

Case Study on Fault Analysis Using PMU

Prithwish Mukhopadhyay
General Manager, WRLDC
Mumbai, India
prithwish.mukhopadhyay@posoco.in

Abhimanyu Gartia
Deputy General Manager, WRLDC
Mumbai, India
agartia@posoco.in

Pushpa Seshadri
Chief Manager, WRLDC
Mumbai, India
pushpa_seshadri@posoco.in

Rajkumar Anumasula
Senior Engineer, WRLDC
Mumbai, India
rajkumar@posoco.in

Chandan Kumar
Engineer, WRLDC
Mumbai, India
chandan.wrlc@posoco.in

Sunil Patil
Engineer, WRLDC
Mumbai, India
skpatil@posoco.in

Abstract— Synchronphasors are used extensively in Indian Grid to detect and analyze faults occurring in the system. This paper majorly discusses the case studies of power system faults that occurred in the Indian grid and its identification and classification using data obtained from Synchronphasors. The types of faults identified include symmetrical and unsymmetrical faults in power system. Further, in case of single phase to ground faults, the successful, unsuccessful and non - operation of autoreclosure has been verified. Data from Phasor measurement units (PMUs) helped in identifying the fault recovery time and operation of autoreclosure and provided a strong tool for monitoring the status of the protection system in the grid. A comparative analysis of the disturbance recorder files and the synchronphasor data has also been discussed in this paper. The comparative analysis is used for validation of the DR and Synchronphasor data. This paper has led to the development of disturbance analysis tool for fault analysis using both DR and Synchronphasor data which will ease the system operator decision making ability while taking decision during a contingency in the system.

Index Terms—*Synchronphasor, Faults, Autoreclosure, Indian grid, Disturbance recorder.*

I. INTRODUCTION

Power system operation in India is complex due to disparity in geographical distribution of resources and loads, network complexity with rapid changes in network configuration and increasing combination of UHV, EHV, HVDC lines and FACTS devices in the system. Synchronphasor measurement units also known as “Phasor measurement units (PMUs) have become a very effective tool for system monitoring and analysis.

The Indian Grid is a large synchronous grid which constitutes of Eastern, Northern, North-Eastern, Southern and Western grids. Synchronphasor measurement units have been deployed in each regional grid under the pilot projects for monitoring and development of analytics which will help in system operation [1-2]. This has proved to be a boon for understanding the behavior of Indian power system. The high

resolution data obtained from PMUs (25 samples/sec) with accurate time stamping provides a continuous snapshot of the system. Among the various applications explored from this technology, fault analysis is used extensively for understanding the sequence of events and also for strengthening protection schemes. It has helped in post facto analysis and real time detection of faults occurring in the grid.

In the Western regional grid, PMUs are placed strategically covering all types of buses like generator buses, intermediate pooling stations, load centers, HVDC substations etc. [2]. The potential transformer (PT) of the Bus and current transformer (CT) of the feeders have been used as analog inputs to the PMUs. Prior to Synchronphasor technology implementation in India, the identification, detection and classification of fault was confirmed from the Disturbance recorder (DR) files, Sequence of events (SOE) from the Relays and Sub-station SCADA. Obtaining these details from various substations resulted in delayed analysis and information about the power system phenomenon. With the PMU data available at control centers, the fault can be detected identified and classified in real time by observing the trends in various parameters of the system. This has saved a lot of time for analysis as the nature and type of fault can be confirmed at the control center itself although the DR and SOE are still used for its confirmation.

This paper is focused on the fault analysis of EHV transmission lines and bus bar, their characterization using synchronphasor and their validation using disturbance recorder data. Section II illustrates the single phase fault in the Indian power system followed by the Sections III and IV where phase to phase and three phase fault have been discussed. Section V discusses the validation of observations from Synchronphasor data with DR for power system. Section VI concludes the paper.

