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Prioritization of network transformers in electrical distribution system by considering social welfare index

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ABSTRACT

To supply a meshed distribution system, network transformers are required. When few transformers are not in service, they must be repaired or replaced. A method is proposed for prioritizing the transformers considering the critical loads. Repair or replacement of transformers can be done by giving priority based on risk reduction. By addressing the possibility of network collapse due to failure of the feeder and impacted customers, risk can be predicted where the loads are extremely used at feeders section, network transformers and secondary mains. To select the transformer that needs to be replaced quickly and economically, an algorithm is proposed and it was tested on IEEE test system using GridLAB-D, MATLAB softwares. An index is proposed to give priority to emergency needs like hospitals and water pumping stations. Replacement or repair can be done by prioritizing network transformers incorporating social welfare index.

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1. INTRODUCTION

In order to reduce the duration of major failures in bulk power supplies, restoration actions are required. Network transformers are required to feed the heavily meshed secondary grid distribution systems. In the case of outages of these network transformers, replacement or repair must be done to get those network transformers into the service. Replacement or repair of the network transformers can be easily done if they are prioritized. Priority can be given to the transformers based on the number of customers affected. Prioritizing the network transformers can be done by using a risk index [1] algorithm for mesh type distribution networks at the time of normal loading conditions. Transformer outages may happen due to overload of an equipments or tank leakages or damage in protection or due to maintenance etc. These can be identified by using a bonding method [2], line outage distribution factors (LODF) [3] and power flows [4]. In real time, distribution transformers are monitored by using RMS (Real time Monitoring System) integrated with PLC (Power Line Carrier) technology. From this, status of transformer, terminal voltages, temperatures, loading etc can be known easily. Z bus matrix [5] is preferred for large meshed underground networks. Loads near the network transformers can be easily identified with Z bus matrix construction.

Flow violations can easily calculated for branch, generating unit and load outages using bounding method [6]. In general LODF's are used in transmission systems to find the line flows after line outage [7], to calculate multiple line outages for system security [8], and contingency analysis for multiple line outages [9-10]. For contingency analysis, many power flows methods have been proposed to get fast and efficient solution [11], and to execute contingency list independently [12]. Even though by providing sufficient data to the contingency tools as mentioned above, no tools can able to prioritize the return of network transformers. So by using risk index [1], priority can be provided to the transformers in normal loading conditions.

In the case of emergency conditions, priority of the transformers may not be possible as per risk index terms. Priority must be given as per critical loads and constraints.

In order to prioritize the network transformers, social welfare index is proposed such that all the network transformers are given priority by considering social issues and benefits. Later remaining network transformers can be prioritized as per normal loading conditions. The above algorithm has been tested on IEEE 342 Node Low Voltage Network Test System (LVNTS) [13-16]. LVNTS is flexible for new algorithms and analysis can be easily done for meshed distribution networks. It is a heavily meshed network systems, system with more parallel transformers and on parallel low voltage cables. The main contributions of the paper are:

a) To rank the priority of distribution transformers, a rigorous and robust algorithm is proposed by considering social welfare index.
b) To verify the proposed algorithm to rank distribution transformers, of IEEE 342 node low voltage networked test system.

A computer program is developed to compute the load contribution, while running the program by power flow, reliability evaluation and replacing one transformer at a time [17]. Prioritizing the return of network transformers, the service can be restored according to load contributions of the number of customers per network.This paper is organised as follows: Initially in this section, the introduction and literature survey is discussed. Next in Section 2, the risk index formulation for transformers under normal loading conditions is discussed. Section 3 presents the social welfare index formulation for transformers under emergency conditions. In Section 4, the social welfare index algorithm to prioritize the transformers under emergency conditions is explained. In Section 5, sample calculations are shown to find the risk index of a transformer. In Section 6 the results are analysed and in Section 7, the conclusion for work done is presented.

2. RISK INDEX FORMULATION

Predicting the loads in networks and network reliability performance, the restoration of failed transformers depends on experience and tools developed in recent years. Here risk can be expressed in different terms such as:

a) Number of customers with interrupted service in a specific time period.
b) Customers who would have been exposed to low voltages.
c) Financial risk resulting from loss of power.

