APPLICATION ASPECTS OF SYSTEM PROTECTION SCHEMES

By

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Abstract

The paper discusses some problems being faced in the application of certain protection schemes and their impact on the system security and stability. Some of the reasons are due to the conservative utility practices and non provision of certain important protections. Some of the important problems are discussed through case studies related to Western regional grid.

1. Introduction.

Protection schemes are provided in the power systems for protecting the components from faults or dangerous operating conditions. Even though most of the protections are meant for protecting the equipment, some of the protection schemes especially remote back ups, Zone-III settings, bus bar and LBB protections can affect the power system components beyond the protected component. The o/v, U/F protections come under the category of those protections that relieve the equipment or system from dangerous operating conditions. However, some of the protection schemes are also meant for ensuring the security of the system as a whole and as such are important not only to safety of the equipment but also to the transmission system as a whole. The protection meant for safeguarding the equipment from overloads and faults can be termed as component protections whereas those protections which help in providing relief to the equipment or enhances security of the system are termed as system protections. Auto reclose feature, power swing blocking feature of distance relays can also be included under the class of protections which give relief to the equipment as well as enhance system stability and security. Improper application of system protections, bypassing or using conservative settings can lead to lowered security margins and grid may be vulnerable in the event of some faults. Certain case studies have been selected to highlight the application aspects of these protections and the recommendations have also been given for proper application of these protections.

2. Discrete frequency and frequency trend relays

2.1 Case Study-1: System Disturbance at Trombay

On 10th March 2002, a system disturbance took place at Trombay due to bursting of A & B phases of CT of Unit-5 (500 MW) connected to 220kV bus section-2. Since the fault is located within the CT core at a blind spot not covered by the bus bar protection. As such, the fault was cleared after 500 ms (zone-II time) through tripping of all feeders at remote ends in zone-II. Since the fault was phase to phase in nature and persisted for 500 ms, heavy fault current circulated causing severe voltage dips. It is interesting to note the sequence of events in this disturbance. Due to voltage dips in the TPC system during the fault, several motors tripped in the TPC system and reduction of load was also obtained through other voltage dependent loads. Initially, the system frequency was around 48.72 Hz. Due to the transients generated by the faults and voltage dip, the df/dt relays set at 49 Hz, 0.5 Hz per second operated at Parel, Dharavi, Kalyan, Borivli and Salsette in TPC system and at Padghe & Apta in MSEB system. A total load of around 600 MW was thrown off – 300 MW through voltage dips and 300 MW due to operation of df/dt relays. Consequently, frequency shot up to 48.95 Hz. The rate of rise in frequency as recorded by Frequency Trend System supplied by ERDA and commissioned at Jambua (GEB) Load Despatch Centre recorded is 0.45 Hz per second. The clearing of fault after 500 ms led to loss of generation of 685 MW at Trombay. Unit-4(150 MW), Unit-7-A (120 MW) and Unit 7-B (60 MW) tripped due to problems in auxiliaries due to the voltage dip. With the loss of generation, frequency decayed from 48.98 Hz to 48.78 Hz and df/dt observed was around 0.15 Hz per second. Subsequently, the system frequency was restored by running hydro machines of TPC and Koyna of MSEB. The frequency and df/dt curves as recorded by Frequency Trend System of ERDA are enclosed. As can be seen from these recordings, the frequency rise and fall 0.23 Hz and 0.2 Hz with the frequency rise preceding the drop. The rate of rise of frequency is very high as compared to the rate of drop in frequency. This indicates that the first effect to come is the load reduction/loss due to voltage dip while the last effect to appear is the loss of generation (with unit-5 of 500 MW capacity tripping first due to operation of GT and overall differential protection) with both the effects separated in time by 500 milli seconds. The effect of load shedding through df/dt relays could have been superimposed on both these effects as initiation of the relay operations to actual relief could be separated by 300 to 350 milli seconds. It is also notable that the plots do not reveal either frequency touching 49 Hz or rate of change of frequency fall touching 0.5 Hz/sec which are the preconditions for operation of the U/F relays. The operation of the relays could have possibly been influenced by the wrong measurement of the instants of zero crossing due to the distortion in wave form.

