

CHAPTER 4

A NEW ALGORITHM FOR CONSIDERING LOADS IN THE ORDER OF HIGHEST PRIORITY

4.1 INTRODUCTION

In the operational planning problem of the Electric Power Distribution Systems (EPDS), an important task that must be considered is Service Restoration.

In the distribution networks, some of the feeders or transformers may get isolated by the protective devices when faults occur and hence some of the critical loads are left without power supply. For the distribution system to survive it is necessary to restore the power supply to the vital loads. The loads having different priorities are to be considered during restoration of power supply in the EPDS. By using goal programming technique, the problem of considered load priority can be effectively solved. The preemptive method of goal programming technique (Hamdy 2002) is suitable for considering the loads in the order of their highest priority. The preemptive method is effectively implemented which helps the Electrical Power Distribution Engineers/Distribution System Sub-Station Operators to consider the highest priority order loads first and the least priority order load next. This load switching according to the priority order helps in minimizing the interruption of power supply to high priority order loads.

4.2 PRIORITY ORDER OF LOAD SHEDDING

Shedding of the load takes place in several stages which reduces the distribution substation load within the capacity of EPDS. If load shedding is not sufficiently reduced in stage one, then additional stages have to be activated after a time delay to further reduce it. The non-vital, semi-vital and vital load classes in load shedding are treated as follows:

Least priority loads also called non-vital loads, can be disconnected immediately without affecting the operations of EPDS. Semi-vital loads are important to the EPDS, but can be shut down or switched to the nearest EPDS in order to prevent the total loss of power. Highest priority loads, also called the vital loads, are given importance in restoring the power supply and are avoided from disconnection. The vital loads have two paths for supply. However, the available energy managed overall depends on making proper decisions for the Voltage/VAR violation problems and voltage management.

4.3 OVERLOAD DETECTION AND LOAD REDUCTION

In real power systems, there is always a real, non-zero probability of a system over load. Reduction in load is required to be applied, whenever overload is detected. This reduction can be achieved in a number of ways, for example: load shedding on priority basis, load management and remote load priority, availability and power distribution capacity of EPDS are the three categories in which the factors affecting the load shedding schedules are divided. The amount of shifting of the EPDS capacity and load reduction depends on the overload, network topology, line/ load capacity limit.

4.4 GOAL PROGRAMMING ALGORITHMS

By using linear programming (LP) method the problem of priority order consideration of the loads in the restoration of power supply upon occurrence of the fault can be solved. LP models are based on the optimization of single objective function. This drawback of LP method is overcome using the multi-objective models of Goal Programming Technique (GPT). The GPT converts the original multiple objectives into a single goal. The resulting model yields an efficient solution.

The GPT is implemented using two algorithms. These algorithms convert the multiple goals into a single objective function. In Weights Method, the single objective function is the weighted sum of functions representing the goals of the problem. The Preemptive Method starts by prioritizing the goals in the order of importance. This model is then optimized using one goal at a time, such that the optimum value of higher priority goal never degraded by a lower priority goal.

In this thesis the multi-objective function preemptive method has been employed, considering the loads in the order of their highest priority.

4.5 RANKING OF LOADS IN THE ORDER OF THEIR HIGHEST PRIORITY

The following order is defined for the loads in EPDS:

- i) Vital Loads
- ii) Semi-Vital Loads
- iii) Non-Vital Loads

If there are 'nload' total number of loads in EPDS, then the ranking for vital load is '1' and for the non-vital loads it ends with 'nload' and the ranking for the semi-vital loads lies between vital and non-vital loads. In this thesis, the order of ranking the loads is given in the input data of various distribution systems.

4.6 PREEMPTIVE METHOD FOR THE CONSIDERATION OF LOADS IN THE ORDER OF THEIR HIGHEST PRIORITY

Depending on the capacities of the connected Transformers/Feeders in the post fault power distribution network (PDN), in the preemptive method, the decision maker considers the loads in the order of their highest priority

The objective function of the problem with a "k"-goal situation can be stated as

Maximize $NLOAD_1 = PRL_1$ (highest priority)

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Maximize $NLOAD_k = PRL_k$ (lowest priority)

Subject to

$$I_{LOAD} \leq I_{FDRMAX}$$

$$I_{FDRMAX} \leq I_{STFRR}$$

where

$NLOAD_1$: Number of loads to be considered in the first case with highest priority loads

