TESTING OF COMPLICATED BUS BAR PROTECTION USING SMART TESTING METHODOLOGY

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ABSTRACT : In this paper, protection of a complicated bus arrangement with dual bus coupler and bus sectionalizer using low impedance differential protection applicable for very high voltages like 220kV and 400kV is discussed. In many power generation stations, several operational procedures are implemented to utilize the transfer bus as main bus and to facilitate maintenance of circuit breakers and current transformers (in each section) without shutting down the bay(s). Owing to this fact, the complications in operational philosophy have thrown challenges for the bus bar protection implementation. Many bus topologies allow any one of the main busses available in the station to be used as an auxiliary bus. In such system, pre-defined precautions and procedures are made as guidelines, which are followed before assigning any bus as an auxiliary bus. The procedure involves, shifting of links, changing rotary switches, insertion of test block and so on thereby causing unreliable operation. This kind of unreliable operations or inadvertent procedural lapse may result in isolation of the bus bar from the grid due to unpredictable operation of bus bar protection relay which is a commonly occurring phenomenon due to manual mistakes. With the sophisticated configuration and implementation of logics in modern intelligent electronic devices, the cumbersome procedures are totally eliminated and the operator is free to choose the transfer arrangement without compromising the protection need of a bus differential system for a reliable operation. This paper deals with the procedure to test the security logics for such special scenarios using Megger make SMRT, implemented in bus bar protection relay to ensure system stability and eliminate all the special operational precautions / procedure.

Keywords – Bus bar protection, by-pass isolator, blind spot, breaker failure, Intelligent electronic device (IED), end fault, bus unification, directional principle, zones of protection, breaker re-trip, under voltage security, smart megger relay tester (SMRT)

I. INTRODUCTION

Increasing demand in power sector has resulted in need for more inter connection substations and addition of more bays [1] in existing substations (SS). Addition of bays at later stages in a substation may result in situations where the newly added bays have current transformers (CT) from different manufacturers and hence the error percentage of the measured current varies enforcing a need for better tuning of the protection system settings. Bus bar protection gets further complicated with various arrangements like bypass isolator or transfer bus arrangement for circuit breaker (CB) maintenance, single CT arrangement in bus coupler (BC) and bus section (BS) for cost reduction. The bus bar protection relay should be capable of handling any type of operational philosophy without intervention of operational personal. In case of improper indication of the switchgear status to the relay, prevention of unwanted operation has lead to enhanced challenges in the logics of bus bar protection. Sample single line diagram (SLD) with complicated switchgear arrangements are considered and the solution is discussed in this paper.

II. SYSTEM DESCRIPTION

A simplified version of the system under consideration is shown in Fig.1 (Complete system can have higher number of bays). This is a complicated system with various types of arrangements which leads to discussions about how the logic in the relay can be adapted to accommodate these variations. A double bus arrangement with two generators and two lines are shown. The bus bar is divided into two sections using bus section CB. Each side of the BS has a BC. The top bus is divided into two buses using 452CB as bus A and bus B. The bottom bus is divided into two buses using 552CB as bus C and bus D. Each bay is named in sequence and the associated equipments start with the respective bay number. The BS and the BC are provided with a single CT on the left side of the CB. The generator bays have the CT located on the bus side whereas the line bays have the CT located on the line side. Line 1 (L1) has a bypass isolator for CB maintenance which isolates the CB and the CT, whereas line 2 (L2) has a bypass isolator which excludes the CT. This difference has a huge impact in bus bar protection which is discussed in the next section.