The significant feature of the above occurrence has been that load shedding through voltage dips and operation of df/dt relays preceded the frequency drop due to generation loss. The undesirable operation of df/dt relays possibly could be due to the principle used for frequency and rate of change of frequency measurements based on timing the zero crossing instant of the 50 Hz voltage wave form with respect to a standard reference pulse. However, in the presence of harmonics, the zero crossing can occur at number of points and may cause mal-operation of these relays. As is evident in this occurrence, the transients generated by the multi phase fault consisting of various frequency components (harmonics) might have distorted the wave form and caused number of zero crossings which led to mal-operation of the relays. Further, the relays have to block their operation for voltage dips below 0.5 p.u. Such blocking feature need to be designed properly considering the possible mal-operation for close in faults. Further, the conventional frequency and df/dt relays use only measurements on one phase. Due to inherent disadvantages as explained above, need arises for designing frequency (discrete), df/dt(trend) relays based on different principles other than zero crossing. Since, mal-operation of these relays are likely to cause load shedding and may improve the system conditions and security levels and as such, some mal-operations can be tolerated. However, in cases where precision of operation is needed (like in islanding schemes), duplication/redundancy may be thought of with one relay operating on conventional zero crossing principle and the other based on sampling of phasor measurements (3 phase).

2.2 Case Study-II: System disturbance at Gandhinagar TPS on 12.9.2001.

On 12.9.01 at 0516 hours, Y phase CT of station transformer No.3 on 220kV bus-1 burst due to corona of the early morning hours. At the same time, B phase pole of generator breaker of Unit-4 also burst. Due to simultaneous bus faults on both the buses, bus bar differential protection for both the buses operated leading to tripping of all 220kV feeders and generating units connected to both the buses. Due to consequent generation loss of 700 MW, frequency dipped from 48.1 Hz to 47.8 Hz. Normally, the frequency dip for a loss of 700 MW will be around 1 Hz at this time due to the frequency response characteristics of 700 MW per Hz of W.R system. Frequency dip was minimized due to the operation of df/dt relays set at 49 Hz, 0.4 Hz/second and 49 Hz, 0.2 Hz/sec in Gujarat only and no operations reported from other states. This occurrence points out to the operation of df/dt relays close to the source of disturbance and non-operation elsewhere in the system. It can also be seen from the enclosed frequency plots (f & df/dt) obtained during disturbance at Trombay on 19.3.2002, df/dt of 0.3 Hz/sec was recorded for a loss of generation of 680 MW while df/dt relays set at 49 Hz, 0.2 Hz/sec at far away substations did not operate. As such, the automatic U.F load shedding through df/dt relays should be provided at sub-stations close to the generating stations. The settings of df/dt at these sub-stations (customized and tuned) should also correspond to the possible df/dt that can occur due to loss of generation at the particular nearby stations.

The present practice having two settings 0.2 Hz/sec and 0.4 Hz/sec everywhere in the system and even at locations for away from the generating stations should be discontinued. It is also recommended that discrete U/F relays should not be bypassed relying on the expected relief from df/dt relays due to these uncertainities.

2.3 Case Study-III: System disturbance at Bhusawal on 4.3.1997.

A bus fault occurred at 400kV Bhusawal substation at 1006 hrs due to bursting of CT of TBC. All the 400kV lines emanating from 400kV Bhusawal S/S and 400kV Kalwa-Lonikhand ckt.I tripped. Due to loss of upper corridor in Maharashtra, the lower corridor (Chandrapur-Parli-Lonikhand-Kalwa-Karad got critically loaded. MSEB did distress load shedding of 3000 MW at several substations along with backing down at Chandrapur, Koradi & Parli power stations. Frequency shot up from 48.76 Hz to 51.9 Hz leading to tripping of one unit at Tarapur and one unit at Nasik and stabilized at 51.4 Hz. The sudden load shedding caused power swings in all the corridors and Gujarat system separated from the grid due to tripping of 400kV Indore-Asoj D/C lines and 220kV ties between MSEB & GEB. This occurrence in Maharashtra reveals that sudden load shedding of large quantum could lead to potential dangers due to power swings generated in the system.

