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OUT OF STEP DETECTION USING WIDE AREA MEASUREMENTS

by

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A. SUMMARY

I. Distance Protection :

Distance protection is one of the most widely used methods to protect power transmission lines. However, the conventional distance relay operation is challenged with both static and dynamic power system events such as load encroachment, power swings, and voltage instability, that may force mal-operation of relays.

Through this paper we have proposed a new scheme for power swing detection which can distinguish stable and unstable power swing and can block tripping of distance relays on a stable power swing, detailed in section A.III.

II. Out Of Step (OOS) condition and protection schemes :

During severe power system disturbances, unstable power swings may evolve and they cause large fluctuation in voltages, currents and eventually loss of synchronism which is known as out-of-step condition.

There are many techniques available in literature and in practice to detect out-of-step conditions. Most popular conventional out-of-step detection techniques use of blinders in the impedance plane and a timer. The blinder and timer settings require knowledge of the fastest power swing, the normal operating region, and the possible swing frequencies, and are therefore system specific. Such techniques require extensive offline stability studies for obtaining the settings and their complexity increases when applied to multi-machine systems. Another technique monitors the rate of change of swing centre voltage (SCV) and compares it with a threshold value to discriminate between stable and out-of-step swings. With some

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approximations, the SCV is obtained locally from the voltage at the relay location, which subsequently makes the SCV independent of power system parameters. Energy function criterion, has also been applied for loss-of-synchronism detection for a complex power system. Recently, OOS detection using WAM based differential resistance is applied but it takes longer time of detection than the conventional approaches.

III. Proposed OOS detection scheme using WAMS :

With the advent of Phasor Measurement Unit (PMU) with time stamped Global Positioning System (GPS) enabled Wide Area Measurement System (WAMS), eliminate biases from the geographic spread and separation of power systems and also measurements are able to give real time power system phasors at a rate of 20-60 phasors / second.

This paper proposes a WAM based OOS protection scheme based on synchronised data measurement from both ends of the transmission line. The scheme basically works on resistance, rate of resistance, impedance and rate of impedance obtained using synchronised measurement of data from both ends of a transmission line. The rate of change of resistance, the rate of change of impedances and their respective differences are analyzed continuously to confirm whether the power swing is a stable or a unstable power swing. This scheme is not affected by the fault resistance, source impedance, power swing and also allows to set closer to actual stability limits of the transmission line. The performance of the scheme has been tested on a simulated system using PSCAD and MATAB software.

B. KEYWORDS

Out-of-step (OOS), Wide Area Measurement System (WAMS), Phasor Measurement Unit (PMU), Rate of change of resistance or impedance.

C. INTRODUCTION

The power grid is a very dynamic network connecting generation to load via transmission lines. Any change in the power generated, load demand or in the transmission line network causes the power flow to change across the system until a new equilibrium is established between generation and load. These kinds of small changes in power flow occur continuously and are automatically compensated via control system, and normally have no detrimental effect on the power grid or its protective systems.

However, in the era of fast growth and rapid development in power systems, there is a demand for a reliable and quality power system network. For a utility company, meeting ever-increasing demand via network expansion would incur large costs. Hence they set up tools & processes to fully enable energy markets to ensure dynamic participation of end users and also deduce a logical solution to raise the existing system operational level to meet with the growing demand. In doing so, the system may face new operational challenges from the protection & control point of view [1].

Distance protection is one of the most widely used methods to protect transmission lines. There are many techniques available in literature and in practice to detect out-of-step (OOS) conditions. Most popular conventional OOS detection technique is to use a distance relay with blinders in the impedance plane and a timer. The blinder and timer settings require knowledge of the fastest power swing, the normal operating region, and the possible swing frequencies, and are therefore system specific [2],[3]. Such techniques require extensive offline stability studies for obtaining the settings and their complexity increases when applied to multi-machine systems. The performance also depends on the guidelines used for blinder and timer settings. The technique ensures better protection only in the worst case scenarios [4] and the performance is affected by the swing frequencies encountered [5].