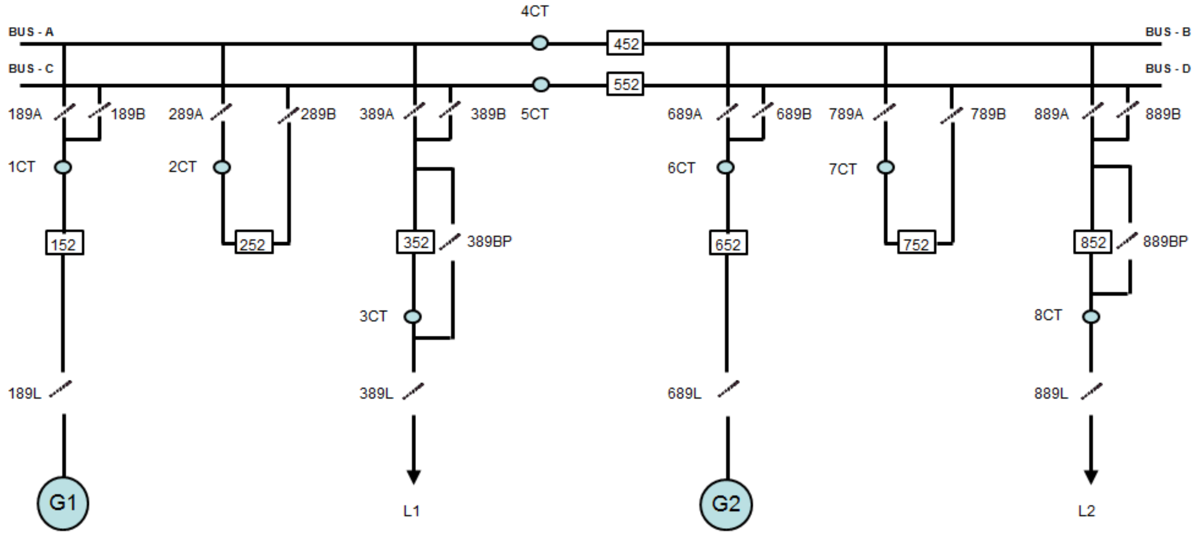


Fig. 1. Description of the system

III.OPERATIONAL PHILOSOPHY

Various operation philosophies have been carried out to maintain the CB or CT and the relay logic has to be fine-tuned to ensure that no area of the bus bar is left unprotected. Typical conditions are 389BP (By-pass) and 889BP which leads to specific protection complication which is discussed independently below:

A. By-pass isolator isolating the CB and the CT (389BP close scenario)

The generators and lines will normally be connected to a single bus bar from which the power is evacuated. If maintenance activity is planned for 352CB/3CT, where closure of 389BP isolator isolates them, then bus C will be fed from bus A through 252BC and L1 will be fed from bus C. On closure of 389BP, the distance protection of L1 will switch its CT from 3CT to 2CT and bus C of bus bar protection will be blocked. Bus C is now treated as a line as it carries only L1 current. In case of any fault in bus C or in the line, the distance protection relay detects the fault in forward zone and 252CB will be tripped, hence there is no unprotected zone in this operation. If 2CT and 3CT have different ratios, then by utilising group settings, this can be handled in the distance protection relay. Fig 2 shows the blocking logic implemented in B90. Based on the isolator position, the respective bus in B90 is blocked to prevent unwanted operation of bus bar relay, without compromising protection to the bus bar. In this scenario, VO73 would be sealed in and bus C will be blocked. Virtual output (VO) shown in Fig 2, is a programmable logic of B90 relay where any kind of logic can be designed and assigned to it and the same can be used for any other application depending on the requirement.

In this case, it is to be noted that bus C is treated as an extension of line and the bus differential zone for bus C is blocked.

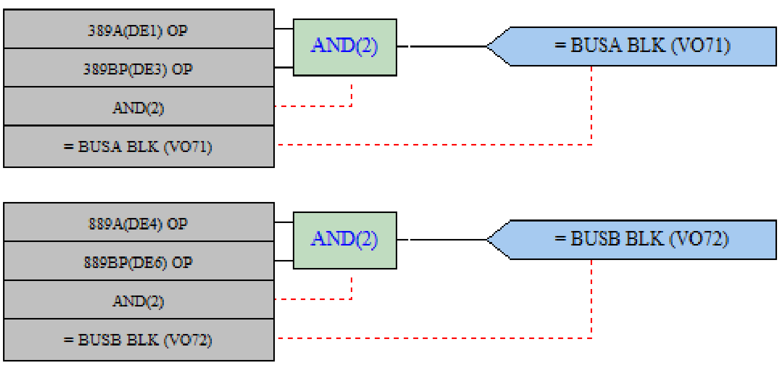


Fig. 2. Bus blocking logic during bypass isolator closing

B. By-pass isolator isolating the CB (889BP close scenario)

If maintenance activity is planned for 852CB where closure of 889BP isolates only the CB, then bus D will be fed from bus B through 752 BC. In this condition, bus D would not be blocked in B90 since the CT is not eliminated from the circuit and will actively contribute in determining the differential current of bus D. In case of any bus fault in bus D, the only CB in bus D is 752CB which will be tripped by B90 as bus D fault. The fault is still being fed from the remote end and to accelerate the tripping, the remote end would be tripped on a direct trip transfer method since the remote end is directly connected to bus D with remote end CB.

