A Three Phase Fault Detection Algorithm for Radial Distribution Networks

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ABSTRACT

Distribution networks, unlike in transmission system may not be provided with protective devices or circuit breakers in each branch of the feeder. For any fault in the feeder, a large part of the feeder. may be isolated depending on the circuit breaker installation. For the purpose of speedy repair work and maintenance, it is important to find the exact fault location and type of fault. This paper presents an algorithmic approach for finding the location and type of fault based on the three phase measurements obtained for state estimation Results of the simulated fault conditions on practical distribution systems are presented.

1. Introduction

Utilities are installing distribution automation (DA) system to improve the efficiency of the system. The success of DA system, largely depends on the availability of reliable measurement data base of the control center. DA analytical tools include various application functions[1].

The utility industry desires to detect the distribution feeder faults for operational reasons and public safety. Faults are abnormal events that frequently occur in distribution feeders. Dismbution feeder faults modulate primary current and generate noise through arcing phenomena. Owing to their nature (presence of low or no current); the conventional protection scheme is not capable of detecting them. Usually they are identified only when the consumers inform the company that a cable has been broken or complain about the cut of energy A methodology for the detection of high impedance faults is presented in [2]. High impedance faults in distribution feeders are of two types, the active faults and passive ones. The technique consists of making comparative analysis of the responses of the feeder to pulses injected at the feeder inlet for different configurations. The feeder responses are periodically analyzed by the neutron-set, which classifies them according to the pre-defined standard responses.

In this paper a three phase fault detection algorithm for radial distribution systems is presented. Normally distribution networks are radial in nature. In the event of fault, alternate power flow path is required to provide uninterrupted power supply. This is done by various switching configuration. The faulty measurements are simulated considering different types of faults. Fault measurements are simulated without load and negligible fault impedance and with load and high fault impedance. Simulated fault measurements for different source impedances are presented. Under operating conditions in the presence of some fault, the measurement data are expected to be abnormally high currents in the fault path and beyond the fault location the current measurements are low or close to nil. The algorithm detects the fault location and the type of fault under unloaded and loaded conditions and also with and without fault impedance. This paper presents an algorithmic approach for finding the location and type of fault based on the three phase measurements obtained for slate estimation. Results of the simulated fault conditions on a sample and a practical distribution system are presented.

2. The approach

The basic blocks of the state estimator are shown in figure 1. The state estimator reads the measurement data. The bad measurement data are detected eliminated and replaced by pseudo or calculated values by the bad data detector. State estimator, computes the voltage magnitude and phase angle at all the load buses from the available real-time measurements, usually consisting of the real and reactive power flows and injections. If the data is abnormal, or a protective device operation is noticed. then the data goes to the fault detector.

The abnormal data are compared with the normal measurement data. A reasonable threshold value that is crucial is used to detect the fault path. During post fault conditions, the measurement data are abnormal and the fault detector algorithm analyses the data under two conditions: (i) with negligible fault impedance (ii) with high fault impedance. When there is negligible fault

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impedance, the branch flow measurement values until the fault location are expected to be very high while the branch flow measurement values beyond the fault location will be close to nil. The path without fault has close to normal values (may be little lower values due to voltage drops). The network connectivity tree is scanned The fault path are the branches until the fault location. The fault location is that branch beyond which the values are close to nil. The branch beyond fault location has values close to nil.

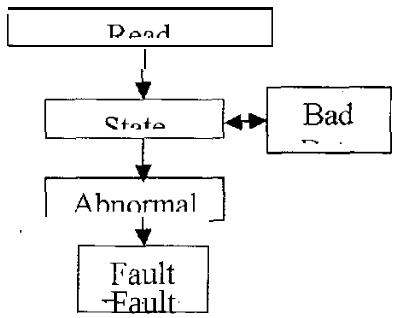

Figure 1 : Basic Blocks of the State estimator

With high fault impedance. the healthy branches (no fault path) have normal or little low values while the faulty path have high measurement values. The normal values prior to fault is compared with the measurement data set that is read. Scanning the connectivity tree the normal flow measurements are classified as low values or healthy branches. The flow measurements that are beyond a threshold value are classified as high values. The fault location, is that branch beyond which the high values become low. The computational modules in the approach are shown in Figure 2. The various modules explained'in the following sections, detects the fault location with and without fault impedance under light load and peak load condition, and also identifies the type of fault.

