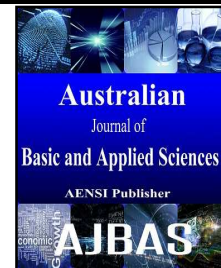




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CT Open Bay Detection Logic in Centralised Low Impedance Bus Bar Protection IED

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ABSTRACT

In this paper, identification of faulted current transformer (CT) in centralized low impedance bus bar protection applicable for extra/ultra-high voltages like 220kV, 400kV, 765kV is discussed. Bus bar protection purely depends on CTs and failure of its circuit or itself would through challenges in the performance of protection. Such challenges are addressed by modern numerical relays, called as intelligent electronic device (IED) s, where several protections for additional security are embedded. These security logics prevent the IEDs from providing unguaranteed operation during CT failure, however exact identification of the faulted CT is equally important, as a secondary open CT will result in hazardous voltages which may in turn lead to blasting of the CT, thereby creating damage to life and other switchyard equipment. To prevent such occurrences, the concept of symmetrical components can be used to sense a faulty CT or its circuit. If a CT/circuit becomes faulty, an unbalance current will be measured by the IED, which results in negative sequence current in that particular bay which in turn will be utilized by the IED to announce or trip the faulted bay. Such concept cannot be always implemented in centralized bus bar protection, as this architecture dictates the concept of phase segregated protection. To adhere to this concept, in some busbar architectures each phase will be connected to a separate IED, thus the calculation of symmetrical component is defeated, without which the above solution cannot be employed. Hence the necessity for alternate solution is required, which should be capable of addressing other challenges thrown by dynamic bus replica. Such a solution has been engineered in a centralized low impedance IED (GE make B90) and implemented in 220kV Bus (two bus arrangement) and 400kV Bus (1½ breaker arrangement) at Tamil Nadu Electricity Board 400/230kV Karamadai Sub Station located in Tamil Nadu, India.

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INTRODUCTION

Increasing demand in power sector has resulted in need for more inter connection stations and addition of more number of bays in existing substations (SS). Addition of bays at later stages in a substation would result in situations where the newly added bays have current transformer(CT)s from different manufacturers resulting in increased error percentage of the measured current, enforcing a need for better tuning of the protection/control system settings. Bus bar protection gets further complicated with various arrangements like single bus, double bus, double main with a transfer bus and 1 ½ half breaker system. Bus bar protection relays, depend purely on the inputs from the CTs and during failure of its circuit or itself, the relays require additional security logics for guaranteed performance. This kind of security logic encompasses key features like;

CT trouble detection, directional principle, under voltage (UV) supervision, to name a few. The relay should be capable of detecting any issues with the CT and block the protection. With the availability of modern numerical relays, called as intelligent electronic device (IED), such sophisticated logics are programmable and the relays work as per the expectation even during CT trouble conditions including indication of the bus in which the faulty CT circuit / CT is present, however the detection of the exact CT is critical for further action. To understand the process of providing, accurate failed CT information, understanding of two common architectures called centralised and de-centralised system is important. These two architectures are well described in literature (IEEE Std C37.119-1996). Both the architectures depend on the inputs from the CT and failure of the CT is a frequently occurring phenomena due to several reasons (IEEE

Std C37.110-1996). Identification of such a CT is one of the key requirements, as an open CT secondary would result in hazardous secondary voltages which may result in CT blasting. This forces the necessity to identify the bay in which the CT issue has occurred, thereby the operator or the relay can detach the respective bay to arrest further amplification of the problem. In de-centralised architecture, all the three phases of the CTs (R,Y,B) are connected to one relay called as the bay unit. Thus, the bay units are capable of deriving symmetrical components within the relay. In case of issue with any one of the CT, the relay reads negative sequence component which in turn can be used to identify the faulty bay. This principle cannot be used in centralised architecture since the concept of phase segregated protection prevents the connection of all the three phases to it. In some centralised architectures, each phase is connected to a separate relay which prevents calculation of sequence components, thus creating a challenge in CT trouble bay detection. This challenge is amplified further, due to dynamic switching of CTs in various bus arrangements. These complications and the challenges in proper identification of bays where the

CT issue is present in centralised architecture, along with the ways to address it, are discussed in the forthcoming sections of this paper.

