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DISCRIMINATING FACTORS TO MEASURE PROPAGATION OF CASCADING FAILURES IN THE POWER SYSTEM

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***Abstract*— The most challenging problem for the design and implementation of a defense system is performance in accuracy and speed in a real time environment. For instance, the relay can differentiate between actual faults and load encroachment and be blocked. To calculate the overloads occurring due to the outages and measure propagation of cascading failures across a transmission network a sensitivity factors based generation shift factors (GSF) and line outage distribution factors (LODF) can be used. It is proposes a new methodology DFCA to distinguish line overloads from actual faults and to measure the "Discriminating" factors the sensitivity based power flow analysis can be used for distance relays. The main purpose of this proposed algorithm is to improve disturbance monitoring and system event analysis for discrimination between load encroachment and real system faults. The cascaded events can be measured in a sample-6 bus power system interconnected network and work has been carried out in MATLAB-environment.**

***Keywords*— Discriminating factors calculation algorithm (DFCA), Blackouts, cascading events, wide-area control, zone 3 distance relay.**

I. Introduction

Cascading Failure as "the uncontrolled loss of any system facilities or load, whether because of thermal overload, voltage collapse, or loss of synchronism, except those occurring as a result of fault isolation"[1]. The mal-operation of zone 3 impedance relays with mho characteristics is a factor for causing cascading failures as seen in several previous large scale blackouts. This mal-operation could be due to the increase of the load level to the limit that the relay interprets the system voltage and current relation as if it is a fault although it is not, e.g. load encroachment, Fig.1 [1]. Although the line characteristics are far from the load characteristics, it is not possible to set zone 3 to take into account only the line characteristics because it has to accommodate for the existence of fault resistance. Once cascaded events are initiated for various reasons, the zone 3 elements of distance relays play an important role during its propagation [2][3] [13]. If a transmission line experiences overload as a result of line flow transfer from another outage line, the zone 3 relay may disconnect the line based on the fault clearing scheme. The tripping may trigger more serious line flow transfers to other lines and other overloaded lines can also be tripped by zone 3 elements by the same mechanism. Even if a defense system can gather information and make a decision to control the situation, it is very difficult to interrupt the propagation of cascaded events because protective relay operations are very fast.

The important task is to "discriminate" whether the overload is due to an actual fault or load transfer. In order to identify whether the overload of these lines is caused by line flow transferred from the removed line or not can be tested from the cascaded events discriminating algorithm. Once cascaded events are initiated for various reasons, the zone 3 elements of distance relays play an important role during its propagation [13]. If a transmission line experiences overload as a result of line flow transfer from another outage line, the zone 3 relay may disconnect the line based on the fault clearing scheme. The tripping may trigger more serious line flow transfers to other lines and other overloaded lines can also be tripped by zone 3 elements by the same mechanism. Even if a defense system can gather information and make a decision to control the situation, To distinguish between actual faults on the protection zone with line flow transfers from other disconnected lines, a real-time power flow calculation technique and Internet based secure communication are used.

The organization of this paper is as follows: In section II, zone 3 problems in cascaded events and issues involve during modeling of CEDA. In section III, describes the measurement of positive sequence voltage magnitude and phase angles can be incorporated with PMU and the proposed algorithm CEDA to distinguish the line overloads from actual faults for distance relays. Simulation cases to establish the feasibility of the method and calculation is reported in section IV.

II. THEORY OF OPERATION

A. Discrimination between real faults and load encroachment

Fig. 1 shows a transmission line section between two busses A and B. The transmission line could have two states, one of which presents a real fault case as shown in Fig. 1(a). The value of fault resistance in this case will range between zero (bolted faults) to HIF values. For practical values of Rf during HIF refer to [8].

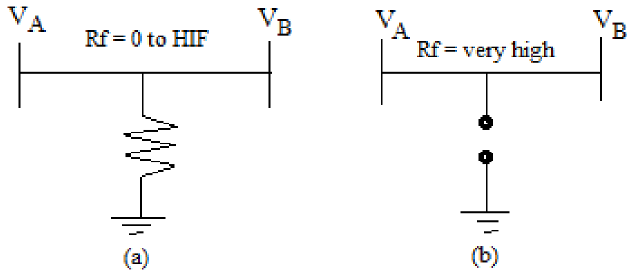

Fig.1. Transmission line with & without fault

The use of the change of Rf as a criterion in protection applications enhances the performance of the protection system in two main aspects. The first one is the discrimination between real faults and load encroachment (or no-fault conditions) using a single measure (Rf). Hence, the operation of distance relays could be enhanced under these conditions as will be shown in the next section. The second one is the recognition of the value of the fault resistance regardless of being low or high and so HIF and normal values of Rf can not influence the protection operation even when a combination between a real fault (with Rf between 0 to HIF) and load encroachment occurs [3][4][6][15].