3.0 Block 1: Read Measurement Data

The two types of measurements are - normal measurements and abnormal fault measurements. the measurement data input to the proposed fault detection algorithm. The short circuit level at the source point are Simulated fault measurement data are used to prepare assumed as 10000 kVA (light load condition) and 15000 (peak load conditionj. The simulated short circuit levels at respective nodes and flow measurements in lines during fault at node 4, on a sample 7 node system (Figures 4, 5), are obtained from power flow and short circuit programs. The normal flows and flow in the branches during a three phase fault at node 4 are given in Table 1a and Figure 4. The short circuit levels at-respective nodes under light load and peak load conditions are given in Table 1b and Figure 5.

Table 1a: Normal flows and flows in lines during fault

From Node	To Node	Normal Data	Simulated data (high fault impedance)
[illegible]	[illegible]	[illegible]	[illegible]
2	3	116	114
2	4	131	237
3	5	34	33
4	**6**	28	27
A	7	43	AZ
Type of fault : Three phase fault			

Table 1b 7-node system, three phase short circuit levels in kVA

Node No.	Simulated data (negligible fault impedance)	
	Light load condition	Peak load condition
2	2922	4068
3	2162	2636
4	2271	2817
5	1796	2080
6	1720	1973
7	1649	1876

4.0 Block 2 : Generate connectivity table

In a large distribution system where the nodes are generally given numbers and names feeder-wise and branch network data is available in static data bank Node renumbering is the process of generating new node numbers for feeder nodes, which are initially numbered, arbitrarily. This is very useful particularly when the network is reconfigured using various switching options to meet the demand during different configuration. The process of node renumbering is explained considering the sample distribution feeder shown in figure 3. The fault analysis algorithm obtains the network connectivity tree table based on the parent (source side) /child (load side) relationship for the given configuration. The connectivity tree is used to scan to detect the normal flow measurements and abnormal flow measurements, in all the branches starting from the source node.

4.1 Forward-Backward Propagation Path

In the sample network in figure 3, the node numbers encircled are the arbritrary numbers. The source node, substation is given the new numbet1 (old *6*- new 1). Referring to the figure **3,** square boxes show the optimally ordered feeder nodes with new numbers. The following table **2,** showing source (parent) node to load (child) node is obtained. The table is arranged to give the forward path from source (parent) no& to load (child) node and backward path from load (child) node to source (parent) node. The forward path helps in tracing faulty path from source no& to fault location.

Table **2.** Parent node child node for the feeder shown in figure **3.**

Parent node	1	2	2	3	4	4
Child node	2	3	4	5	6	7

From the table, Forward path: **1-2, 2-3, 2-4, 3-5, 4-6,** and **4-7**.

5.0 Block 3 : Scan measurement values and classify data

The connectivity tree is scanned and the branch measurements are classified. When the system considered has negligible fault impedance, the data set is classified into three ranges. When the measured flow is beyond a threshold value (τ_a), in any phase, they are classified as abnormal values. If the measured flow is close to nil in any phases, they are classified as close to nil values. All other measurement flows in the measurement set are grouped **as** normal values. The fault location **is** the branch where the close to nil data begins in the tree structured network table. Consider the sample single phase 7-node system in figure **4** under light load condition, having an equivalent three phase fault level of 10000kVA. If a fault occurred in branch **(2-4),** the fault path (1-2) and **(2-4)** have flows **2922** kVA and **2271** kVA respectively. These are abnormal flow values. Beyond the fault location that is, in branches (4-7) and (4-6) the flow values are close to **nil.** The other healthy branches have close to normal values.