Another technique monitors the rate of change of swing centre voltage (SCV) and compares it with a threshold value to discriminate between stable and out-of-step swings. With some approximations, the SCV is obtained locally from the voltage at the relay location, which subsequently makes the SCV independent of power system parameters. However, the approximation is found to be true only if the total system impedance angle is close to 90^0 [6]. For a multi-machine system, the voltage measured at relay location does not give an accurate approximation of SCV.

An out-of-step detection technique based on the classical equal area criterion (EAC) in the power angle domain is reported in [7]. This technique requires pre- and post-disturbance power-angle (Pe -δ) curves of the system to be known to the relay. As the Pe -δ curves are dependent on the system configuration, many measurement and communication devices at various locations are required to gather the current system information.

A recent approach is proposed in [8] on the energy function criterion for loss-of-synchronism detection for a complex power system. During unstable swings the entire power system oscillates in two groups, and series elements (called cutset) connect them. The stable and unstable conditions are predicted by evaluating the potential energy of the cutest, but this technique requires the measurements across all series elements as any of the series elements could form a cutset depending upon the pre-disturbance system conditions, type of disturbance, and its duration of the disturbance or fault.

Wide Area Measurement System (WAMS) :

For an affective operation of the adaptive protection of the system, very precise and consistent system monitoring parameters like magnitude and angle of voltage, current and power flows are essential. Now a day's, in most of the electrical networks asynchronous measurements that are collected in the control centre and state estimation is performed. Steady state models are used in Supervisory Control And Data Acquisition (SCADA) system while measurements of various electrical quantities (voltage & current magnitudes, active & reactive power flows and injections etc) also through a SCADA. This leads to a biased state estimation, where biases mainly stem from utilization of single phases, positive sequence models and measurement time skewness. These biases can be eliminated using Phasor Measurement Units (PMU) measurements in combination with highly accurate, three phase and asymmetric power system models [9],[10]. Moreover, synchronized and time tagged measurements that are referenced to the Global Positioning System (GPS) signal eliminate biases from the geographic spread and separation of power systems.

WAMS based measurements are able to give real time power system phasors at a rate of 60 phasors / second. This is now possible with Phasor Measurement Unit (PMU) enabled wide area measurement system (WAMS) [11],[12].

D. PROPOSED WORK

I. WAM based power swing detection techniques

The complexity in the electrical parlance is increasing day by day with addition of micro grids, interconnection of different electrical grids at different voltage levels, FACT's etc. During normal operating condition, electric power system maintains a dynamic balance between generation and load. When a system disturbance occurs, it may break the said balance and can result into power swings in the system, as the generators attempt to find stable operating point relative to each other, they continue to swing until stability is achieved. The extent of oscillations depends upon the severity of the disturbance, duration of the disturbance and the characteristics of the prevailing system. During unstable power swings it is likely that some of the generators might lose synchronism, the severity of oscillations during unstable power swing will be more compared to that observed during stable power swing. This severity in the oscillations is likely to be reflected in the power flowing through the transmission lines and hence can be indirectly monitored by monitoring the resistance, impedance and also its rate of change as seen from the breaker / relay locations . This approach is used as a driving principle of out of step detection in the proposed WAM based schemes. A single line infinite bus (SMIB) system and WSCC 9-bus system have been used for implementing these schemes.

II. Resistance based scheme:

Resistance Difference & Rate of change in resistance difference scheme :

The system consists of two 400KV buses M and N connected to two generators E_M and E_N respectively and two parallel lines connecting the buses. The relay is placed at bus M. Phasor

Measurement Units (PMU) are placed at the buses M and N. PMU's placed at the buses calculate voltage and current of the three phases of the line at a sampling rate of 20 – 60 samples / cycle. A fault occurs on one of the lines and the line is tripped. As a result of which there is an imbalance of power in the other line and thus it experiences power swing. The data collected by the PMUs is then used in the Data Concentrator to calculate the positive sequence voltage and current phasor at fundamental frequency using Discrete Fourier Transform algorithm.

