TAMPEREEN TEKNILLINEN YLIOPISTO
TAMPERE UNIVERSITY OF TECHNOLOGY

MD TANVIRUL KABIR CHOWDHURY

# IMPLEMENTATION OF INTERLOCKING SCHEME FOR BUS BAR AND ARC PROTECTION USING IEC 61850

Master of Science Thesis

Examiner: **Professor Sami Repo**
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# ABSTRACT

**MD TANVIRUL KABIR CHOWDHURY**: IMPLEMENTATION OF INTERLOCKING SCHEME FOR BUS BAR AND ARC PROTECTION USING IEC 61850
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The main scope of the thesis is to focus on bus bar protection in the medium voltage level. It is important for designing the protection setup according to the intended protection scheme, planning for circumvent the arc fault and set up the protecting device in a required manner. In this thesis there are different protection schemes for the bus bar have studied. The arc incident has discussed and put emphasis on the process of arc development. For mitigating the arc faults and other unwanted fault incident, it is important to have a co-ordination between the protecting devices. IEC 61850 is an important protocol of communication that has discussed from the basic idea. In the thesis it has given effort on the implementation of busbar protection scheme with the protection devices in the substation. Those devices are communicating with each other for exchanging the GOOSE message using IEC 61850. The protection devices are connected with arc sensor and getting the input signal from it. A proposed design scenario has implemented with different fault situation in different location. The thesis has given the idea about the protection scheme of busbar implementation in a medium voltage substation perspective. It is also helps to understand how the protection devices are working and communicating with each other via GOOSE message. The thesis is also able to demonstrate the role of protection scheme on the bus bar and the co-ordination of protective devices for implementation of the scheme. It has also ability to accommodate the arc flash sensor which increases the protection sensitivity.

# PREFACE

The Thesis is written for fulfilling the partial requirement of the master degree in Electrical Engineering with smart grid major. The thesis has given opportunity to study the related topics in a deep manner. It helps to enrich the knowledge of thesis writer and reader perspective. During the writing of Thesis, Professor Sami Repo as a supervisor has provided the guideline and comments to fulfill the requirement of the Thesis. It is very praiseworthy that he provide some time from his busy time schedule. I am as a thesis writer very grateful to my mother. She helps me to provide motivation for complete the thesis which is a painstaking task. And also I am delighted to thank most merciful almighty creator of the universe.

Tampere, 2017

Chowdhury, Md Tanvirul Kabir

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| kV | Kilo Volt |
| DC | Direct Current |
| AC | Alternating Current |
| MPa | Mega Pascal |
| “IED | Intelligent Electronic Device” [42] |
| “IEC | International Electro technical Commission”[42] |
| “GOOSE | Generic Object Oriented Substation Event”[44] |
| “IEEE | Institute of Electrical and Electronic Engineers”[43] |
| CT | Current Transformer |
| “NFPA | National Fire Protection Association”[43] |
| “NEC | National Electric Code” [43] |
| “OSHA | Occupational Safety and Health Administration” [43] |
| CB | Circuit Breaker |
| CDC | Common Data Class |
| XML | eXtensible  Markup Language |
| SPS | Single Point Status |
| SV | Substituted Value |

| | |
|---|---|
| ASCI | Abstract Communication Service Interface |
| SCL | Substation Configuration Language |
| CID | Configured IED Description |
| SSD | System Specification Description |
| ICD | IED Capability Description |
| SAS | Substation Automation System |
| GSE | Generic Substation Event |
| GSSE | Generic Substation State Event |
| OSI | open systems interconnection |

# 1. Introduction

## 1.1 A Perspective

The demand for the electricity is becoming higher day after day. The population of the world is also increases with the time. Due to the increasing number of population, the economic development has also moving to advance. Economic development is also a notable indication for higher demand of electricity. The infrastructure development of power system with the economic growth is required for fulfilling the demand of electricity. The power system infrastructure development has included with building new generation plants, distribution and transmission structure. As the number of customer for the power consumption has increased, the power system is also become large. Electrical energy is a converted form of energy that produces centrally and transmitted economically over a long distance. The adaptability of the electrical energy is very efficient for the domestic and industrial purpose. The production of electrical energy has also done in a distributed unit form. Generally, the production of electrical energy has come from the fossil fuel like coal, gas, oil. Nuclear and hydro are also an important source for production of the electrical energy. The hydro power plant could be also a good solution for avoiding the production of greenhouse gasses. The produced power will be distributed from the generating station. Maintaining a quality power supply is also a challenging matter for recent scenario. Power system reliability and quality supply are vital factors for the network and distribution operator. The distribution of power to customers has required a infrastructure called substation. The busbar is one the vital part of the substation. The basic idea of bus bar is to connect the incoming generators supply with the outgoing distributed destination. In this thesis it has been focused to design about the protection system of the bus bar. [01]

## 1.2 Overview of the Power System

The power system of a geographical location is consisted of generation unit and network unit. The network unit has divided into two segments. The name of one segment is transmission and other segment is called distribution. The generating station and distribution system both are connected by the transmission system. The transmission lines are also responsible for merging different power station together. The distribution line and its related accessories are also responsible for connecting the loads in an area with transmission line. The power system of different geographical location is also join and formed regional grid. These regional grids are different frame of unit which based on economic and technical reasons. Those regional grids are interconnected and formed national grid.

Power generating station could be built close to the load center or the near to the production center of the fuel. If the generating station far from the fuel production center than the fuel has transported to the generating station. The generation of the electrical power at voltage 11 to 25 KV. After the power generation, it will have stepped up from 66 KV to 400 KV for the transmission purpose. Higher the value for transmission it will makes lower the loss on transmission line. DC transmission for long distance will be more economical process for transmitting the power. The conversion process for AC to DC and from DC to AC has required converter and inverter arrangement. The stepdown of voltage has happened at bulk power substation. Some industrial consumer has expected to take power at this level. this step down is called sub transmission level. Next voltage is dropdown in another substation which is dedicated for distribution. Power distribution has done at two different voltage value. One voltage value is called feeder voltage and the other one is secondary or consumer voltage. According to the British standard the magnitude of the primary or feeder voltage level is 11 KV and the secondary or consumer voltage level is 415 V for three phase/ 230 V for single phase. [01, 04]

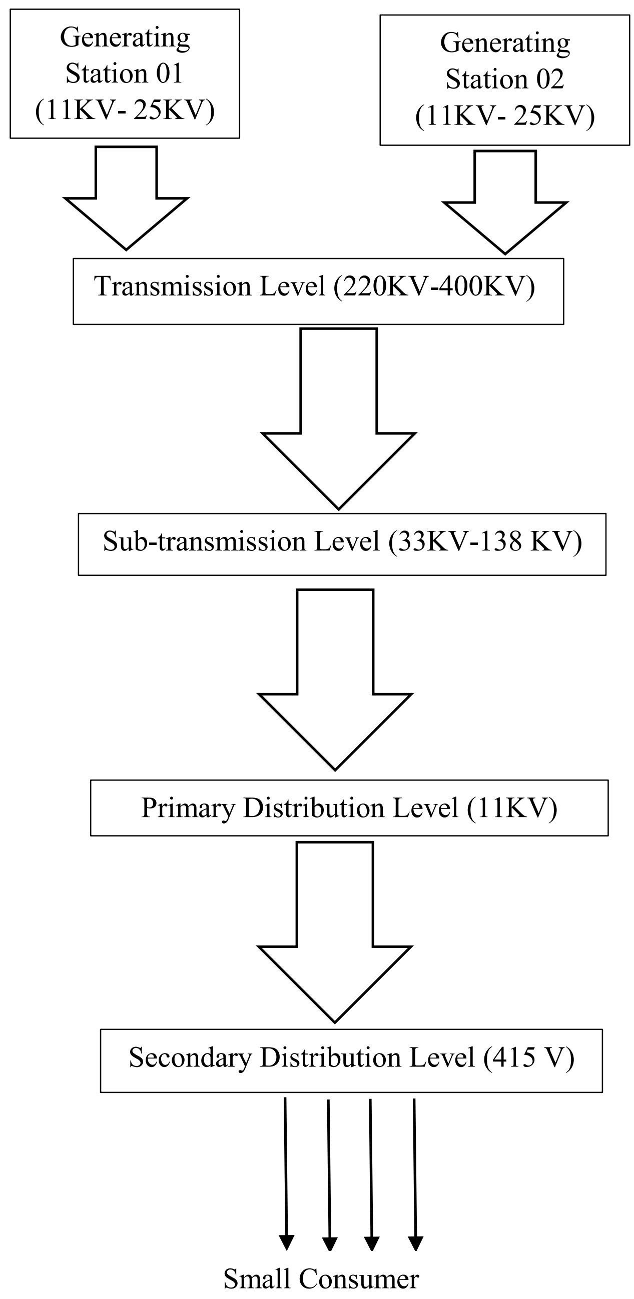


Figure 1.1 Power System Schematic Diagram, Source: ([01])

The network part reliability is the most challenging issue for the power system. The number of higher customer premises causes the network is spread in a large scale. The reliability and the stability of the power could be interrupted due to operating error or environmental reason. To erase the operating error it has been a burning question to make the system more automated by new technology.[02] Reducing the scope of the human interaction with the system operation could be helped to avoid the risk of accident. So integrating the manual system with automation. Embedded system has introduced for making the system operation smoother. The natural calamities cannot be avoided and that causes also operational disruption. Depending on the voltage levels, the Finnish electrical network can again be segmented into three parts. High Voltage level is between 110–400 kV. The total length of the high voltage level line is approx. 20,700 kms of total network length. Medium Voltage level is between 1–70 kV. The total length of the medium voltage level line is approx. 137,000 km of total network length. Low Voltage level is from 1 V to 1 kV. The total length of low voltage is approx. 232,400 km of network length. [03][04]

## 1.3 Background of Research Idea

From the generation to customer end the electrical power has delivered with long transmission line. Connecting the transmission line and related equipment in a correct manner is very important. An erroneous connection is responsible to increase the ohmic resistance. As a result it will dissipate energy and in the end the contact junction will be melt. The short distance between two contacts, air is going to be ionized. This is known as single phase arc. This low current arc is not so much significant. When such insignificant single-phase arc is short circuited with the neighbor phase makes high current arc fault. The protection modules are available in the consumer level, substation level and generation level. These protection module or switchgears are also contained with lot of mechanical contacts. The switchgear or protection module that affected by this arc fault will be out of order. It will not resume in operation until the replacement has done.

The analysis of arc fault protection can be done in different ways. In this study the discussion has based “on the analysis of harmonic spectrum of the phase currents” [06]. The harmonic spectrum has impacted significantly if the short, single-phase arc occurred. The changes have noticed and measurement done after switching off the system. The power is dissipated when arcing is done due to current amplitude, time of burning and materials that are used. The mechanical stability of the switch gear equipment has decreased due to high temperature and pressure during arcing. [06] The rising of several MPa in the pressure can cause the melt of metal cladding. The passive or active protection concept has used to protect from damage of the device itself and human. [05]

The internal arc test effectiveness is standard for low voltage. It has derived from the medium voltage standard. The generation of an arc fault has tried to avoid in active protection. Preventing to touch live parts and clearance or creepage distance have increased are the steps to do active protection. The protection level has increased by the entire protection concept. These protection concepts can able to reduce only the certain sources of errors. Some components need to replace during the life time of switchgear that decrease the protection level. The arc fault impact has tried to reduce by passive protection. [06] The possible foot points of an arc can be prevented with the use of plastics. Fire is the threat against the protection due to the extensive use of plastics. Passive measures are used to protect the people. From the arc point of view, it can only make less amount of damage. [05]

## 1.4 Electrical Bus Bar

It could be a conductor or a bunch of conductors which collect electrical energy from different feeders in an inward way and supplies towards outward. The inward and the outward current starts from a junction point. The junction point is known as electrical bus bar. During the fault regime in bus bar, circuit components are disconnected and faulted bus bar has disconnected from the power system. It is generally made by Aluminum. Aluminum has higher conductivity, lighter weight. The shape of electrical bus bars in the substation is rectangular in cross sectional view. The other available bus bar shape are round tubes, solid round bars or shape tubes. Aluminum have quite a lot of benefits over copper such as greater conductivity, lesser cost, exceptional corrosion resistance etc [07] There are several factors that are responsible for selecting the configuration of bus bar. These are system voltage, position of substation, supply reliability and cost. List of the electrical fact that take into account to select any bus bar arrangement in a substation are

i. The pattern of bus bar should be general and not hard for over hauling.

ii. It should have the flexible design for adding the extra load to the bus bar.

iii. The pattern of the bus bar should not be extravagant with quality service.

iv. The spare parts should be available for putting the bus bar in to the operation from the outage.

Different types of bus bar have described below.

**a) Single Bus-Bar Arrangement**

The bus bar arrangement for the single set for total length of the switch board. This kind of busbar can able to give opportunity to connect all generators, transformer and feeders. The bus bar arrangement has shown in the figure 1.2. This kind of bus bar arrangement has low initial cost, less cost for maintenance and very simple for operation. [07]

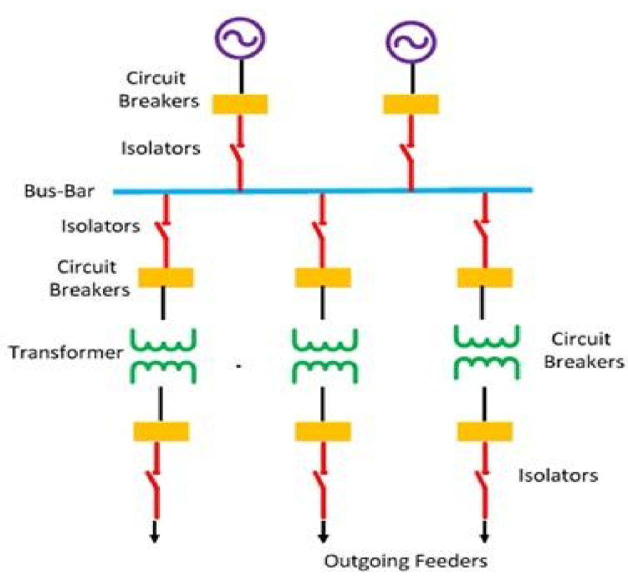


Figure 1.2 Single Bus Bar Arrangement diagram. Source: ([07])

### b) Bus Sectionalized Pattern with single Bus Bar

The bus-bar is divided into a circuit breaker and an isolating switches. The fault on one portion does not causes a whole blackout. In a sectionalized bus bar pattern only one extra circuit breaker is required. This does not charge greatly in association to the whole cost of the bus bar system [07]. During the maintenance of one section does not affect the other part of the bus bar.

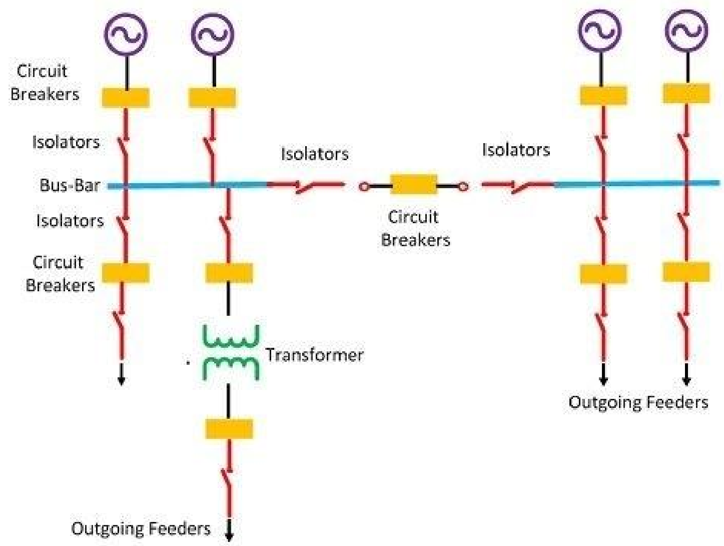


Figure 1.3 Single Bus bar arrangement with bus sectionalized. Source: ([07])

### C) Main and Transfer Bus Arrangement

This type of pattern has used dual bus bars. One bus-bar is called main bus bar and second one is called supporting bus-bar. The generators and feeders are connected to one of the bus bar using coupler. The coupler is involved with both circuit breaker, isolating switch. The bus coupler is responsible for shifting from main bus-bar to supporting bus bar or vice versa. This operation has done during the load has connected. During the fault time it could also possible to shift from one bus to another bus. This arrangement has worked if the bus is not under fault. The subsequent stages may be reserved however relocating the load to the reserve bus (transfer bus). These steps are

Shut the bus coupler and established equal voltage in both buses.

Shut isolator and open it in reserve bus.

The load is now shifted to the reserve or auxiliary bus (Transfer bus) and the main bus is detached [07]. The bus coupler has opened in the end of the process.

Figure 1.4 shows the main and transfer bus arrangement.