II. SINGLE PHASE TO GROUND FAULT

Single phase to ground fault is the most common type of fault in power system. Such faults are very common in

transmission lines and can be either temporary/transient or permanent in nature. The ground path provided by trees, fogs etc. are temporary in nature and these ground paths gets cleared immediately. The permanent nature fault appears in case the conductor breaks down (in case of transmission line), current or potential transformer bushing burst (in sub-station) or by some other permanent grounding path. To avoid permanent isolation of an element in case of a transient fault, auto-reclosure (A/R) for single phase faults is provided for 400 kV and higher level EHV transmission lines. On the basis of that, four cases of phase to ground fault are discussed here which are:

1. Single phase to earth fault on transmission line with successful A/R
2. Single phase to earth fault on transmission line with unsuccessful A/R
3. Single phase to earth fault on transmission line with no A/R.
4. Single phase to earth fault on Bus bar.

The first case of single phase to earth fault with successful autoreclosure is shown in figure 1 and figure 2 where a fault on B phase to earth occurred on 400 kV Jabalpur-Vindhyachal circuit 4. It can be observed that when a single phase fault occur on transmission line the voltage of faulty phase dips to a lower value while remaining phases will observe a smaller dip due to unbalance in the system as the fault is being fed by the bus whose voltage has been as shown in Figure 1.

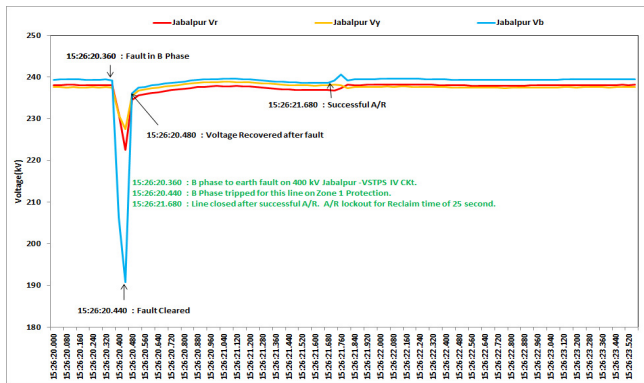


Figure 1. Voltage of 400 kv Jabalpur bus from Synchrophasor data during single phase to ground fault on 400 kV Vindhyachal-Jabalpur circuit 4.

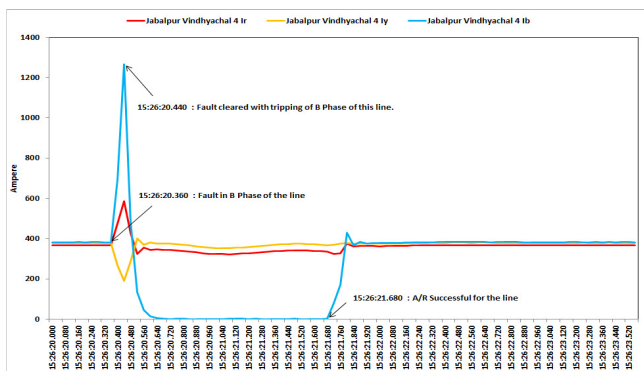


Figure 2. Current of Vindhyachal-Jabalpur circuit 4 observed from Jabalpur end from Synchrophasor data

Figure 2 shows how the fault current is increased in the faulty phase of the circuit indicating fault feeding from the affected phase. The line protection operated in zone 1 from both end and the faulty phase got isolated from both end resulting in recovery of voltage in faulty phase while current in the phase became zero. This has resulted in A/R initiation for the faulty phase and after 1 second, that phase got reclosed and further no fault was sensed resulting in successful auto reclosure. The line came back in service and the system again came to a balanced state. The voltage channel in PMU is obtained from the Bus PT so it will not become zero but due to the fault, the voltage of bus will get unbalanced and will observe a large dip in faulty phase.