Once, the transformer is once prioritize and return to the service, the risk of the transformer is identified and the process is repeated for prioritizing subsequent return of other transformers, this must be done by examining the all failed transformers.

Failures can be caused by overloading of transformers and it can be prevented by prioritizing the restoration of failed transformers. This method evades the costly and ineffective dispatch of personnel for low priority transformers, and this allows the resources to be allocated for higher priority transformers. Restoring the transformer into service, other transformers results in lowering the loads and therefore the likelihood of the failures get decreased. The sum of the number of customers impact due to failure of transformers, feeders and secondary mains is expressed as risk index.

$$\text{Risk Index} = \delta 1+\delta 2+\delta 3 \tag{1}$$

Where δ1 represents the number of consumers interrupted due to overload in transformers, δ2 represents the number of consumers interrupted due to overload in primary feeders; δ3 represents the number of consumers interrupted due to overload in secondary mains. Alpha (α) is the factor which measures the relative load of each of the equipment and it is calculated as

$$\alpha = \frac{\text{equipment loading}}{\text{equipment rating}} \tag{2}$$

The number of consumers interrupted due to overload in transformers (δ1) is computed as

$$\delta_1 = NC\left(\sum_{j=1}^{NT} f(\propto_j)\right) \tag{3}$$

Where,

NC : number of customers supplied by the network
NT : number of transformers which pickup extra load when a transformer is failed
$f(\propto_j)$: Probability of a failed load with an in service transformer engaging in network collapse

$$f(\propto_j) = f_1(\propto_j).(c_j) \quad (4)$$

Where
$f_1(\propto_j)$: The probability of transformer failing at its relative load ∝_j
c_j : Conditional probability of collapsing a network due to the transformer j failure and the feeder that serves it

The number of customers interrupted due to overload in feeders (δ2) is computed as

$$\delta_2 = NC\left(\sum_{j=1}^{NF} g(\propto_k)\right) \quad (5)$$

Where
NC : number of consumers supplied by the network
NF : number of overloaded feeders
$g(\propto_k)$: Probability of an in service feeder failure engaging in network collapse

$$g(\propto_k) = g_1(\propto_k)(d_k) \quad (6)$$

Where
$g_1(\propto_k)$: Probability of feeder failure at its relative load ∝_k
d_k : Conditional probability of collapsing a network after feeder k failure

The number of customers interrupted due to overload in secondary mains (δ3)

$$\delta_3 = \frac{\text{Increment in Load}}{\text{Average Load per Customer}} \quad (7)$$

By evaluating the risk associated with number of devices, the restoration of failed transformers can be planned through the described approach. The variable d_k is the probability of network collapse after the failure at feeder ‘k’ which is similar to that c_j is the conditional probability of network collapse after the failure of transformer ‘j’ fed by the feeder ‘k’.

Ranking is done for all the out of service transformers, risk is calculated and priority is given to restore the transformers from the resulting list.

3. SOCIAL WELFARE INDEX FORMULATION

Prioritizing of transformers can be done easily by using risk index at normal loading conditions where in the case of emergency conditions priority may not be given to network transformers due to social issues and constraints. During emergency conditions, prioritizing of network transformers must be given to the transformers which supply the power to hospitals, water pumping stations etc rather than supplying the power to based on number of customers. Repair and replacement of network transformers is done based on critical loads and remaining transformers are prioritized as per loading conditions. Social Welfare Index (SWI) is defined as shown below:

SWI = (No. of hospitals x 1) + (No. of water stations* 0.9) (8)

4. SOCIAL WELFARE INDEX ALGORITHM

The flow chart of the algorithm is shown in the Figure 1. In the computer program all the equations that are related to the risk index and social welfare index are implemented.

