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A NEW METHOD FOR FAULT DIAGNOSIS BASED ON FAULT CURRENT MAGNITUDE

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Abstract- Regarding the existing concern about global warming, governments have allocated major financial resources on development of clean sources of distributed generation. Therefore, it is supposed that distribution network structure will be different from now, including considerable number of these sources. With the advent of distribution generation sources, fault current magnitude will change and current protection systems will not work anymore. In these circumstances, communication system-based protection plans seem to be crucial. One basic need for the function of protection systems is fault diagnosis. In modern protection systems, fault type diagnosis, in addition to fault diagnosis, provides capabilities such as quick fault location and cut. In this research, a simple but efficient method for diagnosing the type of faults occurred in distribution systems with distributed generation sources is presented. In the method proposed in this paper, fault current magnitude is used for fault type diagnosis. According to multiple software simulations on 134-bus distribution system, the method proposed here will diagnose all types of faults occurred in various parts of network and it has no sensibility toward potential changes in network structure, arrival and departure of DGs or existing disorders in measured amounts or transmission systems.

Keywords: Fault Classification, Distributed Generation, Fault Current Magnitude.

I. INTRODUCTION

A Reliable and continuous supply of electrical power is essential for producers and consumers. Traditional power systems, burning massive amounts of fossil fuels in power plants and having long transmission lines and control centers, are changing. Today, many distributed generation units including renewable energy sources such as wind turbines, PV generators and combined heat and power fuel cells are being replaced in power systems [1].

With the advent of DGs, short circuit level in traditional distribution power system will change. Fault current level and also, features such as value and direction of fault current in system change and this threatens the function of protection system. Therefore, a protection system should diagnose and cut a fault immediately in order to minimize interruptions and damages to power system [2].

Transmission lines are integral parts of a power system. A fault in transmission line occurs when conductors connect to each other or to the ground. Faults in transmission lines are divided into balanced and unbalanced faults. Balanced faults include 3-phase short circuit and 3-phase-to-ground fault. Most transmission line faults are unbalanced. Single-phase-to-ground, phase-to-phase, phase-to-phase-to-ground and high impedance faults are classified as unbalanced faults.

Transmission line faults may be transient or permanent. Permanent faults impose destructive effects on power system facilities. However, transient faults affect power quality. As a result, these damages must be prevented as soon as possible. Multiple algorithms for fault type diagnosis have been reported [3-7]:

1) Under-impedance; 2) Torque; 3) Over-current techniques.

Due to increased complexity of modern power grids, improving and developing the existing protection methods gained a lot of attention. Traditional analogue protection cannot meet all the needs, so digital protection relays with benefits they have, seem to be appropriate; especially, because they have a reasonable speed and accuracy compared with an analogue protection relays. In the past, additional protection facilities, such as fault classification, were less considered than the original ones. However, today, due to high investments on these goals, they are regarded much more important.

Fault classification is as important as diagnosing it. Knowing the type of fault occurred, single-phase cut can be performed which increases system stability, power transmissibility and system availability in case of single-phase-to-ground faults. Fault type diagnosis, also, for location algorithms, is considered as a prerequisite, so that without a knowledge of fault type, more and unnecessary time and calculations are needed to locate the fault. Additionally, knowing fault type, impedance area range can improve, wrong function of distance relays decrease and dependence and security of protection system increase [8-9].

Fault classification can be done using two different methods. First, using changes in voltage and current known as "delta quantities with imposed components", second, methods which have become much popular during last decade and are based on artificial intelligence, neural networks, pattern recognition, fuzzy logic and a combination of them [10].

In this paper, a simple but efficient method for fault type diagnosis using current phasor is presented in which, using 3-phase current phasor and its asymmetric components, fault type can be diagnosed. According to multiple simulations carried out in ATP on 134-bus distribution system, our method can diagnose all types of fault occurred in various points of considered network and it also shows no sensitivity toward potential changes in network structure, arrival and departure of DGs or disorders in measured values or transmission systems.

II. ASYMMETRIC COMPONENTS

Variable faults, in 3-phase systems, may occur due to involved phase or ground interference. In unusual circumstances such as short asymmetric circuit (wire cut or tear) of conductors of transmission line, wires get asymmetric in which there are 3-phase currents and asymmetric voltages as well. Therefore, wires with single phase cannot be studied. Total 3-phase asymmetric currents are not zero, so there occurs an IN current between zero points. Fortescue conversion is used to study asymmetric circumstances in power systems and their components such as generators, transformers and electric engines. According to Fortescue theory, an asymmetric n-phase system can be converted to n-phase n-system. This means that an unbalanced 3-phase asymmetric system can be converted to three balanced 3-phase systems and calculations are done in this space. System components include: Positive-Sequence Component, Negative-Sequence Components and Zero-Sequence Components.