In this case bus D is treated as an extension of the remote line and bus differential zone is kept intact and for the fault on the same the local CB (752CB) and the remote CB are tripped.

The main zone blocking logic (case A) and remote end tripping logic (case B) for different bypass isolator conditions were detailed in this section and the main zone segregation philosophy is discussed in the next section.

IV. ZONES OF PROTECTION

Fig. 3 shows the four main zones of protection in different colours for this system. In generator and line bays [1], the CTs form the boundary of the zones if the isolator is closed, else the isolator acts as the boundary. In BC and BS bays, the zone extension will depend on the CB and not the isolator. The dotted area indicates that they are dependent on the CB status i.e., if 252CB is closed then the dotted area of bay 2 will be treated as zone3 else zone1. The traditional way of protecting this dotted area is by the use of end fault; however a different approach is implemented here (hence the assignment to zone1) which is detailed in section V.

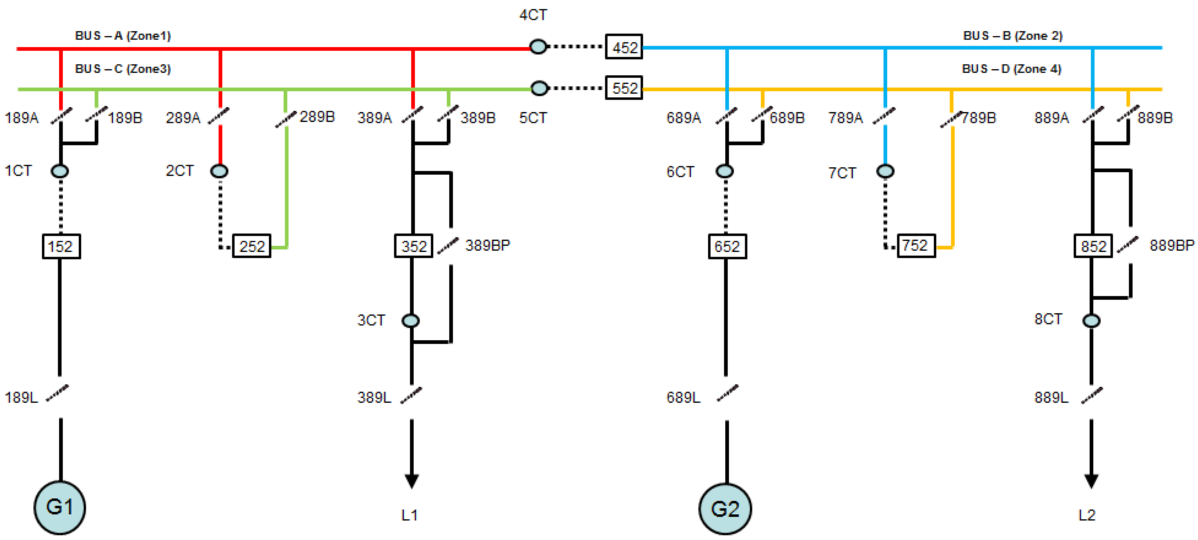


Fig. 3. Zones of protection when all isolators are open

Fig 4 shows the zone selection logic for G1. G1 bay is switched between zone1 and zone3 based on the isolator position as shown. In similar lines, the logic is repeated for L1, G2 and L2.

