bus voltage magnitude limits, system power losses, capacitor size to be placed.

Power flow studies of the network are performed using Newton-Raphson method. Finally, reliability analysis is done in terms of SAIFI, SAIDI, CAIDI, ASAI, ASUI and AENS for the network. The respective formulae for these reliability indices are taken from [2]. An algorithm is developed based on the above ideas and given as flowchart in Figure 1. Cost functions Z_1, Z_2, Z_3 & Z_4 are taken from [8].

3. CASE STUDY

An IEEE 33 bus system is considered for case study [1]. In Figure A1 (given in Appendix), depicted system with 33 busses and 32 lines. It is known that, it consists an active power load of 3715 kW reactive power load of 2300 kVAr. Substation voltage is taken as 12.66 kV. In Table A1, given the respective data of the network. An algorithm with Pareto Front Technique is developed in MATLAB software. The required data for this method is taken from [8].

4. RESULTS

The load flow studies for the considered system are performed, and optimal capacitor placement is also done which is included in the methodology here. In Table 1, given the capacitors location and their size. In Table 2, shown the corresponding values for the voltage profiles. The voltage profiles of the system before and after capacitor placement are presented in Figure 2. The buses are so selected that for capacitor placement the bus with lowest voltage is considered (which is less than desired level of 5% considered), one by one and load flows studies have been made. The satisfactory voltage profiles have been obtained by placing the capacitors at various buses as presented in Table 1. In Table 2, the voltage profiles before & after capacitor placement are presented and corresponding graphs are shown in Figure 2.

Table 1
Capacitor Placement for IEEE 33 Bus System

Bus No.	6	9	10	18	28	29
Capacitor size (kVAr)	600	100	100	400	100	1400

Table 2
Voltage Comparison for IEEE 33 Bus System

Bus number	*Before capacitor placement*	*After capacitor placement*
1	1.0000	1.0000
2	0.9970	0.9979
3	0.9829	0.9882
4	0.9754	0.9841
5	0.9678	0.9800
6	0.9489	0.9737
7	0.9458	0.9731
8	0.9416	0.9699
9	0.9350	0.9664

Bus number	*Before capacitor placement*	*After capacitor placement*
10	0.9289	0.9629
11	0.9280	0.9622
12	0.9264	0.9610
13	0.9200	0.9563
14	0.9180	0.9548
15	0.9163	0.9535
16	0.9148	0.9528
17	0.9122	0.9512
18	0.9116	0.9534
19	0.9965	0.9973
20	0.9928	0.9937
21	0.9921	0.9929
22	0.9914	0.9922
23	0.9795	0.9848
24	0.9757	0.9811
25	0.9753	0.9806
26	0.9469	0.9728
27	0.9442	0.9716
28	0.9323	0.9691
29	0.9242	0.9677
30	0.9217	0.9653
31	0.9178	0.9616
32	0.9172	0.9610
33	0.9167	0.9606

Reconfiguration (ties placement considered in this paper) of the considered system is performed by using WMINLP. After performing, the obtained reconfiguration of network is shown in Figure 3. The losses before reconfiguration are 201.04277 kW, and after reconfiguration it is reduced to 137.7819 kW. In Table 3, shown the placement of ties.

