Control Actions Measurement to Propagation of Cascading Outages in the Power System

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Abstract— *Cascaded events can damage to equipment of power plants, interruption of production cycles, and great economic losses. To locate the fault a positive sequence voltage and current phasors at both ends of a transmission line can be used to determine the faulted area. This includes identifying whether the action of protective relays are related to fault conditions or overloads. Meanwhile, the 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) can be used. It is proposes a new methodology CAMA to measure the necessary control action and combination of local and wide area information that is time synchronized provides the ability to stabilize electric power system in ways that minimize necessary control actions. The main purpose of this technique is to improve disturbance monitoring and system event analysis. The efficacy of this control actions can be measured in a sample IEEE-6 bus power system interconnected network and work has been carried out in MATLAB-environment.*

Keywords— *Control Action Measurement Algorithm (CAMA), Cascaded Events Discriminating Algorithm (CEDA), cascading events, wide-area control, protective relay, phasor measurement unit (PMU), 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]. In power grids flow dynamics depend greatly on the electrical characteristics such as the voltages, impedances, and the difference in the angles of the voltage phasors of a given pair of buses between which the transmission line is present. If we assume that all the voltages are constant at 1 PU and angle difference is very small, we can say that the amount of power flowing through the transmission lines is inversely proportional to their impedances. If a single line gets *overloaded or breaks*, its power is immediately re-routed to a different line and the disturbance can be suspended. But sometimes, the other line is also already *overloaded* and must re-route its increased load to its neighbors. This redistribution of power may lead to the subsequent overloading of other lines causing their *malfunction* at the same time and the consequence could be a *cascade of overloading failures*. Recently, there has been a growing concern about the *overload* status of the power grid networks, and the increasing possibility of cascading failures [2],[3],[4].

The U.S.- Canada Power System Outages Task Force report indicates that primary causes for cascading failures are [5]:

- A lack of reliable real-time data
- Thus, a lack of time to take decisive and appropriate remedial action
- Increased failure in aging equipment
- A lack of properly automated and coordinated controls to take immediate and remedial action against system events in an effort to prevent cascading
- Overloading
- Malfunction of zone 3 relay operation

Adaptive relaying (i.e. malfunction of third zone of distance protection relays) was the main cause of many cascaded trips in the system. A novel wide area backup protection system using Phasor measurement units (PMU) as an alternate to the conventional distributed backup protection in substation[6]**.**

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 [7], [12],[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 modelling 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 to measure "Discriminating" Factors 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. Zone 3 problem in cascaded events

Distance relays have been successfully used for many years as the most common type of protection of transmission lines. The first zone of distance relays is used to provide primary high speed protection and it covers about 80 to 85 per cent of the line without any time delay. The resulting 15% safety margin ensures that there is no risk of the Zone 1 protection over-reaching the protected line due to errors in the current and voltage transformers, inaccuracies in line impedance data provided for setting purposes and errors of relay setting and measurement of the distance protection must cover the remaining 15% of the line. The second zone covers the remaining portion of the line plus 25 per cent of the next line and operation time is set to about 0.25 to 0.5 seconds. Third zone covers the entire area protected by the first and second zones plus 25 per cent of the next long line (third line) and delay time is set between 0.6 to 1.5 seconds. This zone is used for backup protection. Distance relays are designed to measures the impedance between the relay location and the fault. If the resistance of the fault is low, the impedance is proportional to the distance from the relay to the fault. A distance relay is designed to only operate for faults occurring between the relay location and the selected reach point and remains stable (or inoperative) for all faults outside this region or zone. Each relay operates independently according to zone of protection as shown in fig 1[10],[15].

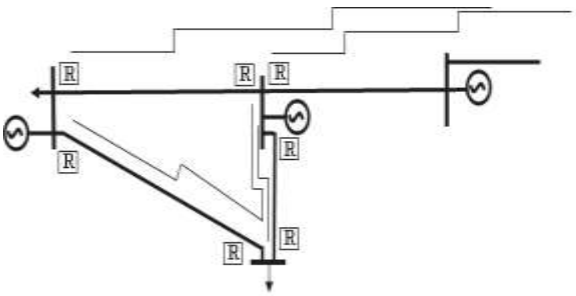

Fig.1. Three Zones of operation in each standalone relay.