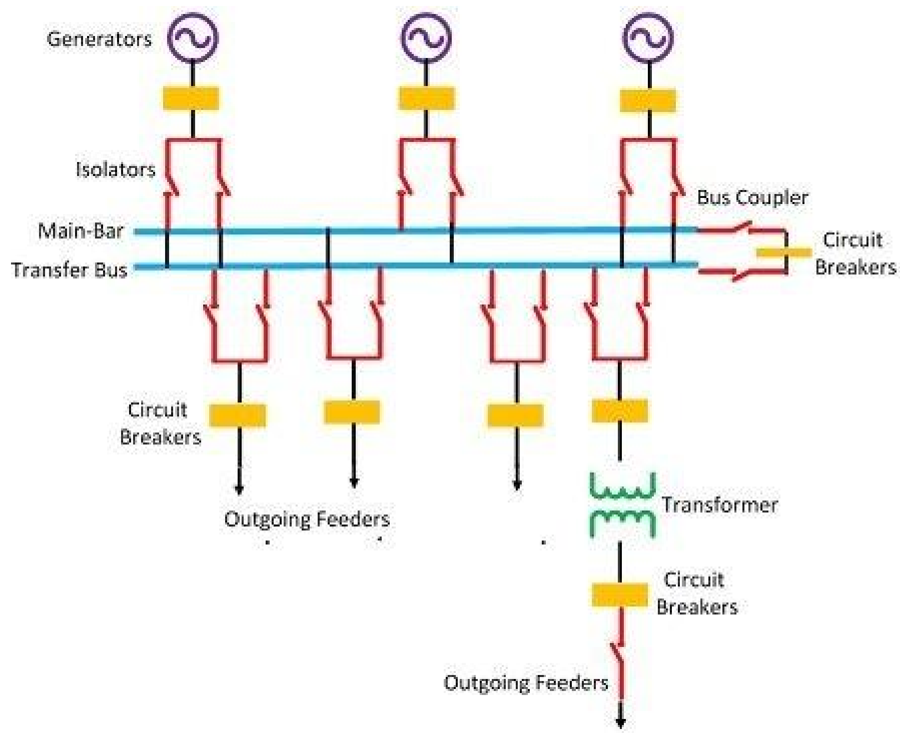


Figure 1.4 Main and transfer bus arrangement. Source: ([07])

### d) Dual Bus and Breaker System

This kind of arrangement dual bus bars and double circuit breakers are used. This system does not ask for bus coupler. The arrangement is consistent and easier for avoiding the fault disturbance to the reduce rate. It has endurance in power supply. The load could be transfer to alternate circuit breaker in the course of the main circuit breaker goes under repair situation. For the dual buses and circuit breakers it rises the budget of pattern. The double bus double breaker arrangement does not use so much in the substation bus-bar establishment design. The figure 1.5 shows the dual bus and twofold breaker arrangement. [07]

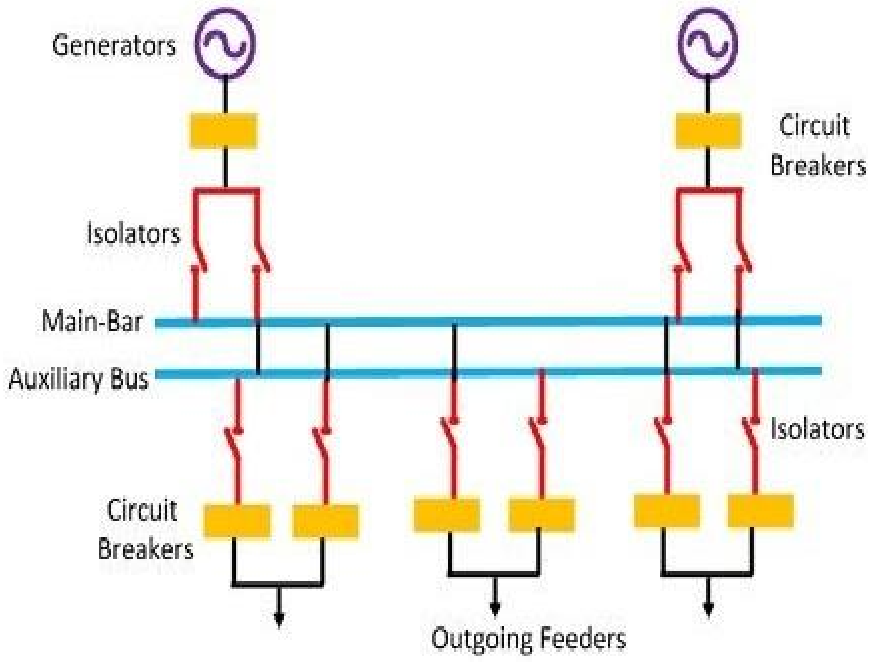


Figure 1.5 Dual Bus and Breaker System [07]

### e) One and a Half Breaker Pattern

The pattern proposed that three circuit breakers are necessary for two circuits. The amount of circuit breakers per circuit arises out to be one and a half" [07]. This arrangement bus bar could be use in high power capacity substation where large amount of power has handled per circuit. Figure 1.6 has showed the one and a half breaker pattern. It offers great safety contrary to loss of supply as a fault in a bus will not interfere the supply. The supplementary circuits are easily additional to the bus bar. The bus Voltage can be used as a source for relays [07]

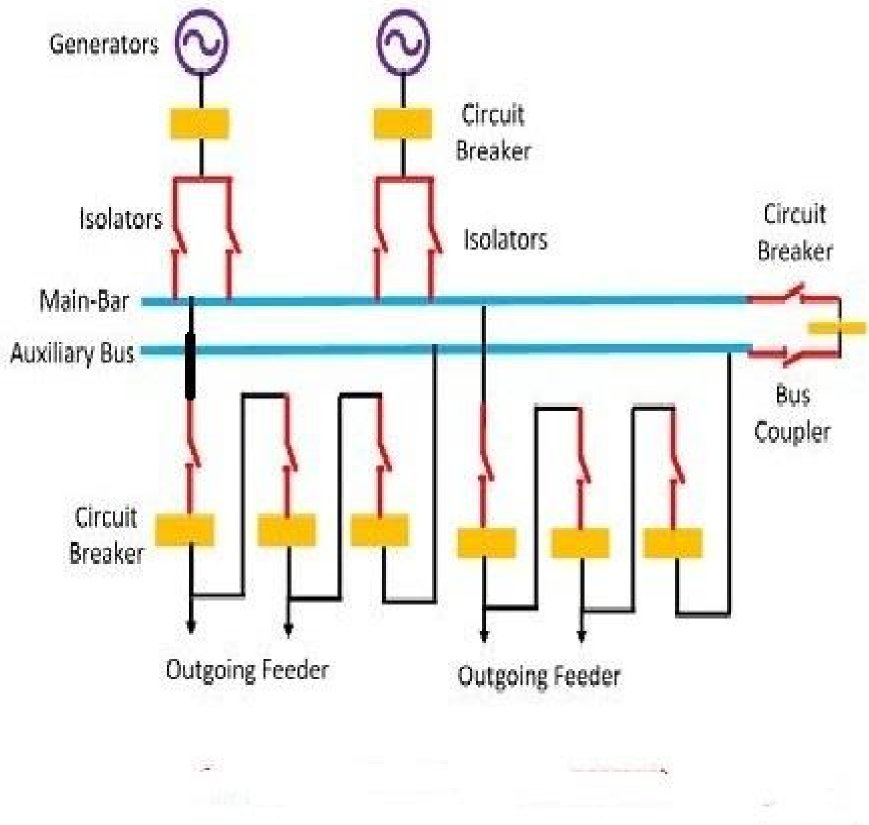


Figure 1.6 one and a half breaker pattern [07]

## 1.5 Objective of The Thesis

The research objective of the thesis can be fragmented into the following segments

- Study the different component in the substation and its working process. The components are busbar, Intelligent Electronic Device (IED), arc sensors, feeder cubicle, IEC 61850 system bus etc. The equipment are relevant with this thesis need to study rigorously because it will increases the knowledge about the operation and process.

- Discuss the different busbar protection schemes. The impact of those protection schemes during different design scenario.

- Develop the knowledge on the arc flash origin, characteristics and different properties of arc. The study has covered the arc short circuit incident and arc protection system arrangement.

- Get familiarization with the IEC 61850 communication protocol. The study of the protocol has included with protocol outline study, decomposition of logical device concept, common data class, logical node and protocol mapping aspect.

- Design a laboratory experiment model. The model will encompass the protection of the bus bar in the medium level voltage. The goal of the thesis is to implement a protection scheme for bus bar protection. The Intelligent Electronic Device (IED) will be considered as a protecting device for the protection scheme implementation. For the purpose of the coordination between the IEDs in the Substation, the IEC 61850 standard communication protocol can be used.

## 1.6 Study Procedure

In this thesis, the research has done as required for reach it ultimate destination. The study has started following the different scientific papers, books and web pages. It helps to know rigorously different keywords that are important for this thesis. Busbar protection is an important matter for running the power system more in a reliable way. It is important to know the basics of busbar and its role in a substation. The arc protection scheme could be the next part of the thesis goal. Arc flash could be the more hazardous situation that causes a great extent of harm to the busbar. Developed technique selection and study have done in the next stage. The device that have need to realize the protection scheme is called IED. This IED has different role and functionalities. Its need to make the proper settings for the IED to put a protection duty. The study is approaches towards the basics of IED and the functionalities. These IEDs are commercial products and the manufacturer has set the basic operating process with brochure. The brochure will have guided the primary operating process. To fulfill the requirement of the thesis this activity has play a vital role. The setting of IED would be developed with two focusing part. These are electrical parameters setting and the other one has focuses on the communication settings. The communication settings are need to follow the IEC 61850 standard. That helps to communicate different IEDs from different manufacturer. In the last part of the research goes towards the simulation model designing in a real-time platform. It helps the research to be more fruitful.

## 1.7 Organization of The Thesis

The Thesis has documented with five chapters. The beginning chapter is describing about the initial knowledge about the power system and voltage levels. Thesis goal and other relevant topics have covered in this chapter. The second chapter has described about the protection scheme in the power system. The detail description has included in this chapter. Different kinds of protection scheme have used to protect the system from risk hazard. The third chapter has discussed about the arc flash. The description of the arc flash entity has focused in this chapter. The fourth chapter is about the communication protocol IEC 61850 with GOOSE messaging. The Coordination of IED and the interaction between the IEDs have described. The fifth chapter is about the implementation procedure of arc flash protection. Conclusion and future of this research work has described in this chapter.

# 2. Bus Bar Protection Schemes

## 2.1 Introduction

The arc flash hazard is a vital concern due to human safety issue. Occupational safety has given more emphasis to avoid any kind of unexpected incident. The IEEE standard 1584 has associated concerning about the arc hazard which depends on energy level of arc flash. The duration of the arc flash, short circuit current and distance between the electrodes are the factors that concerning about the arc flash energy. It will be risk full situation when working close to an energized part of electrical system. It should need to define a flash protection boundary. The possible distance for flash protection boundary means a person can avoid or can able to sustain burn that not affect deeply. The fault clearing time can be possible to control. The grounding method of the network could able to reduce the fault current.[11]

The current flows in the power system cannot be over the rated value. The protection regarding the overcurrent considered as an important tool for industrial and commercial sector. The protection system composed of protecting device that responsible for the measurement of short current and trip the breaker if the current limit is excessive. The protecting device could be functionally integrated inside of circuit breaker or stand-alone protection relays.[37] The selectivity has determined on time grading. The devices are situated in long distance from the current source can be adjusted by short operating time. The closer devices of current sources can be adjusted gradually extended operating time. To accomplish discerning protection, the required lowest functioning time (denoted as $\Delta t$) among overcurrent protection devices which are organized in a sequence. [16]

The Bus bar of power system is an important infrastructure. The protection system dedicated for bus bar can detect the short circuit current and tripping can be done of all the current feeding sources to the bus bar. The tripping should be done by the protection system without any intentional delay. The bus bar protection function is more complex comparing to overcurrent protection due to higher selectivity. The challenging part of protection system is the increased cost and complexity. There is another hazard that causes the power system could be unselective due to breaker failure. The failure for opening the breaker in the response to trip commands from relay and inductee's backup dissipating using negligible delay. This system of safety also deals with complication and cost. A balance of all influences compared to the increasing value of more quickly glade faults. The feeder breaker failure has causes delay in clearing of the fault. The feeder breaker failure is not so common incident. But the protection system must be aware about this scenario. The reasons of breaker failure are the mechanical linkage within the breaker. There is cabling among the breaker and distinct overcurrent safety device [38]. The battery failure is also an important reason.

There are different schemes that have used to protect the bus of the power system.

## 2.2 Reverse Interlocking Scheme

The reverse interlocking system which has used for distribution busses in medium voltage level. This scheme has able to make a trade-off between economical solution and performance. It is one of the fastest fault clearing option for faults in bus. The longer fault clearing time can be avoided in the case of faults near to bus during the co-ordination with the relays of radial feeders. The numerical relays are normally used for materialize the reverse interlocking scheme. It has different setting groups. These groups could be put in action at any time. The working set up of the relay has selected during the time energized condition of Arc fault. Due to favor of higher protection for working personnel, the normal coordination has deactivated. [08] The basic target of the settings is to trip the system due to arc fault and reactive the original setup which is responsible to coordinate all other relays.

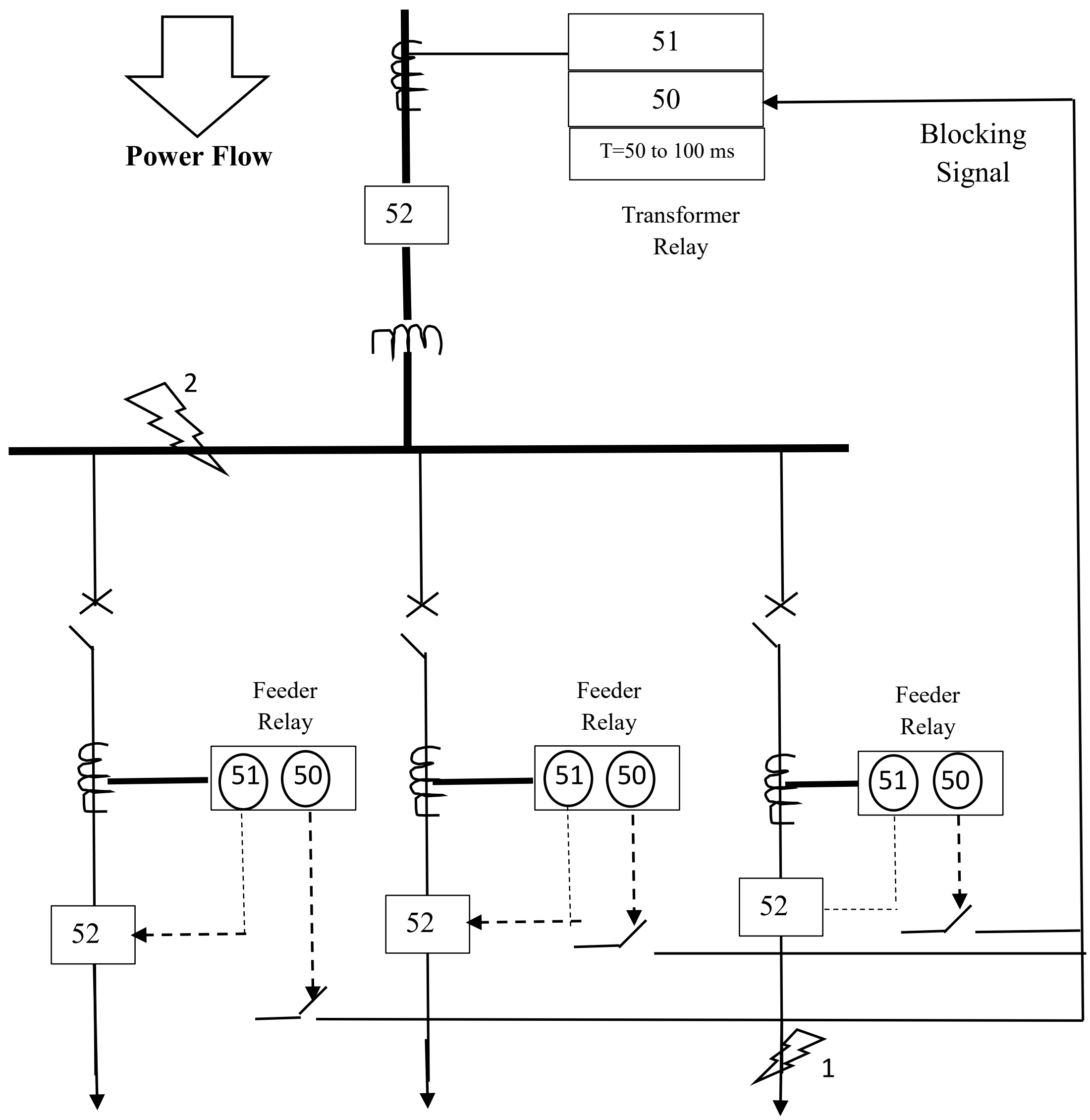


Figure 2.1 Reverse Interlocking Scheme. Source: ([08])

The reverse interlocking scheme has shown in the figure 2.1. The circuit breaker, inverse overcurrent element and instantaneous elements are denoted as 52, 51, 50 respectively. The denotations are same for figure 2.2, 2.3, 2.4 and 2.5. The time overcurrent protection relay has connected to the incoming feeder with transformer. For the fault location 1 in the figure 2.1 the feeder relays are responsible to select the block signal for source feeder. The feeder relays pickup is cast-off to interrupt the main inward line to the bus bar. This block signal will block the instantaneous over current from source feeder. The time limit for the delay of the instantaneous element of the transformer relay should be 30ms to 50 ms. It will help to understand the transformer relay an interrupt signal that interpret from the pickup signal of a feeder relay. The scheme has support the interlocking process between the feeder relays and transformer relay. Due to the block signal coming from the pickup signal of the feeder relay in a reverse process, the scheme has named as Normal reverse interlocking scheme. [08] [12]

In case of fault in the bus (in figure 2.1 fault location 2), no feeder relays will refer pick up signal. For the circumstance of the fault in bus and transformer the prompt overcurrent element on the source will trip instantaneously. The reverse interlocking scheme is generally castoff on medium voltage distribution buses and heavy business organization buses [08]. Feeder arrangement in radial manner of substation has used reverse interlock scheme for instantaneous tripping. The scheme can able to shut down the bus instantaneously but that will not degrade the feeder relay co-ordination. The scheme will stay active without switching setting group. The switching setting group has used for controlling the relays in feeders or other protection arrangement. The fault clearing time for feeder fault will not depend on the proximity of energized feeders. The feeder has protected by over current relay in this scheme. The transformer relates to the source feeder.