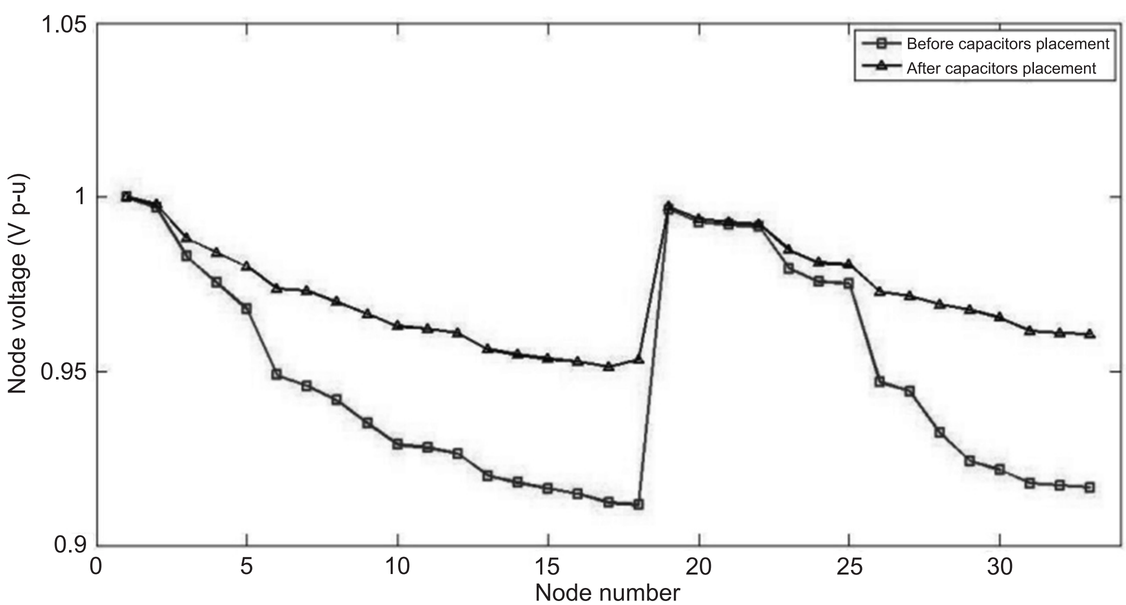

Figure 2: Voltage profile of IEEE 33 bus system

Table 3
Tie Switches Placement

Tie switch No.	*From bus*	*To bus*
1	8	21
2	9	15
3	12	22
4	18	33
5	25	29

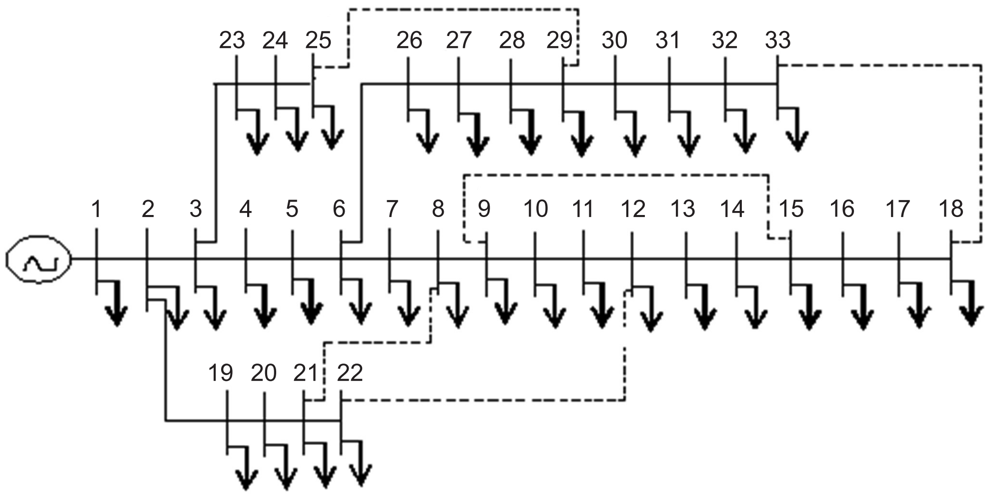

Figure 3: Reconfigured network

The reconfigured network is also combined with capacitor placement. The optimal placement and size of capacitors for the reconfiguration network are shown in Table 4. The losses before capacitor placement are 137.7819 kW and after capacitor placement it is reduced to 88.2650 kW. In Figure 4, given the voltage profiles with different cases considered.