B. Discrete Fourier Block Set

For phasor estimation many methods are available at present condition like *kalman filtering, zero-crossing detection, least square, filter-based methods, methods based on wavelet transform*. However, most commonly used method is DFT. The DFT is very fast recursive calculation of phasors. Discrete Fourier transform block computes the fundamental value of the input phase current signal over a running window (it is the number of samples required to compute the phasors using DFT) of one cycle of the specified fundamental frequency as shown in Figure 2. First outputs return respectively the magnitude and phase degrees of the fundamental. The magnitude is taken as a percentage from its steady state value. The rate of change of this percentage is compared with a threshold value. For the first cycle of simulation, the outputs are held constant to the value specified by the parameter "Initial input"[8] [9].

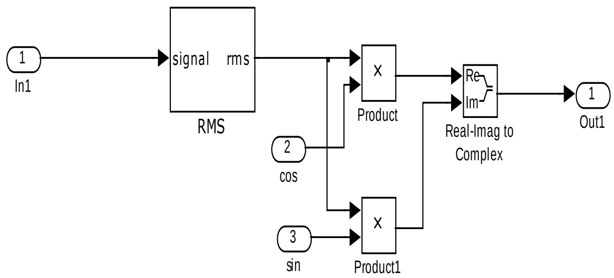

Fig 2 SIMULINK model for DFT

C. Modelling of CAMA

Since, modeling of CAMA 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. CONTROL ACTION AND FAULT LOCATION MEASUREMENT ALGORITHM

The proposed algorithm consists to locate faulted area by using PMUs for sample 5-area power system interconnected network to measure positive sequence voltage magnitudes at the main bus of the each area and absolute angle difference between the lines and locate the faulted area. The DFT (discrete Fourier transform) is used to compute the phasors of voltages and currents. 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:

Min {|V1|, |V2|,.. |Vm|, …|Vn|} (1)

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 Line Outage Distribution Factor (LODF) and Generation Shift Factors (GSF) for sample-6 bus system. These factors can be derived in a variety of ways and basically come down to two types:

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

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

$$a_{li} = \frac{\Delta f_l}{\Delta P_i} \quad (2)$$

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

$$\Delta P_i = - P_i^o \quad (3)$$

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

$$f_l = f_l^o + a_{li}\Delta P_i \;\; for\; l = 1 \dots \dots L \quad (4)$$

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:

$$d_{l,k} = \frac{\Delta f_l}{f_k^o} \quad (5)$$

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.

$$f_l = f_l^o + d_{l,k} f_k^o \quad (6)$$

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

$$d_{l,k} = \frac{{x_k}/{x_l}\left[X_{in} - X_{jn} - X_{im} + X_{jm}\right]}{x_k - \left[X_{ii} + X_{jj} - 2X_{ij}\right]} \quad (7)$$

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 proposed method is not intended for zone 2 relays. The operating time for zone 2 is much shorter, i.e., 250–500 ms. It is less certain that the computation, communication and control actions can be completed within 250 ms. 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.