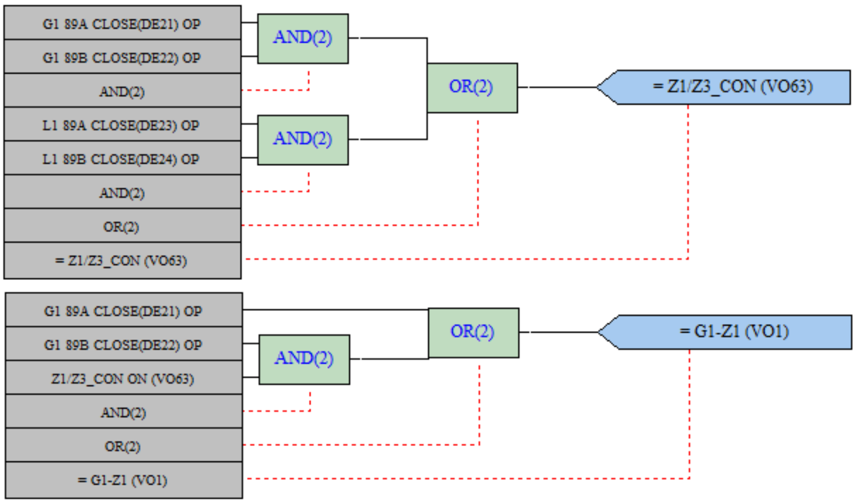


Fig. 4. Zones selection logic in IEDs

Blind spots are denoted as dotted lines in Fig 3, which is of critical importance since it is not covered under any zone when the associated CBs are kept open. The conventional philosophy of eliminating this blind spot is by providing CTs on either side of the CB, thus creating a zone overlap. This convention is modified and the blind spot is eliminated using a single CT which is explained in section V and VI.

V. Blind Spot coverage between CT and CB in BS and BC bay

Let us assume that 452 is closed, such that the area between 4CT and 452CB is covered under zone 2 as shown in Fig. 5 and the positions of all the isolators are shown in table1. If a fault occurs at F1, the relay will detect this fault in zone 2 (based on CT location) and it will trip all the CBs associated to zone 2. However the fault will not be cleared since the fault is located in zone 1 (based on CB position). This fault is located outside 4CT and B90 will treat this fault as external fault for zone 1 thereby creating a blind zone. This fault will be cleared after a time delay of 200ms by CB failure protection (explained in section XII), which is not acceptable. In order to provide an accelerated tripping for this scenario, this blind spot has to be covered under zone 1 when 452CB trips. This logic has been incorporated in the relay as shown in Fig 6.