When the system considered has high fault impedance, the measurement set is classified **as** high and normal values. When it is a **hgh** impedance fault the postfault values are higher than the prefault values (normal values), but not abnormal When the measured flow is beyond a threshold value (τ_h), in any phase, they are classified as high values. Ths threshold value (τ_h), is smaller compared to the negligible fault impedance situation. The high value measurements indicate the fault path. The fault location is that branch beyond which the high value in the fault path changes to low. The sample single phase 7-node system in figure **4** gives the postfault flow values when high impedance fault occurs. When a fault occurs in branch **(2-4)** the flow values in the fault branches (1-2) and **(2-4)** are 419 kVA and **237** kVA respectively. These values are higher than the normal flow values. The flow values beyond the fault location in branches **(4-6)** and (4-7) are low values. The other healthy branches also have low values or close to normal values. The fault location is where high value indicating fault path becomes low value. In this example it is branch (2-4).

6.0 Block 4 Identify the **type of** fault

The algorithm first determines the fault location, next it identifies the type of fault. Phase fault indices are initialized for each phase and for all branches as 1 When the abnormal or high values are present, the index of that phase is made index 2. When the abnormal or high values are not present, that is if the values are normal then, the index of that phase remain as index 1 in that particular phase. When the values are close to nil in any phase then, the index of that phase is made index 0. The algorithm checks every phase for the index and identities the type of fault. If index **2** is identified in all the three phases, then the fault is identified as three phase fault. If the algorithm finds the abnormal measured flow in only one phase, then the fault is identified as single line to ground fault.

In **this** case, one of the three phase has an index 2, and the other two phases have index 1. For example, if the fault is in phase A then the abnormal values are in phase A So it **is** a phase A to ground fault. If the abnormal or high values are in any two phases, then the index of the two phases are identified as index **2.** The third phase index value is either index 1 or index 0. This fault ***is*** classified as L-L-G fault. When there is abnormal or high values in any two phases but flow in one of the phase, is in the opposite direction, then it is identified as L-L fault. Finally, if the index in all the phases are 1, there is no fault and the algorithm identifies it as normal branch.

7.0 Sample system studies

Based on the proposed algorithm a computer program has been developed and tested on a few distribution networks. Results for a typical system, of *52* node practical distribution network with mulii feeders are presented. Under prefault conditions, the normal measurement flows are obtained from the state estimation algorithm Under post fault conditions the simulated values are used.

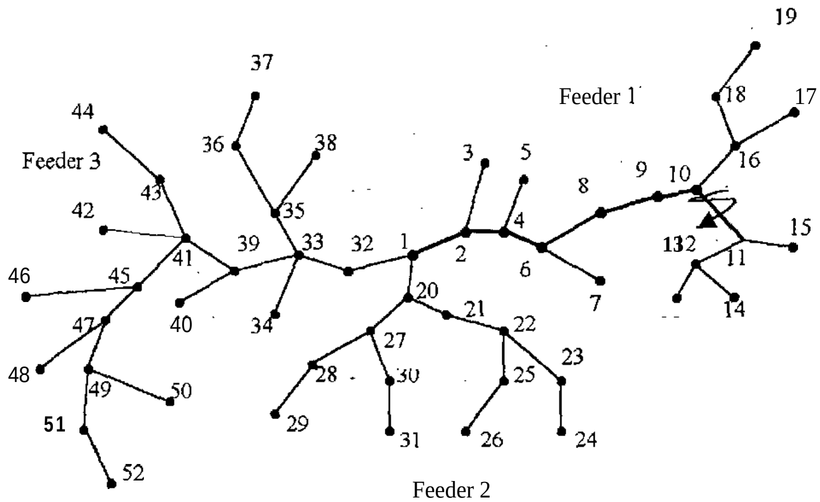

Figure 6: A 52 Bus distribution Feeder with SLG fault in branch (10-11)

The single line diagram of the 52 node, multi feeder is shown in figure 6. The total load met by the system is **3718** kW. This practical distribution network has three feeders Branches from nodel to node19 forms feederl. The feeder2 branches from nodel until node31, while the third feeder is from nodel to 52. A single line to ground fault simulated in the branch (10-11) of feeder I to obtain the measurement **data** The fault path is shown in thick lines from node 1 to node 10. The faulty path are (1-2), (2-4), (4-6), (6-8), (8-9), (9-10) and (10-11).