Second case is the single phase fault with unsuccessful auto re-closure of the line. In cases where the fault is not of transient nature, permanent tripping of the line is required. One such case was observed in 400 kV Solapur Parli circuit 1. Figure 3 shows the voltage of 400 kV Solapur Bus during the fault while figure 4 gives the current observed in the faulty circuit from Solapur end.

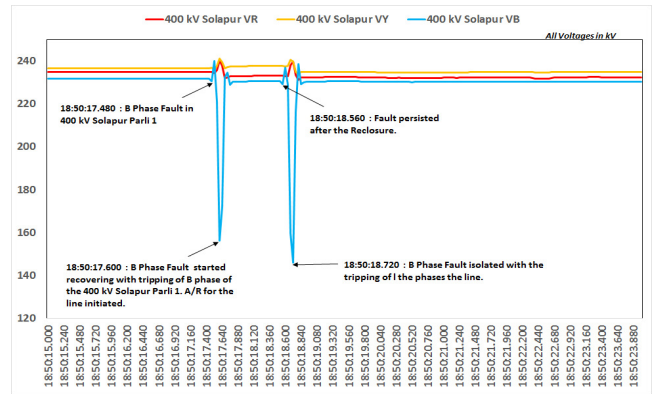


Figure 3. Voltage of 400 kv Solapur bus during single phase to ground fault on 400 kV Solapur Parli 1 circuit from Synchrophasor data

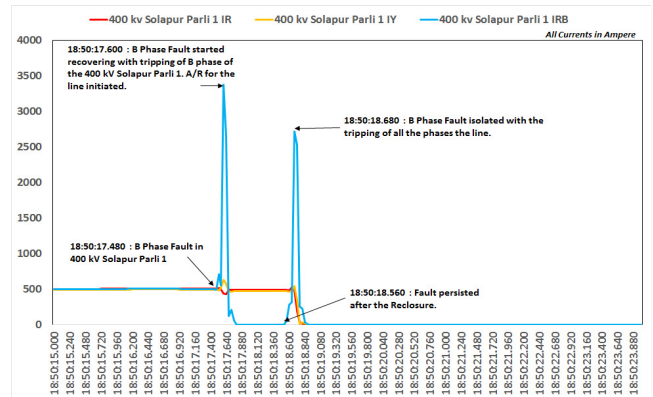


Figure 4. Current of 400 kv Solapur Parli circuit 1 observed from Solapur end from Synchrophasor data

B phase to earth fault occurred in the 400 kV Solapur Parli circuit 1 due to the heavy rainfall in the area. As observed from the voltage of 400 kV Solapur in figure 3, the voltage of faulty phase dipped to a very low value due to feeding of the fault through the bus. The fault current as shown in figure 4

increased and with carrier aided zone 1 protection, the line tripped in the faulty phase from both ends. A/R was initiated after one second. The faulty phase of the circuit got reclosed but due to permanent nature of fault, all the three phases were tripped thus isolating the faulty line.

There are cases in which the Auto-reclosure did not occur on the line in case of single phase to ground fault. This is mainly due to issue with the carrier communication or relay. Such cases are very much essential to be analyzed and informed to the concerned utility to rectify it at the earliest. One such case has been shown in Figure 5 and 6 where the auto reclosure activity was not observed during single phase to earth fault on 400 kV Korba-Bhatapara.

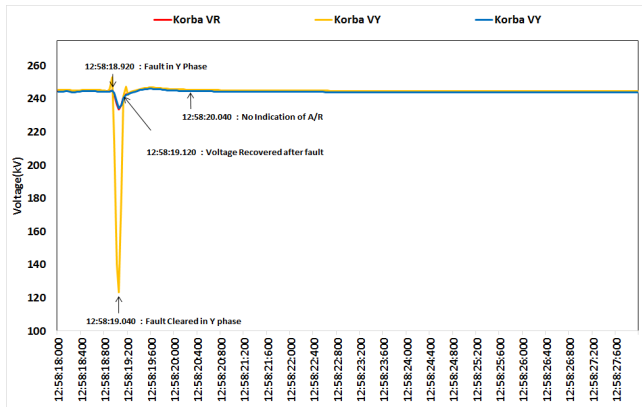


Figure 5. Voltage of 400 kV Korba bus during single phase to ground fault on 400 kV Korba Bhatapara circuit from Synchrophasor data