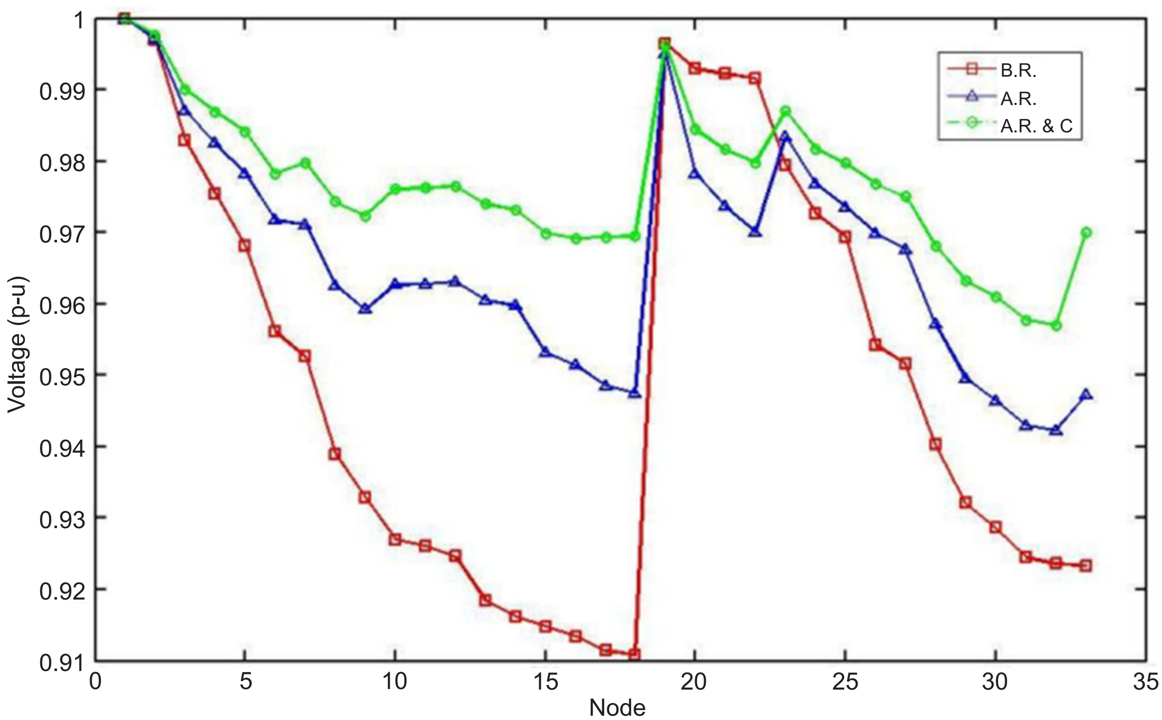

Figure 4: Voltage profiles of reconfiguration network

where

B.R – Before Reconfiguration

A.R – After Reconfiguration

A.R & C – After Reconfiguration and Capacitor Placement

Table 4
Capacitor Placement for Reconfiguration Network

Bus No.	7	12	25	30	33
Capacitor size(kVAr)	600	300	300	600	300

Table 5
Comparison of Voltage Values

Bus No.	B.R	A.R	A.R&C
1	1.0000	1.0000	1.0000
2	0.9970	0.9971	0.9977
3	0.9829	0.9870	0.9900
4	0.9755	0.9825	0.9869
5	0.9681	0.9782	0.9841
6	0.9561	0.9717	0.9782
7	0.9526	0.9711	0.9798
8	0.9390	0.9626	0.9743
9	0.9328	0.9592	0.9723
10	0.9270	0.9627	0.9761
11	0.9261	0.9628	0.9762
12	0.9246	0.9631	0.9765
13	0.9185	0.9605	0.9740
14	0.9162	0.9597	0.9732
15	0.9148	0.9532	0.9699
16	0.9134	0.9514	0.9692
17	0.9114	0.9485	0.9694
18	0.9108	0.9475	0.9695
19	0.9965	0.9951	0.9963
20	0.9929	0.9782	0.9844
21	0.9922	0.9736	0.9816
22	0.9916	0.9701	0.9798
23	0.9794	0.9834	0.9870
24	0.9727	0.9768	0.9817
25	0.9694	0.9735	0.9797
26	0.9542	0.9699	0.9768
27	0.9516	0.9676	0.9750
28	0.9403	0.9571	0.9681
29	0.9321	0.9496	0.9632
30	0.9286	0.9464	0.9610
31	0.9245	0.9430	0.9577
32	0.9236	0.9423	0.9570
33	0.9233	0.9472	0.9701

In Table 5, compared the voltage values obtained before reconfiguration and after reconfiguration. The comparison between before and after reconfiguration network is done in terms of losses, costs and reliability indices. In Table 6, given the comparison of initial losses of network.

Table 6
Initial Losses of the System

--	*B.R*	*A.R*
kW losses	201.0427	137.7819
ENS losses (kVAh/yr)	63904.2000	36064.9200
ENS losses (mu/yr)	127808.4000	72129.8400
Losses (mu/yr)	147966.5740	77246.0444

Table 8
Various Costs of the System

--	*B.R*	*A.R*
Investment cost (in lakhs)	₹ 11.32	₹ 9.49
ENS cost (in lakhs)	₹ 5.08	₹ 2.68
Capacitor cost (in lakhs)	₹ 1.65	₹ 0.92
Losses cost (in lakhs)	₹ 3.86	₹ 2.13
Total cost (in lakhs)	₹ 18.43	₹ 14.40

In Table 7, compared the results with B.R & A.R. In Table 8, compared the reliability indices and losses before and after reconfiguration, without corrective actions such as increase in number of operators, upgrading communication system, system automation, reinforcing lines, placing parallel lines and redesign of layout.

Table 8
Various Values Before Corrective Actions

--	*B.R*	*A.R*
SAIDI	12.9022	9.5241
SAIFI	5.2853	3.7328
CAIDI	2.4411	2.5514
ASAI	0.9958	0.9960
ASUI	0.0042	0.0040
AENS (kWh/customer yr)	9.4081	6.5362
ENS Losses (kVAh/yr)	63904.2000	36064.9200
kW	201.0427	137.7819

In Table 9, the comparison of reliability indices and losses before and after reconfiguration are presented. The multi objective technique in this paper improves reliability of a radial distribution system.

Table 9
Various Values after Corrective Actions

--	*B.R*	*A.R*
SAIDI	9.6317	6.6375
SAIFI	4.3791	3.2502
CAIDI	2.1995	2.0422

--	*B.R*	*A.R*
ASAI	0.9961	0.9965
ASUI	0.0039	0.0035
AENS (kWh/customer yr)	4.9379	2.9812
ENS Losses (kVAh/yr)	21394.2533	13252.8444
kW	176.8576	92.2650

For the considered IEEE-33 bus system, reduction in SAIDI & SAIFI for before reconfiguration are 25% & 17% respectively and after reconfiguration the reduction is 30% & 13% respectively. The total cost for investment actions in after reconfiguration is lesser than that of before reconfiguration by 22%.