The differential relay system does not need to use. In the differential relay system, it has required to set up two current transformers for protecting a certain zone. This relay system has needed design effort of engineer and relevant equipment for setting up those current transformers. The differential protection relay system has required also space and that is also costly in urban area. There are also maintenance and installation cost related with additional this differential relay system. Due to implementation of this reverse interlocking scheme, the cost may be save. “The reverse interlocking scheme” [08] has reduced the cost as the existing over current relay has done all required purpose. “The instantaneous element (50) on the source feeder” [08] has responsible for normal operation. The over current element (51) is responsible for coordination. The coordination is happening between feeder relays and the transformer of incoming connection towards bus bar. The consequences of coordination are time delayed fault mitigation, introduce of bus and transformer faults dedicated critical arc energy. In this scheme both elements are used independent but it has also a backup connection. The communication protocol like IEC61850 has made the communication easier and manufacturer independent relay to relay peer communication. It was hard to maintain before due to the wiring for connecting the relays. The information has picked up by the help of GOOSE message to the transformer relay. Different kinds of troubleshooting can be done by the GOOSE messages in IEC61850 such as if the connection in power line is broken than it could be detected. GOOSE messages are delivering earlier than wired system. The GOOSE message contains the information about the protection, interlocking, blocking orders among the feeder IEDs information. The scheme can be applied where it required to clearing the fault in 8-10 cycle. For the earlier tripping, it needed a differential relay bus. If radial feeders are used as load feeders than the reverse interlocking scheme is applicable. A directional relay must be installed in case of generator is connected in any feeder.[09]

## 2.3 Reverse Interlocking Scheme with Multiple Infeed

The figure 2.2 has small extent different scenario than the figure 2.1. There is a generator (G) unit has connected in the middle branch of the substation arrangement. Consideration for the analysis of figure 2.2 is that the fault location 1 and fault location 2 have not occurred simultaneously. When there is a fault occurs in the location 1 than the corresponding feeder relay will send a pick-up signal towards the transformer relay and the feeder relay in the branch with generator. The pickup signal will work as the blocking signal for those relays. [08] [13][14]

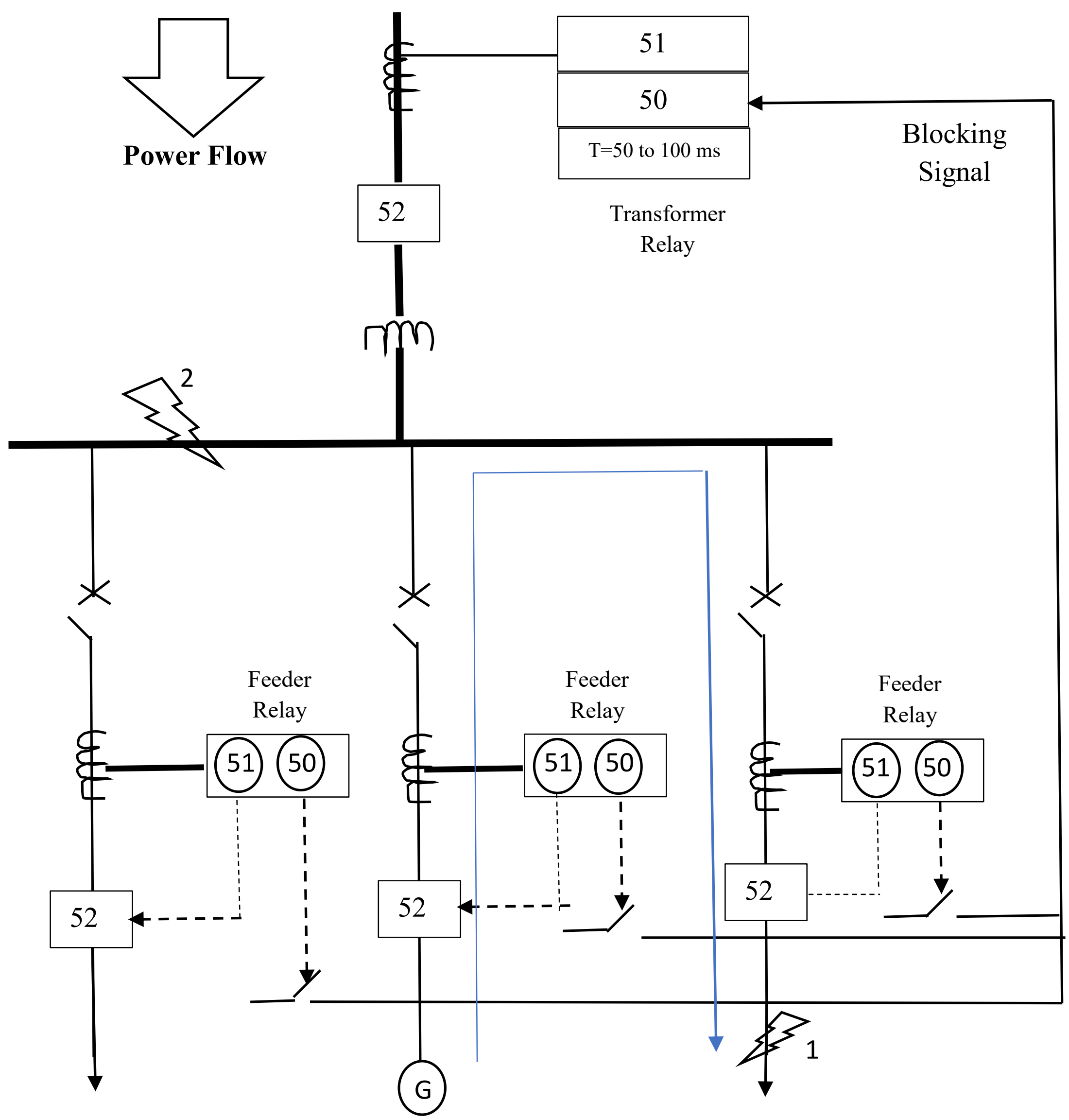


Figure 2.2 Reverse Interlocking Scheme (with generator). Source: ([08])

Generally generator always "contribute to the fault current" [45] towards the fault location. In the figure 2.2 if the protection system is works properly than the generator connected feeder will not tripped. Because the generator feeder relay has blocked by other relay. In the figure 2.2 the blue line has showed the flowing current direction towards location 1. As a result, the feeder with generator goes under the sympathetic tripping. During the fault occurred at the bus bar location 2 the impact of the generator will also significant. The incoming feeder transformer relay will trip and send signal towards the feeder relay of the generator to trip. Due this feeder relay of generator branch tripping the continuation of power supply on that certain feeder will not possible anymore.

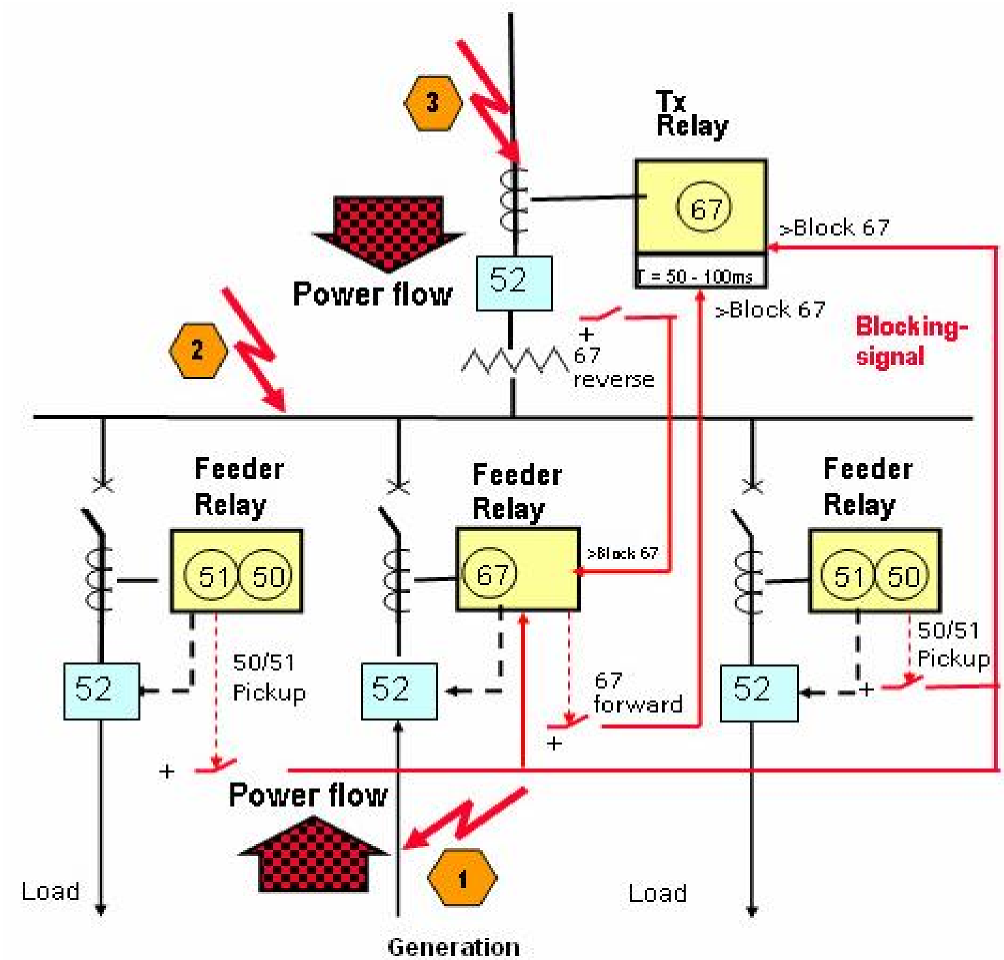


Figure 2.3 Reverse Interlocking with multiple in feeds. Source: ([08])

In the figure 2.3 the reverse interlocking scheme can also be applied. There are two load feeders and a single generation feeder. The blocking signal has responsible to block the trip. The signal has generated by 50/51 of any relay in the load feeder for all outgoing feeders from the bus system. The directional over current relays on the generation feeder can also able to send blocking signal as if it senses a fault in the opposite of bus path. When the generation feeder relay found a fault, which propagating towards the bus but there is no block signal has received from other relays then the trip occurred in 30-50ms time delay. In the fault location 01 when the fault occurred in the generation input the relay 67 forward blocks the current towards feeder and issue a block massage for transformer relay with a trip. In the direction of bus, the transformer relay 67 forward element and the feeder relay 67 reverse issues a trip signal after 30-50 ms. The incident has happened in fault location 02 when no blocking signal has received from the feeder relays or from the other infeed feeder like 51 & 50. At the fault location 03 as fault current has found in the generation direction the transformer relay 67 reverse element send a block signal. The trip signal has issued after 30 to 50 ms. It happens if no block signal has received from other relays. Fast bus protection could be archive in an economical and effective way. The scheme needs to use transformer measurement and 67 protection elements. The bus voltage has applied to measure transformer potential. The scheme has made the wiring system complex between the relays. The different infeed conditions have used for coordinating the settings sensitivity. "Sequential tripping of a bus fault" [08] is the consequence of setting sensitivity coordination. The application of "the reverse interlocking scheme" [08] depends on the fault clearing time requirement.

Faster tripping time for bus fault can be archive by the reverse interlocking with single source and multiple sources. An additional CT needed for clearing bus faults by a real bus differential potential scheme. It will reduce the fault duration and arc flash energy that will not degrade the security and protection reliability. The over current relay 51 and the downstream relay are coordinately clear the fault as the fault arose next to the feeder CT. The relay 51 will permits for interruption for fault in the feeder. This relay 51 is very close to the bus. "A certain arc flash hazard" [08] has created inner part of the substation zone due to faults behind the Current Transformer (CT). So, this is a hazard for the people inside that area.

## 2.4 Advance Reverse Interlocking Scheme

The focus of this scheme is shortening "the tripping time" [46]. The arc faults occurred on the bus bar and to the feeder positions near of the bus. These faults are given priority in this scheme. So, if these kinds of arc fault occurred than by applying this "advance reverse interlocking scheme" [08] can be possible to lessen the length of "tripping time". When "the tripping time" [46] reduced than the amount of incident energy will be less. Only one infeed has integrated with the simple reverse interlocking scheme in a modified manner to apply advance reverse interlocking scheme. Several infeed can also be added with the simple reverse interlocking scheme. According to the figure 2.4 the zone facts of remoteness elements 21 has used to identify the faults near to a bus bar. The basis of the "simple reverse interlocking scheme" [08] is the instantaneous over current element 50. This instantaneous over current element 50 has replaced by distance function 21 in transformer relay. For the case of bus faults there is no difference between normal reverse interlocking scheme and advance reverse interlocking scheme. [08]

In the figure 2.4, it shows that feeder relay 50/51 pickup is works to send the block message to transformer relay. For the feeder fault, the fault location 1 the 21 pickups have send message to release feeder instantaneous over current element 50. During the fault occurred in the bus bar at fault location 2 not any feeder relay sends "pick up" [08] signal. The distant element will operate instantaneously after certain time duration. The time delay 30 to 50 ms has used. It will help to know surly that a feeder relay picks up signal could be detected within this time. Advance reverse interlocking scheme can able to handle a fault on feeder intelligently. In the feeder relays pick up by the inverse over current element 51. Then the timer has started up. Later, the source the distance element tripping has blocked. The fault location has detected by the distant element. This location detection has done by measuring the fault impedance of fault location 01. The feeder relay will receive that information.[08] Without doing time delay it will release an instantaneous over current element 50 on the feeder relay to clear the fault.

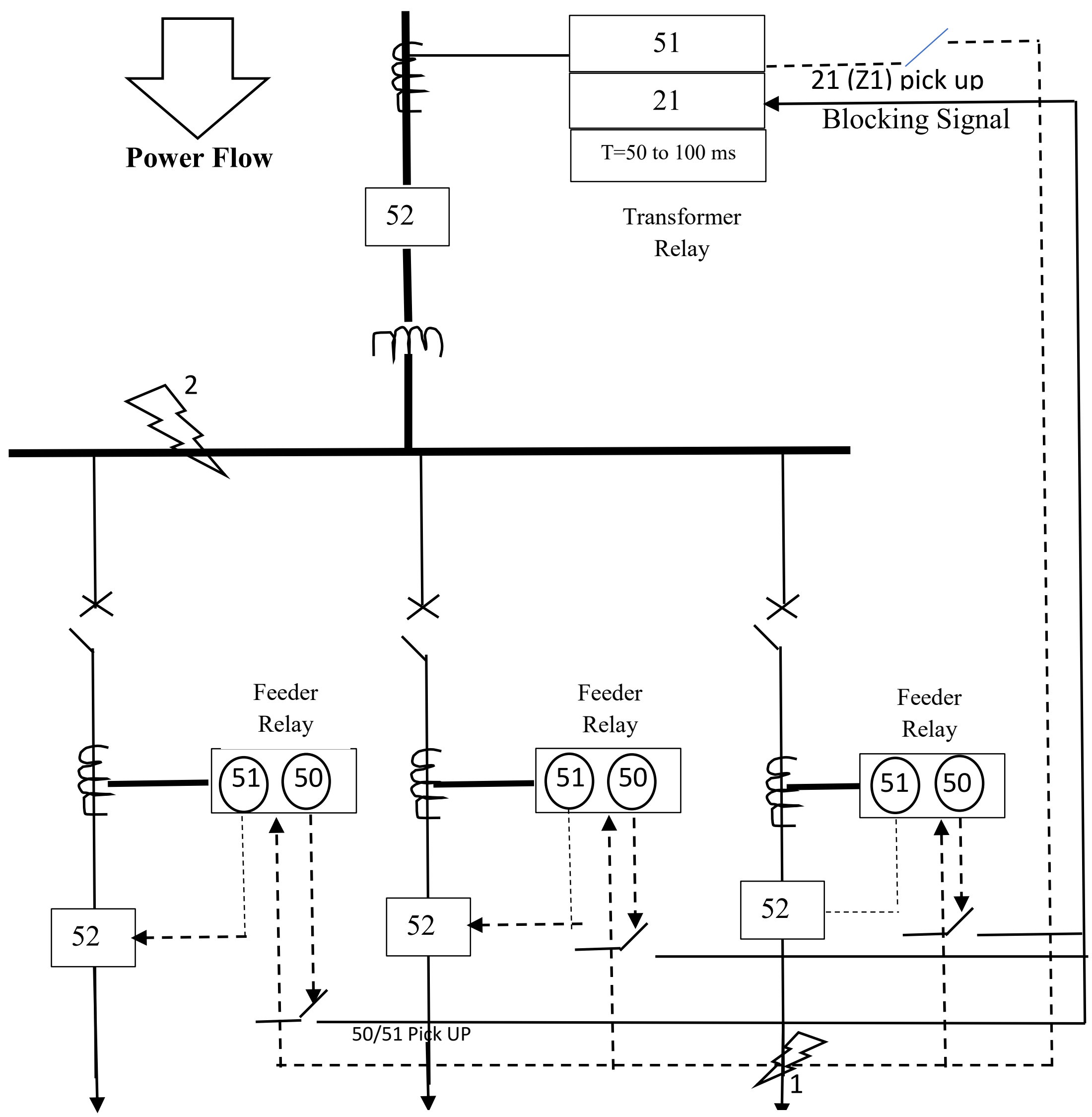


Figure 2.4 Advance Reverse Interlocking Scheme. Source: ([08])

Advance reverse interlocking provides advantages but it needs higher cost distance relay and extra potential transformer should install on the bus. For many users it was not permitted extra wiring between the relays. The information of "pick up" [08] produced by the "feeder relays" [08] should propelled to the detachment relay and vice versa. The extensive wiring problem has solved by a modern protocol IEC 61850. The figure 2.5 has shown the idea of station bus. The detail idea of station bus has discussed on chapter 4. IEC 61850 has allowed independent relay to relay communication. All relays are connected via an Ethernet based station bus. All information will exchange between the relays using GOOSE messages. There could exchange the information in a multicast system. There will be a detail discussion on the IEC 61850 and GOOSE message has included later chapter. [09][10]