On 400 kV Korba Bhatapara circuit, Y phase to earth fault occurred on the circuit. As observed from the figure 5, the faulty phase voltage dipped at Korba and the fault got cleared with operation of line protection [2]. While figure 6 shows the current of the feeder from Korba end which confirms that all the three phases of the line tripped rather than single phase with A/R initiation. This was informed to the concern utility and rectified.

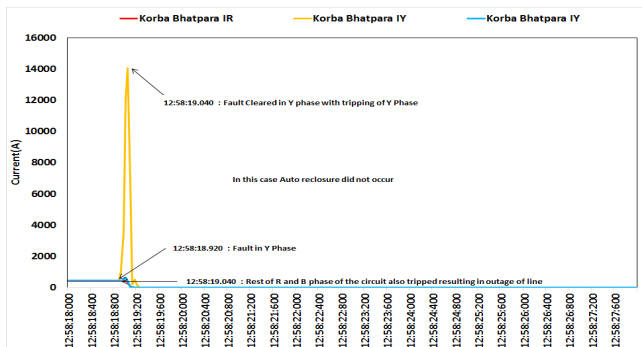


Figure 6. Current of 400 kV Korba Bhatapara circuit observed from Korba end from Synchrophasor data

The last case in the section of single phase to ground fault is associated with bus fault, which in general occurs due to problem with CT/PT bursting. One such case of bus fault at

220 kV level was observed by the synchrophasor unit installed at 400 kV nearby Bus is shown in figure 7.

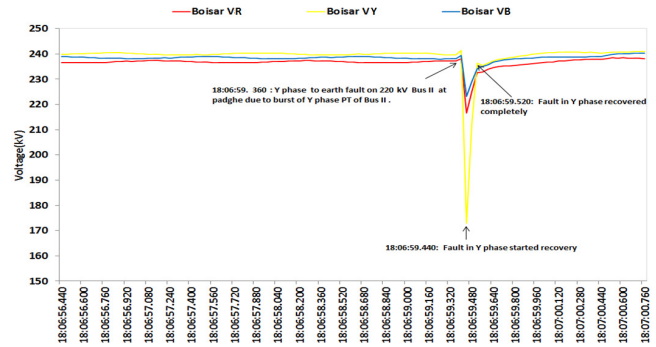


Figure 7. Voltage of 400 kV Boisar bus during single phase to ground fault on 220 kV Padghe Bus II from Synchrophasor data

From Figure 7, it can be observed that Y phase to ground fault occurred at Padghe Sub-station on 220 kV Bus II due to bursting of Y phase Bus PT. This resulted in fault feeding by the nearby buses resulting in voltage dip as observed in figure 7. The fault got cleared in 160 ms with the operation of 220 kV Bus bar protection of Bus II.

With this it can be understood that how easily single phase fault can be analyzed at control centre without any DR/EL from the sub-station with the help of synchrophasor data.

III. PHASE TO PHASE FAULT

The second category of fault in the power system is phase to phase fault. In such cases, the fault may involve a ground path or may not. Such types of faults are rare in nature and generally occur transmission lines.

The case as shown in Figure 8 and 9 is of the R-Y Phase fault on 400 kV Dehgam-Gandhar circuit 2. It can be observed from Figure 8 that the phase voltages of the faulty phases have dipped to a lower value till the fault got cleared with the tripping of line. The current observed from Dehgam for this line shows that the fault current in the faulty phases has increased drastically and it got cleared with tripping of the line from both ends on zone 2 protection.