The overall organisation of this paper is, as follows: description of various bus arrangements in section II; various challenges in bus bar protection relay due to CT trouble in section III; proposed / engineered solution for identification of the faulted CT in various bus arrangements is discussed in section IV to VIII; directional principle which prevents the IEDs from mal operation during CT issues is explained in section IX; dynamic blocking/release of CT trouble for situation where fault is following a CT issue is discussed in section X; and finally section XI concludes the discussion.

II. System Description:

Fig.1 shows a single bus arrangement where a generator bay and a line bay are connected to the bus bar. The CTs are denoted as NCT where N represents the bay number. In similar lines, N52 represents the respective circuit breaker (CB), where 52 is the American national standard institute (ANSI) number for breaker (IEEE C37.2-2008) and the nomenclature for isolator follows similar format.

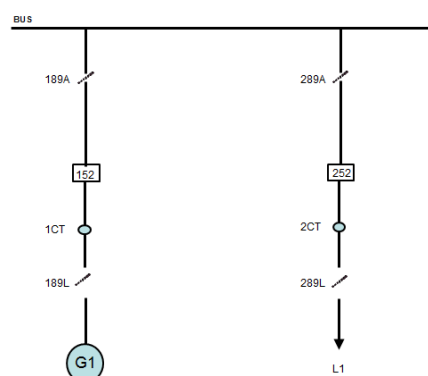


Fig. 1: Single bus bar Arrangement.

Fig.2a shows the double bus arrangement, where a generator bay, line bay and a bus coupler (BC) bay is represented. This kind of bus arrangement provides greater flexibility and load sharing capacity during power transfer; however this enforces the concept of dynamic bus replica in bus bar protection relays. Dynamic bus replica is the process of switching the current measured by the CT, subject to isolator position. The current measured by 1CT will be accounted for Bus-A differential calculation if 189A is closed and the same current will be accounted for Bus-B differential calculation if 189B is closed. If both the isolators are in closed condition, then the concept of bus unifications will come into picture where the measured current will be accounted in both the bus zones. Fig. 2b is a different kind of two bus arrangement where the design adopts three CBs for two bays. If two lines necessitate three CBs then for one bay, one and a half CB is required (i.e $3/2=1.5$), based on which this arrangement is

named. This is a highly redundant scheme where the faulty area alone can be isolated during a fault. On the other hand, the cost increases due to the use of an additional CB, which prevents the use of this arrangement in medium voltage levels.

Fig.3 shows a double bus with transfer bus arrangement, where a generator bay, line bay, a BC bay and a transfer bus coupler (TBC) bay is represented. This kind of bus arrangement provides higher flexibility and load sharing capacity during power transfer with the provision of bus / bay maintenance; however this enforces the concept of dynamic bus replica in bus bar protection relays similar to double bus arrangement. The additional encounter for BB protection relay in this arrangement is the increase in number of zones.

Increase in number of zones enhances the switching philosophy, which enforces the bus bar IED to be dependent on the isolator status. This status is wired from the field, and an inappropriate

status will result in allocation of measured CT current in a wrong differential zone, resulting in measurement of differential current in the respective zone, however proper operation of the IED is ensured by directional principle which is discussed in section

IX. Further to such disputes, an improper measurement of the CT referred as CT trouble will pose challenges, and the major factors causing it is discussed in the coming section.

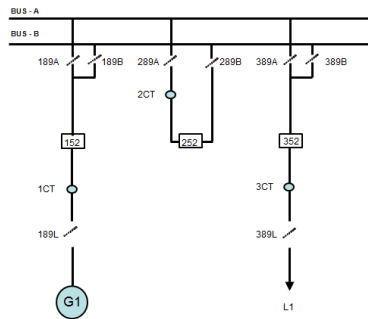


Fig. 2a: Double bus bar arrangement.