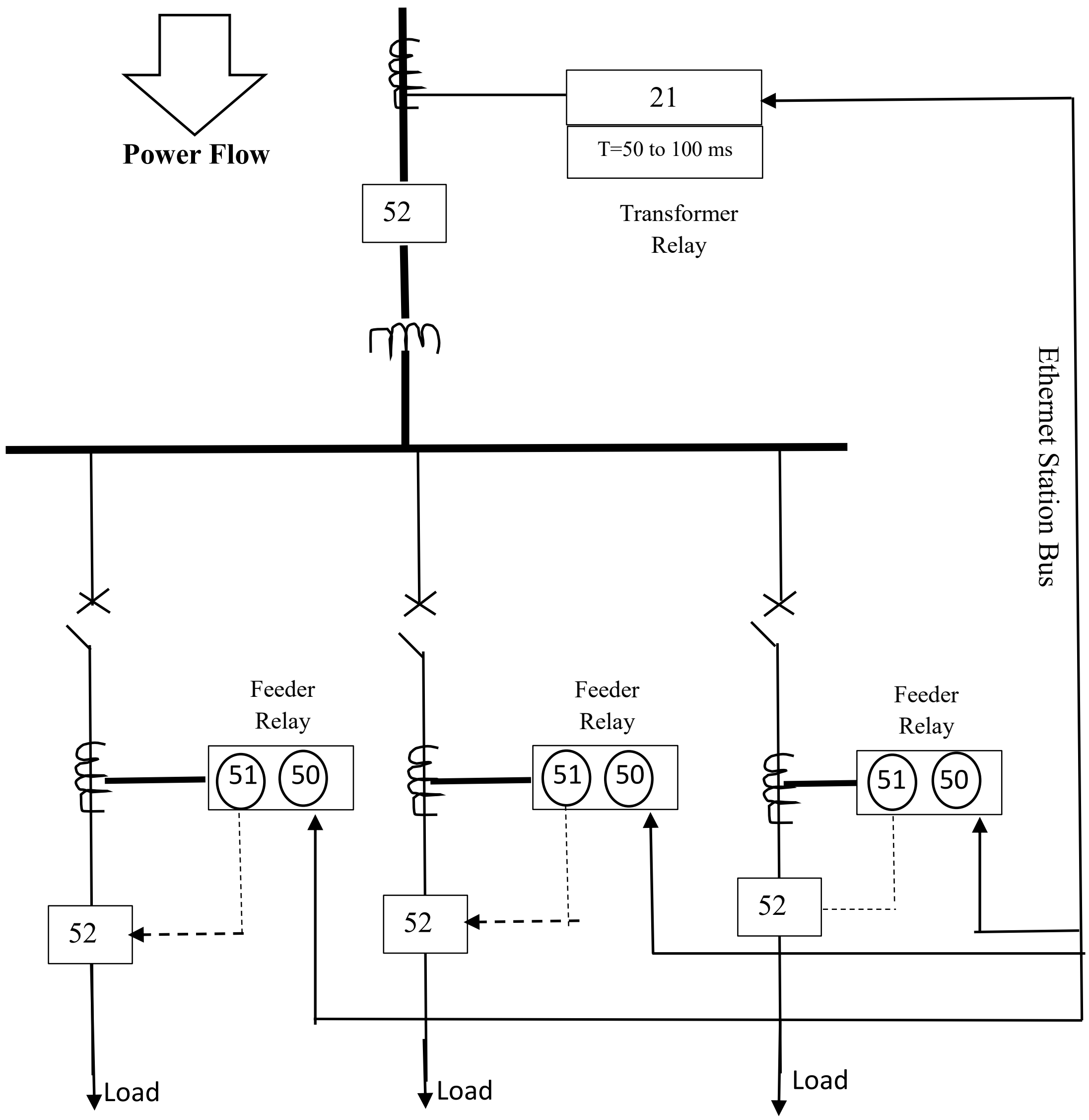


Figure 2.5 IEC 61850 Station bus. Source: ([08])

A distance relay cannot able to identify the fault location certainly due to the length of the cable is not long enough. The fault location could be on the track or after the following bus unit. The scheme cannot able or partially able to find the location. The modern numerical distant relay can able to protect line or cables. The zone element should set in a way that it will able to detect fault in a single distance zone (shows in the figure 2.6). The detection of fault will be 60%- 80% of the straight cable link associated with the bus [08]. The measured impedance is small among the relay and the fault site. The measurement of impedance is based on fault free feeder load. The attention should be given towards the supreme load situations. The length of the feeder is different that connected to the bus. The main reason of different distance zone due to the feeder length is different. There are several distance zones. [16] Generally, five or more zones could be use with modern numerical distance relays. In the figure 2.6 there are three zones with different length of feeder.

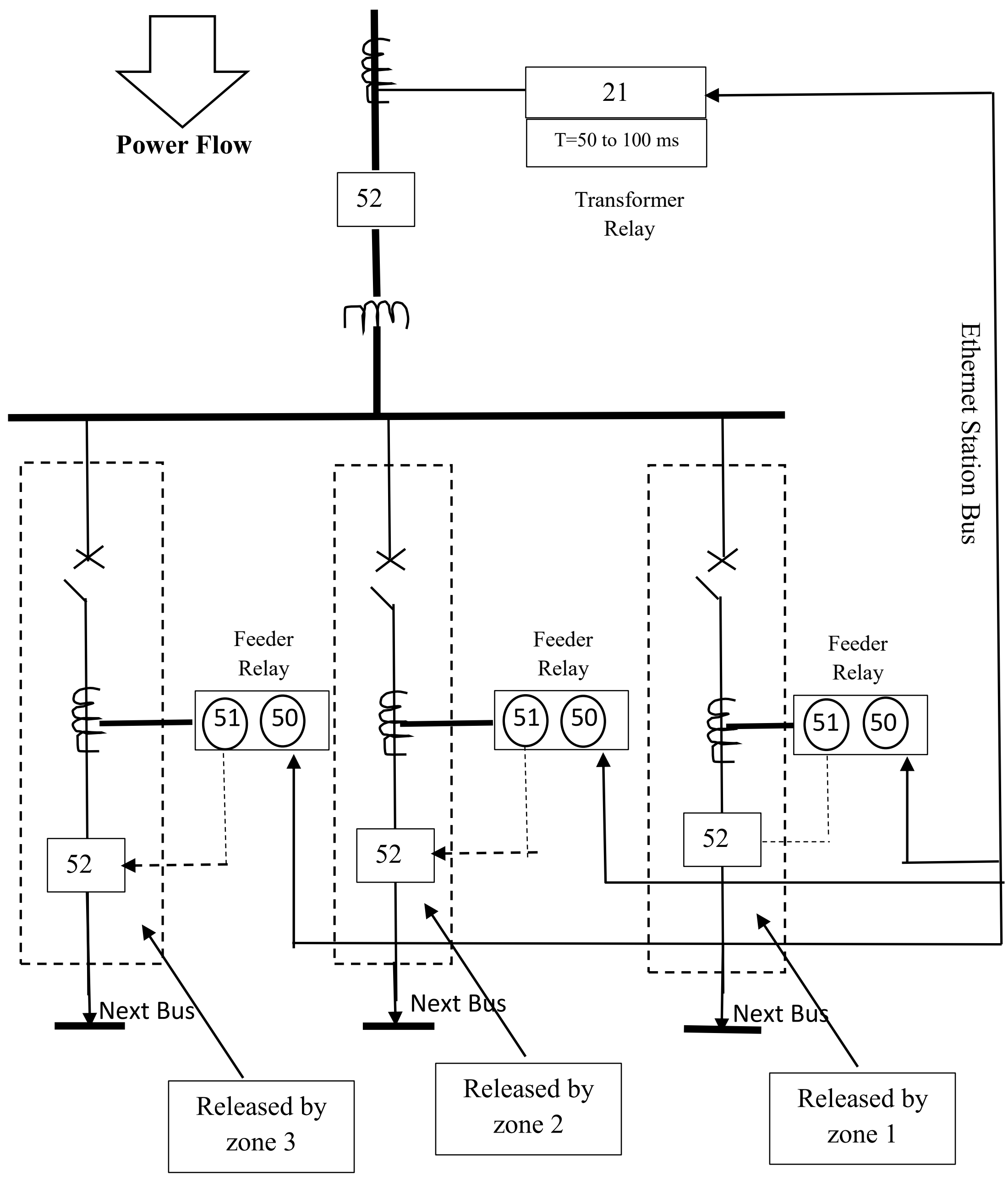


Figure 2.6 Advance reverse interlocking scheme with several distance zones. Source: ([08])

"Fast tripping" for all buses faults and bus close faults are the focus of the "advance reverse interlocking scheme" [08] The significant improvement has found in the power eminence to loads due to this scheme. For this scheme, the long clearing time that responsible for transformer damage risk will reduce. Fault location protection public safety has improved due to the reduction of arc flash incident energy.

## 2.5 High Impedance Differential Protection

For the electromechanical relays, IEC 61850 has not used. The technology of electromechanical relay was use in the beginning of 20th century where the IEC 61850 has started into use in 1990 when solid state relay and later microprocessor relay were in the market. This scheme has been used for electromechanical relay. Different manufacturers have introduced several versions of this scheme. According to the figure 2.7 the main, tie and feeder has connected with bus bar. The current transformers are situated for all types of connections with the bus bar in parallel. The current transformer secondary side currents is accumulated at the joining port. The total current produces a voltage across the impedance and the allocated relay will quantify a voltage. The relay will issue “a trip signal” [38] if the voltage goes above the preset verge value. The term “High Impedance” has given because the relay possesses large inner impedance. The bus zone outer fault consequences the nil level secondary currents vector totality. The relay should not function. The amount of the currents will be huge as the outer part of the bus zone the fault has transpired. On the relay port there will be voltage available and the relay will work immediately. The relay verge settings authorization means as one CT douses to certify process constancy of the relay [38]. This protection scheme is profligate, comparatively simple. The scheme has castoff for together “electromechanical and numerical relays” [38]. The shortcoming of “high impedance scheme” [38] is that it needs there will be Current Transformers on individual circuit associated to the bus. Typically, these CTs will be alike and devoted to the bus discrepancy task. [38]

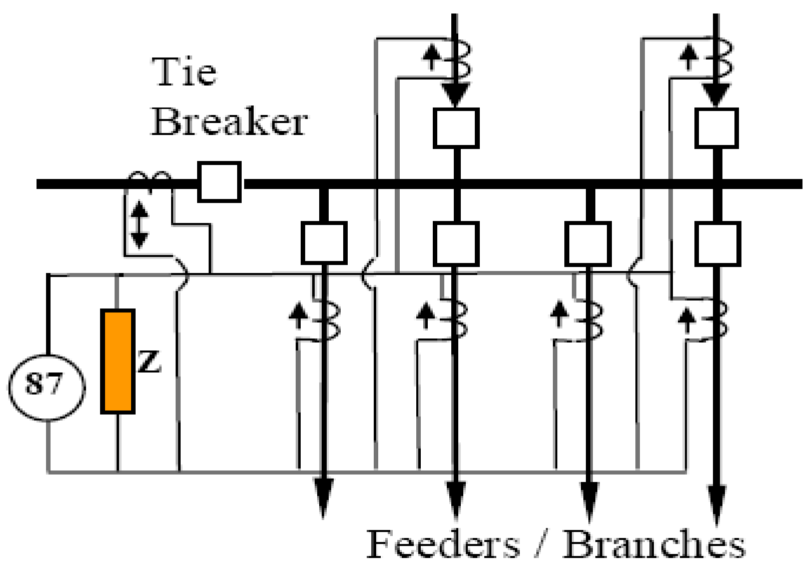


Figure 2.7 High Impedance Bus Differential Protection. Source: ([38])

## 2.6 Multiple Restraint Differential Protection

This scheme named also per-cent differential protection. The transformer protection is the main idea for this protection scheme. Fig 2.8 demonstrates a multiple restraint bus differential protection [38]. The accumulated inputs have used to activate current relay. The CT's average output scale is used to lock up the relay operation. It has provided operational stability. Per-cent restraint bus differential relays normally have numerous restricted feedbacks [38]. The main drawback of the system is the quantity of restraints on the relay may boundary the Bus scope. It can be fruitfully functioning. This type of system is taken into account for numerical relays as the rundown and close to of the CT's output. It is completed arithmetically in the relay. This built the relay contacts less difficult than "electromechanical relays". [38]

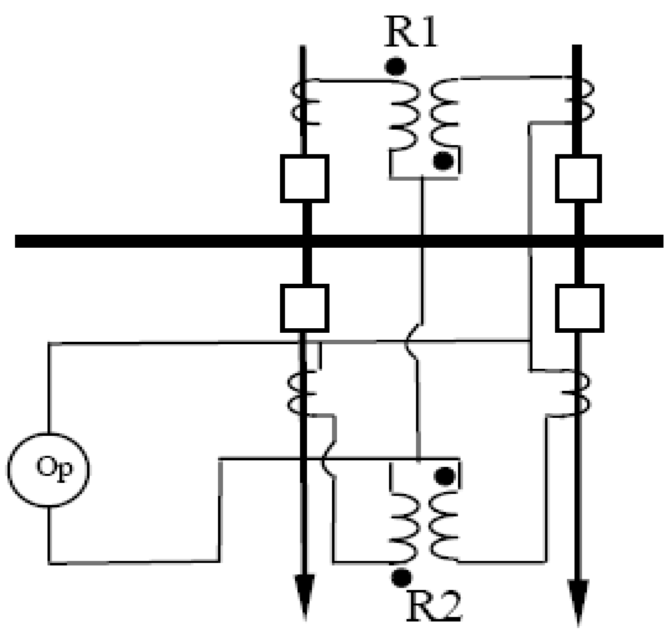


Figure 2.8 Multiple Restraint Differential Protection. Source: ([38])

In the figure 2.8 R1 and R2 are the restrain coil and Op is operating coil. Restraining coil has used for flowing the restraining current. If there is external fault, load condition with ratio mismatch and saturation of current transformer than a restraining current quantity has use as a reference for the differential signal. [40]

## 2.7 Comparator Differential Protection

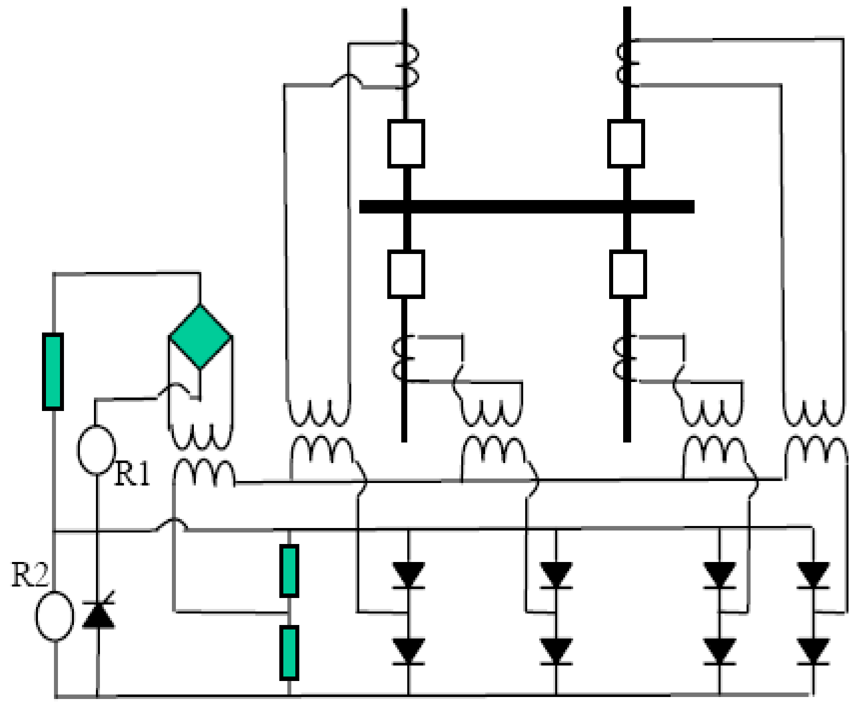


Figure 2.9 Comparator Differential Protection. Source: ([38])

The secondary current instantaneous value of current transformer will take in to account in this protection scheme. This current has put in to a diode bridge. The link added the all branches currents rapid value of that connected to the bus into two amounts. Fig 2.9 shows comparator differential protection. The first summation is the incoming current towards the bus. The following amount is the current outgoing from the bus. The relay will relate the incoming and outgoing currents values. There will be equal as there is no interior bus fault. When there is difference among these double values, then the relay will take operational activity. [38] Even if started in the analog domain similar idea could works for the digital domain of the relays. By short interruptions to permit suitable sampling of the CT's secondary side currents, relay acts in digital system. This scheme of protection has supported parallel and ring main system. This scheme another advantage is it can provide instantaneous protection to ground faults.  The drawbacks of this system is the Current transformer need to match perfectly. The diode bridge should need to be perfectly matched without discontinuity. The cost is high which is not economical for the protection purpose.