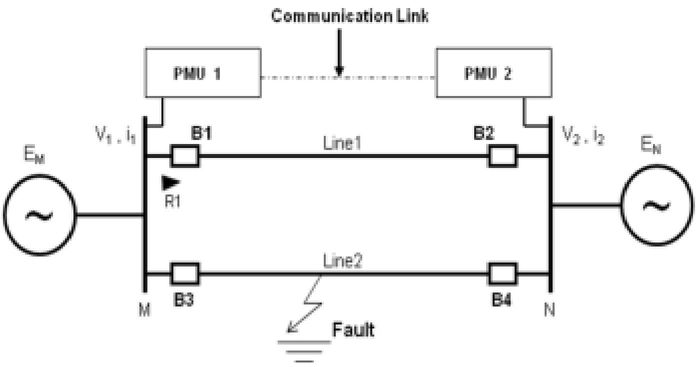
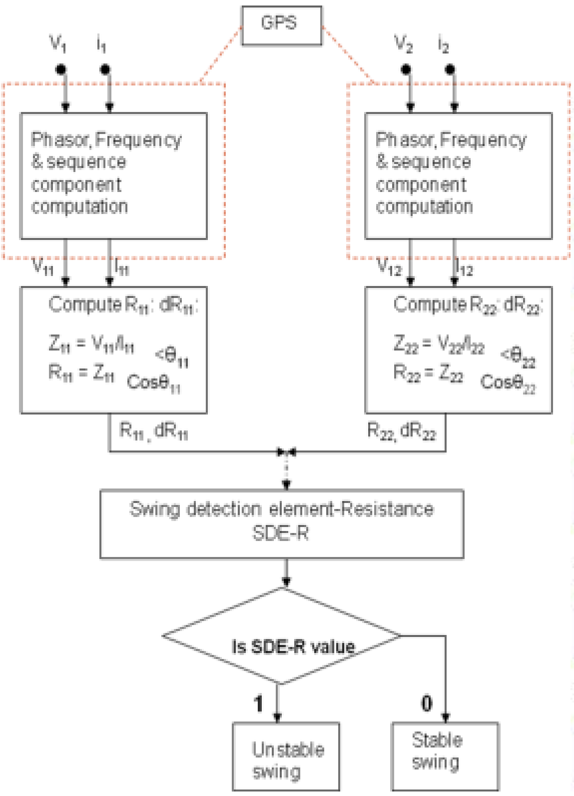


Fig.1. PMU based schemes for SMIB system

Flowchart for the resistance difference scheme used is as shown in Fig.2. The Voltage and Current phasor quantities are converted into sequential components to calculate the positive sequence resistance seen from the buses M&N of Fig.1. The computations are carried out as per algorithm of swing detection element (SDE)..