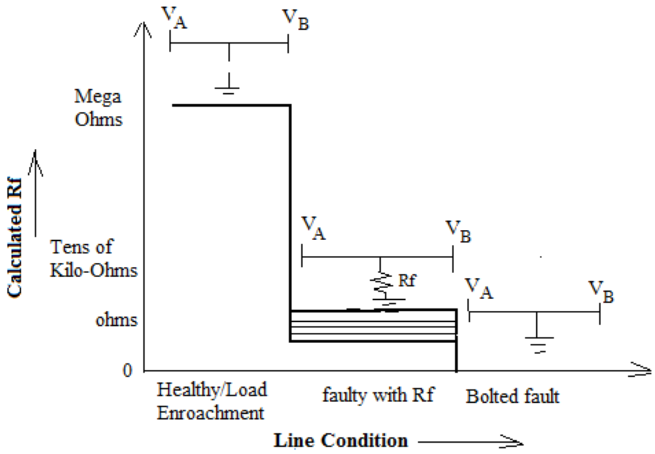

Fig 2 Different cases of R_f values

B. Calculation of R_f

From fig 3, the voltages and currents at terminal A & B during a fault with fault resistance R_f can be described by the following equations:

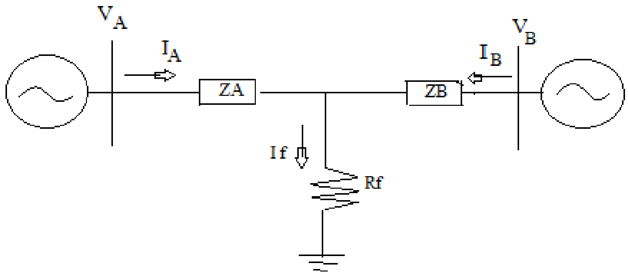

Fig 3 Illustration for calculation of R_f

$$V_A = I_A Z_A + I_f R_f \qquad (1)$$

$$V_B = I_B Z_B + I_f R_f \qquad (2)$$

By rearranging & adding equation (1) and (2), we get;

$$\frac{V_A}{I_A} + \frac{V_B}{I_B} = Z_A + Z_B + R_f \left\{ \frac{I_f^2}{I_A I_B} \right\} \qquad (3)$$

Where, $Z_A + Z_B$ is equivalent to the total impedance of the protected transmission line [Z_{TL}].
From equation (3), the fault resistence is equivalent to:

$$R_f = \left\{ \frac{V_A}{I_A} + \frac{V_B}{I_B} - Z_{TL} \right\} \times \left\{ \frac{I_A I_B}{I_f^2} \right\} \qquad (4)$$

Where, $I_f = I_A + I_B$

C. Modelling of DFCA

Since, modelling of DFCA involves of each contingency and distinguishes line overloads from actual faults for protective relays on the base case model of the power system. Three major difficulties are involved in this analysis:

- Difficulty to develop the appropriate power system model;
- Choice of which contingency case to consider;
- Difficulty in computing the power flow and bus voltages which leads to enormous time consumption in the Energy Management System.

III. DISCRIMINATING FACTORS CALCULATION ALGORITHM

The main purpose of proposed technique is to make mitigate & to improve disturbance monitoring and cascading event analysis using N-X contingency with *"cascaded events discriminating algorithm"*.The proposed algorithm consists to discrimination between load encroachment or no-load fault case and real system faults.The condition of the fault occur on transmission line is mainly detected by two components. First is reduction in voltage of the transmission line because of the fault occurrence. The other component is the direction of the power flow after occurrence of the fault. Fault current direction is determined with the help of phase angle with respect to reference quantity.