# 3. Electrical Arc Protection

## 3.1 Introduction

The arc flash due to electricity is created by short circuit fault. The failure of switchgear of a power system causes the short circuit fault. Due to the electrical arc heat and pressure could create that is responsible for mechanical damage of the system. This kind of incident will be a great hazard for the stuff that working in the vicinity of the arc affected area. This phenomenon has happened from the very beginning of the electrical power system. The electrical arc could also be able to generate due to ionized gas. Due to the furnace or welding it requires the intentional arc production [17]. An undesired arc phenomenon is always very dangerous. The usage of the electrical power has increased day by day. So the risk of short circuit fault has also increases. Because the power system increases in size which increases the need of better protection in longer period of time. The fire that set by the arc on the conductor could be reduces by shutting down the fault point feeding arc current. The arc could be eliminating from the power system using a different protection system. [18] [23]

There are different guidelines and standard done by IEEE, NFPA, NEC and OSHA. According to the IEEE standard 1584 there will be a hierarchical process. The calculation of the available incident energy will be done by this process. The workers could be in touch with electrical strengthened apparatus. This is known as “Guide for Performing Arc-Flash Hazard Calculations” [47]. The “NFPA 70E” [47] is known as “Standard for Electrical Safety in the Workplace” [47] [24]. The arc fault is not so frequently happened. In the medium and low voltage level protection devices are affected due to arc fault. The High level voltage load are also impacted with this arc fault. The fault incident creates radiation, thermal convection, arc blast, flying particles and toxic gas. The cost due to fault hazard could be direct and indirect consequences. The post fault situation is outage of the system. It will cost not only the production efficiency of an industry but also that makes a bad impression in the market. Medical expense and post trauma process of the injured personnel are also a big impact from the institutional point of view. [24]

## 3.2 Concept of Arc Protection System

In the arc protection system there could be several kinds of sub units. These are arc sensing unit, relay unit, specialized arc protection unit and wears. The sensor inputs are connected to line protection relay with arc sensor. A large amount of radiant energy has released during the arcing fault. The intensity of the light of the arc is thousands time higher compare to the normal light. The sensor input directly in touch of the arc light. It has detected the high peak of light intensity. This sensor has excited by that arc light. The instantaneous over current elements will be responsible to generate the sensation of relay tripping. The fault detection signal has sent to the relay via the sensor inputs unit. The over current relays with arc light sensor can be use as a reliable arrangement of switchgear in the busbar. The breaker tripping will perform by the relay in the feeder during the fault situation. The arc light and high fault current need to detect in the same time for performing the tripping on the breaker. The arc sensor input and fault current stage limit are both coincide in the same time of arc stage output. The arc stage output of Arc Matrix setup in IED has found as a part of configuration. So when the fault current stage limit has exceed and arc sensor output have received both give the output of arc stage. According to Arc Matrix-Output has generate tripping command for tripping the breaker. So only the arc sensor signal or fault stage current is not enough alone. The arc sensor has put in to the vicinity of each junction of the feeder line in the substation. Junction of the feeder line indicates about the cabinets in the substation where long feeder line has joined with the bus bar. Before the IED has introduced for high speed tripping solid state tripping output coil relay was used. The operation period is generally less than 2.5 ms.

## 3.3 Electrical Arc Features

Electrical arc produces if the current conducts through the isolation material such as air or gas. The galvanic contact will not present in the conductors. In the high temperature like 3000 $^{0}$C or more, the air turns in to conductive state. When a conductor is occupied with highly dense electron flow, then there could be temperature rise of it. This temperature make the surface contact air also heated. The fault current is a high quantity which is responsible for burning a conductor. The arc is visible during the burning of the conductor. The arc voltage is also a key issue for burning arc temperature.

The conventional circuit theory describes an electrical circuit should be path with proper source as well as the resistive wear with different loads. Without the proper load in the circuit makes the path of electron flow control free. This situation makes a huge rush of electron flow through the conductor and heated the material. The power lines are heavily loaded due to the supply demand of the customer premises. During the arc fault this power line become impedance free that makes huge flow of fault current. This high flow of current increases the temperature up to 10,000 K or could be 20,000 K in the middle of arc current flow zone. The edge of the arc faulted zone is about 3000 K to 4500 K.

As the temperature raises the gaseous state of materials are broken in to atoms. The continuous temperature raise could also liable for breakdown of the atoms in to ions and electron. The loss of electron turns the atom into ions. Collision with other atoms, electron loss due to the hit with other subatomic particles and interaction with the photons are the reasons works behind of the ionization. As because of the ionization material becomes conductive. Radioactivity also causes ionization where the atom center part nucleus emits energy to the nearer shell electrons. Due to the gain of energy from the excited nucleus the electrons become free and make ions. When the fault occurs in the power line the excessive electron flow increases the temperature around the conductor. The increase of temperature increases the energy level of the atoms. In more deep sense the electrons become free due to gaining extra energy which provokes the electrons to exceed the binding energy of the atom.

The arc energy has split into different component. Arc energy can be fragmented from the source to the environment into infrared, ultraviolet and visible light. These happen for division in different wavelength of light. Radio frequency has generated as part of radiated arc energy component. The arc has produced radiated energy and heated the materials. After the arc ignition the most intense illumination has appeared within 100 ms to 200 ms. Later on the smoke and metallic gas has destructed the visibility of peripheral environment. The arc energy produced radiation could be 01 to 10 W/cm$^2$ and the distance should be 1.5 meters. The radiation of sun light to surface of earth is 0.1 W/cm$^2$ so it means that the radiation energy is much higher value compares to sunlight. [23]

The arc generation point could be move due to some reasons. If the center air is becoming warmer than the arc will be move to upward. It causes because the convection process of heat. There is also another reason that makes the movement of arc. During the arc fault current flowing it will creates the electro dynamic force. So the energy flowing direction has changed the arc position. In the system protecting devices the arc changes the position towards the conducting bar end. There are different voltage values for different level of voltage. It is 500 V to 1 KV for medium voltage level and 300 V for low voltage level. The arc confrontation generation point is fewer than 0.1 Ω or could be neglected. If it needs to calculate the arc short circuit's accumulated power and energy than considering the total of individual electrical arc burning in the system. The most possible cases for arc burning could be between two phases or all phases in the system. The protection device mechanical organization is an important factor that provokes the possible arc faults.  The possible power limit of the arc fault is between 08 MW to 60 MW. The radiated arc energy is consumed in different factors like heating the air and materials, creating the pressure, electrode material melting and evaporation, thermal loss of electrode and radiation. [23]

## 3.4 Arc Short-Circuit Damages

The electrical arc has caused personal and infrastructure damages. The fault is also creating the interruption of power transmission. Due to this interruption makes huge economical losses.

Figure 3.1 Arc short circuit effected Substation cabinet. Source: ([23])

The electrical arc hazard has generally followed some typical steps. These steps have shown in the following figure.

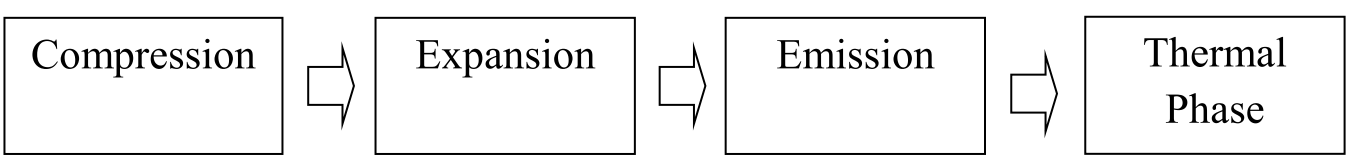


Figure 3.2 Stages for electrical arc events

The gas has compressed in a closed space and it will increase the pressure. The pressure releases in the expansion stage. When the gas gets the free space it will occupy the volume and reduces the pressure. The pressure release mechanism should be available in the cubicle of the switchgear room. It will take only 05 to 15 ms for the first two stages. The emission stage stays for 100 ms. Thermal phase has finished after the arc has extinguished.

The arc has burning effect that raises the temperature and expanded the air. The high pressure of the arc air causes the weak wall or ceiling breaking of the switchgear. The mechanical part of the feeder in the switchgear could be detached because of the arc air pressure. Modern protecting mechanical devices have tested under higher pressure like 120 KPa. The arc burning could be effected the physical structure of the substation feeder. The physical structure could be included the electrode, the feeder cabinet door, walls on the bus bar. The material of these physical structures would be affected due to temperature of arc splashed around it. Burning sports have found on the outer part of the adjacent equipment. As long as the burning exists the spot will be deeper.[ 23] The bus bar and wire could be cut down due to the arcing attack. If the temperature goes so high that the wire could lost its conductivity and temperament. The high hot gas from the arc has generated from arc burning could damage the valuable equipment near to it. The humans could become injured due to this harmful toxic gas. This toxic gas may contains carbon monoxide, copper or Aluminum steam. [27]

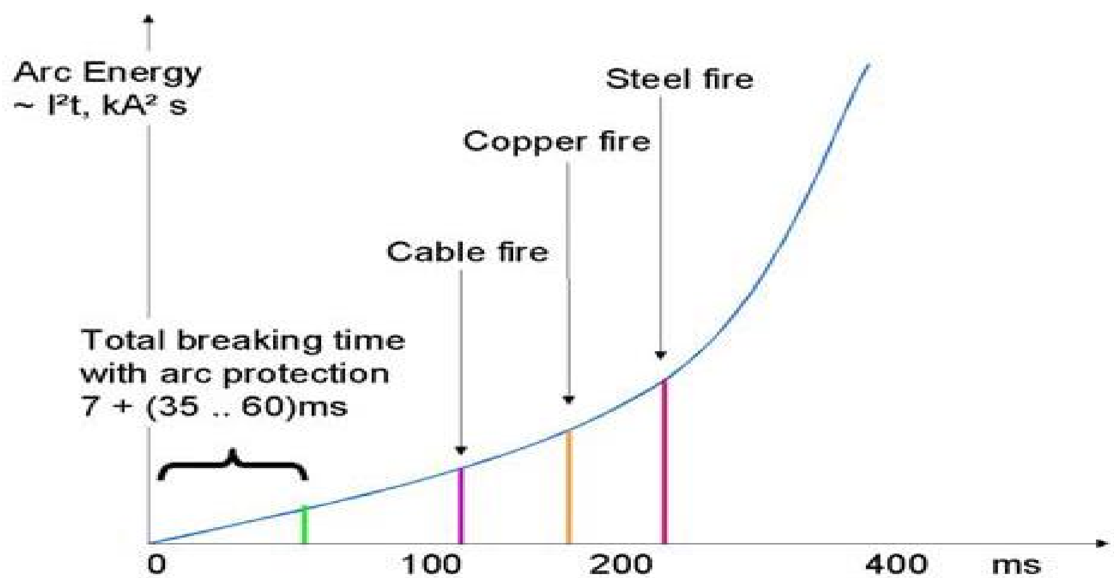


Figure 3.3 The burning time compare with the energy release. Source: ([23])

## 3.5 Reasons To Arc Short-Circuits

There are different issues that contribute to work of the Arc short- circuits. These could be divided into as the erroneous operational situation of the equipment and misleading situation due to equipment condition. The operational safety of the personnel is one of the important factors for running the system in a most efficient way.

In the substation the feeder there could be different kind of switchgear unit which could be known as cubicle. There different cubicle panel has manufactured from different companies. These cubicle panels have separated ratings and capacity for handling voltage, breaking current, withstand current, Frequency etc. If the required cubicle has placed in a wrong site that not able to maintain the proper operation. The wrong site means the part of substation where it supposed to be placed, due to the designing error the cubicle has not placed in a right manner. So in this situation human error during the designing or maintenance can able to occur fault that turns to arc short circuit.

Isolator is switch that has used is the substation for disconnection. This equipment has capability to de-energize the electrical circuit during the maintenance period. There are some amounts of current that can be flow after the shut-down of the system. For removing that kind of current flow probability isolator has play the vital role in the substation premises. As the isolator has left close for the under-maintenance part of the substation that could be liable for the short circuit current. Right selection of the isolator during the switching purpose of current is important. If the selection of isolator for handling the substation operational process, than it can causes high flow of unwanted short circuit current and produces arc flash.

In an electrical system structure, grounding has done for safety reasons. It provides protection from the high level of unwanted electrical hazard. The insulation of the equipment not work properly in such a case the grounding could help to avoid that situation. Due to the grounding has presented in an electrical installation, the accumulation of static charge is not possible. Proper grounding system can able to provide protection to the user personnel. The neutral connection of the substation electrical equipment grounding system has used. So if the grounding of the substation has not done properly than the lack of proper protection of substation equipment may cause short circuit fault and also arcing flash.

Lack of proper insulation and grounding system the substation's different working panel could be become very risky. Accumulation of static charge can increase the voltage on the equipment surface or different accessories. Due to that static voltage accumulation the arc short circuit error could be happen. Before starting any kind of maintenance work or other kind of operational process it needs to check the voltage. Unexpected high voltage presence can make arc fault and causes working personnel accident. To avoid static voltage accident testing should need to do. [23]

In the substation there could be hundreds of different types of equipment. Some equipment are mechanical and some are electronic structure. When the station goes for an operational condition all of these equipment are running in a harmony. As the time goes on these equipment are become older and the performance is going down. Metallic corrosion is a factor that makes the mechanical structure of the substation equipment weaker. Some equipment used by the operation more and some are less. It means some parts become weaker compare to rest of the parts due to heavy use. This situation makes the fault as the equipment not able to withstand the load. During the operation time the heat has produced in the different substation equipment like current transformer, power transformers etc. If proper cooling system has not been worked than it may generated over heated situation which makes the reasons of fault. The insulation leakage due to over voltage, high current flow are also play important role to cause bus bar fault in the substation. It is a general phenomenon to create arc due to this bus bar fault. High moist air causes to create stain on the bus bar metallic structure. The longer ageing of stain growth makes weaker the bus bar.[23] The dirty object dropping on the bus bar or any livable object (like birds) intervention can causes fault on the bus bar.

## 3.6 Arc Short-circuit Damage Reduction

The arc short circuit can occur in any electrical system. This damage can be small in amount if some precaution steps would take under consideration. The focusing points for the damage reduction could be quality development of substation equipment mechanical strength, the arc short circuit power can be reduces and the burning duration due to the faults.

The mechanical structure strength of the switchgear will need to be developed. So the switchgear equipment can able to resist the pressure and heat effect due to arc fault effect. The pressure vents and channels should be improved with proper design and strong metal. The total contour of the switch gear equipment can be divided into small compartments. As a result that makes the equipment not totally damage in a very short period of time. If the fault occurs in any moments it can make out of order some compartment of the equipment. During the period as the switchgear has made it requires to concern about the testing with respect to mechanical strength. The manufacturer of the switchgear product should be aware about the incident of faults situation and their manufactured device behavior. The product should design in a way such that it won't be made any personnel injuries around of it under the faulted situation. Arc fault time there could be found poisonous gases for the burning of the materials. There should be possible path inside of the product where the poisonous gas could pass away.

The arc short circuit faults period a huge rush of current have flowed. If the emission of the energy in the form of light, smoke and heat can be control than the damage situation was not so much intense. But this is not possible to control the power of the short circuit fault. The capacity of the protecting devices should be large as the high amount of short circuit current could be mitigate. The amount of the damage due arc short circuit fault can be possible to control by limiting the time of arc burning. As soon as the circuit breaker trips the connection, it will stop to supply the fault feeding current. The burning time length could be an important factor that determines the damage possibility. The damage is not notable when the burning time is less than 35 ms. The damage is small and it requires to repair if the burning time is approximately 100 ms. Large damage could be possible for the person and the protecting device during 500 ms or more burning time. [23] [25]

## 3.7 Arc Detection

The main motivation of the arc fault elimination system is to secure the system from any unwanted occurrence. It will reduce the risk of property damage and also save the personnel physical trauma. The protection system should detect the arc flash and consequently it shut down the flow of current. The circuit breaker will break down the current flowing path and that will not give any privilege to flow the current that responsible for occur the fault. Arc is comprises of light, sound, heat and electromagnetic waves. Arc has detected by assessing the light, acoustic wave, infrared and RF radiation. Mechanical wave like pressure has also used to detect the arc. But the flash light is the most commonly used for detecting the arc fault. The flash light of arc has detected by the arc sensor. An arc sensor has shown in the figure 3.4. For more precise operation of protection purpose short circuit current is also consider with the arc flash light. [19]

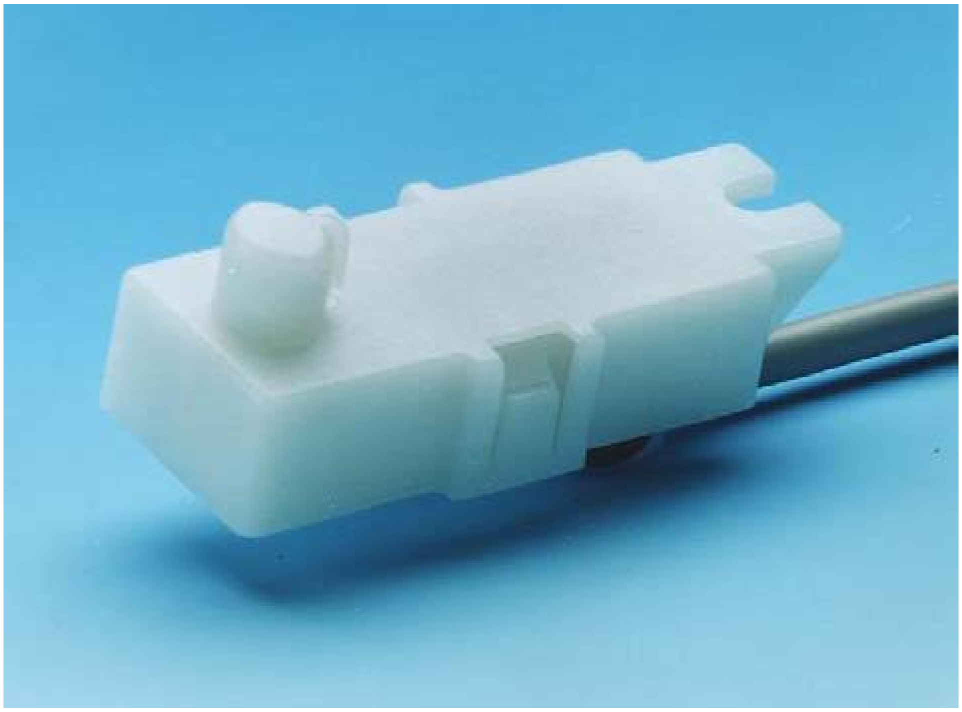

Figure 3.4 An arc sensor. Source: ([23])

Partial discharge has happen due to the damage of insulation. Generally in a short duration the damage due to the partial discharge is not so intense. But in long duration this partial discharge has caused greater extent of insulation damage. This damage of insulation should detect in proper time. If the insulation with partial damage is not take under proper treatment in prescribed time than the partial discharge will turn into disruptive discharge. As a result of disruptive discharge the complete system goes through the failure stage. The disruptive discharge makes the arc fault which follows the partial discharge. High frequency electrical field has formed due to the partial discharge.  For the detection purpose of partial discharge search coils has used.  So arc is final stage of partial discharge. So the alarm should use when the partial discharge has detected to prevent the arc fault. [20] The partial discharge sensors are not use so much. For the maintenance purpose and protection purpose partial sensors have used for off-line, on-line measurement respectively.