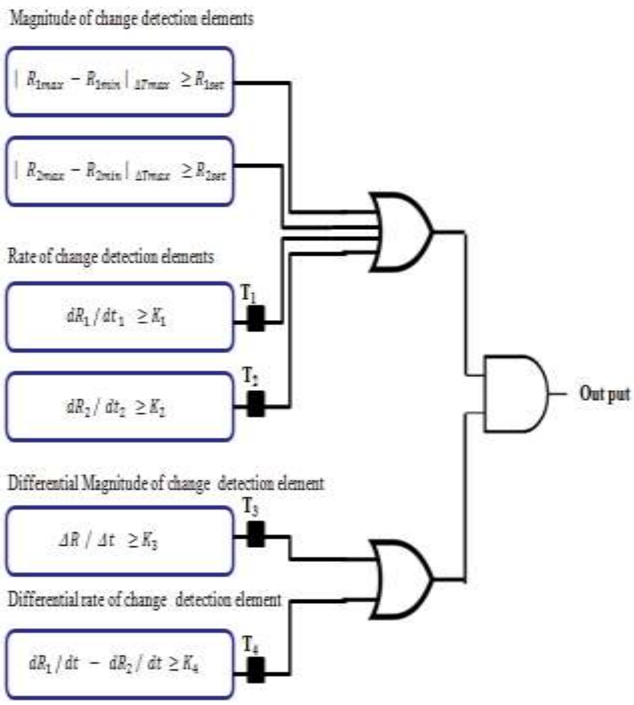


Fig.2 Flowchart for the resistance based Scheme

Fig.3 Algorithm of Swing Detection Element-Resistance based scheme

Swing Detection Element :

This element acts as checking criteria to ascertain the out of step condition during stable or unstable power swings. The algorithm comprises of four types of sub-elements as shown in Fig.3, namely “Magnitude of change detection element “, “Rate of change detection element”, “differential magnitude of change detection element” and “Differential rate of change detection element”.

-“Magnitude of change detection element”, detects the size of the resistance fluctuation. The value Rset detects the sensitivity of resistance fluctuations magnitude, Rmax and Rmin the maximum and minimum value of resistance as seen from the breaker/bus locations during the predetermined time interval ΔTmax. If the magnitude of change is ≥ Rset, then the detection element operates and sets the OR gate.

- “Rate of change detection element”, detects the presence of power swing. The dR /dt is the rate of change of resistance value during the time interval dt. The rate of change detection element operates when its dR/dt is greater than constant K and continues longer than time T.

- “Differential magnitude of change detection element”, quickly detects the resistance fluctuations due to presence of power swing caused by sudden load through off or of any other specific reason. The value K_3 sets the sensitivity of resistance difference in magnitude as seen from breaker locations . ΔR is the difference in resistance value between R1 and R2 as seen by from locations B1 and B2 respectively during the predetermined time interval ΔT. If the magnitude of change is ≥ K_3 and continues for duration of time T_3, then the detection element operates and sets the OR gate.

- “Differential rate of change detection element”, fastly detects the presence of power swing. The (dR_1 /dt – dR_2/dt) is the differential in rate of change of resistance value as seen from relay locations B1 and B2 during the same time interval dt. The differential rate of change detection element operated when its ≥ K_4 and continues for duration of time T_4.

All the parameters like T_1 to T_4, K_1 to K_4, R_{1set}, R_{2set}, ΔTmax and ΔT are precisely set after conducting thorough study of the system configuration & its transient analysis. If either of the “Magnitude of change detection element “and “Rate of change detection element” sets along with either of the “differential magnitude of change detection element” and “Differential rate of change detection element”, then only the Swing Detection Element gives a positive output, this signal can be used for controlled tripping or for any power shedding application etc.

III. **Impedance based scheme :**

Impedance difference & Rate of change of impedance difference scheme

This scheme instead of resistance and differential rate of change of resistance, impedance and differential rate of change of impedance is monitored to distinguish the stable and instable condition of the power swing. Fig. 4 depicts the Flowchart for the scheme and Fig. 5 depicts the algorithm of swing detection element. All the parameters like T_1 to T_4, K_1 to K_4, R_{1set}, R_{2set}, ΔTmax and ΔT are precisely set after conducting thorough study of the system configuration & its transient analysis. If either of the “Magnitude of change detection element “and “Rate of change detection element” sets along with either of the “differential magnitude of change detection element” and “Differential rate of change detection element”, then only the Swing Detection Element gives a positive output, this signal can be used for controlled tripping or for any power shedding application etc.

