Simulation of Power System Faults for Protection Performance Analysis -
Case Studies of Tata Power

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SYNOPSIS

The paper describes The Tata Power Company Ltd. (TPC’s) practice of analyzing Power system faults using Dynamic Simulation Tool. A microprocessor based Relay Test Kit allows simulation of power system disturbance as well as replay of captured current and voltage signals from fault disturbance records. Two case studies described in this paper shows importance of simulation tool for selection of appropriate Protective Relays. Analysis of protection performance during occurrences has significant impact on selection of proper relays and will help in improving the power system reliability and stability. Conventional way of testing relay functions may not reveal the deficiencies in the relays either due to inherent protection algorithm problem or due to incorrect configuration / settings adopted. The disturbance records, captured by numerical relays and fault disturbance recorders, assist in simulation of Power System disturbances through Dynamic Simulation Tool. The typical disturbance records captured during occurrences can be preserved as fault library and used for evaluation / acceptance of new relay products.

1.0 INTRODUCTION

The Tata Power Company Ltd (TPC) is the largest private sector utility in the business of power Generation, Transmission and Distribution in India. TPC has been supplying uninterrupted and reliable power to Mumbai City for the past ninety years. The customer base in Mumbai area operations of the company constitute a large number of industries like refineries & fertilisers, sophisticated laboratories and atomic research centre, essential public services like railways and water supply, other continuous process industries, residential and commercial complexes and Distribution Licensees. TPC is one of the constituents of the Western Regional Grid of India with an installed capacity of about 1800 MWs, comprising of three Hydro power stations at Khopoli, Bhivpuri, and Bhira and a Thermal power station at Trombay. Power is being supplied through 220kV/110kV transmission lines and 33kV, 22kV, 11kV, 6.6kV & 415V distribution networks.

As part of protection upgradation program, TPC has inducted numerical Protection relays since late 1990s. Analysing and comparing the performance of numerical protection relays during dynamic power system condition has been a challenge due to complex algorithms and various configuration options offered by the relays. In this paper, the authors have described the TPC’s practice regarding analysis of Power system faults using a Dynamic simulation tool provided by microprocessor based Relay test kit which allows simulation of power system conditions as well as replay of captured current and voltage signals from fault disturbance records. Analysis of protection performance during the faults has significant impact on reliability of power supply and also on selection of appropriate relays and it’s settings for the protection.

2.0 METHODOLOGY ADOPTED FOR POWER SYSTEM SIMULATION

TPC has introduced stand-alone type Fault Disturbance Recorders in 1980’s for analysis of Power system disturbances. Most of these devices were initially commissioned on 220kV & 110kV transmission lines and on Neutral CT of Power Transformers to capture LT disturbances. These FDRs were recording events on a Magnetic tape and a plotter were being used to draw the disturbance records. With the advent of Digital Fault Disturbance Recorders, which was introduced in 1990’s, the events were analyzed with proprietary software supplied by device manufacturers. Some of these softwares had the ability to give a) Distance to fault location...
b) Impedance locus c) Harmonic contents etc. The advantage of these stand-alone type Fault Disturbance Recorders is its high sampling rate to record the events. Many a times, reproduction of Disturbance Records captured by these stand-alone type FDRs were found to be better than the events recorded by Numerical Protective Relays (where the sampling rate is around 800Hz). The stand-alone FDR used in the system has a scanning rate of 2.0 KHz and total recording time of 2.0 sec. The Digital Inputs and Analogue Inputs are stored in FDR memory (which has 32Kb memory for Digital Inputs and 500 Kb for Analogue Inputs). These FDRs transfer events from FDR memory to a dedicated PC in batch mode (on line).

TPC has built its own Wide Area Network for data transfer at most of their Receiving and Generating Stations. TPC’s high-speed communication network (100 Mbps) is based mostly on fiber optic. All FDRs in the system are configured to down load their event files directly into a local PC on continuous basis (batch mode) and further these events are down loaded at Central Relay Control Centre through private WAN of TPC. This facilitated creation of a library of event files at Relay Control Centre. The event library stores all critical system fault disturbances recorded either by stand-alone type FDRs or by Numerical Protective Relays. The event library constitutes Line faults, df/dt condition, power swings, equipment failures such as CTs, LAs etc. triggered by either protective relays ’OR’ by analogue quantities such as Voltage/Current - High/Low.

One of the most important features of the new software provided by Relay / FDR manufacturers is conversion of “Event File” into “Comtrade File” comprising of ‘Configuration’ and ‘Data file’ to define the event. This comtrade file is understood by other device manufacturers viz. relay testing simulators. One of the Numerical Test Set procured by TPC has Fault simulation tool. TPC extensively uses a Computer aided system simulation tool for analyzing mal-operation / non-operation of protective relays. This tool can be used without PC (local mode) or with PC. The test kit can be used for testing of protective relays based on Voltage, Current and frequency etc. in local mode. However operating through PC, few advanced functions such as “Replaying of disturbance records”, injection of Harmonic voltages / currents, Automatic Relay Testing etc. are possible. Both static and dynamic testing can be performed, such as creation of pre-fault and fault condition, simultaneous ramping of several quantities and waveform editing etc.

The disturbance records can be replayed using the ‘transient function’ in the kit. In this function, there is also a possibility of adding normal sinusoidal waveform before the fault. The simulation software converts comtrade files obtained from standalone FDRs / Numerical Protection Relays into ‘sdf’ file. While converting the file, one can change the CTR / PTR of the signals i.e depending on 1 Amp / 5Amp for Currents and PT ratio for Voltage waveform. Thus peculiar wave shapes can be replayed on new relays to observe their performance. Pinpointing the portion of the waveform where the relay has operated can also be obtained by truncating the waveform and replaying it again and again.