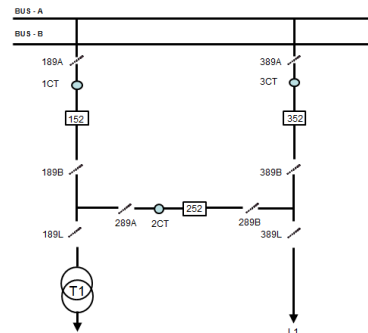


Fig. 2b: 1 1/2 CB arrangement.

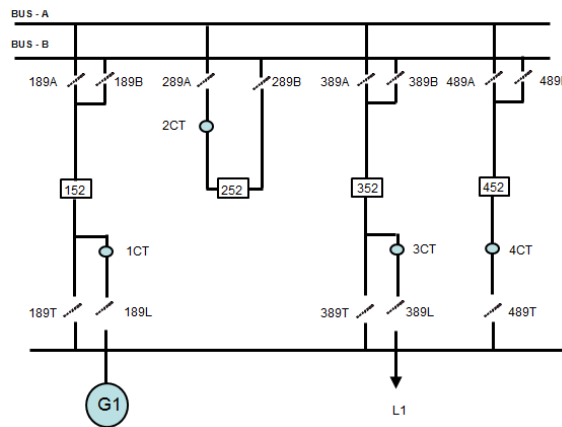


Fig. 3: Double bus bar with transfer bus bar arrangement.

III. Ct Trouble Conditions:

Several conditions can result in improper measurement of the CT out of which the problems related to saturation and its effect is well detailed in literature. In addition to saturation issues, problems in CT secondary circuit can be broadly classified as; short circuit condition and open circuit condition. A short in CT secondary circuit will result in measurement of differential current since majority of the CT secondary current flows through the short circuit path which has a relatively lesser resistance than the IED internal CT. However the measured differential current will not satisfy the tripping criteria (Detailed in section IX), but the pickup of this operand 'CT Trouble' is also based on differential current with an independent setting, which will be used to annunciate the operator of such issue in the system. In general, these kind of issues in CT or its circuit are referred as CT trouble in this document.

Open circuit conditions are perilous situations, as the CT secondary would result in hazardous voltage which may lead to threat for life and

property. This imposes the need for detecting such situations followed by precautionary actions such as tripping the respective bay. Such a solution for various bus arrangements discussed in section II is detailed in the following sections.

IV. Identification Of Ct Troublebay In Single Bus System:

The CT open detection logic for a single bus arrangement is shown in Fig 4. The first input; 'CT Trouble Z1' operand shown is based on differential current whose setting is lower/independent of the protection setting used for tripping. This operand will be high when there is a CT trouble condition. The second input; 'B1-CB close' is a binary input which is wired from 52a contact of the circuit breaker. This input will be sealed in when the CB of bay 1 is in closed condition. The third input; 'IOC1 DPO' is the drop off signal of instantaneous over current (IOC) element of Bay1. This operand will be high when there is no current measured by the IED in that bay.

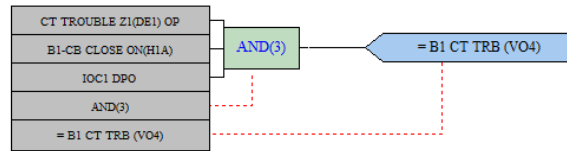


Fig. 4: Zones selection logic in B90 relay.

These three inputs together confirm that a differential current is measured, when the CB is in closed condition, without current in that bay, thereby confirming an open CT secondary in bay1. This logic will seal in VO4, which can be further used for annunciating. The similar solution for double bus will include the zone selection logic which is discussed in the next section.