. Comparison of the measured values of the positive sequence voltage magnitude at main bus for each area is used to achieve this.The result of this, the minimum voltage value which shows the nearest area to the fault. Additionally, the absolute differences of the positive sequence current angles are calculated for all lines interconnected with this faulted area. On comparing these angles with each other, the maximum absolute angle difference value is selected to identify the faulted line. This operation can be mathematically shown as follows:

$$\text{Min } \{|V1|, |V2|,.. |Vm|, \ldots|Vn|\} \qquad (5)$$

Where, PMU measures the positive sequence voltage magnitude of area "1", "2", "3", "m", to "n". When the fault occurs on the grid output of the (4) shows the minimum positive sequence voltage magnitude. From this calculation the nearest area to the fault can be determined. In this case this area is shown by "m"

It is "Cascaded Events Discriminating Algorithm" to calculate the overloads occurring due to the outages. The scheme makes use of DC load flow studies and sensitivity factors, such as;

- Generation Shift Factors (GSF**)**
- Line outage Distribution Factors (LODF)

The Generation Shift factors (GSF) are designated a_{li} and have the following definition

$$a_{li} = \frac{\Delta f_l}{\Delta P_i} \qquad (6)$$

Where, *l = line index*
i = bus index

Δf_l = change in MW power flow on line l when change in generation ΔP_i occurs at bus i
ΔPi = change in generation at bus i.

If the generator was generating MW and it was lost, it is represented by *ΔPi,* as the new

$$\Delta P_i = - P_i^o \qquad (7)$$

power flow on each line in the network could be calculated using a pre calculated set of ***"a"*** factors as follows:

$$f_l = f_l^o + a_{li}\Delta P_i \;\; for\; l = 1 \ldots \ldots L \qquad (8)$$

Where, = flow on line *l* after the generator on bus *i* fails;
= flow before the failure.

The line outage distribution factors (LODF) are used in a similar manner, only they apply to the testing for overloads when transmission circuits are lost. By definition, the line outage distribution factor has the following meaning:

$$d_{l,k} = \frac{\Delta f_l}{f_k^o} \qquad (9)$$

If one knows the power on line *l* and line *k***,** the flow on line *l* with line *k* out can be determined using ***"d"*** factors.

$$f_l = f_l^o + d_{l,k} f_k^o \qquad (10)$$

The determination of line outage distribution factor used following equation as :

$$d_{l,k} = \frac{{x_k}/{x_l}\left[X_{in} - X_{jn} - X_{im} + X_{jm}\right]}{x_k - \left[X_{ii} + X_{jj} - 2X_{ij}\right]} \qquad (11)$$

By pre calculating the line outage distribution factors, a very fast procedure can be set up to test all lines in the network for overload for the outage of a particular line. After the power flow changes take place, the proposed method must determine which zone 3 relay(s) to block within 0.5 s, including computation, communication and control times. As a result, it is believed that dc power flow is an acceptable compromise for practical reasons.

When a fault occurs on the line and the line is correctly removed by the protective relay, the power flow on this line will be transferred to other lines. As a result of an overload on another line, zone 3 element of distance protective relay could trip the line, leading to a more serious situation. The important task is to **"discriminate"** whether the overload is due to an actual fault or load transfer. In order to identify whether the overload of these lines is caused by line flow transferred from the removed line or not, which can be calculated from pre-fault line flow, LODF and GSF. If the difference is within a tolerance, it is certain that the overload is caused by line flow transferring. Otherwise, there should be an internal fault. The other consideration is that zone 2 reach (impedance) is much smaller than that of zone 3. It is less likely that heavy loading conditions can enter the zone 2 reach.