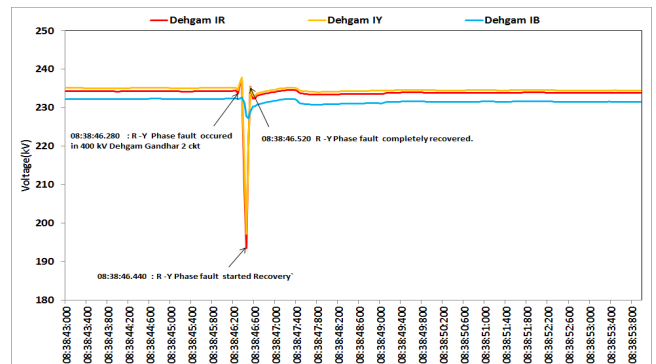


Figure 8. Voltage of 400 kV Dehgam bus during Phase to Phase fault on 400 kV Dehgam-Gandhar circuit 2 from Synchrophasor data

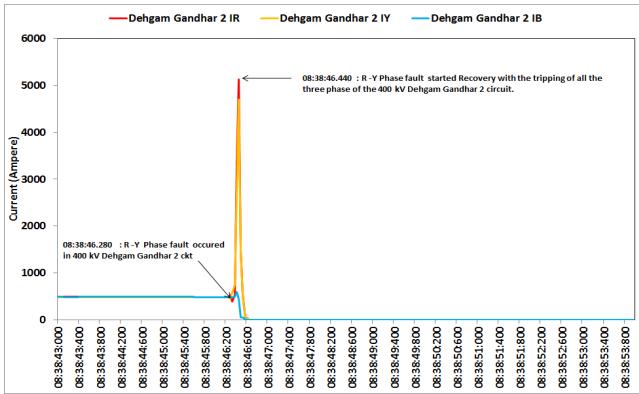


Figure 9. Current of 400 kV Dehgam- Gandhar circuit 2 observed from Dehgam end from Synchrophasor data

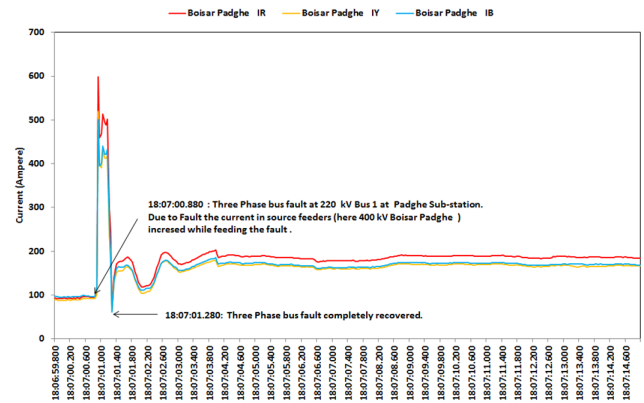


Figure 11. Current of 400 kV Boisar-Padghe circuit during the three phase bus fault on 220 kV Padghe Bus 1 from Synchrophasor data

It can be observed that how easily the phase to phase fault can be detected with the synchrophasor data. This has reduced the time taken for analysis of any complex fault in power system.

IV. THREE PHASE FAULT

One of the most severe and rare fault in the power system is the three phase fault. This fault may or may not involve ground. The severity is very high and may result in commutation failure of nearby HVDC or stalling of AC motor in the nearby area.

Two cases are considered here for example, one on a bus and other on the transmission line. Figure 10 shows the voltage of nearby bus during a three phase fault on 220 kV Bus 1 at Padghe. Voltage has dipped in all the three phases as the fault was being fed by the nearby buses. Figure 11 shows the current in the transmission line connecting the two substations, which has increased as the Boisar Bus is feeding the fault at padghe. The fault got cleared after the operation of bus bar protection.