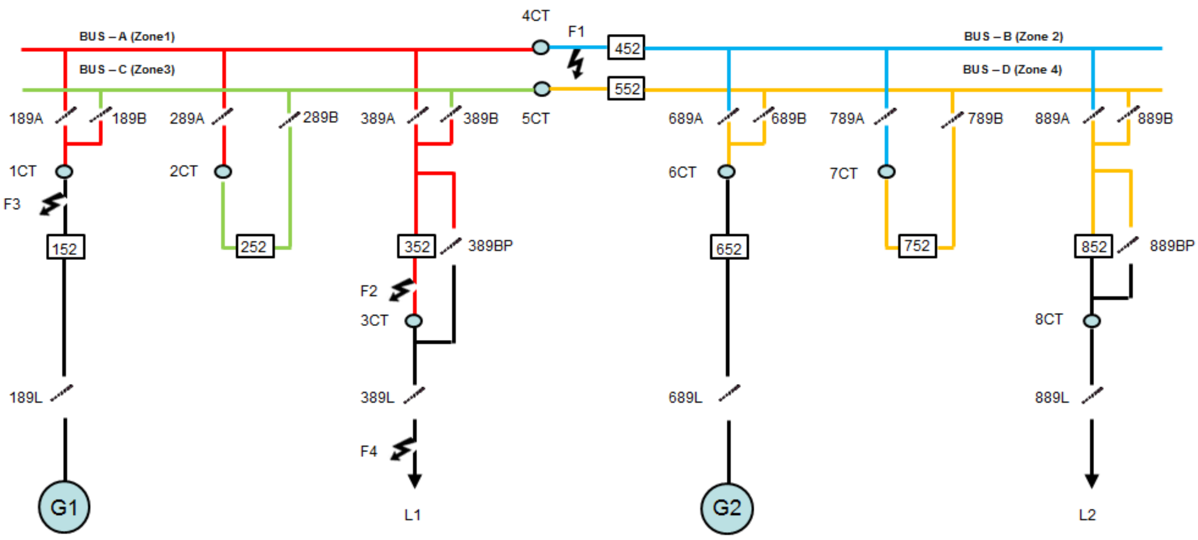


Fig. 5. System with various fault locations

Table1 : Isolator positions of Fig 5

Isolator position in bus A and bus C	
Closed	**Open**
189A	189B
389A	389B

Isolator position in bus B and bus D	
Open	**Closed**
689A	689B
889A	889B

In BS bay, if a CB close command or the CB close feedback (derived from 52a and 52b contacts) [2] is extended then VO82 is set as shown in Fig 6. The same inputs are inverted and assigned to VO86 which is called as 452 reset. The above logic for VO82 will set Latch 15 in high condition and it will drop off only if VO86 is high. Thus Latch 15 will be high when the CB is closed and it will be low if the CB is open. This latch 15 is in turn used in conjunction with zone1 and zone2 trip logic to make VO22 high which is used to read 4CT in zone1 and zone2 which ensures proper imitation of circuit breaker status. The first condition of VO22 being the 452CB in close position and the second condition is the absence of any zone trip which is used for additional security to ensure that in the event of absence of CB feedback due to failure of CB auxiliary contact or cable, the relay will still execute the logic perfectly after 150ms and hence B90 will execute the logic securely even in the absence of feedback.

In the absence of this logic, the relay will receive a breaker fail initiation command from BC bay and zone 1 will be tripped in breaker failure after 200ms under the assumption that the breaker failure initiation was extended for bus faults also. Tripping of bus bar on breaker failure when no CB has failed is a misconception which further complicates the fault analysis and a delayed bus bar tripping.

The logic for BC is almost similar except for an additional input that needs to be considered in the logic of VO22. It should be a three input 'AND' gate with the third input being both zones separated. This input is used to ensure that BC current transformer is not read in the zones if there is a bus unification condition, since it acts as a parallel path to that circuit resulting in wrong current measured by B90. During this scenario there will be a circulating current which will be handled by directional principle / voltage supervision ensuring stability of B90 which is discussed in section VII and VIII.

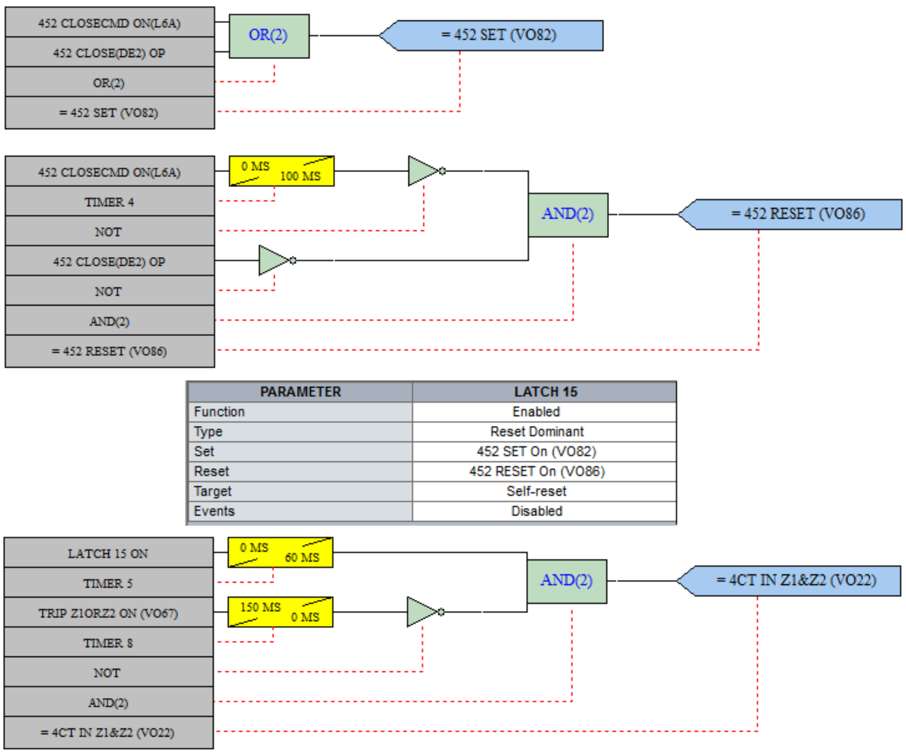


Fig. 6. B90 Logic for accelerated tripping for faults in blind spot

For operational conditions where the CB in BS or BC bays are open before the occurrence of a fault, then the logic permits tripping of only the faulted bus however during CB close conditions, tripping of both busses for faults located in F1 is unavoidable.