The arc protection system has made for implemented the process of the arc protection. The arc sensors are responsible for detecting the arc flash and help to protect the system from the arc short circuit. The protective relays are responsible for take care of the power line protection. The protection system for arc is composed of arc sensors, slave unit and the master unit. The arc sensors are sensing the arc light. The fiber coil sensor or the photo transistor sensor have used. The arc sensors are connected to main relay. The master has also the information about the measured current on the feeder line. The master can able to make decision based on the sensor data and measured over current data. In the figure 3.5 all the sensors are connected to the main protection unit via an input/ output unit that is in here called slave unit. The slave unit accumulate those sensors input and that makes the output connected towards master unit. During the time of the arc fault it produces also heat. Heat sensor has also used for the detection purpose.

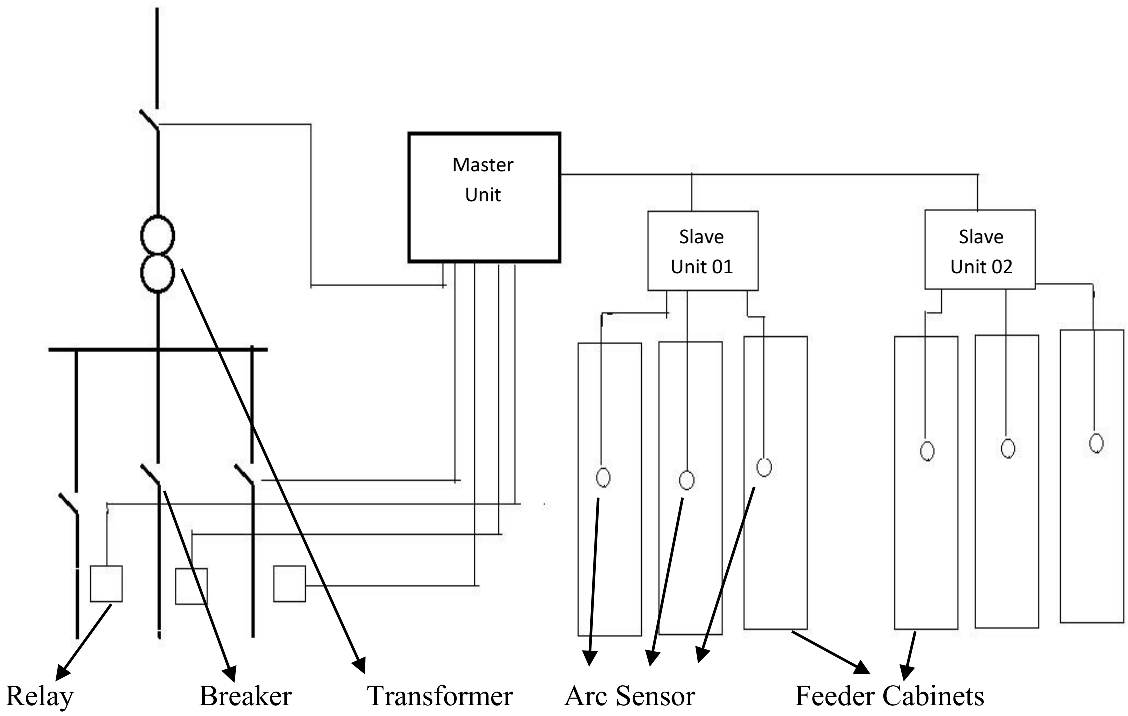


Figure 3.5 Modern Arc Protection System. Source: ([23])

The substation operational diagram has consisted with an incoming feeder and divided in to several feeder branches. The feeder branches are also known as cubicles. During the arc short circuit has occurred, the breaker belong to the main feeder opens. If the system has divided into different zones than during the faulted situation the affected zone will separated from the other part of the system. This has done by opening the breaker of the faulted zone. The figure 3.6 has shown about the case where multiple zone has presented. The zones have divided into numeric value like 01 and 02. Both zone consist with similar kind of arrangement. Master unit has marked with VAMP and the slave unit has marked with VAM. The slave unit has accumulated the sensor information from all the feeder branches. Zone 01 and zone 02 has connected with the breaker CB5. If there is any fault in zone 01 then the breaker CB5 and CB1 will be opened. The master units are presented in the system can be able to communicate with each other. The sensors are detecting the flash light in any zone can share the information from one zone to another. The active arc sensor data can be share from one zone master unit to other master unit. This information sharing can help the master unit to take the decision about the tripping. Because the master unit also have the information about the over current measurements [19]. In the same manner, the overcurrent information for all the zones is also share from one zone to another zone of the system. The flash light of arc has detected in one zone but the information about the current has received from the other zone used together for the tripping. [21][22]

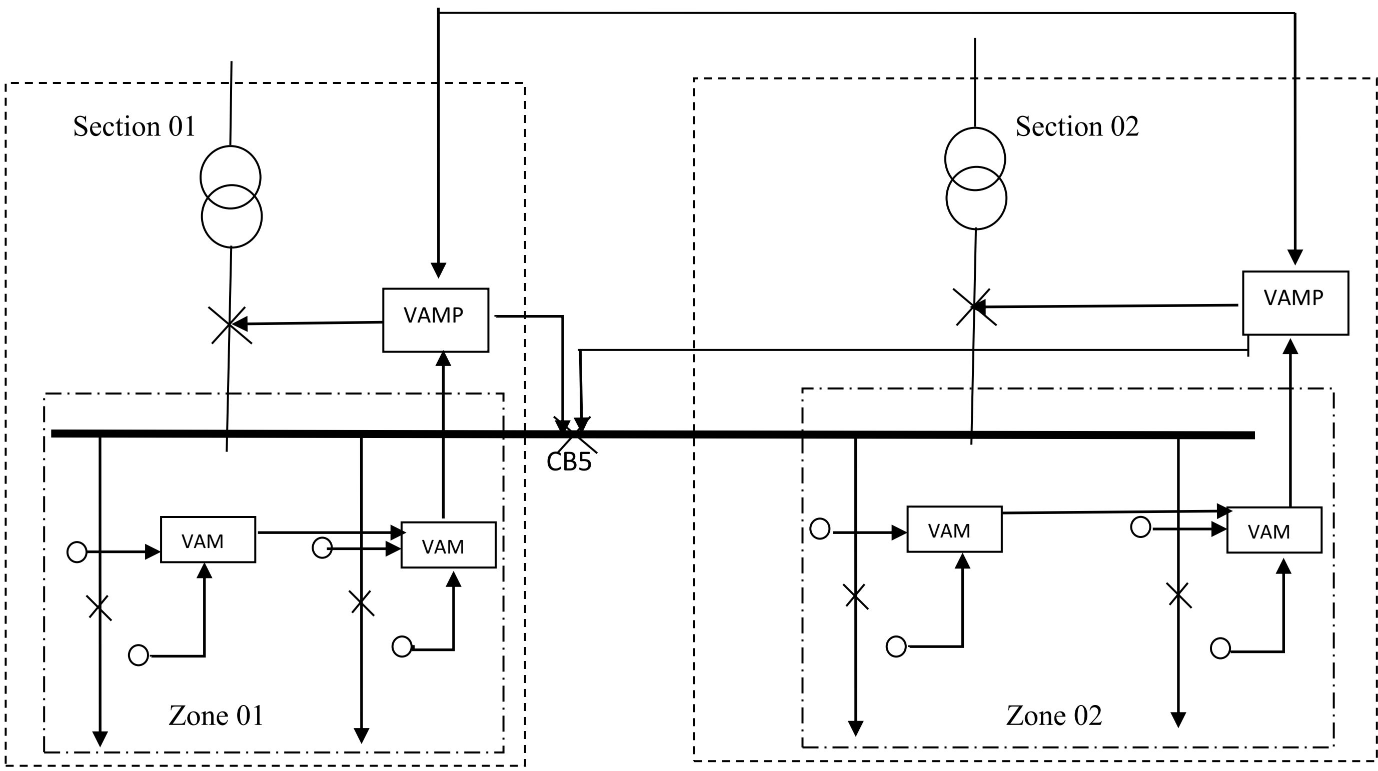


Figure 3.6 Arc Protection System with two Zones. Source: ([23])

### 3.8 Integrated Arc Protection System

The arc protection system can also be described with protection relay that associated with arc sensors have connected. The arc protection system has become the integrated part of the main system in more convenient way with minimal cost. The arc sensor input will compose of three terminals. Two terminals are for sensing the arc, one terminal for binary input and single output terminal for the conveying or receiving data for arc sensor to other relays. Overcurrent and earth fault have included to the relays that operates the arc sensors. This arc sensor with protection relay can be useful for arc protection selectivity enhance, arc protection compatible for feeding point changing, economic arc protection implementation and coverage enhance arc protection.

The connection of arc sensor of the leaving feeder to the feeder relay will increase the selectivity of the arc protection system (See the figure 3.7). The breaker of the feeder will open as the arc fault happen in the feeder area. The rest of the part will remain unchanged in to the operation. The incoming breaker will be opened by the main arc protection system. This is happened only during the arc short circuit in the power system part that not able to measure short circuit current. In the outgoing feeder cubicles cable chamber Arc1 and Arc2 arc sensors have installed. Arc 3 and Arc 4 will be fitted to the truck and bus bar chamber as a part of main arc protection chamber. The initiation information of arc sensors Arc3 and Arc4 have send to the overcurrent relay with the help of Binary input (BI).

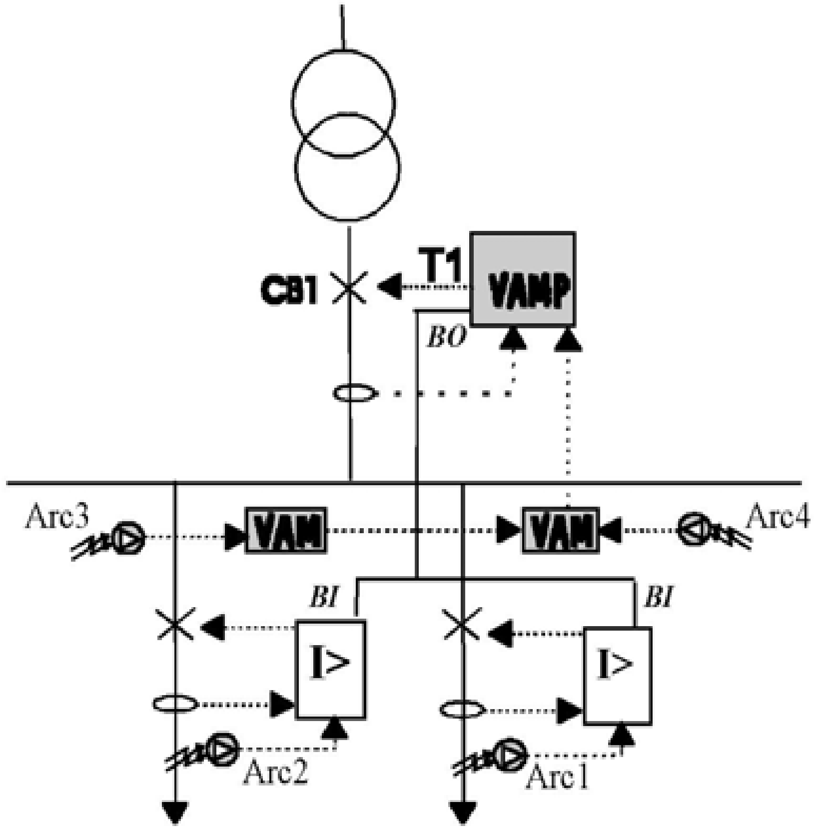


Figure 3.7 Specialized protection system (With VAMP and VAM). Source: ([23])

The example in figure 3.7 shows the power is feeding through the transformer a fragment of a switchgear. The power can also be served with the outward feeders. The overcurrent relays play role of the feeder arc protection. The arc protection relay safeguards the bus bars segment. The power is served to one of the usually outbound feeders. As a switchgear gear segment the overcurrent relay of the feeder is playing role of arc protector. The arc protection system's component arc sensor functioning information send to the overcurrent relay through the binary inputs and outputs. The overcurrent relay can trip the breaker as a part of the arc protection function. The relay can quantify the short-circuit current by its own measurement system. The arc sensor (figure 3.7 demonstrates sensors Arc3 and Arc4) connected with relay can also able to perceives an arc. The presence of fault noticed by arc sensor and overcurrent quantified by relay both plays role for breaker tripping.

The arc sensors and protecting relays are together make a general arc protection system with fault current measurement (see figure 3.8). The arc sensor initiation information transferred to the relays through binary inputs and outputs same as specialized protection system in figure 3.7. The tripping by relays works with the association of overcurrent and connected sensor's sensation. The exposure of this protection system is restricted paralleled with a specialized arc protection system. The arc sensor's number is inadequate compare to specialized arc protection system. [23] [24] [26]

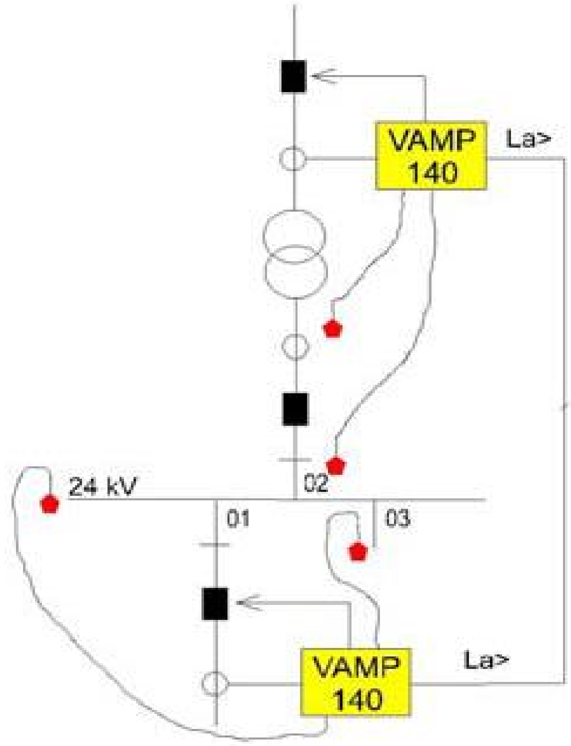


Figure 3.8 Arc protection with fault current measurement. Source: ([23])

The arc sensor feature has made easier option for measuring the arc short circuit if the arc short circuit current can't able to determine in such a certain location of the power system. The situation has depicted in figure 3.9. The denoted site of arc in the figure 3.9 occurred does not possible to measure with the VAMP 220 relay. The current can be dignified by over current function of the transformer differential relay VAMP 265. The instigation information of arc sensors is fetched from the VAMP 220 relay to VAMP 265 relay with the binary output and input similar as earlier figure 3.7 and 3.8 [23] The VAMP 265 relay unlocks the breaker. As the relay notices fault current produced by the arc. This unlocking of breaker happens also for VAMP 220 relay's arc sensors in this situation. Due to the presence of the arc sensor it helps to make open the breaker faster.

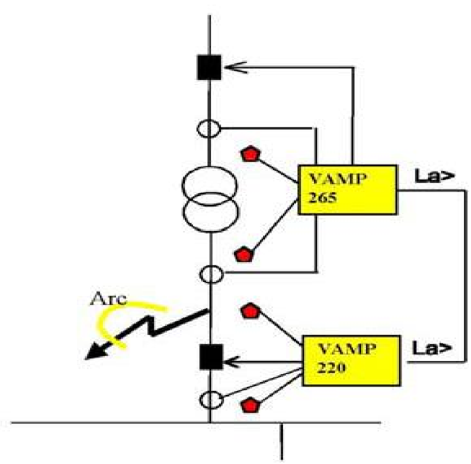


Figure 3.9 Protection with Arc Sensor Option. Source: ([23])

### 3.9 Significance of Arc Protection System in Bus Bar Protection

The Bus bar has protected with the implemented protection scheme. The IEDs has its own measurement system for detection of over current flows in the bus bar. The arc flash can be created due to the flow of current and makes over heated. It has created flash light which detected by the sensor and confirms the IEDs to take necessary reaction as per requirement. Previous discussion on Article 3.5, 3.6 have also indicated about the phenomena that works behind of the Bus bar protection scheme. The detection of arc flash light by arc sensor will make the breaker opens more faster than the overcurrent measurement done by itself.

# 4. IEC-61850 & GOOSE Messaging

## 4.1 Introduction

The electronic entity has converted towards the digitization from the last decade. It has grown in an exponential rate progress. Different types of consumers like industrial, commercial, utility and residential are transforming their system into digital arena. Transforming the domain in to digital from analogue the operational equipment should be possessing different settings of control. The monitoring characteristics of the device has needed to make proper control. The practical operation of the power system has an indispensable part is communication. In the earlier 1930 telephone switched remote control unit was used. On the 1960's data acquisition systems has introduced that able to collect the measured data from the substation. The data acquisition system has needed to use the small bandwidth in a prudent way because of the bandwidth unavailability. The optimization that required for this data acquisition system need to pay as a cost are time, configuration, mapping and various data bit location that protocol gained. [29]

With the development of the technology the thousand bits of data are now available in a simple Intelligent electronic device. The bandwidth for the communication purpose could be increased if it is needed. Typically the communication path speed is around 64,000 bits per second from the substation to main control center in earlier period of time.[29] The communication speed could be varies depends on the scenario. The communication system for the IED should be able to describe by data and services perspective. There are other requirements such as high-speed device to device communication, can be able to connect to the network to the entire service structure. The IEDs communication should have a certain time for delivery, file transfer capability and configuration can be done automatically. The system should have a secured support for exchange the data. [29]

## 4.2 Discussion on the outline of IEC 61850

The standard IEC 61850 can be separated into 10 major points. These are starter and summary, appendix of terms, general necessities, system and scheme supervision, communication requirement for determinations and device models, configuration narrative language for communication in electrical substation associated to IEDs, simple communication assembly for substation and feeder equipment, specific communication service mapping (mappings to MMS and sampled values over multidrop point to point relation) and conformance analysis.