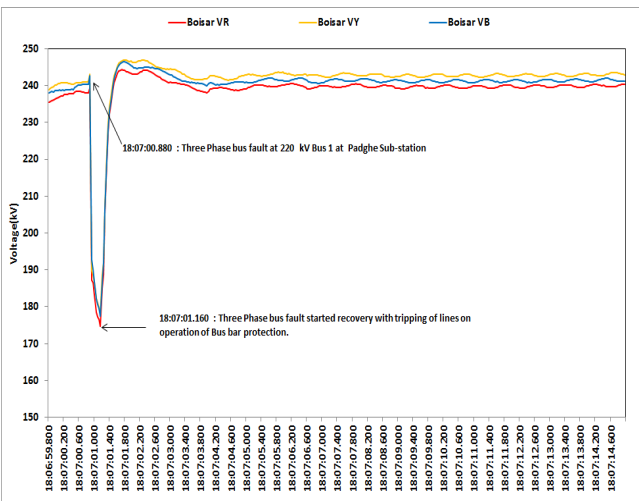


Figure 10. Voltage of 400 kV Boisar bus during three phase fault on 220 kV Padghe Bus 1 from Synchrophasor data.

The second case is of the three phase fault on a transmission line. Figure 12 and 13 shows the synchrophasor data for the three phase fault on 400 kV Raipur Wardha circuit 1. From Figure 13, it can be seen that during three phase fault on 400 kV Raipur wardha 1 circuit, the voltage on all the three phases of the Raipur bus I dipped to a lower value and recovered with tripping of the circuit on zone 1 line protection.

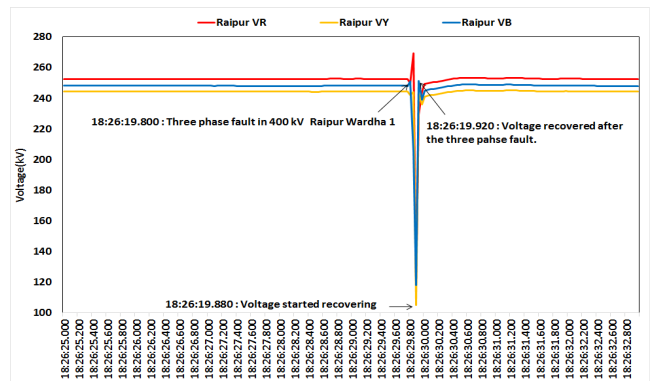


Figure 12. Voltage of 400 kV Raipur bus during three phase fault on 400 kV Raipur -Wardha circuit 1 from Synchrophasor data.

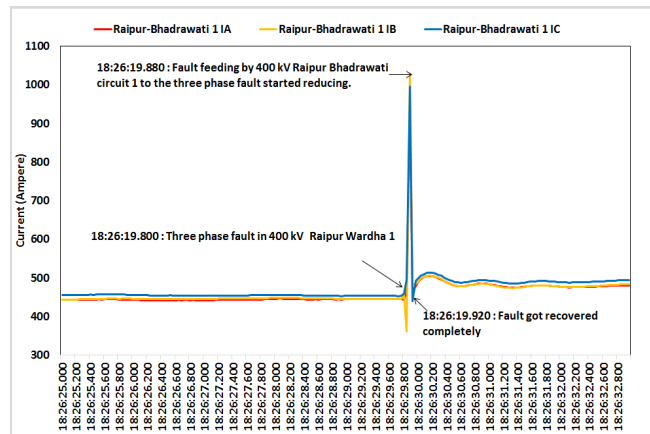


Figure 13. Current of 400 kV Raipur Bhadravati circuit 1 observed from Raipur end from Synchrophasor data

With this all three types of fault has been analyzed with the help of synchrophasor data. This has shown the importance of synchrophasor measurement units in fault analysis and event detection at control centers. In the next section the validation of synchrophasor data with the disturbance recorder file is discussed for determining up to what extent it can be used and what are their limitations.