Using the above mentioned logic, the 4CT is switched in Zone1 and Zone2 which works perfectly for most of the cases. In case of dead bus charging, the above logic will issue an unwanted trip to the healthy zone. This can be handled in the following manner. Let us consider a scenario where Bus A is dead and Bus B is live, and F1 fault is present (e.g. grounding because CB maintenance). During this scenario, if we issue a close command to 452 CB, then based on the above logic, there will be an unwanted trip of Bus B. To prevent this Zone 2 trip, the logic shown in Fig 7 can be utilised. VO15 is a logic used to detect a dead bus charging condition based on under voltage protection and 452 CB close pulse. This logic along with non-directional zone 2 differential element will trip 452 CB and also block zone 2 trip for 2 seconds; thereby eliminating the isolation of a healthy zone.

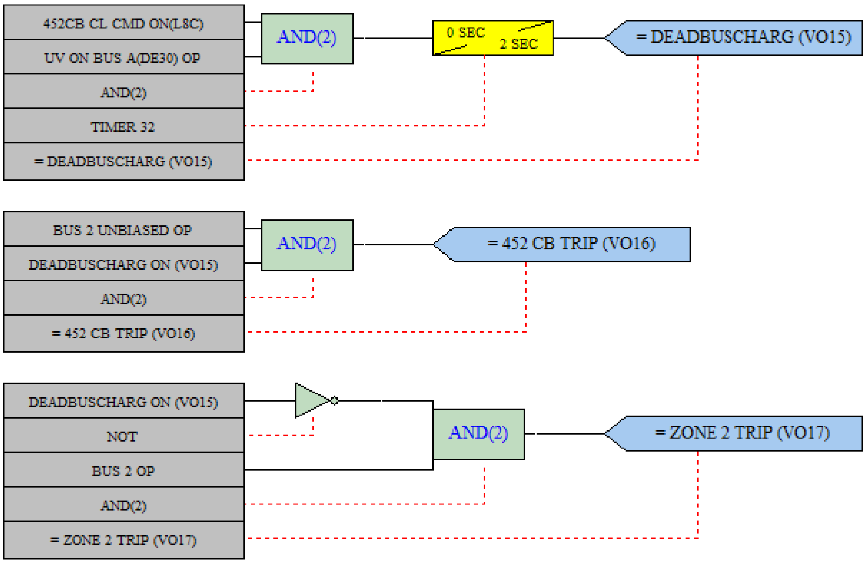


Fig. 7. Logic for tripping only BC & Zone1 for faults in blind spot

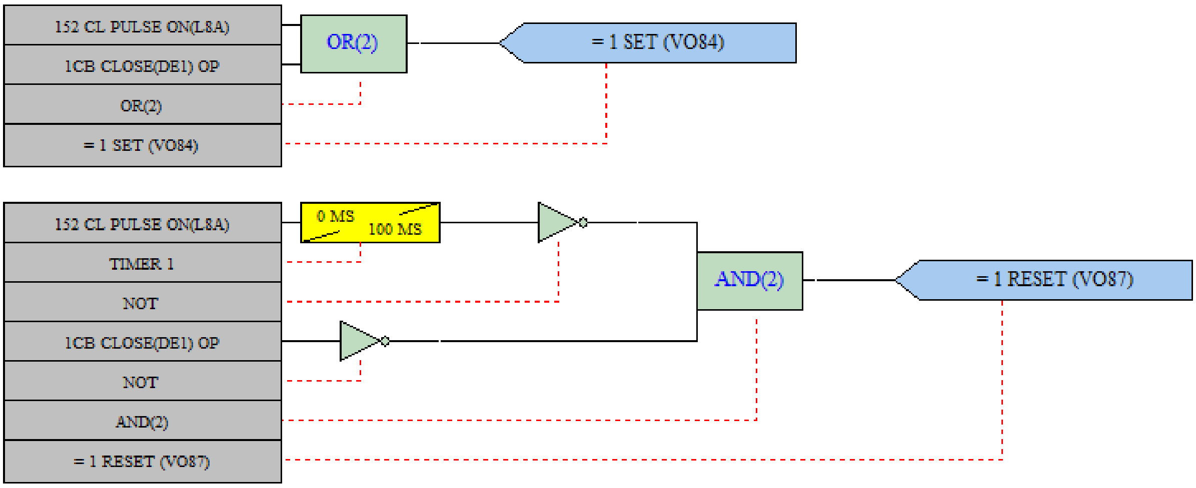
The above mentioned scenario and logic is applicable for all BS bays (4, 5) and BC bays (2, 7). In similar lines, the blind spot issue for generator and lines are protected by a concept called as end fault. The location of the CT has a huge impact on the trip logic which is explained in the following section.