PRL_1 : Highest priority loads (i.e. Priority Order of the Load '1')

PRL_k : Lowest priority loads (i.e. Priority Order of the Load 'k')

I_{LOAD} : Total load current

I_{FDRMAX} : Maximum current ratings of the feeder

I_{STFRR} : Secondary current rating of the transformer

Starting with highest priority $NLOAD_1$, and terminating with lowest priority $NLOAD_k$, the solution procedure considers one goal at a time. Due to the fault, disconnection of some of the Feeders/Transformers reduces available power transfer capability limit in the post fault PDN. The solution procedure mentioned above has been repeated in such a way that solution obtained from lower priority goal never degrades any higher priority goal.

To consider the loads in the order of their priority, the following steps are used.

Step 1 : Identify the type of connected load to EPDS and rank them in the order of priority.

$$NLOAD_1 = LPRO_1 > NLOAD_2 = LPRO_2 > NLOAD_3, \dots$$

$$\dots NLOAD_k = LPRO_k.$$

Step 2 : Compute the total load in each step and then compare with capacity of feeders, and then check for violation of over loading of the corresponding transformer in the post fault PDN.

Step 3: Compute the line flows, branch currents and also currents in the various feeders.

Step 4 : Compute the total load current and then compare capacity of the feeders, and check for violation of overloading of the corresponding feeder/ transformer in the post fault PDN.

Step 5 : Repeat the steps 1, 2, 3 and 4 until

$$I_{LOAD} \approx I_{FDRMAX} \text{ and}$$

$$I_{FDRMAX} \approx I_{STFRR}$$

In implementation of preemptive method and ranking of loads, the following points are considered

i) Number of loads to be ranked or the total number of loads
(nload) = nbus-fno

where nload = Total number of connected loads

fno = Total number of feeders.

ii) $LPRO_i$ = Priority order of the i^{th} load

iii) SMLP = Sum of the priority order of loads $SMLP = \sum_{i=1}^{nload} LPRO_i$

iv) If all the loads are restored with the power supply then, the Load Priority Order Ratio (LPOR) is given by

$$LPOR = 1$$

$$\text{where } LPOR = \frac{SMLP}{nload (nload + 1) / 2}$$

The rated current of the transformer (I_{TFRR}) depends on its MVA capacity in the pre/post fault PDN as given below:

$$I_{TFRR} = \frac{MVA_{RATING} \times 10^6}{KV_{RATING} \times 10^3}$$

With the type of conductor employed for feeders in the EPDS, the maximum current rating (that is, capacity) of the feeder varies. Types of conductors for feeders and their capacity commonly used are given below in Table 4.1.

Table 4.1 Conductor Data for various types of Feeders in EPDS

SI No	Conductor Name	Resistance in ohms/Km	Reactance in ohms/Km	Capacity I_{max} (A)	Cost Rs/ Km
1	Squirrel	1.3740	0.3915	115.00	1260.00
2	Weasel	0.9116	0.3820	150.00	1420.00
3	Ferret	0.6795	0.3760	181.00	1600.00
4	Rabbit	0.5449	0.3720	208.00	1785.00
5	Mink	0.4565	0.3660	234.00	1785.00

4.7 RESULTS OF PREEMPTIVE METHOD FOR THE CONSIDERATION OF LOADS IN THE ORDER OF THEIR HIGHEST PRIORITY

Under different fault conditions of the various EPDS, the preemptive method for considering the loads in the order of their highest priority has been analyzed. The calculation of transformer rating and the actual load currents through the feeder for 16-Bus System is presented here:

4.7.1 Results of Preemptive Method for 16-Bus, Three Feeder Distribution System

The 16-Bus, three-feeder distribution system is shown in Figure 2.3 in Chapter 2.

The Bus Data, Line Data with Transformer and feeder conductor rating is given in Appendix 2 of this thesis. The type of conductor employed in this test system is Mink. The capacity of ‘Mink’ type of conductor of the feeder is 234A. Hence, the loads are restored with power supply until actual load current reaches 234A. The detailed analysis for the consideration of loads in the order of their priority is presented below:

4.7.1.1 Results of Preemptive Method for 16-Bus, Three-feeder Distribution System under normal operating (pre-fault) condition

In the pre-fault Power Distribution Network (PDN), all the feeders and transformers are connected under normal operating conditions. At various nodes the load current and priority order of the loads (LPRO) are given below in Table 4.2.