V. VALIDATION OF SYNCHROPHASOR DATA FOR FAULT ANALYSIS AND ITS LIMITATION

Synchrophasor has come out as a very effective tool for analyzing faults in power system in real time. But the synchrophasor data has its own limitation compared to the disturbance recorder file which has higher sampling rate (kHz). Figure 14, 15, 16 shows the DR for the first three events discussed in section II in case of single phase to earth fault with successful A/R, unsuccessful A/R and no A/R respectively using SIGRA [3]. The Synchrophasors are the fundamental frequency component calculated using Discrete Fourier Transform (DFT). So, higher harmonic are being neglected which may result in different fault current observed from synchrophasor data and actual data from fault recorder.

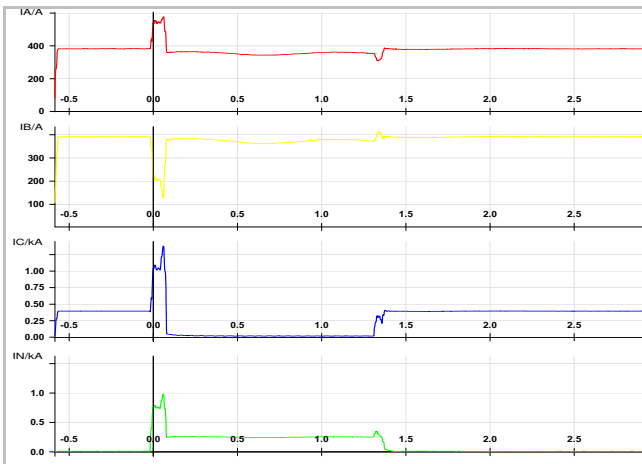


Figure 14. Current from the DR of 400 kV Jabalpur -Vindhyachal circuit 4 from Jabalpur end for the single phase fault (successful A/R).

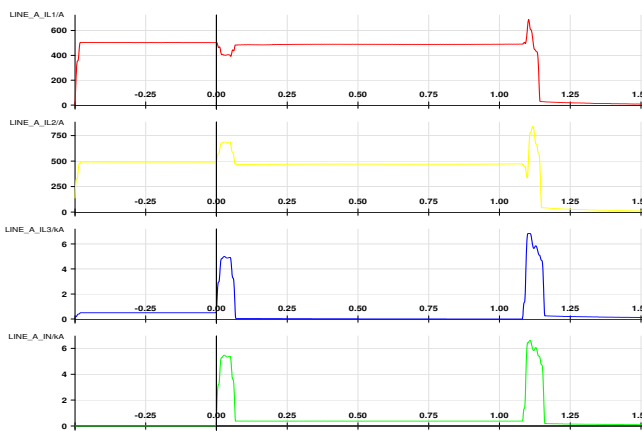


Figure 15. Current from the DR of 400 kV Solapur -Parli circuit 1 from Solapur end for the single phase fault (unsuccessful A/R).

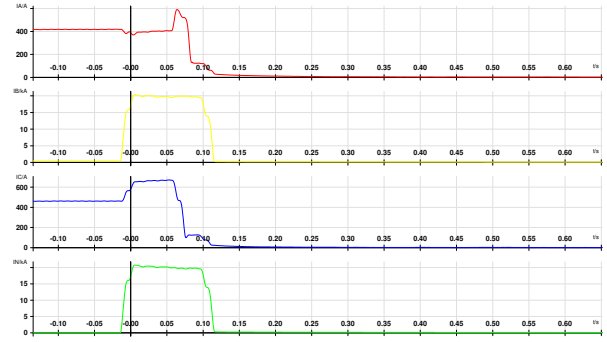


Figure 16. Current from the DR of 400 kV Korba Bhatapara circuit 1 from Korba end for the single phase fault (No A/R).

The validation analysis of the three cases is shown in table 1. Here major two parameters i.e. fault current value and fault clearing time has been tabulated for all the three cases.