VI. END FAULT FOR DIFFERENT CT LOCATIONS

Consider the line L1 being fed from bus A with 389A isolator closed as shown in Fig 5. If a fault occurs at F2, this fault is treated as a bus fault and all associated CBs of bus A are tripped. The fault is not fully cleared as the remote end CB is intact and feeding the fault. This necessitates the tripping of the remote end for an effective clearance of the fault. This remote end tripping is facilitated through a direct trip mechanism, provided the CT reads current after successful tripping of bus bar. In this manner, protection is provided without any blind spot for CTs located towards the line side. The trip logic for CTs located towards the bus side is discussed below.

Consider the generator G1 being fed from bus A with 189A isolator closed as shown in Fig 5. If a fault occurs at F3, this fault is treated as an external fault for B90 as it is outside its zone. This fault will be detected by the respective bay protection relay and the generator will be tripped. The opening of 152 CB does not clear this fault as it is still fed from the bus bar. In this kind of bus arrangements, the bus bar has to be tripped and there are two methods of executing this logic which is explained below.

The first method incorporated in the relay for a perfect operation for the above mentioned scenario is shown in Fig 8. When CB close pulse or a CB successfully close feedback (derived from 52a and 52b contacts) [2] is extended to the relay, VO84 is set in the relay. These inputs are inverted and assigned as VO87 in the relay. In other words VO84 will be high when the CB is closed and VO87 will be high when it is open. The logic is to ensure the absence of feedback and presence of close pulse command will still execute the logic successfully as it is assigned to the latch logic. These inputs are assigned to a latch function which becomes high when the CB is closed. Latch becomes low when the CB is open. Depending on the Latch position, 1CT is switched in the zones. If 152 is open, then Latch 1 removes 1CT from B90 which operates the differential function if the fault is located at F3. The simple concept used in this application is that the CT acts as a boundary for differential function and on removal of the CT, the boundary extends till CB thus eliminates the blind spot.



PARAMETER	LATCH 1
Function	Enabled
Type	Reset Dominant
Set	1 SET On (VO84)
Reset	1 RESET On (VO87)
Target	Self-reset
Events	Disabled

Fig. 8. Relay Logic for Blind Spot detection

The second method for clearing the F3 fault is by the use of end fault (EF) and zone selection logic. End fault protection is the well-known current monitoring feature during CB open conditions [3]. Fig 9 shows how the bus would be tripped after executing the zone selection logic for two bays. Let us assume that G1 is connected to bus 1. The zone selection logic explained in section IV will execute and VO01 will be high as described in Fig 4. After the generator trips 152CB in generator differential, EF function will detect the CB open condition and since the current is persisting, EF feature will be sealed in. EF is the internal function of B90 and if it is sealed in, it would enable VO51, which in turn would trip zone1. The same logic will repeat for VO52 if G1 is in zone3. In this manner the blind spot between the CT and the CB is still protected by B90.

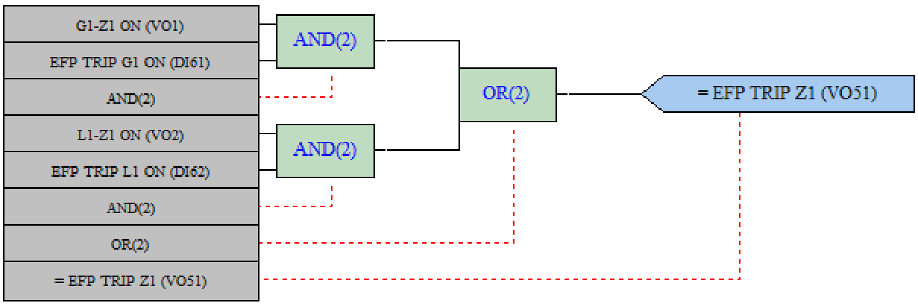


Fig. 9. End Fault Trip logic

End fault for various CT arrangements has been discussed and with the introduction of so various logics, the need for proper testing comes into picture which is taken up in the next section.