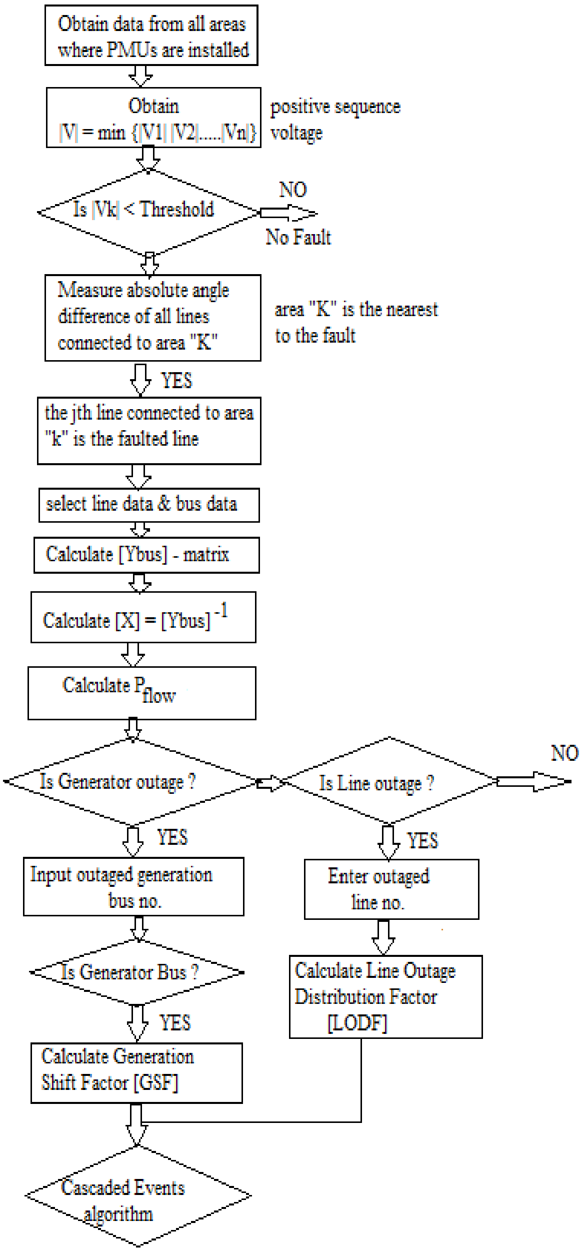

Fig 3 Control action measurement algorithm

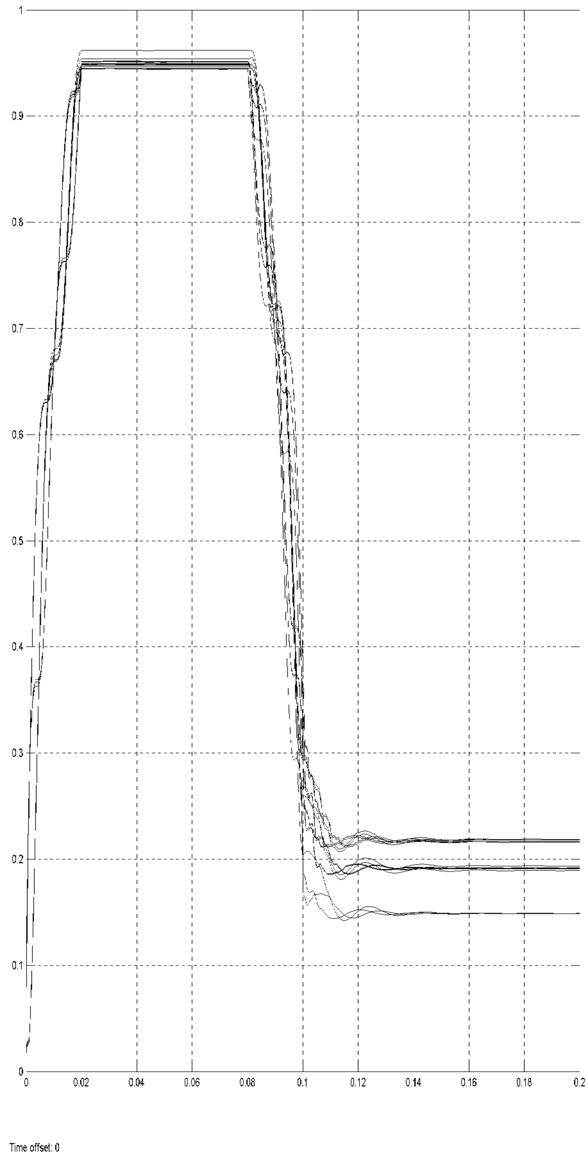

Fig 4 Output of PMUs of Sample 220 KV , 5-area Power System Network.

IV. PERFORMANCE

A. Measurement of positive sequence voltage and current signals related to faulted area

The output waveform from the five PMUs is shown in fig.4, which distinctly shows the five positive sequence voltage magnitudes for different five areas during three-phase-to-ground fault. The minimum voltage value which is indicates the nearest area to the fault (i.e. area 1) for the given network.

B. Measurement of "Discriminating Factors"

The contingency analysis, sensitivity 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.