The IEC 61850 standard established with the general requirements regarding the communication in the substation based on device requirement and general system requirement. This will work as a key factor for identifying the service and data model. Familiarization with core transport, network, data link and physical layer will important factor for IEC 61850 standard implementation. [36] The IEC 61850 has made the abstraction of the data items. This creation of data items is liberated of any other original protocols. The data abstraction has created the mapping of the data objects. The data object which are built from the similar pieces called common data class (CDC). An actual protocol can be mapped from the abstract services. On the Ethernet data frame the abstract data object mapping and the service for the manufacturing message specification defines on the last part of the IEC 61850 protocol. The final part of the protocol has defined the process bus.

All the pieces of data object need to accumulate together for put them into work a noteworthy extent of configuration is essential. The function of the process in a smooth way and avoiding the human mistake factor an XML based Substation Configuration Language has used. The language will help to build a relationship between the substation automation system and the switchyard. The topology of switchyard and relation with the logical nodes can be configured on the IEDs. The SCL file is responsible for describing the configuration for every device. The IEC 61850 fundamentally describes about the communication protocol for the internal system. There are diverse quantities of the IEC 61850 standard that makes the communication between the substations. In the ending part of IEC 61850 has proposed a test which determines the conformance with different protocol and finds the limitations.

The transmission of bytes through the wire can be defined by the protocols. Data organization have not specified by the protocol on the application level. The object is configured manually by the power system engineers. The configured objects have mapped to power system variables, low level register numbers, index numbers, I/O modules etc. The IEC 61850 protocol has offer a complete model that power system devices should arrange data that is dependable for all kinds and brand devices. [33] This process will to configure the non-power system configuration which is very cumbersome job. For example, if a measuring device like current transformer or voltage transformer has connected to the IEC 61850 standard relay then it will register automatically as a measurement unit. This registration for measurement unit to the relay does not require any user interaction. For configuration process of the object some devices needed the SCL file. The SCL file will imported to the device for configuration. The IEC 61850 client software can abstract the object of the device using the network. It will help to save the cost in a large scale. The IEC 61850 device configuration effort is also reduced. [29]

## 4.3 Modelling Approach for IEC 61850

The modeling for the IEC 61850 has develop based on the physical device. This physical entity is the structure that connect to the network directly. The physical device has an identity in the network called the network address. The physical entity has divided in to single or multiple logical entity. This logical entity could be able to give entrance provision for multiple devices. This could provide a standard representation of a data concentrator. The logical device has defined through single or multiple logical nodes. A group of data and the associated services that is logically related to different power system functions named as logical node.

The logical nodes that are intended for the programmed regulator started with the letter “A”. The node that is responsible for determining the extent and metering begins with the letter “M”. So, the similar situation could be defining for supervisory control (C), generic functions (G), Interfacing/Archiving (I), System logical nodes (L), Protection (P), Protection Related (R), Sensors (S), Instrument Transformers (T), Switchgear (X), Power Transformers (Y), and Other Equipment (Z). The logical node has defined with LN-instance-ID as a suffix for node name. The device has two measurement inputs which responsible to measure double three phase feeders and the name selected for this device is MMXU in a standard way. For defining the measurement of two feeders logical name for the nodes will be MMXU1 and MMXU2. The LN prefix could be used for providing the optional application specific identification purposes.

The logical node is constituted with one or more data components. The data component has a sole name. the data name has selected based on standard and functionally of the power system point of view. The logical node circuit breaker XCBR (denoted in Appendix1) has consist a variety of data such as Loc, OpCnt, Pos, BlkOpn, BlkCls and CBOpCap. For defining if the process is distant or local Loc data has used. Operational count, position, block breaker open, block breaker close and the circuit breaker functioning competency have defined by OpCnt, Pos, BlkCls and CBOpCap respectively. Every data element in the logical node describes common data class specification according to IEC 61850-7-3. The structure and type of the data in a logical node has described in CDC. Different kind of CDC (Common Data Class) can be found in IEC 61850. There are CDCs for status info, governable analog set point information, set point for controllable analog information, status setting and analog settings. The CDC has a certain term with set of characteristics for specific application.
Every individual attribute has a functional constrain set that belongs CDC that groups the points into categories. For instance, in the Single Point Status (SPS) CDC pronounced in Appendix 2, there are functional constraints for status (ST) attributes, substituted value (SV) attributes, description (DC) attributes, and extended definition (EX) attributes. In this example, the status attributes of the SPS class comprises of a status value (stVal), a quality flag (q), and a time stamp (t).

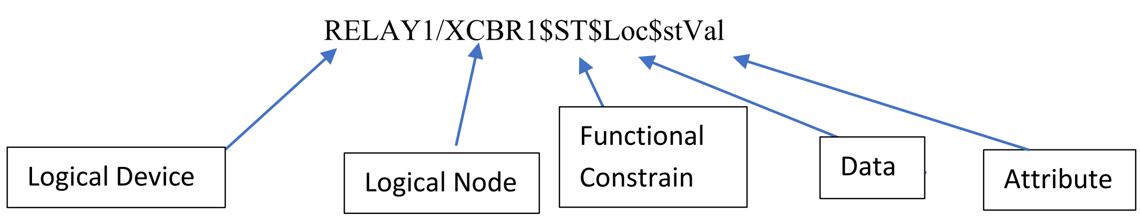


Figure 4.1 Anatomy of IEC 61850-8-1 Object name. (Source: [28][29])

The virtual model of IEC 61850 has an imperceptible device view where object has defined. The virtual model has mapped by specific protocol stack of IEC 61850. The IEC 61850-8-1 object mapping process to MMS transforms the model information to MMS variable object. This process reveals an exclusive and clear reference for individually data component of the model. For example if the logical device name "Relay_01" have single circuit breaker logical node XCBR1 and need to find out the breaker is in the isolated or local operation mode.[29]

### 4.4 Protocol Mapping and Process Bus

The IEC 61850 described abstract data and object models that could able to define power system devices. The standard could able to make all IEDs disclose data associated to power system task using identical structures. The IEDs are work in a similar process in the network according to the instruction of ASCI (Abstract Communication Service Interface) models. The ASCI model of IEC 61850 is a service set and service response. The abstract model essential to operate on a real set of procedures for achieving the interoperability. This power industry's computing environment condition has required to materialize the protocol. IEC 61850-8-1 maps the abstract objects and facilities to the Manufacturing Message Specification (MMS) protocols of ISO9506.

| IEC 61850 objects | MMS Object |
|---|---|
| Server class | Virtual Manufacturing Device (VMD) |
| Logical Device class | Domain |
| Logical Node class | Named Variable |
| DATA class | Named Variable |
| DATA-SET class | Named Variable List |
| SETTING-GROUP-CONTROL-BLOCK class | Named Variable |
| REPORT-CONTROL-BLOCK class | Named Variable |
| LOG class | Journal |
| LOG-CONTROL-BLOCK class | Named Variable |
| GOOSE-CONTROL-BLOCK class | Named Variable |
| CONTROL class | Named Variable |
| Files | Files |

Table 4-a IEC 61850 to MMS object mapping. (Source: [28][29])

| IEC 61850 Services | MMS Services |
|---|---|
| LogicalDeviceDirectory | GetNameList |
| GetAllDataValues | Read |
| GetDataValues | Read |
| SetDataValues | Write |
| GetDataDirectory | GetNameList |
| GetDataDefinition | GetVariableAccessAttributes |
| GetDataSetValues | Read |
| GetDataSetValues | Write |
| CreateDataSet | CreatNamedVaribleList |
| DeletDataSet | DeletNamedVaribleList |
| GetDataSetDirectory | GetNameList |
| Report(Buffered and Unbuffered) | InformationReport |
| GetBRCBValues/GetURCBValues | Read |
| SetBRCBValues/SetURCBValues | Write |
| GetLCBValues | Read |
| SetLCBValues | Write |
| QueryLogByTime | ReadJournal |
| QueryLogAfter | ReadJournal |
| GetLogStatusValues | GetJournalStatus |
| Select | Read/Write |
| SelectWithValue | Read/Write |
| Cancel | Write |
| Operate | Write |
| Command-Termination | Write |
| TimeActive-Operate | Write |
| GetFile | FileOpen/FileRead/FileClose |
| SetFile | ObtainFile |
| DeletFile | FileDelete |
| GetFileAttributeValues | FileDirectory |

Table 4-d IEC 61850 Service Mapping. Source: ([28][29])

The MMS protocol has designed for manufacturing application. It has used as public protocol. The composite designation and facility model of IEC 61850 has supported by MMS. It is a difficult and lengthy process for mapping the IEC 61850 objects and protocol service. The read, write and report service for simple variables can be retrieved by the register numbers or index numbers. The MMS protocol has selected in UCA in 1991 for IEC 61850. MMS helps to upkeep the mapping to IEC 61850 in a direct path. The implementation of ASCI services has done by mapping of IEC 61850 object and service models with MMS. MMS read and write services have mapped by using ASCI control model. IEC 61850 various object models are defined for MMS object. The mapping of IEC 61850 object could be shown in list in the Table 4-c and the mapping for ACSI to MMS has shown in figure 4-d In this thesis it has required to configure the IED. The mapping from IEC 61850 to MMS and ACSI to MMS are important. It makes the process easier to understand.

## 4.5 Sampled Measured Value

The source base quantity can be digitized and transferred the sampled valued information to the substation are important. Sampling is a technique by which the analogue signal can divided in to different value in a discreate time instant. The number of sample has taken on a certain time unit called sample frequency. The modern technology has transformed for the low energy voltage and current sensors. The output control setting and obtaining the status information are the desirable features for sample values calculation. IEC 61850 address have used in the Sampled Measured Values Services and Process Bus operation.

The substation process layer is responsible for collecting the information about different parameters like Voltage, Current and status information from the transformer. It has also capability that getting the information from transducers coupled to the primary power system process of the electricity transmission system. The collection of the data in process layer has defined by two protocol called Unidirectional Multidrop Point-to-Point fixed link resonant and configurable dataset. These protocols have related with the IEC 61850 Part 9.1 and Part 9.2. The part 9.2 of IEC 61850 has proposed that the transmission will done based on multi-cast basis. It means that the data will be transferred from one publisher to multiple subscribers.

The figure 4.2 has shown the basic idea of the process bus. The merging unit has combined the signal from the voltage, current and status signal as an input. The merging unit has sampled the signal at an required and synchronized rate [33]. So some IED be able to input data that are received form different Merging Unit that aligned systematically. The basic sample rate is 80 samples per power system cycle for the protection and observing purpose. For high frequency application, the higher rate could be 256 samples per power system cycle. The high frequency application could be power quality and high-resolution oscillography. The analog data values are mapped into 16-bit registers in this mapping.

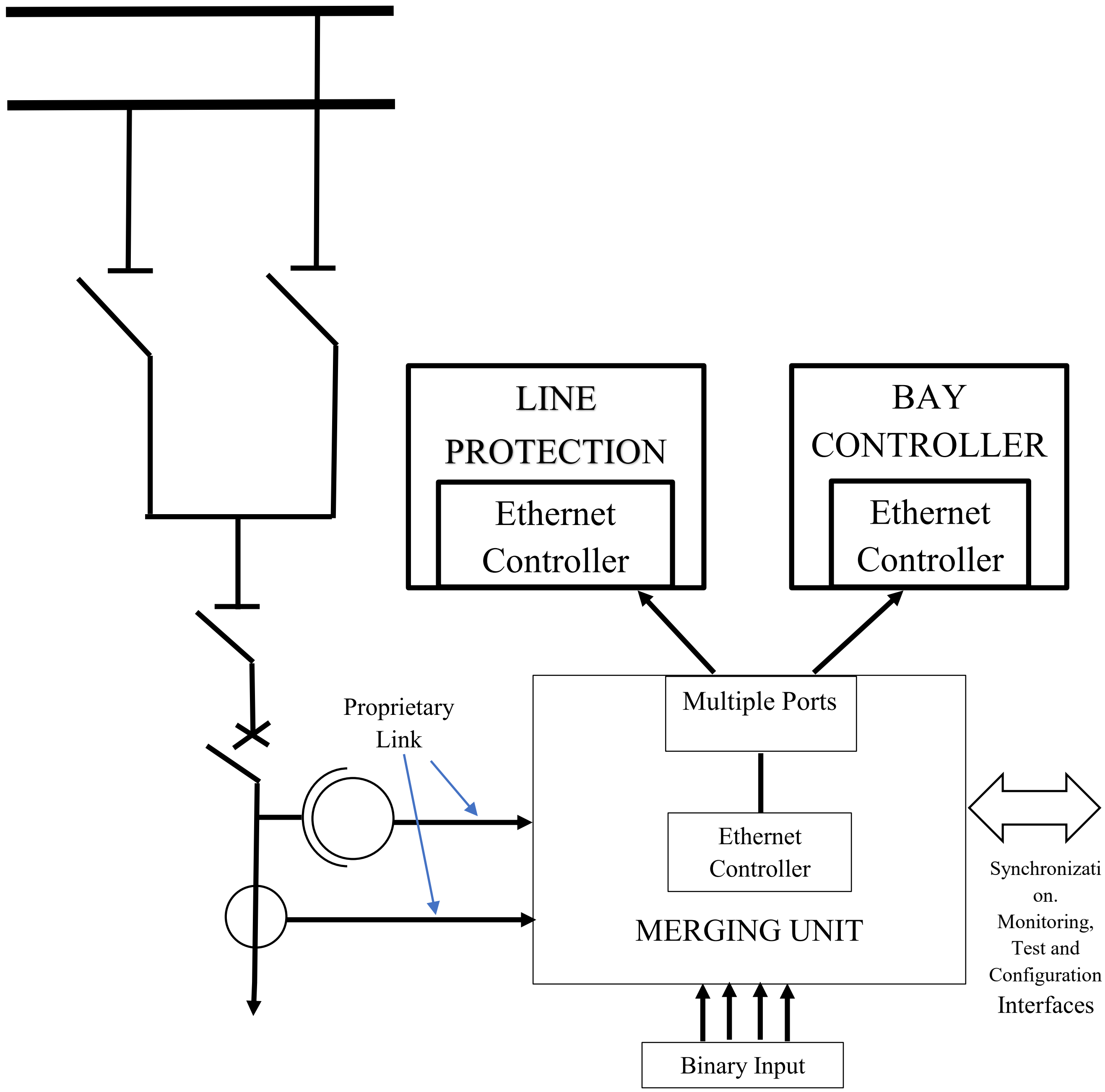


Figure 4.2 Sample measured Value concept. Source: ([28][29])

## 4.6 IEC 61850 Communication Systems

The IEC 61850 standard has defined the pre-configured dataset in the last part. The IEC 60044-8 standard has also given same idea about the dataset. The dataset has included about the data of three phase system voltage, bus voltage, neutral voltage, protection current, measurement current and two 16-bit status words.

The analog data magnitudes are mapped into 16-bit registers. The concept of sampled measured values (SMV) data transmission is also described in IEC 61850 standard. Substation configuration language (SCL) is also another tool that describe the dataset. The data values of various sizes and types can be united collectively. In the figure 4.3 it has described the mapping has described the outline of IEC 61850 functionality and linked communication profiles.

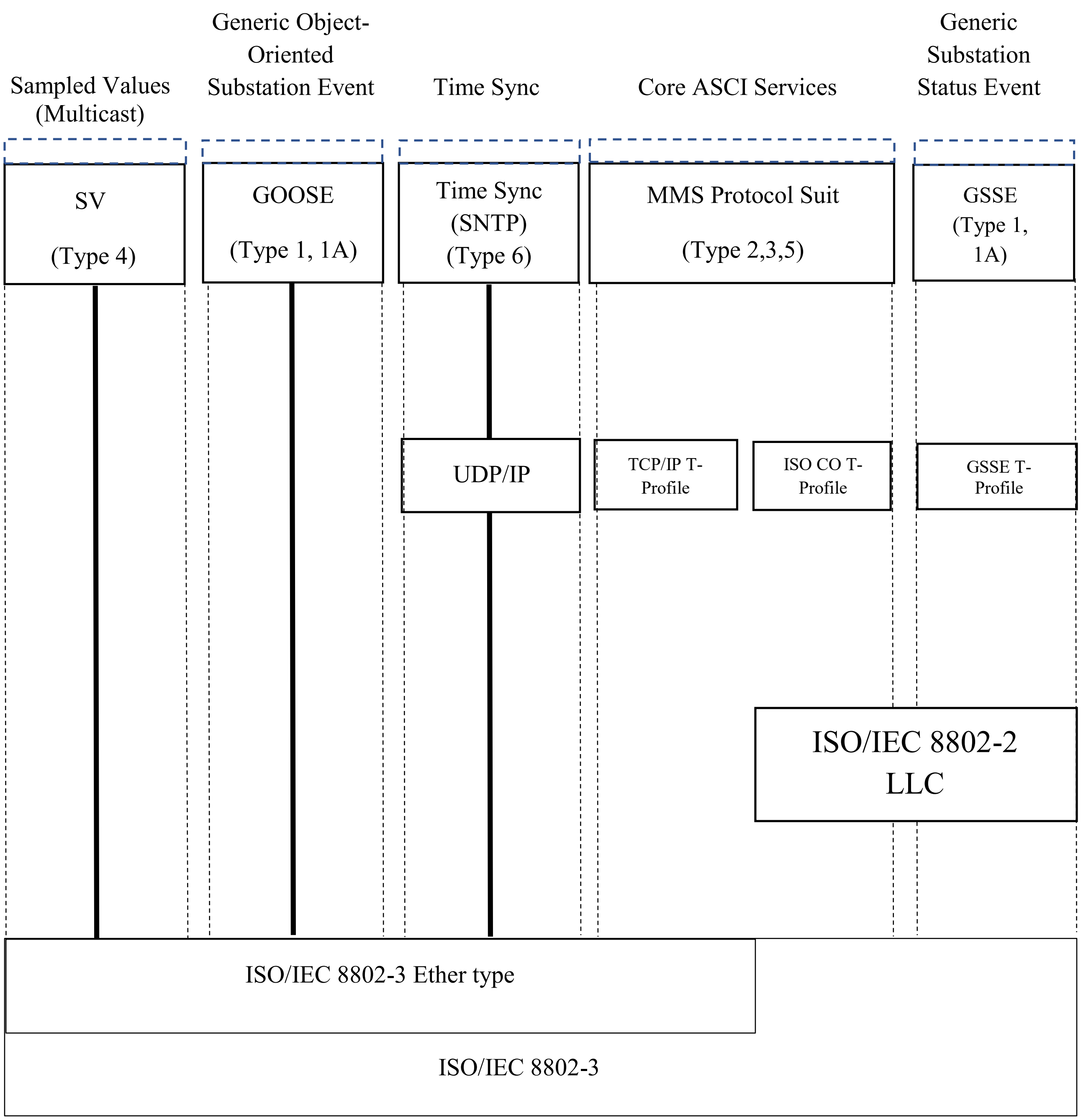


Figure 4.3 Overview of IEC 61850 Functionality and associated communication profiles. Sources: ([28][29])

The support utilities processes have functioned based on the equipment incorporation and controlling system of the electric power process control. The manufacturer follows the standardization rules that enables the equipment integration. The IEC 61850 standards for data acquisition, data description methods and the incorporation idea are very compatible now a day. The standardization helps to ensure the equipment interoperability. The figure 4.3 has exposed also the simple network time protocol (SNTP) for synchronizing the period in the network. The data concentrator function helps a wide range of communication protocol. The GOOSE message has transmitted over the network via IEC 8802-3 ethernet type system. The TCP/IP stack has used with a UDP/TCP interface also in the figure 4.3.