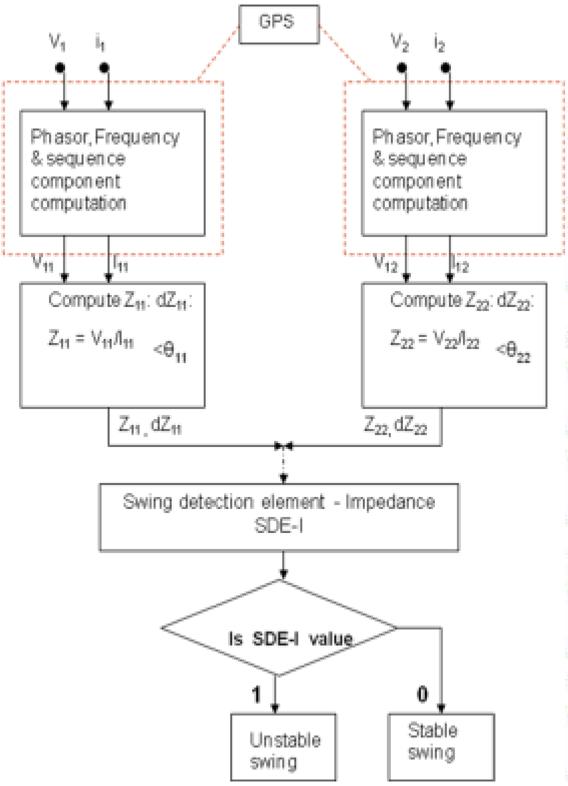


Fig.4 Flowchart for the impedance scheme.

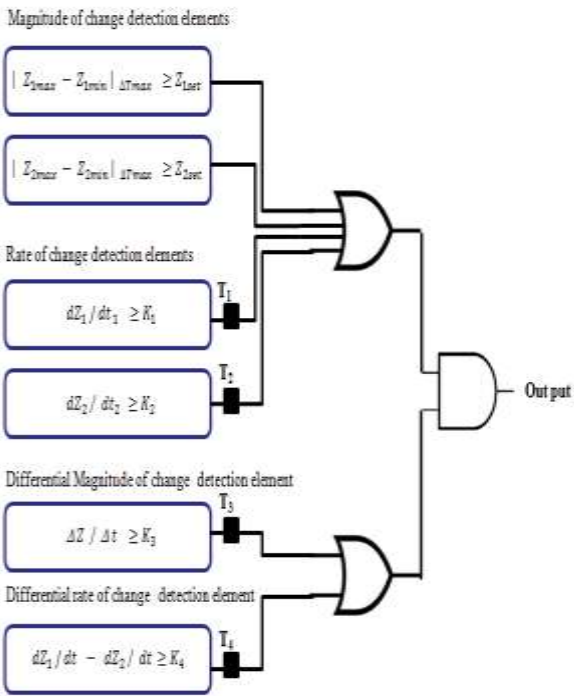


Fig.5 Algorithm of Swing Detection Element – Impedance difference scheme

IV. **Case studies**

The Power Stability studies for both the proposed schemes have been carried for testing on a single machine infinite bus system (SMIB) [13] and the WSCC 9-bus system [14]. The single line diagram of the systems are shown in Fig.6 and Fig.7 respectively. Simulations are carried out on PSCAD & MATLAB.

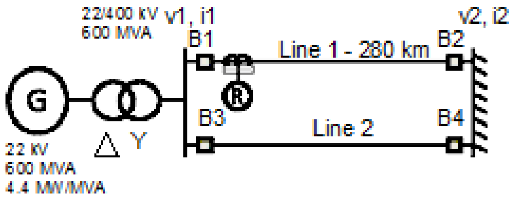


Fig.6 Single line diagram of SMIB.

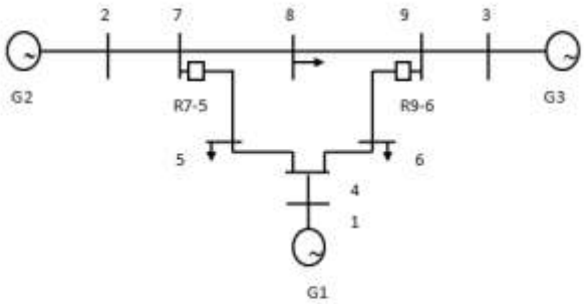


Fig. 7 Single line WSCC 9-bus system.