The results of the phase A, of the *52* node distribution system are shown in table **3.** The algorithm generates the connectivity table. Real power measurement in phase A (kW) is scanned and the **data** are classified **as** normal, abnormal and close to nil branches. Normal branches are provided **an** index 1. All branches having index 1 form the healthy path. Index *2* is given to abnormal measurements and they indicate the faulty path. When the index is 0, these branches are beyond fault path or close to nil flow. The close to nil flow path is (1 1-12), (11-IS), (12-13) and (12-14). The fault location is branch (10-11) and beyond this branch the index is 0. Every phase is checked and phase **A** has index 2 while phase B and C has index 0 in the abnormal branches. The fault type was identified **as** SLG fault with Aphase faulty.

8. Conclusions

An algorithmic approach has been presented for finding the location and type of fault based on the three phase measurements obtained for state estimation. Results of the different simulated fault conditions on typical sample systems with varying **source** fault level and **Lull** impedance show the usefulness of the proposed method for application in Distribution Automation.

Table 3. Results in Phase A with single line to ground Fault on a 52 bus multi feeder system.

Abbreviations:

NR Normal flow — HP: Healthy path
AN Abnormal flow — FP: Faulty path
CN: Close to nil flow — BFP: Beyond fault path

Sl. No	Branch	Real Power In Phase	Measure-ment Classi-fica-tion	Ind-ex	Path
1	1-2	2867	AN	2	FP
2	2-3	36	NR	1	HP
3	2-4	2835	AN	2	FP
4	4-5	22	NR	1	HP
5	**4-6**	2821	AN	2	FP
6	6-7	35	NR	1	HP
7	6-8	2801	AN	2	FP