V. Identification Of Ct Trouble Bay In Two Bus System:

In double bus arrangements in line with Fig 2.a, the logic to identify the faulted CT is shown in Fig 5. The logic will ensure the bay is in a particular zone, along with the respective main zone and check zone CT trouble operand. The logic of implementing check zone, is to confirm the existence of CT trouble, as main zone CT trouble can be high due to improper isolator status. Hence, a combination of these signals will confirm a CT issue.

In addition to this logic, the CB close and IOC DPO signal is implemented in similar lines to the logic discussed in section IV, thus indicating the exact CT which is open for two main bus arrangements. Another two bus arrangement called

the 1 ½ CB arrangement, requires a different logic which is discussed in the following section.

VI. Identification Of Ct Trouble Bay In 1 ½ Breaker System:

In case of 1 ½ breaker arrangement, the concept of zone selection is not applicable and hence the logic will be comparatively simple. The bays cannot be switched between zones and hence the bay detection logic similar to single bus system developed independently for each zone is shown in Fig 6.

In this manner, CT issues in two bus bar arrangements are detected. Similarly, three bus systems logic is discussed below.

VII. Identification Of Ct Trouble Bay In Three Bus (Two Main One Transfer Bus System):

In case of three bus arrangements, the zone selection logic needs to confirm the CT trouble scenario in all the three bays as shown in Fig 7. This logic works in similar lines to two bus arrangement discussed in section V, where the only additional check is for third zone.

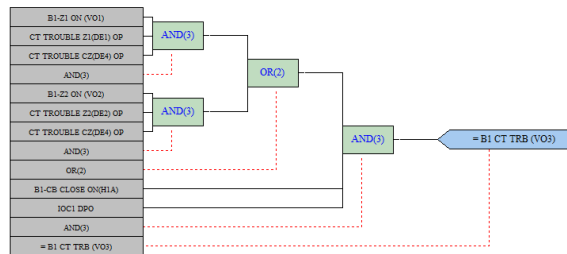


Fig. 5: Zones selection logic in B90 relay.

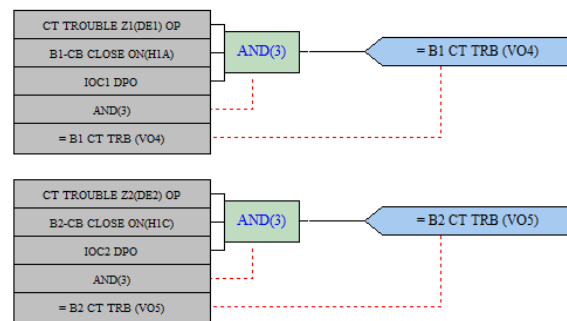


Fig. 6: Zones selection logic in B90 relay.

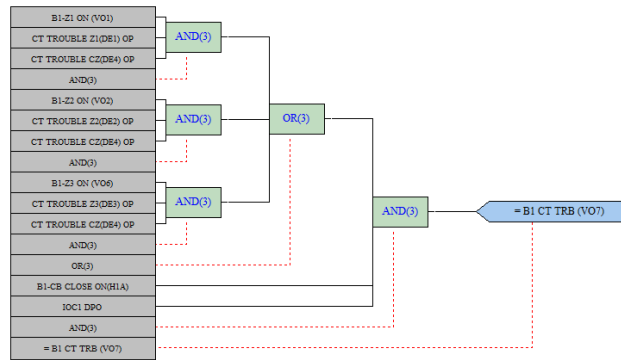


Fig. 7: Zones selection logic in B90 relay.

The logics discussed in section IV to VII, can categorize the exact bay in the absence of current, however it cannot define whether the bay is on ‘no load’ or ‘CT secondary open’ state. Though the purpose of hosting the CT trouble logic, based on differential current will address this issue to a certain extent, it will fail to address in unfortunate circumstances where one bay is on ‘no load’ and another bay is having ‘CT trouble’, and both are located in the same zone. Though such scenario is rare, the principle of designing protection for worst case, forces the identification of this variance, to permit the concept of tripping the bay where the CT secondary is open. The option of annunciation, or annunciation followed by tripping, for CT secondary open scenario, is left to the user based on the practice

followed. To facilitate such practice, a logic capable of differentiating ‘no load’ and ‘CT secondary open’ situation is engineered and discoursed in the next section.