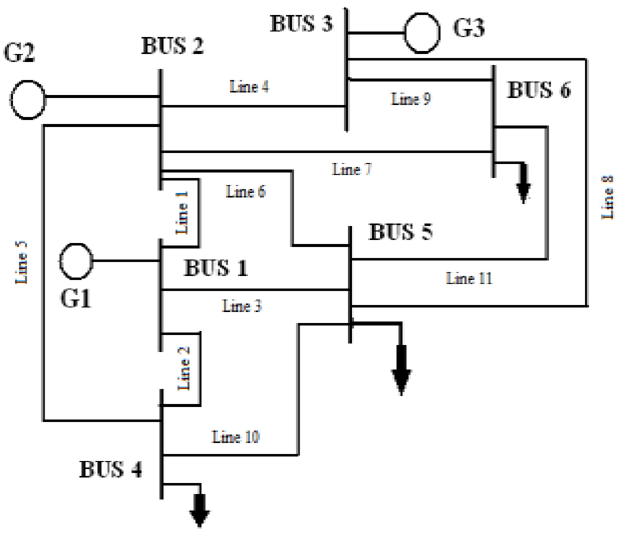

Fig 5 Sample-6 Bus system

The formation of sensitivity matrix for sample-6 bus sytem is given in table 1:

Table 1 The X-matrix for the IEEE-6 bus system

0	0	0	0	0	0
0	0.0941	0.0805	0.0629	0.0643	0.0812
0	0.0805	0.1659	0.0589	0.0907	0.1289
0	0.0629	0.0589	0.1008	0.0542	0.0592
0	0.0643	0.0907	0.0542	0.1221	0.0892
0	0.0812	0.1285	0.0592	0.0892	0.1632

The GSF can be visualized on any one line. Consequently, from bus 2 & 3, the factors could be given as:

Table2 Generation Shift Factor calculation for sample -6 bus system

1	1.0000	2.0000	-0.4706	-0.4026
2	1.0000	4.0000	-0.3149	-0.2949
3	1.0000	5.0000	-0.2145	-0.3026
4	2.0000	3.0000	0.05444	-0.3416
5	2.0000	4.0000	0.3115	0.2154
6	2.0000	5.0000	0.0993	-0.0342
7	2.0000	6.0000	0.0642	-0.2422
8	3.0000	5.0000	0.0622	0.2890
9	3.0000	6.0000	-0.0077	-0.3695
10	4.0000	5.0000	-0.0034	-0.0795
11	5.0000	6.0000	-0.0565	-0.1273

The line outage distribution factor (LODF) calculation from equation (5) & equation (7) can be found where *l* – corresponds to line under study, i.e. between the buses *n* and *m* and *k* corresponds to the outage of the line which is connected between the buses *i and j.*

Table3 Line outage distribution factors calculation for sample-6 bus system

	k=1	***k=2***	***k=3***	***k=4***	***k=5***	***k=6***	***k=7***	***k=8***	***k=9***	***k=10***	***k=11***
l=1	0	0.381	0.336	0.152	0.323	0.172	0	0.076	0.062	0.010	0.062
l=2	0.317	0	0.326	0.018	0.660	0.020	0	0.009	0.007	0.340	0.007
l=3	0.204	0.237	0	0.323	0.012	0.364	0	0.166	0.131	0.361	0.131
l=4	0.084	0.011	0.294	0	0.149	0.352	0	0.514	0.407	0.270	0.407
l=5	0.322	0.790	0.021	0.269	0	0.303	0	0.138	0.109	0.659	0.109
l=6	0.114	0.016	0.400	0.425	0.020	0	0	0.218	0.173	0.368	0.173
l=7	0	0	0	0	0	0	0	0	0	0	0
l=8	0.051	0.007	0.178	0.606	0.090	0.213	0	0	0.592	0.164	0.592
l=9	0.033	0.004	0.116	0.393	0.058	0.138	0	0.485	0	0.106	1.000
l=10	0.005	0.209	0.305	0.251	0.339	0.283	0	0.129	0.102	0	0.102
l=11	0.033	0.004	0.116	0.393	0.058	0.138	0	0.485	1.000	0.106	0

V. CONCLUSION

The proposed technique is to improve disturbance monitoring and system event analysis. The simulation work is carried out in PMU connected a sample 5-area, 220 KV interconnected power system network used to calculate state measurement and location of fault. An adaptive distance relay, PMU based algorithm provides a concept to secure time to perform remedial controls by a defense system during cascaded events in wide area measurements system. In order 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 time synchronized control actions provides the ability to stabilize electric power system**.** The cascaded events control action work has been satisfactorily carried for sample-6 bus system on MATLAB/Simulink.

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