The positive sequence consists of three phasors, one for each phase, with -120 degrees of angular displacement and equal magnitude. Thus, phase *b* is -120 degrees from phase *a*, and phase *c* is -120 degrees from phase *b*. A negative sequence is similar to the positive component, but instead of -120 degrees, the displacement is +120 degrees. The zero sequence is represented by three vectors of equal magnitude and equal angular displacement.

The basic equations of the three-phase symmetric components are:

$$I_a = I_{a0} + I_{a+} + I_{a-} \tag{1}$$

$$I_b = I_{b0} + I_{b+} + I_{b-} \tag{2}$$

$$I_c = I_{c0} + I_{c+} + I_{c-} \tag{3}$$

$$\begin{bmatrix} I_{a^0} \\ I_{a^+} \\ I_{a^-} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha & \alpha^2 \\ 1 & \alpha^2 & \alpha \end{bmatrix}\begin{bmatrix} Ia \\ Ib \\ Ic \end{bmatrix} \tag{4}$$

where the vector α has unit length and +120° angular displacement.

$$\alpha^2 = 1\angle -120 \quad , \quad \alpha = 1\angle 120 \tag{5}$$

III. CASE STUDY

Figure 1 shows a 13.8 kV 134-bus network designed in ATP. More details are presented in [11]. The network is asymmetric with resistance, inductance and capacitance loads including four DGs installed on 45, 54, 90 and 103 buses. This study assumes that smart meters are arbitrarily placed at 5 primary buses: 1, 45, 54, 90, and 103.

The model includes the heterogeneity of overhead distribution lines. ATP simulates the network and provides measurement data regarding pre-fault and during-fault voltages for every bus of the network for all four types of faults. Our proposed method, developed in MATLAB, uses measurement data from ATP to define the type of fault.

IV. FAULT CLASSIFICATION ALGORITHM

In this paper, first, DG currents are read by installed CTs in steady state condition and then, based on type of fault, they are compared with each other. Table 1 shows three phase current values in steady state condition.

Table 1. Three phase current values in steady state condition

	I_a	I_b	I_c
DG_1	262.3 ∠-11.75	263.97 ∠-131.55	262.86 ∠107.59
DG_2	125.1 ∠-10.8	126.13 ∠130.58	125.51 ∠108.38
DG_3	398.8 ∠-11.99	401.23 ∠-131.73	399.75 ∠107.4
DG_4	125.9 ∠-11.13	126.84 ∠-130.93	126.18 ∠108.18
Source	622.8 ∠171.11	629.17 ∠51.51	628.98 ∠-69.89
Total	291.47 ∠-17.48	291.57 ∠-137.73	287.06 ∠102.41

Table 2. Single-phase short circuit to ground conditions

Conditions	Fault Type
$I_{a\,(\text{After Fault})} > I_{a\,(\text{Pre-Fault})}$ $I_{b\,(\text{After Fault})} < I_{b\,(\text{Pre-Fault})}$ $I_{c\,(\text{After Fault})} < I_{c\,(\text{Pre-Fault})}$	Phase A to Ground
$I_{a\,(\text{After Fault})} < I_{a\,(\text{Pre-Fault})}$ $I_{b\,(\text{After Fault})} > I_{b\,(\text{Pre-Fault})}$ $I_{c\,(\text{After Fault})} < I_{c\,(\text{Pre-Fault})}$	Phase B to Ground
$I_{a\,(\text{After Fault})} < I_{a\,(\text{Pre-Fault})}$ $I_{b\,(\text{After Fault})} < I_{b\,(\text{Pre-Fault})}$ $I_{c\,(\text{After Fault})} > I_{c\,(\text{Pre-Fault})}$	Phase C to Ground

Variable faults have been simulated in ATP including:

A. Single-Phase Short Circuit to Ground

When single-phase to ground fault is simulated in randomly selected buses, phase current of all three lines change, however, line current occurred on them change more and since this short circuit affect all DGs and main source, the value of currents measured in each CT which are same phase are summed and 3-phase currents sum during fault are compared with 3-phase currents sum in during zero-fault. In simulated single-phase short circuit, it is seen that the difference between these values is high and current has increased after fault occurred. As a result, if the value of one phase in total current is higher than a pre-determined value, then single-phase short circuit has occurred. Table 2 shows the Single- phase short circuit to ground condition.