Under real time system conditions also, this program can be implemented. The data required for input to the program are feeders out, secondary cables that are burnt out and transformers that are out of service. Operations can be done till the last minute decisions are taken on system hardening before the next day heat wave. The operations are:

a) For transformers, feeders and secondary mains compute ‘∝’ before and after the restoration of an out of service transformer.
b) Analyzing failure rates of individual components.
c) For transformers and feeders, computing the probabilities of contingencies (c_j, d_k).

5. SAMPLE CALCULATIONS

Calculations are shown for the transformer by considering T70 is out of service. To calculate risk index for T70, as shown in (3), (5), (7) need to be solved. Total number of customers (NC) for LVNTS is 624. When transformer T70 is out of service, the number of transformers which bear additional load (NT) is 38. Probability values of transformers and feeders can be computed by their transformer failure rates and feeder failure rates respectively through curve fitting method [1].

From Table 1, the obtained probability and conditional probability values of transformers are substituted in (4), to obtain overall probability as shown.

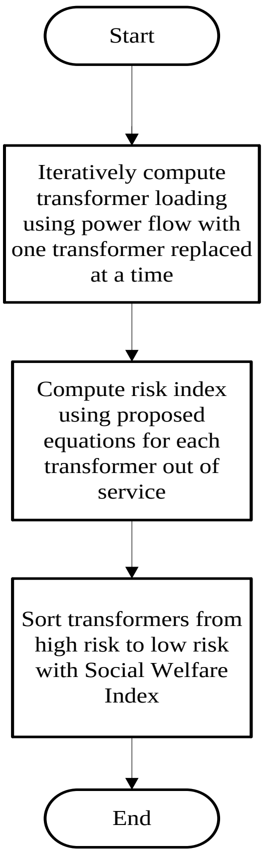

Figure 1. Flow chart for social welfare index algorithm

Table 1. Probabilities and Conditional Probabilities of Transformers Which Bear Additional Load

Transformers	$f_1(\propto_j)$	(c_j)
T6	0.001439	0.0546
T9	0.003025	0.611
T11	0.003652	0.1314
T12	0.003733	0.1306
T18	0.008485	0.288
T20	0.001077	0.0355
T22	0.007678	0.2456
T24	0.009147	0.2865
T25	0.000999	0.0299
T26	0.009097	0.2638
T30	0.007167	0.2006
T31	0.007775	0.2099
T33	0.00992	0.2579
T34	0.007885	0.1971
T37	0.006117	0.1468
T38	0.0053	0.121
T39	0.000999	0.0219
T43	0.010135	0.2128
T44	0.008239	0.1647
T45	0.008609	0.1635
T46	0.003875	0.0697
T48	0.0048055	0.1369
T49	0.00832	0.1331
T50	0.000999	0.0149
T51	0.009971	0.1395
T53	0.004781	0.0621
T54	0.00435	0.0521
T56	0.007274	0.08001
T57	0.00635	0.0635
T59	0.010121	0.0910
T60	0.000999	0.00799
T61	0.007026	0.0491
T62	0.004979	0.0298
T64	0.006217	0.0310
T66	0.000999	0.0039
T67	0.006377	0.0191
T68	0.00624	0.0124
T69	0.005314	0.0053

$$\left(\sum_{j=1}^{38} f(\propto_j)\right) = 0.031701$$

Therefore from (3),

$$\delta_1 = 624 * 0.031701 = 20$$

When T70 is failed, the number of feeders that are overloaded (NF) is 6.

From the Table 2, the obtained probability and conditional probability values of feeders are substituted in (6), then.

Table 2. Probabilities and Cumulative Probabilities of Feeders that are Overloaded

Feeders that are overloaded	$g_1(\propto_k)$	(d_k)
F2	0.0047	0.02824
F3	0.0043	0.02174
F4	0.0046	0.0184
F6	0.0053	0.01602
F7	0.0076	0.01529
F8	0.0041	0.0041

$\left(\sum_{j=1}^{6} g(\propto_k)\right) = 0.000532$

Therefore from (5)

$\delta_2 = 624 * 0.000532 = 1$

Average load per customer in LVNTS is 67.64 kW and Increment in load is 100 kW. By using (7), we get δ_3 as 2. Therefore by using the above obtained values, risk index value of T70 transformer is 23. Similarly Risk index is calculated for remaining transformers from the above process.