A disturbance was created on one transmission line, where the performance of the distance relay to be studied, is connected. The disturbance was created by connecting load on same line for some duration. The load location and amount of loading on the line is varied to study the performance of the distance relay on stable and unstable swings. In these schemes, the system frequency is considered to be constant. For stable swings, the accuracy of the relay to classify a power swing as a stable swing is monitored. During unstable swing, the relays have been observed for speed of detection of OOS condition. Loading of the line has been limited near the margins of stability and unstability of the system depending upon the case of study.

In SMIB simulation based case, Fig.6, Generator is modelled with IEEE SCRX exciter. Two PMUs are connected at the locations B1 and B2 of the transmission line of Fig. 6 and Bus 1 and Bus 7 of Fig.7.

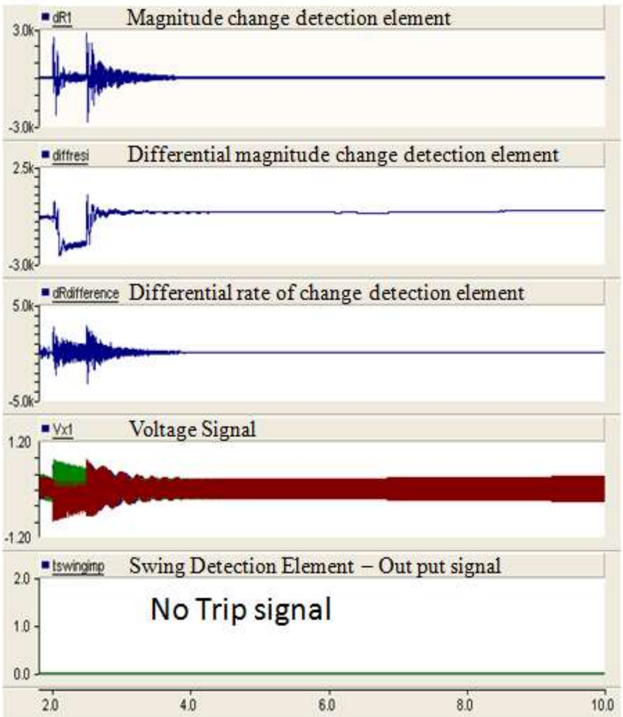


Fig.8 . Stable swing- Resistance based scheme. Created a disturbance at 2 Sec and removed after 0.5 Sec. between line 1-7 of WSCC 9-bus system

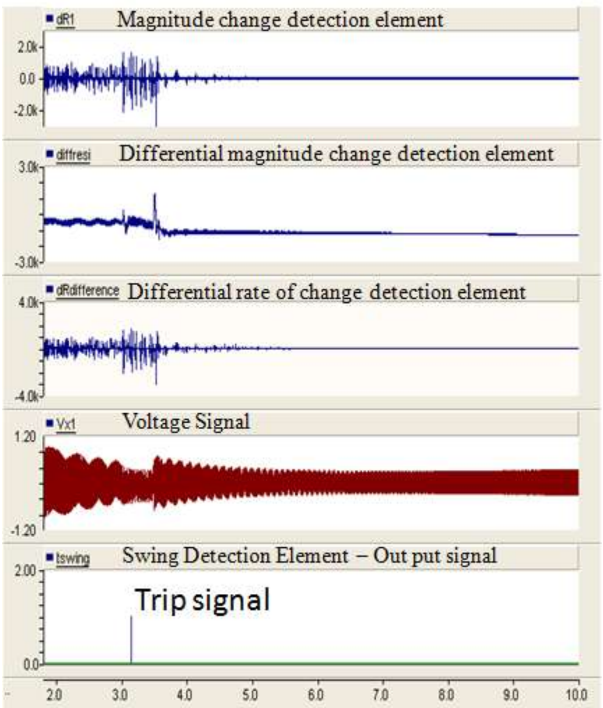


Fig. 9 Unstable swing- Resistance based scheme. Created a major disturbance at 3 Sec and removed after 0.5 Sec. between line 1-7 of WSCC 9-bus system