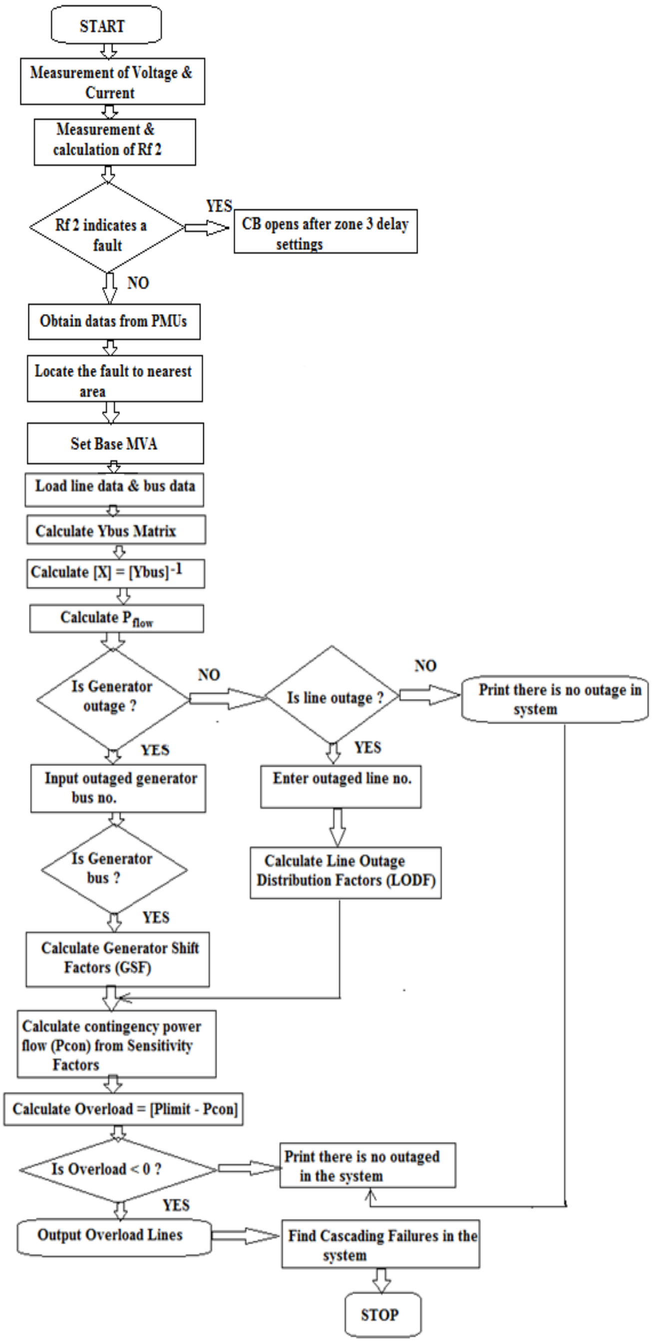

Fig 4 Discriminating factors calculation algorithm

voltage waveforms and current waveforms are shown below in fig 4 & Fig 5. When faulted occur the line, the area 2 and area 3 are affected is shown below.

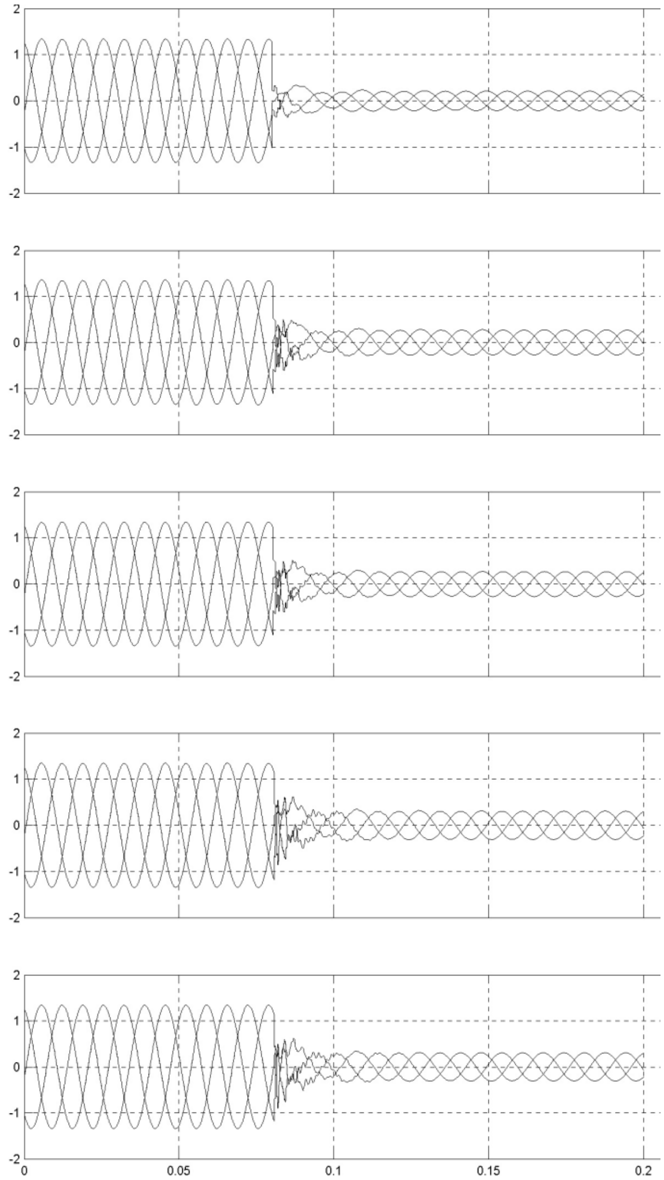

Fig 5 Waveform for three-phase-voltage signals during three- phase to ground faults.