In Western region, 3000 MW load relief was provided at 47.9 Hz frequency setting instantaneously. Such bulk quantum of load shedding in one single step could lead to shooting up of frequency by around 4 Hz which is not desirable in the absence of free governor mode of operation. In certain seasons – monsoon and summer or during off peak hours, the frequency may shoot up by more than 6 Hz. This could result in tripping of nuclear units and gas units and some thermal units eventually leading to a major disturbance. It is, therefore, prudent to decide upon the quantum of load shedding at each frequency step through studies and the frequency steps should be increased with small quantum of load shedding at each step rather than having less number of steps with large quantum of load shedding at each step. Through studies, one can arrive at optimal number of steps and optimal load shedding at each step.

3. Bus Bar & LBB Protections

3.1 In many of the utility sub-stations, all feeders are connected to one single bus and a bus fault at such critical buses could be catastrophic. A case in point is that of Karamsad s/s with 15 feeders. It is required to sectionalise such bus bars and distribute feeders such that loss of generation, loss of load or loss of key transmission elements could be minimized in the event of a bus fault or a stuck breaker condition.

3.2 Bus Bar and LBB protections have not been provided at number of substations. In certain cases, the bus bar protections even though procured have not been commissioned. From the system stability point of view, it is required to clear the faults within 5 cycles so as to ensure system stability. Fault clearance times have an important bearing on system stability and security. If faults are remaining uncleared for more than 100 ms, the circulating fault currents may cause voltage dips and possibly cause damage to some substation equipments. In fact, with increasing fault levels, it may be required to provide B/B protections even on 220kV & 132kV sub-stations (atleast on those close to the generating stations.) In case, a bus fault is not cleared through bus bar protection, the same would be cleared by remote end breaker trippings in Zone-II after 350-500 milli seconds (Zone-II time of distance relays). It is also required to have bus bar configuration in substations so that minimum number of feeders tripped in the event of a bus fault. In the case of 1 ½ breaker scheme, no feeders would be lost in the event of a bus fault and only two feeders will be lost in the case of a struck breaker through operation of LBB protections. The LBB protections are also essential to clear the faults in the minimum amount of time following a struck breaker conditions. These measures would increase security of the system as without bus bar & LBB protections, more lines may be lost (including those connected to healthy bus sections) due to remote zone-II trippings. Bus bar protections should not be kept out while transferring feeders from one bus to the other main bus or transfer bus. In fact, under no circumstances, should this important protection be kept out.

3.3 The CTs should be selected such that they do not saturate within one cycle of fault inception. The B/B protection should be restrained from operating if a CT saturates in ¼ cycle or less after the occurrence of a fault. These measures would eliminate the possibility of B/B protections to operate for external faults. Even though this problem is eliminated in the high impedance relays, the B/B protections maloperated for external faults due to inadequate stabilizing resistance (occurrence at Nasik on 14.6.99, mal-operation of CAG relay) whose ohmic value corresponds to fault levels at the time of the commissioning of the B/B scheme. The stabilizing resistance was upgraded to 400 Ω from 200 Ω.

3.4 Case Study-IV: System Disturbance at Korba STPS on 12.12.2000

This case study describes an interesting event in which the B/B protection operated without a bus fault. In order to attend air leakage of 400kV bus section breaker between bus sections II & IV, earth switches were being closed at both the sides of the breaker. Since this is an ABB make ABCB, air draining was required and hence breaker was in closed condition. As soon as the second earth switch was closed, B/B protections for both the bus sections (Zone II & IV) operated. Due to electromagnetic induction, circulating current in this closed circuit resulted in unbalance both in main and check zones of bus sections II & IV, sufficient enough to operate bus bar protection. All the units and feeders connected to both the bus sections tripped It is also required to stipulate operating practices during maintenance to avoid such disturbances and the requirements of sensitivity (as the case) vis-à-vis stability.

At certain sub-stations, bus section breakers or bus couplers have been provided with over current protection even though B/B protection is available for all zones. On number of occasions, tripping of bus coupler on over current protection led to unbalances on both the buses and led to tripping of other feeders and units. It is required that bus couplers should not be protected by O/C or E/F protections.