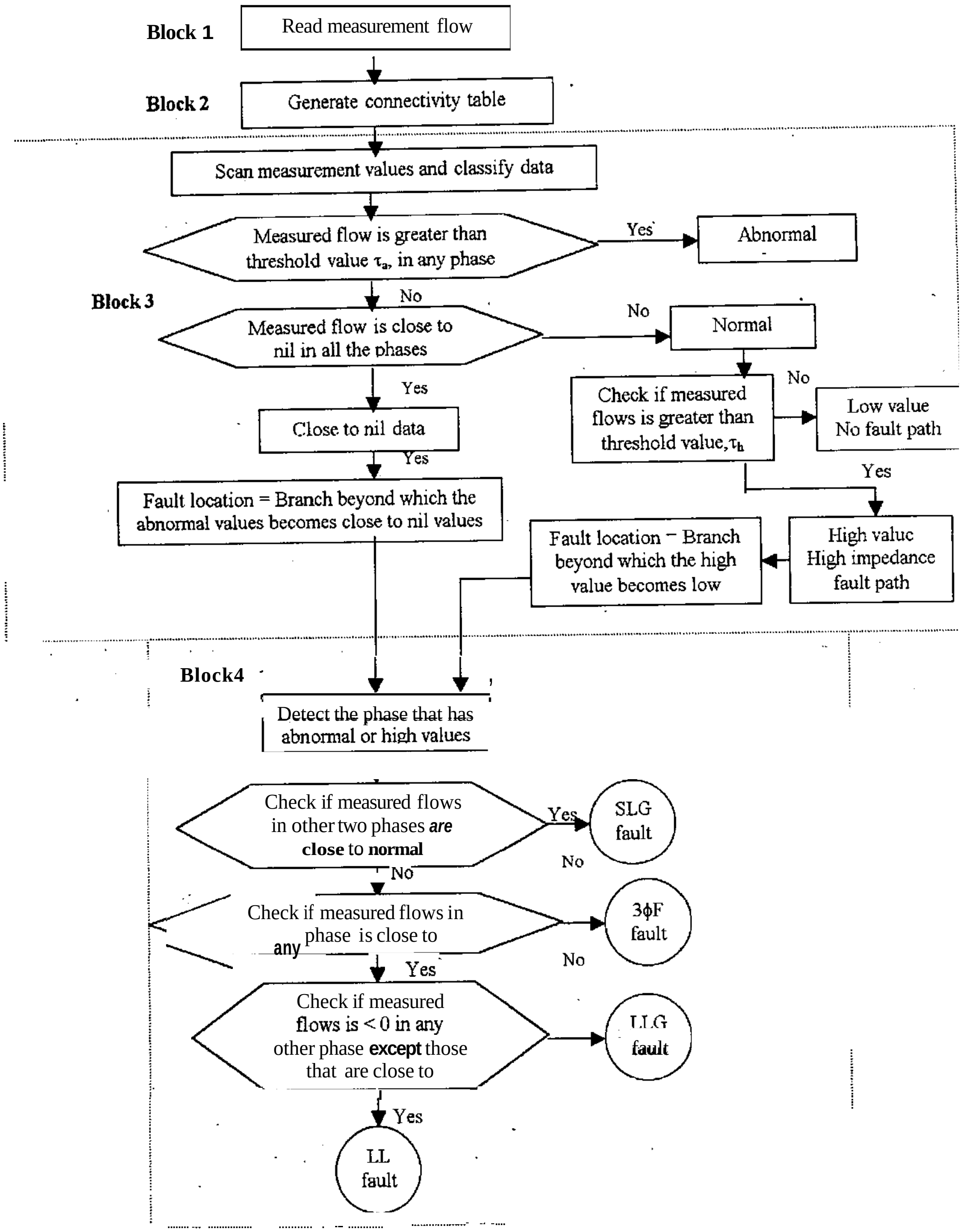

Fig2: Basic steps in the proposed fault detection algorithm

8	8-9	2789	AN	2	FP
9	9-10	2789	AN	2	FP
10	10-11	2667	AN	2	FP
11	11-12	0	CN	0	BFP
12	11-15	0	CN	0	BFP
13	12-13	0	CN	0	BFP
14	12-14	0	CN	0	BFP
15	10-16	135	NR	1	HP
16	16-17	36	NR	1	HP
17	16-18	63	NR	1	HP
18	18-19	36	NR	1	HP
19	1-20	344	NR	1	HP
20	20-21	140	NR	1	HP
21	21-22	121	NR	1	HP
22	22-23	58	NR	1	HP
23	23-24	22	NR	1	HP
24	22-25	53	NR	1	HP
25	25-26	22	NR	1	HP
26	20-27	156	NR	1	HP
27	27-28	44	NR	1	HP
28	28-29	26	NR	1	HP
29	27-30	67	NR	1	HP
30	30-31	35	NR	1	HP
31	1-32	707	NR	1	HP
32	32-33	611	NR	1	HP
33	33-34	36	NR	1	HP
34	33-35	125	NR	1	HP
35	35-36	67	NR	1	HP
36	36-37	31	NR	1	HP
37	35-38	34	NR	1	HP
38	33-39	355	NR	1	HP
39	39-40	13	NR	1	HP
40	39-41	306	NR	1	HP
41	41-42	13	NR	1	HP
42	41-43	86	NR	1	HP
43	43-44	45	NR	1	HP
44	41-45	159	NR	1	HP
45	45-46	27	NR	1	HP
46	45-47	117	NR	1	HP
47	47-48	13	NR	1	HP
48	47-49	80	NR	1	HP
49	49-50	22	NR	1	HP
50	49-51	27	NR	1	HP
51	51-52	13	NR	1	HP