IV. PERFORMANCE

A. Measurement of positive sequence voltage

The three-phase-to-ground faults are located on transmission line between area 1 & area 3 in sample power system interconnected network. The output of three phase faulted

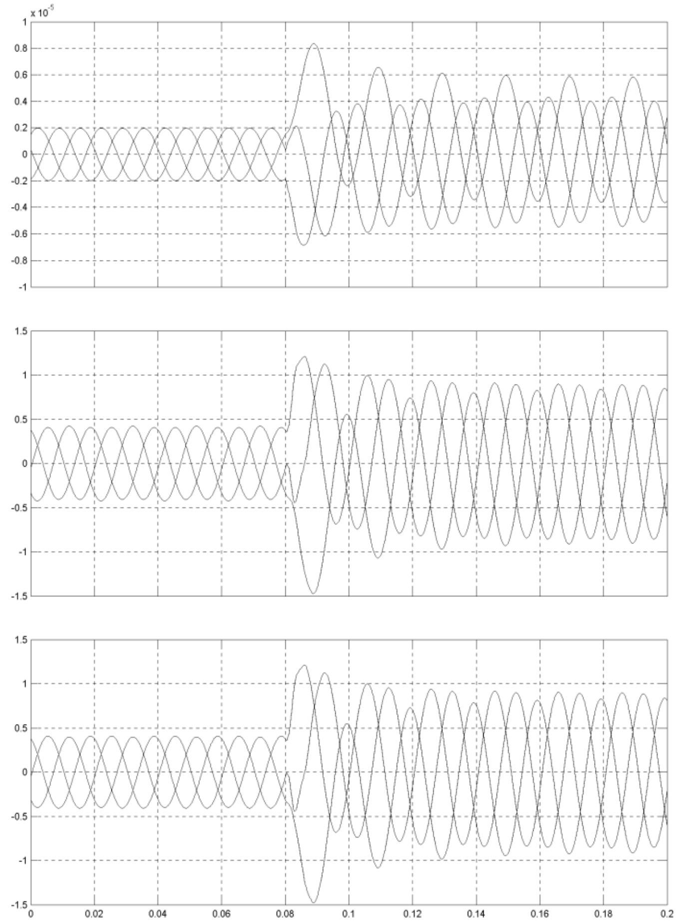

Fig 6 Waveform for three phase current signal for all lines Connected to faulted area

The output waveform from the sample 5-area power system network is distinctly shows the five positive sequence voltage magnitudes for different five areas during single-phase-to-ground fault. The sampling rates are recorded $50x10^{-6}$ seconds.The minimum voltage value which is indicates the nearest area to the fault (i.e. area 1).

Fig 7 Waveform for five PMUs installed in a sample 220 KV Power System interconnected network

B. Measurement of "Discriminating Factors" using CEDA

The sensitivity factors are calculated by using formula in equation (4) and equation (7) of the complete IEEE-6 bus system. Next, an outage is intentionally imparted into the system, which can either be a generator outage or a line outage. Then, using the calculated sensitivity factors and base case power flow, the contingency power flow is calculated. This contingency power flow is compared to the thermal limits of lines to find out the overloads in the system. The results of the contingency analysis are shown in tables 1 and tables 2.

CASE I: The contingency analysis, discriminating factors, pre-outage power flow and post-outage power flow is calculated using "Generation Shift factor". Taking Slack-Bus is G1 and 100 MVA base.

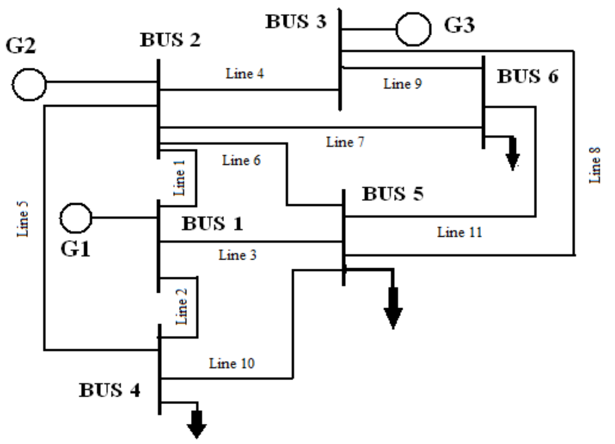

Fig 8 Sample-6 Bus system

Table 1: Discriminating Factors in the Pre & Post- Outage state after G2-outage.