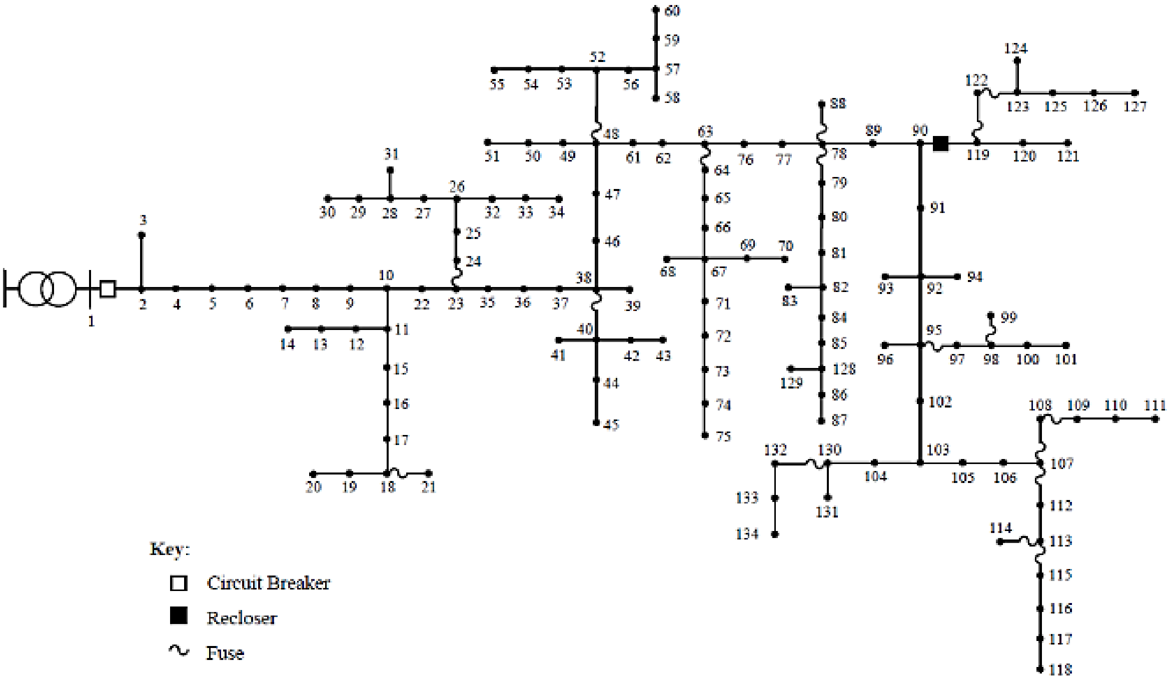

Figure 1. Single-line diagram for the case study

B. Phase to Phase and Phases to Ground Short Circuit

In phase to phase short circuit, total two-phase currents change a lot. In order for a precise determination of fault type and differentiation between two-phase short circuit (LL) and two-phase to ground (LLG), zero component of current is calculated. If the value of zero component of current is close to zero, it is concluded that there is a two-phase short circuit, however; if this value is high, there is two-phase to ground circuit. Table 3 and Table 4 shows the phase to phase short circuit and phase to phase to ground short circuit condition respectively.

Table 3. Phase to Phase Short Circuit conditions

Conditions	Fault Type
I_a (After Fault) > I_a (Pre-Fault) I_b (After Fault) > I_b (Pre-Fault) I_c (After Fault) < I_c (Pre-Fault) Zero Sequence ≈ 0	Phase A to Phase B
I_a (After Fault) < I_a (Pre-Fault) I_b (After Fault) > I_b (Pre-Fault) I_c (After Fault) > I_c (Pre-Fault) Zero Sequence ≈ 0	Phase B to Phase C
I_a (After Fault) > I_a (Pre-Fault) I_b (After Fault) < I_b (Pre-Fault) I_c (After Fault) > I_c (Pre-Fault) Zero Sequence ≈ 0	Phase C to Phase A