6. RESULTS

The Table 3 represents the results for ranking of 68 transformers under normal loading conditions by including risk index. Network transformers T5, T11, T32, and T57 supply the hospitals and water stations which are represented in Table 2. From the above obtained results the following transformers are removed and they are prioritized as per social welfare index.

Table 3. Ranking of Transformers Under Normal Loading Conditions

Rank of the Transformer	Name of the Transformer	Risk Index Value
1	T43	30
2	T46	27
3	T49	27
4	T51	27
5	T41	26
6	T56	26
7	T64	26
8	T24	25
9	T42	25
10	T13	24
11	T26	24
12	T40	24
13	T44	24
14	T45	24
15	T52	24
16	T62	24
17	T67	24
18	T29	23
19	T35	23
20	T36	23
21	T48	23
22	T57	23
23	T59	23
24	T70	23
25	T28	22
26	T38	22
27	T47	22
28	T58	22
29	T68	22
30	T34	21
31	T63	21
32	T65	21
33	T33	20
34	T61	20
35	T3	19
36	T27	19
37	T37	19
38	T55	19

Rank of the Transformer	Name of the Transformer	Risk Index Value
39	T69	19
40	T21	18
41	T30	18
42	T53	18
43	T54	18
44	T18	17
45	T20	17
46	T6	16
47	T16	16
48	T22	16
49	T23	15
50	T31	14
51	T5	13
52	T9	13
53	T14	13
54	T17	13
55	T10	12
56	T19	12
57	T7	11
58	T50	11
59	T4	9
60	T8	9
61	T11	9
62	T15	9
63	T25	9
64	T39	9
65	T66	9
66	T12	8
67	T60	7
68	T32	6

From the Table 3 calculated indices the transformer with highest index value is given the first priority and the transformer having least index value is given as least priority. Based on the indices values, prioritizing of transformers have been done as shown in Table 4. Prioritization of Transformers with SWI values as shown in Table 5.

Table 4. Prioritization of Transformers based on Social Welfare Index

Name of the transformer	Number of Hospitals	Number of Water stations	Social Welfare Index values
T5	3	1	2.9
T11	2	1	2.8
T32	1	2	1.9
T57	1	1	3.9

Table 5. Prioritization of Transformers with SWI Values

Rank of the Transformer	Name of the Transformer	Social Welfare Index value
1	T57	3.9
2	T5	2.9
3	T11	2.8
4	T32	1.9

Prioritizing of network transformers have been done according to the social welfare index at the time of emergency conditions for all 68 transformers can be observed from the Table 6.

Table 6. Prioritization of Network Transformers based on SWI and Risk Index

Rank of the Transformer	Name of the Transformer
1	T57
2	T5
3	T11
4	T32
5	T43
6	T46
7	T49
8	T51
9	T41
10	T56
11	T64
12	T24
13	T42
14	T13
15	T26
16	T40
17	T44
18	T45
19	T52
20	T62
21	T67
22	T29
23	T35
24	T36
25	T48
26	T59
27	T70
28	T28
29	T38
30	T47
31	T58
32	T68
33	T34
34	T63
35	T65
36	T33
37	T61
38	T3
39	T27
40	T37
41	T55
42	T69
43	T21
44	T30
45	T53
46	T54
47	T18
48	T20
49	T6
50	T16
51	T22
52	T23
53	T31
54	T9
55	T14
56	T17
57	T10
58	T19
59	T7
60	T50
61	T4
62	T8
63	T15
64	T25
65	T39
66	T66
67	T12
68	T60

7. CONCLUSION

During Emergency conditions, prioritization of the network transformers can be done by repair or replacement with social welfare index. By this algorithm, transformers can be easily prioritized and can be implemented in system. This method is implemented in IEEE 342 Node distribution system for providing the prioritization of 68 network transformers during emergency conditions. By this method, system reliability also gets maximized. The transformers which do not have an impact will be considered later.

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