Line no.	Maxi^{m} limit of the line flow	GSF	Pre-Outage MW Flow	Post-Outage MW Flow	Overload	Remarks
1	30	-0.538	25.328	69.232	-39.232	overloaded
2	50	-0.356	33.582	51.379	-1.3796	overloaded
3	40	-0.249	29.356	41.848	-1.848	overloaded
4	20	0.052	17.106	14.506	19.493	-
5	40	0.365	29.446	11.190	39.809	-
6	20	0.109	4.121	1.337	19.662	-
7	30	0.062	10.883	7.754	29.245	-
8	20	0.076	20.134	16.335	19.664	-
9	60	-0.004	22.641	22.883	59.116	-
10	20	-0.009	5.169	5.639	19.360	-
11	20	-0.067	11.470	14.842	19.157	-

The above table 1 shows the power flows in the system following the most severe contingency, which is the outage of the generator G2 at bus-2 and discriminating factors of the line could be resulting cascaded events.

CASE II: The contingency, Pre-Outage and Post-Outage active power flows in IEEE-6 bus system using line outage distribution factors (LODF) are being calculated by using the equation (4.5) given as follows:

Table2: Discriminating Factors in each line after outage line-1

Line no.	Max^{m} limit of line flow	Pre-outage MW flow	Post-Outage MW flow	Overloaded	Remarks
1	30	42.307	0	-	outage
2	50	33.582	66.2141	-16.2141	overloaded
3	40	29.356	52.2605	-12.2605	overloaded
4	20	17.106	12.3396	19.660	-
5	40	29.446	-4.0261	10.554	-
6	20	4.121	-5.1473	15.879	-
7	30	10.883	5.1473	29.8527	-
8	20	20.134	13.1698	19.8302	-
9	60	22.641	23.0856	59.9687	-
10	20	5.169	6.0313	19.9687	-
11	20	11.470	17.6538	19.3462	-

Consider *n* power system components are there in a power system, and if one component, i.e. one generator or a one line in transmission system fails or outage, then this event is called N -1 contingency. As N -1 contingency, the several lines are overloaded may exceed the thermal limits of lines and a result cascading events.

Fig 8 depicts the change of the calculated R_f during a simulation study period in which a fault with R_f took place in the transition of fault occurred at 0.08 and fault cleared at 0.2 seconds.

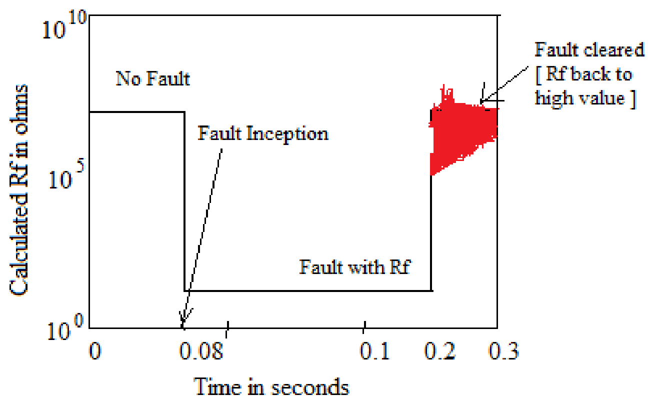

Fig 9 Calculation of Rf using equation [4]

As has been shown in the last section, the detection of the fault is done for each line between area 2 and area 3 but unlike the detection is dependent on the value of impedance R_f as well as current I_f. Since, above algorithm is the advantage of distance protection of cascaded events to distinguish the discriminating factors in the sample power system network.

V. Conclusion

The proposed DFCA has been provided a concept with intent of mitigating the extent of cascading failures. It is concluded that the rate of change of voltage to discriminate between voltage instability and fault conditions. Although this paper focuses on overload-related outages, the method is applicable to other cases as well. The simulation work is carried out in PMU connected 220 KV interconnected power system network used to calculate positive sequence voltage, current and location of fault. In order to calculate flow transfers and "Discriminating" factors the sensitivity based power flow analysis is adopted. To calculate the overloads occurring due to the outages and measure propagation of cascading failures across a transmission network a sensitivity factors based generation shift factors (GSF) and line outage distribution factors (LODF) have been used and concluded the cascaded events in a sample-6 bus power system interconnected network.

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