3.0 Case Studies:
Two Case Studies are presented in this paper. First case identifies mal-operation of Distance relays for evolving faults whereas second case throws light on non-operation of under frequency relay at the time of system disturbance (Islanding operation).

3.1 Case study-1 (mal-operation of Distance Relay)
220 kV Trombay – Salsette line # 1 / 2 Distance relay operated at Trombay for a fault in reverse direction.
The case refers to a fault occurred on one of the 220 kV MSETCL, Trombay - Kalwa Line as shown in fig. 1. This was an evolving fault in the 220KV system i.e. the fault got initiated on B&C-phase and subsequently spread to A-phase as can be seen in the fig.2a given below. ‘B’ phase and ‘A’ phase faults were of severe type whereas ‘C’ phase fault was high resistance type, which can be observed in the waveform record given below.

From the waveform as shown in fig. 2, it is observed that the fault was detected in B and C-Phase to ground and later on spread to A-Phase. For such evolving faults, the Main-2 Distance Relay, which is of switched type mal-operated whereas Main-1 Distance Relay which is of non-switched type, did not operate. As long as fault was between B&C Phase the Main-2 Distance Relay was stable. After the fault had spread to A-Phase, the relay has picked up and tripped after a lapse of Zone-2 time (400 msec.)

![Diagram](image.png)

(a)        (b)

Fig.: 2 – Diagram a: waveform captured during fault by Stand-alone FDR
   b: Waveform as applied on relay after processing.

Since these relays were not to operate for a reverse fault, it was decided to check the mal-operation of Distance Protection using Power system Simulator tool. The waveform captured by stand-alone type FDR was used for this purpose (fig. 2a). Relay mal-operation was verified by ‘replaying’ the FDR file of above event through the automatic relay test kit on a spare relay of similar type and adopting same relay settings.

<table>
<thead>
<tr>
<th>Equipment / Protection Details,</th>
<th>Line: Trombay - Salsette # 1/2</th>
<th>Line Length (km) = 23.98</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTR = 2000/1, PTR = 240 kV / 120 V</td>
<td>Line Parameter = Z+ = 1.457 + j 9.428 ohm</td>
<td></td>
</tr>
<tr>
<td>Zo = + j 30.806 ohm</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Further, the same Disturbance record was replayed on a ‘Non-switched’ type Distance relay and the relay was found to be stable (not operative). The disturbance record shown in above fig.2b gives record before processing through test kit and displays waveform record ready for replaying on relay. The point to be noted here is that the waveforms obtained from FDR & the one ready for Replaying are exactly similar.

The simulation analysis clearly established susceptibility of the particular switched distance relay model and decision to phase out this protection from critical trunk lines.

3.2 Case study-2 (non-operation of under frequency relay)

This refers to a case where Under frequency relay of islanding scheme at 110 kV Salsette R/S failed to operate during one of the System Disturbances.

TPC has deployed Under Frequency Relays at their various Receiving & Generating Stations for Load Shedding and Islanding Scheme. During one of the major system disturbances, the relay at Salsette R/S failed to operate while the relays at all other locations operated correctly. However, the fault got isolated by the operation...
of distance Protection. Hence, it was decided to check the performance of this relay using FDR event captured during the above occurrence.

Under Frequency relay setting adopted on above relay - Stage 1: 47.6 Hz, 0.15 sec. and Stage 2: 47.0 Hz, 0.2 sec. Subsequent analysis revealed that during the occurrence, there was a major system disturbance in western Maharashtra, wherein the system frequency dropped from 50.3 to 46.7 Hz and TPC system got islanded from rest of the grid.

The islanding system operated satisfactory at all tie points except at 110 kV Salsette R/S. The frequency was 50.3 Hz prior to the disturbance and initially fell to 49.5 Hz, further it dropped rapidly at the rate of 2.5 Hz/sec. Frequency remained below 47.5 Hz for 2.43 sec. Since TPC system remained connected to the grid, finally the 110 kV Salsette – Kalwa line tripped by Distance Protection Zone II at Salsette due to prolonged power swings.

Non-operation of U/F islanding scheme at Salsette for 110 kV Kalwa – Salsette line was further investigated. Dynamic simulation of Voltage waveforms from FDR was carried out using the Test kit. By replaying the event the relay did not operate. It was found that U/F relay is a self powered relay (powered by PT supply) with a built-in U/V block at voltage below 70% of V-rated. This was the only relay which remained in the system without modification for functioning with auxiliary DC Supply. Relay operation was getting inhibited due to under voltage condition on 110KV bus, which prevailed during system disturbance due to phenomenon of voltage collapse on overload accompanied by drop in frequency. The same waveform was then replayed on Numerical relay on which U/V blocking can be set manually. Initially Numerical relay also did not operate with U/V setting at 70%. However by lowering the U/V block setting, the relay operated correctly with above disturbance record. Stage-2 U/F (set at 47 Hz-0.2sec) relay did not operate as frequency had gone below 47 Hz and immediately recovered.
Fig.: 5 – Diagram a: waveform captured during System Disturbance by Stand-alone FDR 
   b: Waveform as applied on relay after processing.

The disturbance records before processing and after processing are as shown in above fig. 4 & 5.

4.0 CONCLUSION

Numerical protection relays of different makes, types and version can exhibit different behavior during abnormal power system condition. Conventional testing of the relays may not reveal the deficiencies in the relays, either due to inherent protection algorithm or due to incorrect adopted configuration/setting.

The disturbance records captured by the numerical relays and fault disturbance recorders can be used to simulate the disturbance and play the same on various types of devices. The typical fault records can be preserved as fault library and used for evaluating new relay products. Analysis of the protection performance will help in improving the power system protection and hence contribute to grid reliability and stability.