Table 4.2 Load Currents and LPRO of the 16-Bus, Three-feeder EPDS under Pre-fault condition

Bus No	L P R O	Load Current in A	Bus No	L P R O	Load Current in A	Bus No	L P R O	Load Current in A	Bus No	L P R O	Load Current in A
1	0	255.594	5	1	63.5628	9	13	48.0946	13	5	49.0243
2	0	300.675	6	4	44.9895	10	2	57.6851	14	6	50.6314
3	0	143.393	7	7	55.3802	11	8	35.7544	15	10	67.0750
4	3	75.5269	8	9	46.6227	12	11	127.6174	16	12	36.8141

Actual load current of the feeders (I_{FDA}) is given by

$$I_{FDA1} = 255.594 \text{ A}; \quad I_{FDA2} = 300.675 \text{ A}; \quad I_{FDA3} = 143.393 \text{ A}$$

Rated current of the Transformers are given by

$$I_{TFRR1} = 734.5203 \text{ A}; \quad I_{TFRR2} = 872.7539 \text{ A}; \quad I_{TFRR3} = 418.6446 \text{ A}$$

Total number of loads i.e. $n_{load} = n_{bus} - n_{fo} = 16 - 3 = 13$

$$SMLP = \sum_{i=1}^{13} LPRO_i = 91$$

$$LPOR = \frac{SMLP = 91}{(13 \times (13 + 1)) / 2} = 1.0$$

If the total load current is not exceeding the capacity of all the three feeders and transformers, the result is: $I_{LOAD} < I_{FDRMAX}$ and $I_{FDRMAX} < I_{TFRR}$. Hence all the loads are restored with power supply, and therefore the Load Priority Order Ratio (LPOR) becomes 1.0. If any of the loads is not restored with power supply, then $LPOR < 1.0$.

4.7.1.2 Results of Preemptive Method for 16-Bus, Three Feeder Distribution System with fault at the buses 1 and 3

Disconnection of the transformer 1 and 3 is due to the occurrence of fault at the buses 1 and 3 and the resulting distribution system network is shown in Figure 4.1. Transformer 2 alone has to share the entire load now, and it leads to the overloading of feeder 2 and transformer 2. Use of the preemptive method under these conditions helps to reduce the overloading of the transformer 2 and feeder 2.

$$I_{FDRMAX} = 234 \text{ A};$$

$$I_{LOAD} = \text{Total load current}$$

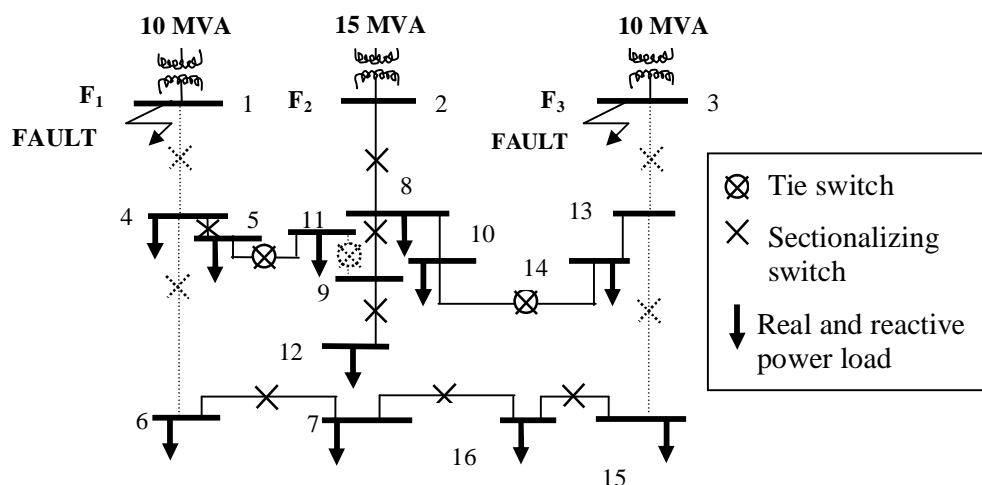


Figure 4.1 16-Bus, Three Feeder Practical Distribution Systems with fault at the buses 1 and 3