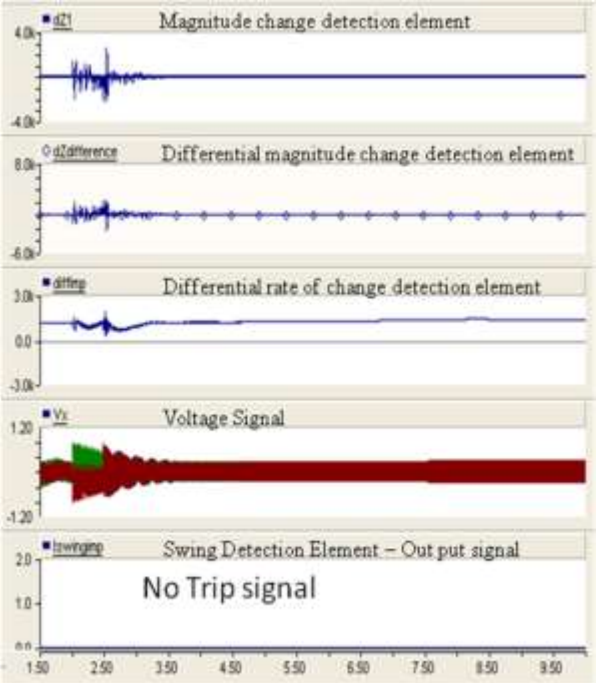


Fig.10 . Stable swing- Impedance based scheme. Created a disturbance at 2 Sec and removed after 0.5 Sec. between line B1-B2 of SMIB system

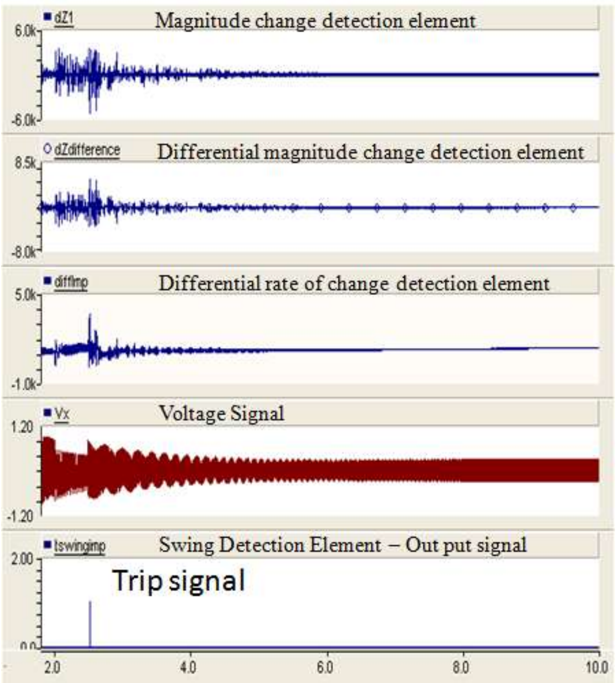


Fig. 11 Unstable swing- Impedance based scheme. Created a major disturbance at 2 Sec and removed after 0.5 Sec. between line B1-B2 of SMIB system

3 Conclusion

Power swing detection schemes based on WAMS - synchronised time measurement is proposed in this paper. Schemes work on the swing detection algorithm for resistance or impedance, where in the resistance, rate of change of resistance and differential measurements made from two sides of the transmission line detects the OOS condition. Similarly monitors Impedance for Impedance based scheme and detects the OOS condition. These methods use PMU data available at both ends of the transmission line. It is observed that as the disturbance severity increases, operating time of both the schemes reduces and this technique can operate for faults during steady state as well. Simulation results in SMIB case and WSCC 9 bus system case reveals that both the proposed schemes can detect and classify the power swing very precisely.

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