Table 4. Phase to Phase to Ground Short Circuit conditions

Conditions	Fault Type
I_a (After Fault) > I_a (Pre-Fault) I_b (After Fault) > I_b (Pre-Fault) I_c (After Fault) < I_c (Pre-Fault) Zero Sequence > 0	Phase A to Phase B and Ground
I_a (After Fault) < I_a (Pre-Fault) I_b (After Fault) > I_b (Pre-Fault) I_c (After Fault) > I_c (Pre-Fault) Zero Sequence > 0	Phase B to Phase C and Ground
I_a (After Fault) > I_a (Pre-Fault) I_b (After Fault) < I_b (Pre-Fault) I_c (After Fault) > I_c (Pre-Fault) Zero Sequence > 0	Phase C to Phase A and Ground

C. Three Phase Short Circuit

Total currents of all three phases change a lot in this circuit and it is considerable compared with total currents of each phase during zero fault. Figure 2 shows the flowchart of proposed algorithm for fault classification.

Table 5. Three phase short circuit conditions

Conditions	Fault Type
I_a (After Fault) > I_a (Pre-Fault) I_b (After Fault) > I_b(Pre-Fault) I_c (After Fault) > I_c (Pre-Fault)	Three Phase

V. SIMULATION AND RESULTS

Variable faults are implemented on a sample bus (bus 67) and results of each are presented in Tables 6 to 15.

Table 6. Short Circuit in Phase A

Bus 67	I_a	I_b	I_c
Dg$_1$	396.23	258.72	236.93
Dg$_2$	213.17	124.02	108.37
Dg$_3$	574.37	393.48	366.63
Dg$_4$	209.26	124.78	110.17
Source	1057.8	593.75	549.02
Total	2448.2	324.71	275.92

Table 7. Short Circuit in Phase B

Bus 67	I_a	I_b	I_c
Dg$_1$	235.03	396.86	256.05
Dg$_2$	107.08	213.54	122.49
Dg$_3$	363.85	575.36	389.81
Dg$_4$	109.13	209.6	123.32
Source	538.5	1060	585.5
Total	279.52	2452.3	323.04

Table 8. Short Circuit in Phase C

Bus 67	I_a	I_b	I_c
Dg$_1$	257.41	235	395.8
Dg$_2$	123.13	107.04	212.99
Dg$_3$	391.52	364.19	574.11
Dg$_4$	123.98	109.12	208.94
Source	588.79	540.93	1042.2
Total	322.9	277.94	2432.2

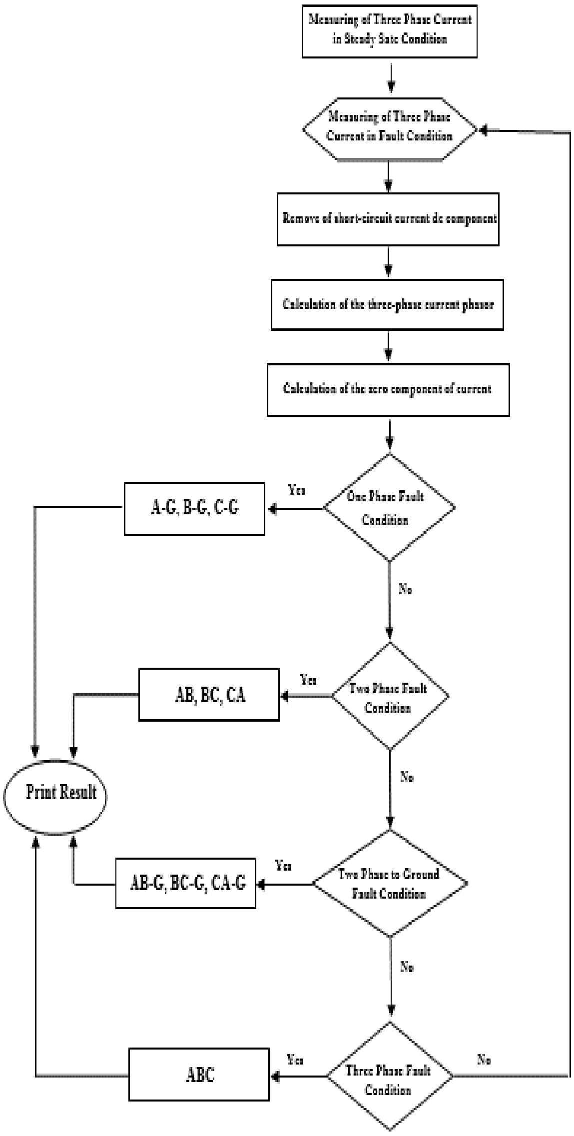

Figure 2. Flowchart of proposed algorithm for fault classification

According to Tables 6 to 8, it has been seen since a single phase to ground short circuit in every phase occurs, the current value of this phase will be increased.