TABLE I. VALIDATION OF DR AND SYNCHROPHASOR MEASUREMENT DURING FAULT

Case No	Maximum fault current observed from DR (kA)	Maximum fault current observed from PMU (kA)	Fault clearing time from DR (ms)	Fault recovery time from PMU (ms)
Successful A/R	1.365	1.25	98	80
Unsuccessful A/R	5.46	3.37	81	120
No A/R	18	14	94	120

It can be observed that fault clearing time from DR and PMU has slight difference which is attributed to mainly three factors:

1. Reporting rate of PMU (here at every 40 ms)
2. DFT Window length (generally varies from two cycles to 10 cycles).
3. Time stamping of phasor (time stamping at the starting/middle/end of DFT calculation window) [4].

This in general result in a ± 40 ms error in the time for fault recovery time [2]. It can be improved by increasing the reporting rate of the PMU.

Also, when the fault current is analyzed it can be observed that there is a difference between the maximum fault current from synchrophasor measurement and disturbance recorder, both of which are taken from the same CT of the feeder. This can be due to various reasons and out of these the major two are:

1. PMU uses measurement core while the DR uses the protection core of the CT which is having higher accuracy. (Although PMU can be made to use protection core of the CT also, but in India measurement core of the CT is used)
2. The second reason is the contribution of higher harmonics during faults.

During faults, the fault current has DC, fundamental frequency component and higher harmonic components. DR

measured currents are having all these components. While synchrophasor gives only the fundamental frequency component resulting in lower current values. Figure 17 shows the various components in the faulty phase current for the three cases discussed for validation in this section. It can be observed that the Current associated with fundamental component of the frequency is very close to that being observed by the synchrophasor units.

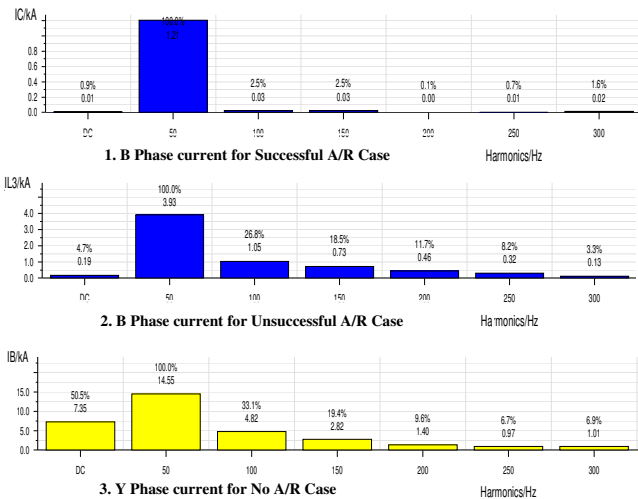


Figure 17. Various component of Current when maximum fault current appear in the three cases 1. Successful A/R 2. Unsuccessful A/R & 3. No A/R.

Thus, it can be inferred that, synchrophasor data has given a very good insight of various aspects of fault occurring in power system. Synchrophasor data can be used for event detection engine at control centers in real time by setting various thresholds to detect the individual type of faults. It also helps in quicker detection of A/R in case it has been enabled during single/three phase fault in zone 1 for transmission line. The magnitude of fault current signifies the severity of fault to the real time operator in taking decision for charging the faulty line. Synchrophasor data in combination with field records makes fault analysis easier.

VI. CONCLUSION

This paper has discussed the various types of faults as observed from the synchrophasor measurements. This has helped in finding the characteristics of different types of fault in power system. The paper has led the basis of disturbance analysis tool development for analysis of the fault in offline mode with the helped of Synchrophasor and DR data. It has also set path to the course of event detection engine in real time using synchrophasor data stream. Such development will help real time system operator to assess the severity of power system faults and take corrective action to reduce its after effects.

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