VIII. Universal Logic For Any Bus Arrangement-Differentiating Ct Open And No Load Condition:

The logic shown in Fig 8, is capable of differentiating a ‘no load’ condition and a ‘CT secondary open’ condition. Thus the user is free to choose whether he wants to trip the CB using the IED on successful identification of a CT secondary open. In addition to this differentiation, the logic also provides the advantage of being applied to any type of bus arrangement without the need for zone selection logic.

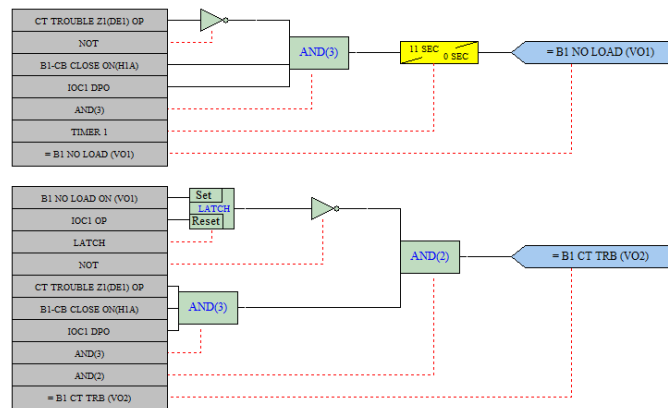


Fig. 8: Universal CT Open logic.

Fig 8 shows a merger of two VO's. VO01 will identify a ‘no load’ condition, and the logic used is a grouping of non-availability of CT trouble indication, CB close status and non-availability of current in the CT. This will inturn seal in V01, after an intentional time delay of 11 seconds, since the practice followed for CT trouble setting is 10 seconds. This timer introduced should have a pickup delay greater than the CT trouble timing which explains the setting of 11 seconds in the logic. On successful identification of ‘no load’ condition with this logic, the ‘set’ path of the ‘SR Latch’ will be high which in turn will

block VO2 logic. After identifying a ‘no load’ condition using VO01 logic, if another bay suffers a ‘CT secondary open’ state, VO2 will still be in blocked, thus differentiating ‘no load’ and ‘CT secondary open’ state. The ‘SR Latch’ use is of ‘Reset dominant’ type, which means if both the inputs are high, the reset path will override and thus the ‘no load’ conditions will be reset when IOC1 operates. The setting of IOC is tuned to ensure that IOC1 will operate for the least current expected in the bay.

The above logic holds good for all bus arrangement, however in case of 'double bus' and 'double bus with transfer bus' arrangements, the BC and TBC bays should encompass main zone CT

trouble operand and not check zone CT trouble. Several conditions have been tested for proper operation of this logic and the results are tabulated below.

Table 1: Universal CT Open Logic test result.

Condition	Bay Status		Bus Zone CT Trouble	CT Open Alarm Indication	
	Bay 1	Bay 2		Bay1	Bay 2
1	Healthy - On load	Healthy - On load	X	X	X
2	Healthy - On load	Healthy - No Load	X	X	X
3	Healthy - On load	CT Open	□	X	□
4	Healthy - No Load	Healthy - On load	X	X	X
5	Healthy - No Load	Healthy - No Load	X	X	X
6	Healthy - No Load	CT Open	□	X	□
7	CT Open	Healthy On load	□	□	X
8	CT Open	Healthy - No Load	□	□	X
9	CT Open	CT Open	□	□	□
10	CT open & CB Close	Healthy On load	□	□	X
11	No Load & CT Open	Healthy On load	X	X	X