Table 9. Short Circuit between Phase A and B

Bus 67	I_a	I_b	I_c	I_0
Dg_1	358.77	332.82	262.78	0.86502
Dg_2	188.3	172.25	125.54	0.56963
Dg_3	526.38	491.75	399.55	0.86502
Dg_4	185.95	171.26	126.19	0.52837
Source	1169	1231.6	625.75	3.1027
Total	2283.2	2290.4	291.15	0.25797

Table 10. Short Circuit between Phase A and C

Bus 67	I_a	I_b	I_c	I_0
Dg_1	333.18	264.04	359.52	0.50208
Dg_2	172.55	126.13	188.83	0.37176
Dg_3	491.96	401.39	527.62	0.65899
Dg_4	171.47	126.85	186.27	0.27593
Source	1212.9	631.45	1154	2.5895
Total	2273.6	288.82	2264.9	1.0101

Table 11. Short Circuit between Phase B and C

Bus 67	I_a	I_b	I_c	I_0
Dg_1	262.35	356.34	330.15	0.87338
Dg_2	125.11	186.68	170.68	0.48462
Dg_3	398.84	523.59	488.54	1.2682
Dg_4	125.92	184.5	169.77	0.44698
Source	623.96	1181.7	1223.9	2.887
Total	290.13	2280.1	2286.8	0.73858

According to Tables 9 to 11, when two phase short circuit occurs, the current value of both phases will be increased also value of current zero sequence component will be low or near to zero.

Table 12. Short Circuit between Phase A and B and Ground

Bus 67	I_a	I_b	I_c	I_0
Dg_1	365.98	397.27	229.74	68.513
Dg_2	193.32	213.67	104.28	44.938
Dg_3	535.43	576.51	356.9	89.082
Dg_4	190.53	210.26	106.62	42.098
Source	1062.8	1371.9	487.64	415.79
Total	2321.5	2753	312.54	655.17

Table 13. Short Circuit between Phase A and C and Ground

Bus 67	I_a	I_b	I_c	I_0
Dg_1	397.05	229.85	367.07	67.747
Dg_2	213.55	104.01	194.11	44.437
Dg_3	576.04	357.4	537.14	88.284
Dg_4	210.12	106.54	191.09	41.595
Source	1352.9	488.42	1050.9	417.43
Total	2734.3	310.81	2313.9	655.15

Table 14. Short Circuit between Phase B and C and Ground

Bus 67	I_a	I_b	I_c	I_0
Dg_1	230.97	364.05	395.15	66.948
Dg_2	104.83	192.06	212.43	44.036
Dg_3	358.38	533.15	573.94	86.937
Dg_4	107.22	189.37	209.08	41.229
Source	492.1	1059.4	1381.6	416.07
Total	310.95	2305.3	2758.1	650.63

According to Tables 12 to 14, when two phase short circuit to ground occur, the current value of both phases will increase also value of current zero sequence component will be increased too.

Table 15. Three Phase Short Circuit

Bus 67	I_a	I_b	I_c
Dg_1	369.59	367.96	368.68
Dg_2	195.39	194.3	194.89
Dg_3	540.84	539.03	540.04
Dg_4	193.07	192.12	192.6
Source	1315.2	1326.9	1355.2
Total	2612.9	2617.8	2650.5

According to the Table 15, in three phase short circuit, all of three phase currents will be increased.

VI. CONCLUSIONS

In this paper, a simple but efficient method for diagnosing the type of faults occurred in distribution systems with distributed generation sources is presented. In the method proposed in this paper, fault current magnitude is used for fault type diagnosis.

According to multiple software simulations on 134-bus distribution system, the method proposed here will diagnose all types of faults occurred in various parts of network and it has no sensibility toward potential changes in network structure, arrival and departure of DGs or existing disorders in measured amounts or transmission systems.

NOMENCLATURES

I_{a0}: Zero Sequence Component of phase A
I_{a+}: Positive Sequence Component of phase A
I_{a-}: Negative Sequence Component of phase A
I_a: current of phase A
I_b: current of phase B
I_c: current of phase C

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