In the power distribution network, load current at various nodes is given in the Table 4.3. Considering highest priority order load, the total number of loads is given by

$$NLOAD_1 = [1]; \quad I_{LOAD} = 63.5628 \text{ A}$$

As the total load current is less than the feeder capacity, next highest order priority load is considered as follows:

$$NLOAD_2 = [1, 2]; \quad I_{LOAD} = 63.5628 + 57.6851 = 121.2119 \text{ A}$$

$$NLOAD_3 = [1, 2, 3]; \quad I_{LOAD} = 63.5628 + 57.6851$$

$$+ 72.5269 = 193.7388 \text{ A}$$

$$NLOAD_4 = [1, 2, 3, 4]; \quad I_{LOAD} = 63.5628 + 57.6851 + 72.5269$$

$$+ 44.9895 = 238.7283 \text{ A}$$

Here it can be observed that, the consideration of the priority orders 1, 2, 3, and 4 (that is, loads at the buses 5, 10, 4 and 6) gives a total load

current of 238.7283A. If attempts are made to consider any further load in the Feeder-2, it leads to overloading of the Feeder-2. Hence power supply is restored to these vital loads which are connected at the buses 5, 10, 4 and 6. The remaining is disconnected from the post fault PDN and these loads are set to zero in analysis of EPDS service restoration procedure. The load currents and priority order of the loads is given below in Table 4.3.

Table 4.3 Load Currents and LPRO of the 16-Bus, Three Feeder EPDS with Fault at Buses 1 and 3

Bus No	L P R O	Load Current in A	Bus No	L P R O	Load Current in A	Bus No	L P R O	Load Current in A	Bus No	L P R O	Load Current in A
1	0	0.0000	5	1	63.5628	9	13	0.0000	13	5	0.0000
2	0	238.728	6	4	44.9895	10	2	57.6851	14	6	0.0000
3	0	0.0000	7	7	0.0000	11	8	0.0000	15	10	0.0000
4	3	72.5269	8	9	0.0000	12	11	0.0000	16	12	0.0000

Actual load current of the feeders (I_{FDA}) is given by

$$I_{FDA1} = 0.0000 \text{ A}; \quad I_{FDA2} = 238.728 \text{ A}; \quad I_{FDA3} = 0.0000 \text{ A}$$

Rated current of the Transformers is given by

$$I_{TFRR1} = 0.0000 \text{ A}; \quad I_{TFRR2} = 872.7539 \text{ A}; \quad I_{TFRR3} = 0.0000 \text{ A}$$

Total number of loads $n_{load} = n_{bus} - f_{no} = 16 - 3 = 13$

$$SMLP = \sum_{i=1}^{13} LPRO_i = 1 + 2 + 3 + 4 = 10$$

$$LPOR = \frac{10}{(13 \times (13 + 1)) / 2} = 0.1098$$

The total load current does not exceed the capacity of the feeder 2 and transformer 2, i.e., $I_{LOAD} < I_{FDRMAX}$ and $I_{FDRMAX} < I_{TFRR}$, that can be

observed here. Hence all the loads are restored with power supply, and remaining loads are disconnected and the Load Priority Order Ratio (LPOR) becomes 0.1098. Bus voltage in the post-fault 16-Bus, three feeder distribution system (after use of preemptive method) is given in Table A2.3 (Appendix 2).

4.8 SUMMARY

For dealing with varying class of loads in the order of their highest priority, preemptive method is effectively implemented in this thesis work. Till the Capacity of the Feeder and, Transformer capacity is reached, load switching is performed. The overloading of the feeder and the transformer are continuously monitored and these violations are minimized while restoring the power supply to the post-fault Power Distribution Network. In addition to maintaining the safe operating condition of the Feeder and Transformer, the vital loads are also given highest priority in restoring the power supply. To various Practical Electrical Power Distribution Systems viz., 12-Bus, 26-Bus, 29-Bus, 33-Bus, 69-Bus, 79-Bus and 133-Bus systems, priority based load switching algorithm have been applied and got the results. The results of this preemptive method based algorithm show that it is a highly suitable load priority algorithm for use in efficient operational planning of EPDS.