Key: □ - High signal / X - Low signal

The first nine conditions tabulated, incorporate all the permutations and provide the exact indication of the bay as per the logic proposed in Fig 8. In addition to these conditions, two special circumstances (10 & 11) were tested. The proposed logic worked perfectly for condition 10 however for condition 11, it failed to give an alarm. This condition describes a bay which was on 'no load', which subsequently suffers an open CT secondary. Since the bay was not loaded, the CT Trouble logic failed to identify this scenario. It is justified that the absence of current will create no harm to the system and hence this situation and similar conditions, where 'CT secondary open' situations occurs in no load situations can be ignored.

Thus the logic projected will identify the CT issue correctly, nevertheless the tripping of the bus bar is provided with additional security called the directional principle which will prevent the IED from issuing unwarranted operation. The working of this principle is detailed below.

IX. Directional Principle For Bus Differential Protection:

In differential protection, there are scenarios when the CT gets saturated due to heavy through fault current and security measures have to be implemented to ensure, that the differential current read by the relay due to saturation does not trip the bus. The use of check zone may work for improper isolator status however for CT saturation conditions, the differential element may mis-behave. IEDs handle this situation using the break point 2 and slope 2 characteristics [4] of the biased differential element shown in Fig 9.a, however in many sites the settings entered in the relay is not a perfect calculated value due to non-availability of exact data. In practice, the break point 2 and slope 2 settings are set as a thumb rule only which may not guarantee proper performance during all scenarios. This issue is over ridden by the use of the directional principle which also has to be satisfied for tripping, in addition to the

biased characteristics. Directional principle for external and internal fault is shown in Fig 9.b and Fig 9.c. During a bus fault, all the currents contributing to it will flow towards the fault and the angle of all the currents will lie in the same quadrant. By the use of patented algorithm, B90 IED will not account the angles of the currents that are not contributing to the fault. In case of an external fault, at least one of the current will be 180 degree apart. Complementary, there is a saturation detector that enables or not the directionality check if CT saturation is detected in any circuit. Thus the IED will be stable during external faults and trip during internal faults irrespective of the healthiness of the CT. However, since earlier times, such sophisticated logics cannot be accommodated in conventional relays. Hence it was not possible to differentiate between differential current measured due to CT/circuit issues, and a real internal or external fault. Thus the bus bar protection philosophy being followed for decades with electromechanical relay was to block differential protection using CT Trouble detection logic.

In IEDs, the need for blocking the protection during CT trouble is no more a mandatory requirement, however based on practice, it is being followed as a custom. The only dis-advantage of blocking the protection is during a rare scenario where a CT issue is followed by a fault, the IED will fail to extend tripping since it is already blocked. Such situations can still be handled by an additional logic discussed in the next section.

X. Differential Blocking During Ct Trouble And Release During A Fault:

The CT trouble logic in bus bar protection relay is used to identify the flow of differential current in the relay due to errors in the secondary system and not a bus fault. The relay can discriminate a bus bar fault and a secondary system fault by the comparison of the additional security measures like the directional principle and the bus voltage supervision check. Check zone cannot identify this issue unless

it is using a separate CT or a different core from the same CT. Even different core of the same CT may not meet the requirement since open CT conditions

affect the CT itself and it does not reproduce the primary current properly.

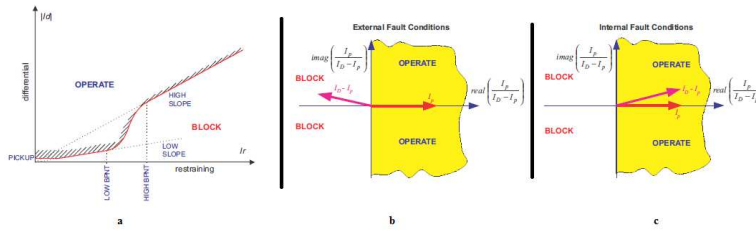


Fig. 9: Biased differential characteristics and direction principle.