FAULT Location : branch 10-1I
Type of Fault: Single line to ground fault

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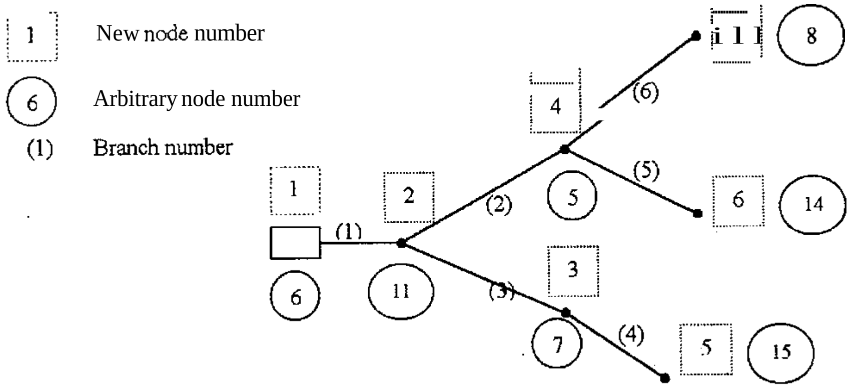

Figure 3 : **Sample** Distribution Feeder

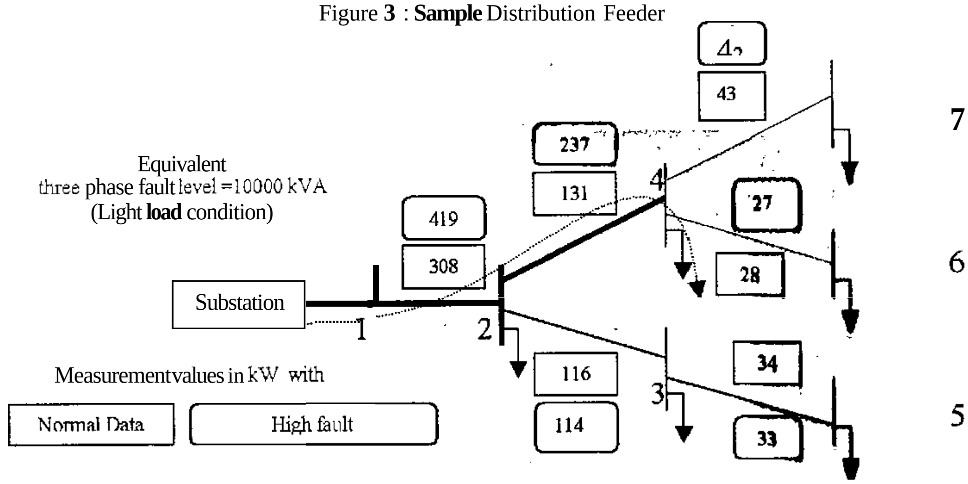

Figure 4 : Normal flows and flows in branches during a three phase fault at **node 4**

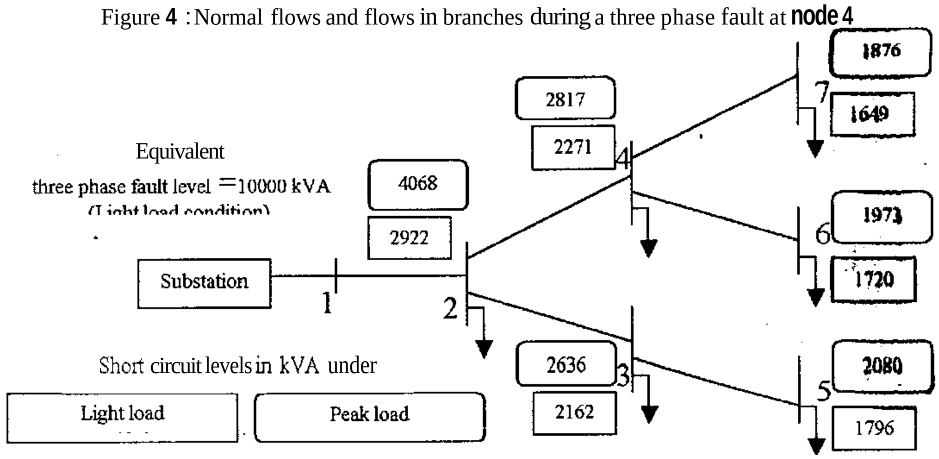

Figure 5 : Short circuit levels at respective nodes under light load and peak load conditions