4. Distance Protection Schemes

4.1 Zone-III settings

The standard utility practice for setting Zone-III of distance relays is to cover the protected section and the longest line from the remote end or even beyond. In some cases, the Zone-III settings are restricted to cover up to the effective impedance of all parallel transformers at remote end and to ensure that faults beyond L.V buses are not covered. Large coverages in Zone-III may lead to load encroachment under low voltage conditions. Further, during power swings in the system, the relays would operate due to entering of power swings locus in Zone-III. During the last 10 years, number of occurrences have power swings as the main compounding factor that led to spreading of the disturbances. In order to ensure system security, load encroachment should not occur in Zone-III of distance relays incase of tripping of a parallel ckt under low voltage conditions. For instance, consider the case of congested corridor like 400kV Itarsi-Indore D/C carrying around 500 MW per ckt or more. In case of tripping of one ckt, the other ckt. is likely to carry about 800 MW and possibly under low voltage conditions. The tripping of the parallel ckt as well as increased power flow on the healthy lines beyond SIL would further aggravate the voltage problem. Under such circumstances, the tripping of the healthy ckt due to load encroachment in Zone-III may culminate into a major disturbance through system splitting into parts with mismatches in load and generation or through voltage collapse. Thus, it is required that relay actions should not cause tripping of critically loaded lines as operator action like load shedding and generation reduction would bring back the system condition to normal. It is therefore necessary to set zone-III settings judiciously.

4.2 Large in feeds at the remote end of the protected line causes under reaching of both Zone-II & Zone-III settings. In such cases, it is difficult to really cover the entire length of the longest line emanating from the remote end in Zone-III as this requires too large a setting with certainity of load encroachment. In such cases, Zone-III coverage could be restricted to about 10% higher than the Zone-II coverage.

4.3 There were instances in the past when the “SFT” feature of RALZB relays (relay based on traveling wave detection) operated due to low voltage conditions occurring out of tripping of a parallel circuit. The SFT setting should operate only when a dead line is charged and not on a loaded healthy line without a fault. After the minimum voltage condition was modified to 60% from 80%, the undesirable operations stopped totally.

4.4 The “BU” feature of RALZB relay operated for faults on other sections and tripped the protected line which aggravated the extent of the disturbances. The “BU” feature is an earth fault relay with a definite timer usually set at 2.5 seconds. However, due to conservative setting of this feature for 1.5 seconds and in some cases 1.2 seconds by some utilities has been the main problem. Since the coverage can not be pre-determined, the possibility of this relay operating for faults on LV lines is likely if the relay location has a strong feed.

4.5 It is also a matter of concern that utilities prevent tripping of ICTs on overloads with conservative settings. This would possibly lead to over loadings elsewhere and culminate in a distance or increase the extent of the disturbance. The ICTs should be tripped only corresponding to winding temperature high. The cooling system should be routinely checked and maintained.

5. Over voltage protections

5.1 Due to inadequate absorption of VARs in the system and lack of adequate bus reactors and other reactive compensation devices in the system, high voltage problem is practically controlled through opening of 400kV lines. This reduces the network security due to lack of redundancy. In addition to already opened lines, the possibility of tripping of some of the remaining lines is a major cause of concern as the over voltage settings for Stage-I are set in a conservative way. In certain cases, the over voltage settings as low as 105% (420 KV) are employed even though all 400kV equipment are rated for continuous operation at 420 KV. All the 400kV equipment are designed to operate at 110% (440 kV) voltage for 15 minutes. Due to adoption of lower settings, the likelihood of tripping of lines on over voltage is very high and these trippings as being unanticipated create alert conditions to the load dispatchers. Further, due to lack of proper coordination, two or three lines may trip in different corridors passing through different utilities and may weaken the transmission corridors seriously. The adoption of 110% settings for Stage-I was recommended by the protection committee after prolonged discussion in number of meetings. Still the utilities have not revised their settings.

5.2 In respect of Stage-II over voltage settings, 150% instantaneous is recommended considering the dynamic over voltages arising out of load rejections. As per the standards, 150% voltage can be allowed for 5 cycles in case of load rejections. However, the settings employed by the utilities are 120% to 130% which may cause unnecessary trippings while charging the lines or during DOV following load throw off.