Based on the above verification measures, the CT trouble function is detected on failure of a CT and differential is blocked. However in case of a real bus bar fault followed by the CT trouble; the relay will not trip, since the CT trouble functionality is blocking its operation. In B90, this issue is handled by implementing the logic shown in Fig 10. In case

of a CT trouble, B90 verifies the healthiness of the bus bar voltage and bus bar protection is blocked only during voltage healthy conditions. When there is a bus fault following a CT trouble, the bus voltage collapses and the blocking command is unblocked dynamically, thereby executing a tripping command successfully as desired.

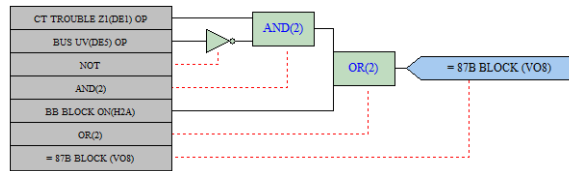


Fig. 10: Dynamic block/release of CT Trouble using Under Voltage.

There are scenarios where Bus PT is not available for executing this logic due to the absence of PT in the scheme or due to the non availability of input in the relay to accommodate voltage. In such scenario, the logic shown in Fig 11 can be utilised to obtain the desired result. This logic is based on over current settings, where the setting is kept above 1.1 pu. A

bus bar with 5 bays are shown in this example. During a CT trouble condition, there is no necessity of higher magnitude current and hence all the IOCs are dropped off, thus permitting CT Trouble signal to block differential protection. When a fault follows CT Trouble, any one of the IOC will pick up, which in turn blocks CT trouble thereby issuing a trip.

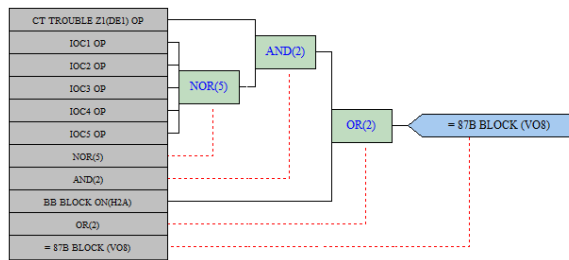


Fig. 11: Dynamic block/release of CT Trouble using Over Current.

The settings adopted for IOC plays an important role, where in unforeseen cases of a high resistive fault, the measured current may be lesser than the IOC settings, which will override this logic. In order to ensure that we address this situation, an alternate logic is proposed in Fig 12. In place of IOC, the Differential current with directional principle is implemented which can handle the above mentioned scenario.

The above sections guarantee proper tripping and blocking of B90 under diverse scenarios with different logics projected for different applications where the user can choose the one suitable to their standard practice.

XI. Conclusion:

This paper presents the most effective ways of identifying a CT open condition for different kind of

complicated bus arrangements. Greater switching arrangements confounds the process of identifying grave situations such as CT secondary open condition, islanding of the faulty bay, indication of the exact CT for maintenance, re-routing of power etc. 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 and critical functionalities. This also helps in eliminating the long procedures for operators

to identify the faulty CT by the use of conventional visual comparison method, and reduces the recovery time without compromising the protection thereby improving the dependability of the system with total elimination of human intervention. To handle these complications a novel solution has been discussed in this paper which has been engineered, tested and commissioned at Tamil Nadu transmission corporation 400/230kV substation situated in Karamadai, Tamil Nadu, India.

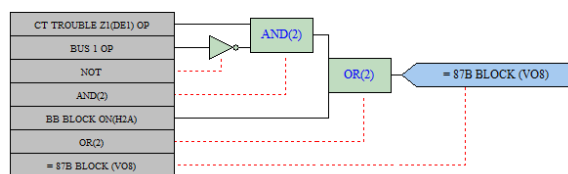


Fig. 12: Dynamic block/release of CT Trouble using Differential.

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