VII. Testing Methodology

All the above scenarios can be built as logics in an IED and being a man-made logic, the need for proper testing is mandatory. Bus bar relays have multiple CTs and also the concept of phase segregation will increase the complexity and testing duration. Such scenarios and complexity can be easily addressed by the use of SMRT 410 which has 10 current sources with which multiple bays can be tested with all the zone selection logics. In addition, multiple test sets can be merged and used as a single unit with many current source as shown in Fig 10.

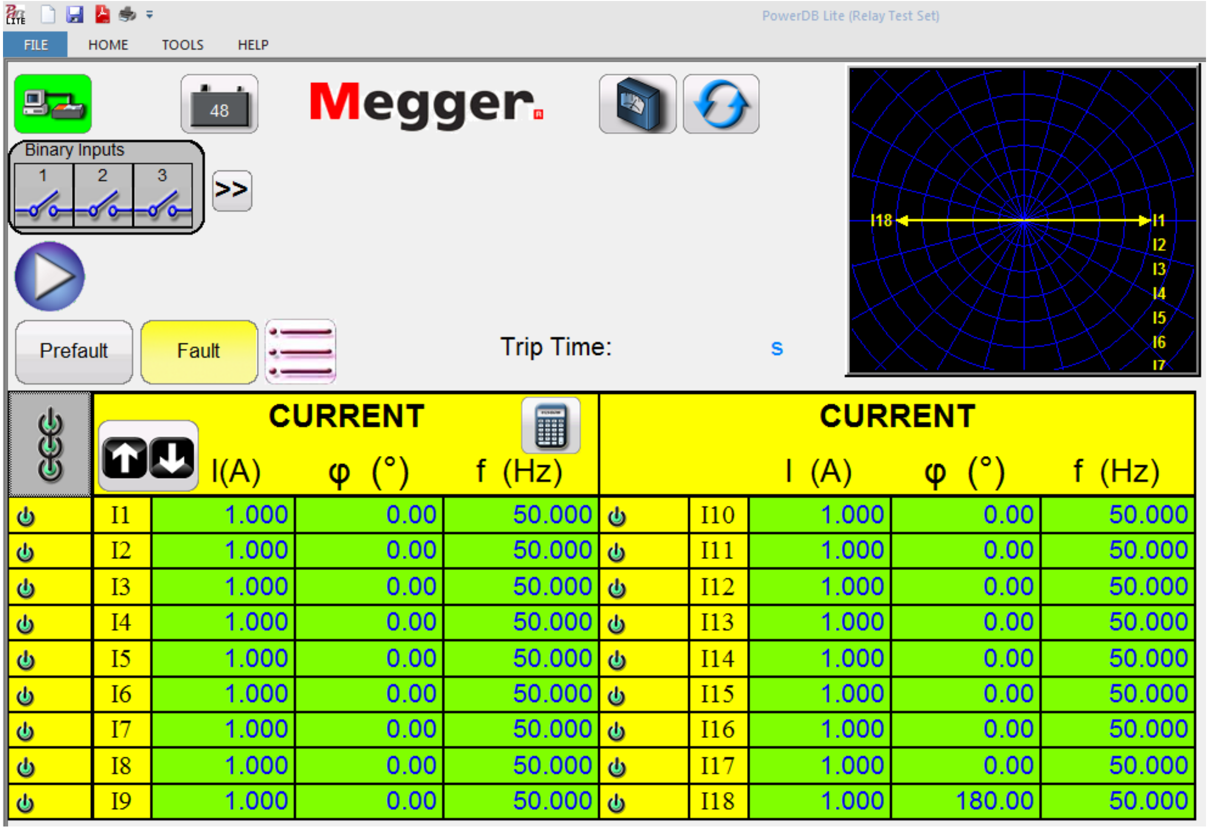


Fig. 10. Multiple bay testing option with SMRT

VIII. Conclusion

This paper presents the most effective ways of protecting a bus bar in a complicated system where the CT locations are different for different bays added with bypass arrangement across the breaker there by facilitating any bus use as an auxiliary bus which in turn challenges the protection philosophy. To handle these complications a novel solution has been discussed in this paper. The advancement of the IEDs in terms of measurement and the ability to include custom based logics permits the IEDs to adapt for complicated applications. This also helps in eliminating the long procedures and operation of many devices to implement uncompromised protection thereby improving the dependability of the system with total elimination of human intervention.

IX. References

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