5.3 Case Studies.

The sudden load shedding carried out in MPSEB on 20.9.2001 led to tripping of 400kV Vindhyachal-Jabalpur ckt.II and Jabalpur-Itarsi ckt.I on o/v. The sudden bulk load shedding of 700 MW in MPSEB led to tripping of two 400kV lines between Itarsi and Jabalpur on 17.8.2001 & 31.8.2001 even though the over voltage settings on these feeders are set at 110% with time coordination. Here, the most important factor is the pick up to drop-off-ratio. In case the over voltage relay picks up, it will not reset unless the voltage falls below the drop off setting (about 95%) before the timer times out. In case two parallel circuits set at 108%, 110% with time setting of 5-seconds pick up due to rise of voltage above 110%. Both the lines may be lost as timers are not coordinated. In another case of one relay set at 110%, 6-second and other relay set at 108%, 3 seconds for two parallel 400kV feeders, if the over voltage at the bus comes to 110%, both the relays would pick up with the relays set at 108% would trip first leading to over-voltage reduction but the relays set at 110% would also trip unless the voltage comes down to 418 kV (1.045%) before the timer times out. These are the complexities in setting of Stage-I over voltage relays.. Such possibilities can be overcome by setting the relays at 110% with timer coordination and choosing relays with high drop-off to pick-up ratios. It is also required to compensate for the CVT errors while setting o/v relays. The CVT errors should be cross checked with bus PT voltage.

6. Over fluxing protections.

6.1 Stringent and conservative settings are imposed on over fluxing protections for transformers. In the case of generating transformers, the settings at times are so conservative that they would come in the way of operating the machines in the over excited conditions for generating much needed reactive power. The settings are based on v/f of 2.2 which consider normal voltage (110 volts) and frequency (50 Hz) kept for alarm and 2.36 for tripping. However, the trip settings can be increased to 2.54 considering 110% voltage and 47.5 Hz frequency. The manufacturers recommendations should be sought on over fluxing settings.

6.2 Over-fluxing relays become even redundant on 400/220kV ICTs as 400kV lines are provided with o/v relays for tripping at 110% and no tap changing is done on these transformers for o/v control. However, o/f relays are required on 220/132kV ICTs as o/v protections are not provided on 220kV feeders and a stuck tap changer can lead to abnormally high voltage. The o/f relays shall be provided on both HV & LV sides to take care of the possibility of energisation of the transformer from either end.

7. Single phase auto-reclose schemes on transmission lines.

7.1 In almost all 400kV lines, single phase autoreclose facility has been provided. However, on most of the lines, the autoreclose feature is kept in “non auto” mode.

Since about 99% of the faults are transient in nature, there is a strong case for employing autoreclosure. The autoreclosure feature enhances stability of the system. It has been seen through EMTP studies that the autoreclosure could be successful even with a dead time of 0.5 seconds. However, the utilities are not keeping the autoreclosure facility in service apprehending success rate of autoreclosure and possible jerks following reclosing on to the fault. Considering adequate margins, it is essential to keep autoreclose relays in service with dead time of one second, which would ensure successful autoreclosure in majority of the cases. As this feature has been provided to enhance system stability, it is recommended to keep the autoreclose always in service. (especially in the congested and critically loaded corridors)

7.2 Problems have also been faced due to non-coordination of auto reclosure settings and breaker pole discrepancy relay settings. With the PDR setting lower than A/R dead time setting, the breaker trip and lockout initiated by PDR during the A/R dead time. If A/R dead time is selected as one second, the PDR setting should be at least 1.2 second.

7.3 Case Studies

7.3.1 In 1985, MSEB had conducted field testing on 400kV Koradi-Bhusawal D/C (344 kV per/ckt) to test the duration of secondary arc after the faulty phase is disconnected from both the ends. The field testing has revealed that under severe conditions (wind velocity, density, length of the arc, absence of shunt reactors/NGR etc), the maximum time for extinction of secondary arc current was found to be 230 milliseconds.

7.3.2 EMTP studies carried out by WRLDC also reveal that the secondary arc current decreases to 20 ampere or below within 500 milliseconds for single/double circuit line of length 300 km even without reactor at one end. Thus, it is adequate to keep the auto reclose dead time as one second.

Conclusions

Both dependability and security are equally important criterion in application of the protection schemes. Dependability implies that the relay will always operate for conditions for which it is designed to operate while security implies that the relay will not operate for any other power system disturbances or outside its zone of operation. However, due to costs involved in the protection schemes, some compromises have to be made in the degree of security. These are the design considerations but no such constraints should exist in the proper application of the relays and in the philosophy of setting the relays. Security against unwanted operations and their consequences have to be properly evaluated especially in devising the schemes for system protections. Some recommendations are given in the paper to increase the security levels of the grid through proper application.

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