In final comparison of before and after reconfiguration, it is observed SAIDI & SAIFI are less in after reconfiguration by 31% & 26% respectively. The proposed methodology is applied to a system for the optimal placement of ties and as well as capacitors and proves that losses are reduced by 48% after reconfiguration when compared to before reconfiguration.

5. CONCLUSIONS

In this paper an algorithm is developed using Pareto Front Technique for the multi objective problem which is called as WMINLP. Load flow studies are performed on IEEE 33 bus system. Capacitor placement and optimal ties placement for this network are obtained. Simulation results are obtained using MATLAB software. Cost evaluation is done and compared for before and after reconfiguration. Power loss is reduced after reconfiguration of the network. Reliability of the considered system is improved after reconfiguration when compared with before reconfiguration. The total cost for the system has been reduced after reconfiguration as compared to the base case of radial distribution system.

Appendix

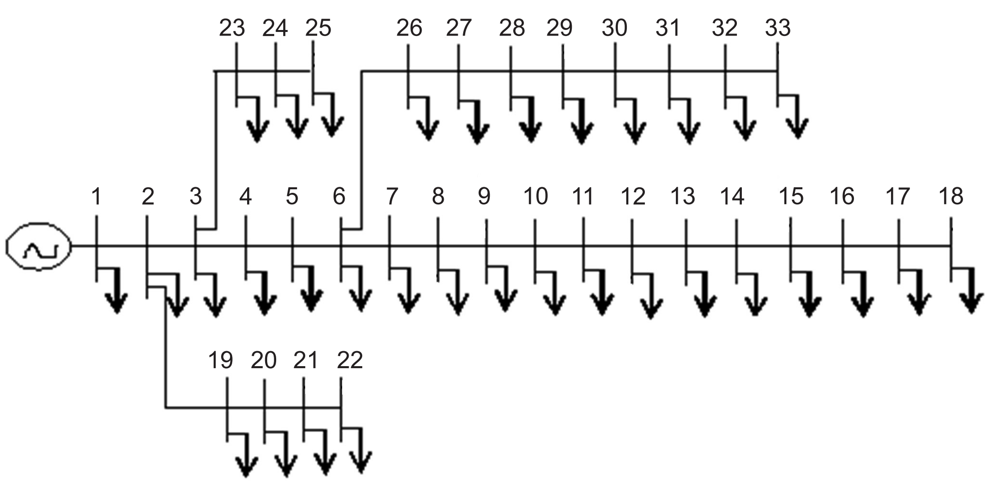

Figure A1: IEEE 33 bus radial distribution system

Table A1
Data for IEEE 33 Bus System

Line No.	*From bus*	*To bus*	*P (kW)*	*Q (kVAr)*	*R (Ω)*	*X (Ω)*
1	1	2	100	60	0.0922	0.0470
2	2	3	90	40	0.4930	0.2511
3	3	4	120	80	0.3660	0.1864

Line No.	*From bus*	*To bus*	*P (kW)*	*Q (kVAr)*	*R (Ω)*	*X (Ω)*
4	4	5	60	30	0.3811	0.1941
5	5	6	60	20	0.8190	0.7070
6	6	7	200	100	0.1872	0.6188
7	7	8	200	100	0.7114	0.2351
8	8	9	60	20	1.0300	0.7400
9	9	10	60	20	1.0440	0.7400
10	10	11	45	30	0.1966	0.0650
11	11	12	60	35	0.3744	0.1238
12	12	13	60	35	1.4680	1.1550
13	13	14	120	80	0.5416	0.7129
14	14	15	60	10	0.5910	0.5260
15	15	16	60	20	0.7463	0.5450
16	16	17	60	20	1.2890	1.7210
17	17	18	90	40	0.7320	0.5740
18	2	19	90	40	0.1640	0.1565
19	19	20	90	40	1.5042	1.3554
20	20	21	90	40	0.4095	0.4784
21	21	22	90	40	0.7089	0.9373
22	3	23	90	50	0.4512	0.3083
23	23	24	420	200	0.8980	0.7091
24	24	25	420	200	0.8960	0.7011
25	6	26	60	25	0.2030	0.1034
26	26	27	60	25	0.2842	0.1447
27	27	28	60	20	1.5090	0.9337
28	28	29	120	70	0.8042	0.7006
29	29	30	200	600	0.5075	0.2585
30	30	31	150	70	0.9744	0.9630
31	31	32	210	100	0.3105	0.3619
32	32	33	60	40	0.3410	0.5302

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