## 4.7 Substation Configuration Language

Substation Configuration Language (SCL) is an eXtensible Markup Language (XML) that describes the IEC 61850 followed configuration. SCL describes a chronological configuration files that enable different system levels. The approach of the description in the SCL is explicit and standardized XML files. There are different types of SCL files. Such as System Specification Description (SSD), IED Capability Description (ICD) and Configured IED Description (CID) files. The purpose of these SCL files could be dissimilar but the organization of those files are same. The client computer can read out the IED's configuration via an application software as the IED has connected to a network. The formal off-line description language can give benefit also to the user. The SCL files enable offline system development tool. It has generated automatically the required files for IED configuration from the power system plan. The cost has reduced in this process by eliminate the guide configuration jobs. [31]

The SCL helps the allocation IED configuration between the users and suppliers to lessen or abolish discrepancies and confusions in system configuration and system requirements. Users can afford their individual SCL files to certify that IEDs are provided to them accurately configured. SCL allows IEC 61850 applications to be configured off-line. The process does not need a network assembly to the IED for client configuration. SCL can be castoff as finest fits separately user's necessities. An user can resolve to use CID files to offer help in IED configuration by means of its present system design processes. SCL can be castoff to reorganize the complete power system design process to eradicate physical configuration, eliminate manual data entry errors. The reduction of misunderstanding between system abilities and necessities are significant application for SCL. SCL can increase the interoperability of the end system. It will escalate the yield and efficacy of power system engineers. [29][31]

## 4.8 IEC Sub Station Model

The Merging Unit at process bus will collect the status information and optical/ Electronic data of voltage, current sensors. The accumulated information will digitalize by the Merging Units (MUs). The MU's physical location could be in the ground or in the control house. A substation architecture has exposed in the figure 4.4. The MU's data can be obtained through 100 MB fiber optic ethernet links. The assembly points will be terminated Ethernet switches. It has 1GB interior data buses and 1GB uplinks. The ethernet switch will support Ethernet priority and Ethernet Virtual LAN (VLAN). The datasets will deliver to certain switch ports/ IEDs. Those IEDs/ switch ports are asking for dataset on predefine manner according to VLAN rules. The producers will afford the capability to assimilate data from the present CTs and PTs with the data from the original optical/ Electronic sensors. The terminated synchronization clock manner will also need to be indicated. On this structural description, the letdown of clock 1, clock 2 have detected. The failure situation should come online automatically. The architecture will provide sampling synchronization.

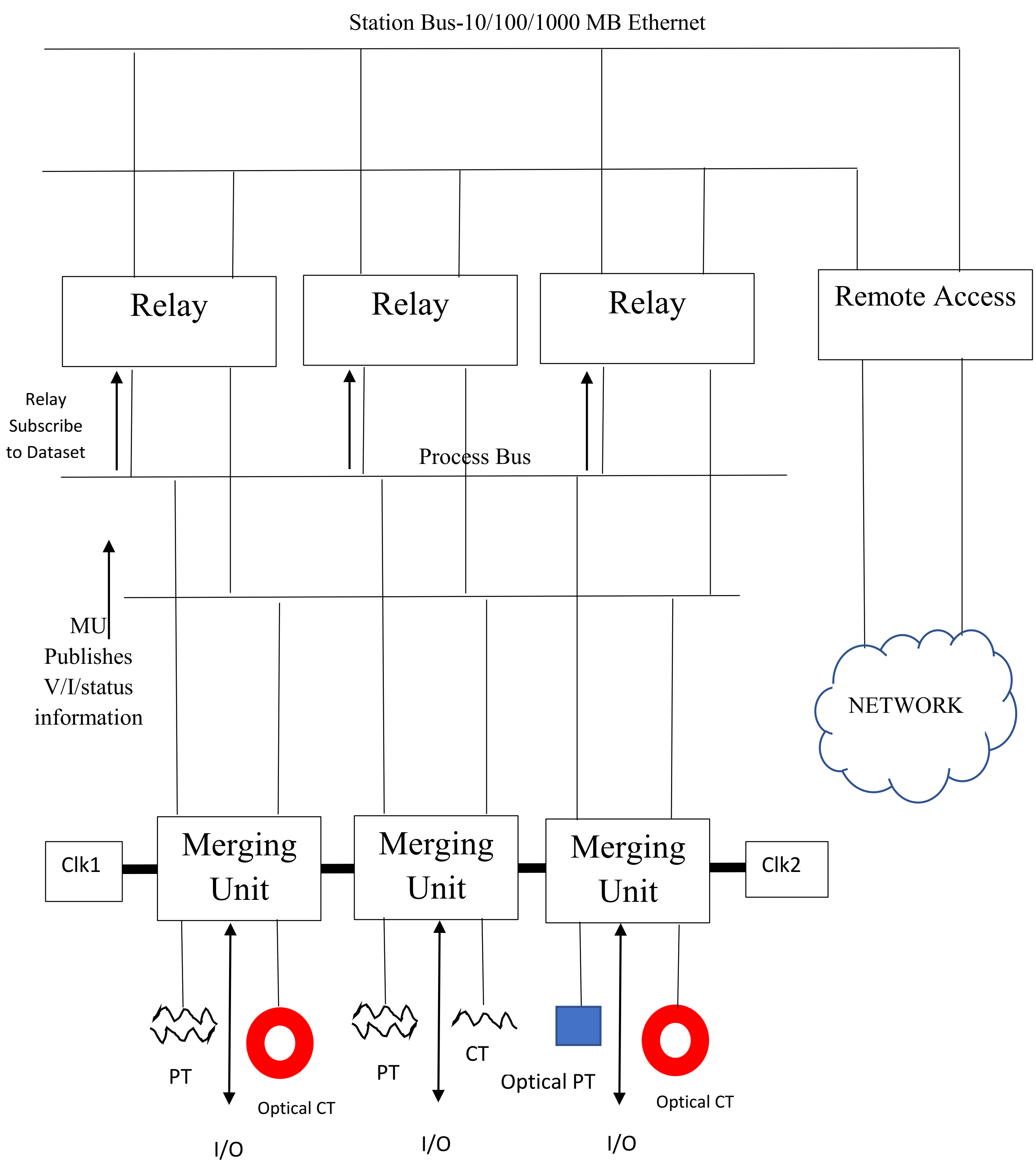


Figure 4.4 IEC 61850 Substation Model. Source: ([28, 29])

The station bus is in the substation has capability of 10MB. The migration path could be 100MB ethernet. It has provided the primary communication between the various logical nodes. These logical nodes are responsible for providing the several station securities, regulator, observing, and logging jobs. The communication will function on both an association orientated origin or a connection less basis. The assembly focused on the basis means demand information, configuration etc. IEC Generic Object-Oriented Substation Event-GOOSE is the example of connection less basis. The data transmission between IED to IED can be done based on the redundant communication architecture. All sorts of data reads and writes have supported the architecture for remote network access. [32] [33] Multiple remote clients will communicate with extended diversified available information. The network is available for all kind of communication. Distinctive clients would contain local HMI, processes, maintenance, engineering, software, application and planning. In the figure 4.4 the distant admission point is one logical position to realize safety functions such as encryption and validation. The implementation will not make any hindrance for the individual IEDs for doing encryption on internal data transfers. The implemented safety function will provide security on all external transections. [28][29][31]

## 4.9 GOOSE Message

The old electromechanical relays are replaced with the modern Intelligent Electronic Devices (IEDs) can interconnect with other devices. The modern IEDs are using embedded microcontroller inside of the device. The advancement of VLAN the data communication has done by the Ethernet. The Ethernet technology was a usual part of this advancement. The IEC 61850 standard has indicated about the two types of communication facilities among objects in Substation Automation System (SAS).[30] Figure 4.5 has described the scenario in pictorial view. One type can use a client-server model which allows facilities like reporting and distant switching. Other type uses a peer to peer model for Generic Substation Event (GSE). The GSE service is accompanied with time-critical activities like speedy and trustworthy communication among protection purpose IEDs. The messages accompanied with the GSE are the Generic Object-Oriented Substation Event message. It allows the broadcast of multicast message in the Local Area Network.

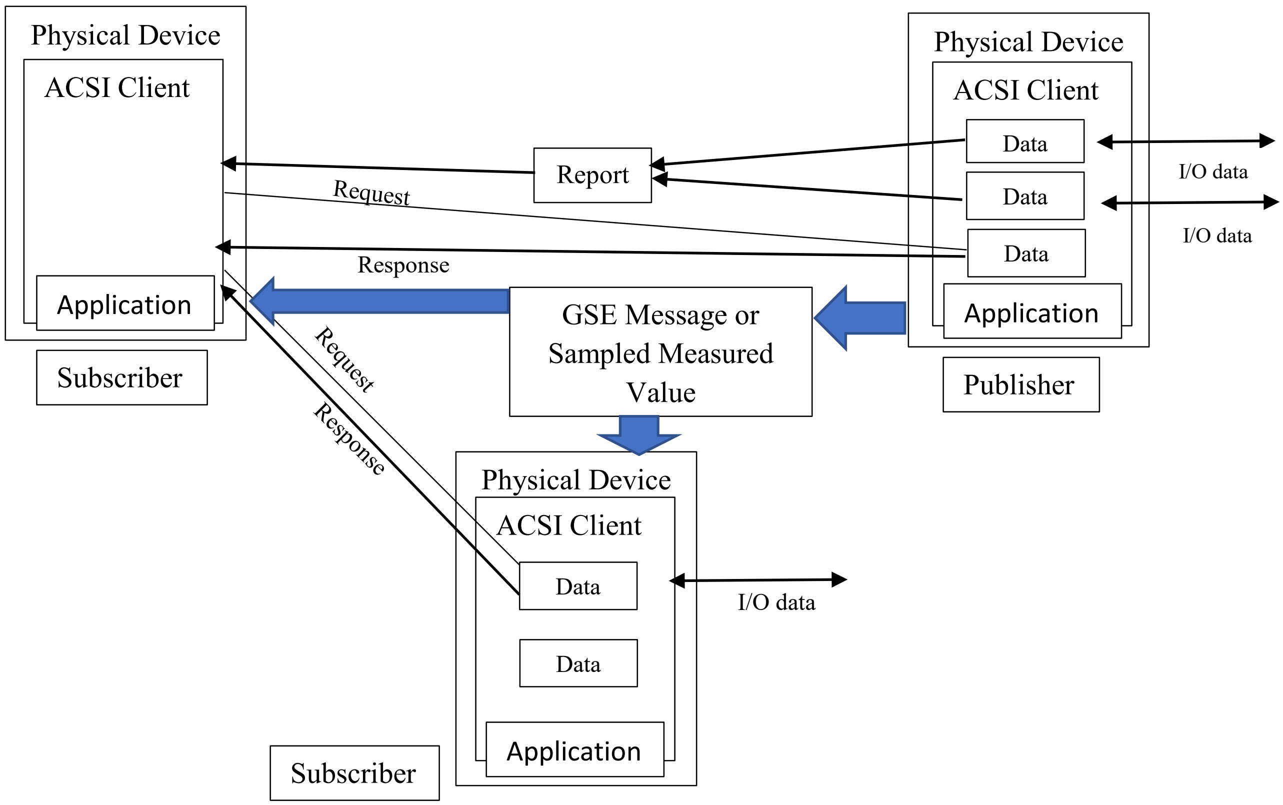


Figure 4.5 Abstract Communication Service Interface (ACSI) service. Source: ([39])

The Abstract Communications Service Interface (ACSI) presented in Fig 4.5. The figure has concealed in bigger feature in IEC 61850-7-2, outlines collective utility services for substation devices. The Publisher device has published the message and other two physical devices are subscriber responsible for receiving the message. The figure illustrates the dual groups of communication facilities for the client-server model and peer-to-peer model. The GSE model has offered a speed and consistent system-wide distribution of input and output data values. The model is depending on a publisher and subscriber instrumentation. It provisions the delivery of the identical generic substation event information. The information could be about further than single physical device over multicast or broadcast facilities. Probable common data with wide variety accumulated by a DATA-SET could exchange by the support of Generic object-oriented substation event (GOOSE). In the figure 4.5 when one device has send request to other than the other device response with referring the data back. Generic Substation State Event (GSSE) offers to covey state variation information capability. The GOOSE message is accompanied by means of three layers of the open systems interconnection (OSI) model. Physical layer, Data-link layer and the Application layer are three layers of OSI [36] which has covered by GOOSE.[33] [34]

## 4.10 Significance of Using IEC 61850 for Bus Bar Protection

Due to the investment on the substation automation the operating cost has reduces day by day. The quality of power supply to the customer has increased. The number of outage and time duration both are also reduces. As the substation has implemented with the automated technology, it requires to setup the developed communication protocols. The previous communication protocols have developed on the basis of important functions that required for electrical power system. It has realized with minimizing the bytes amount. The shortage of bandwidth in the serial link system provokes the minimization of bytes. The TCP/IP-Ethernet helps to develop the networking technology in the substation. But the TCP/IP-Ethernet system also need to minimization of bytes.

The IEC 61850 has defined on the basis of modern networking technology with wide verity of functionality. The basic idea of IEC 61850 protocol is the reduction of cost to build, install, commission and power system operation. The development of networking system has done by IEC 61850 is completely revolutionized. The features of using logical devices, logical nodes, ASCI and CDC helps to define data, diversified use of hardware as per requirement. The protocol will helps to design how the data will transmitted. In IEC 61850 data has described with using descriptive string. Previous networking technology was used the storage location. The objects nomenclature of IEC 61850 have done in a standard process. The power system has taken in to account for defining the data name.

The client device can able to access the data description from the server without any kind of manual interference. The older version communication protocol compatibility has integrated with IEC 61850. The SCL has enabled the device for configuration to define the role in the substation. By using the SCL it is possible to define each device according to user requirement. There is no possibility to misleading configuration in the IEC 61850 compatible device. The IEC compatible devices can switch over message with the help of GOOSE and GSSE through the station LAN. This kind of message sending process does not required any wire. As a result it saves lot of wiring cost and LAN bandwidth used in a full manner. [31] The conversion from analogue to digital data or vice versa generally done by transduces. Instead of using individual transducer unit for every device, a single merging unit can be used. This single merging unit will be more efficient compare to multiple transducer.[35]

Device hiring and configuring cost have become very lower. The reason behind of lower cost is because of the IEC 61850 compatible devices does not asking for bulk of manual configuration. The client premises does not required for manual configuration at every step. The information can be gathered via a SCL file from the server. The integration of new devices will not impact the IEC 61850 enabled system. It does not required any reconfiguration and able to deliver data. For the data delivering purpose it does not required any communication front-ends or reconfiguration devices. The IEC 61850 has capability connecting the devices to substation LAN and that helps to accessing or sharing the resources with less effort. It will be significant features if the devices does not required expensive operating software. [29]

In the Chapter 02 of this thesis it has required to implement a protection scheme to protect the bus bar. The discussion has provide the idea that how much it is significant for selecting the IEC 61850 standard for communication purpose between different protection devices. The most important side is the interaction among the IEDs is required a common platform. These IEDs could made by different manufacturers but when they are in the same arrangement of substation they should be interact with each other. IEC 61850 is the platform and GOOSE message is the building block for exchanging the information.

# 5. Research Implementation

## 5.1 Research Design

According to the aim fulfillment of the thesis it requires to implement a proper design. The proper design has consisted with all of the required characteristics. The figure 5.1 has shown the design with expected requirements. The design has depicted in the figure 5.1 from the receiving station.With the help of this substation model the busbar protection scheme will be studied as well as the IEC 61850 can be implemented. From the generating station, the power has transmitted towards the load center through the High Voltage (HV) line. Receiving station has received the power from HV transmission line. The transformer has used to step down the high voltage towards the medium voltage. There is a bus bar that should situated in the distribution substation. There are three feeder line have connected with the bus bar. Two feeders are load connected feeder and the other is distributed generator (DG) has connected. For measurement purpose, there are current transformer (CT) has connected. CT_1, CT_2 and CT_3 are connected with feeder 1, feeder 2 and feeder 3 respectively. CT_4 is also connected with the main line from the transformer. Circuit breakers (CB) are also connected with feeders. CB_1, CB_2 and CB_3 are connected with feeder 1, feeder 2 and feeder 3 respectively. CB_4 has connected with the main line from the HV/MV transformer. The PI section on each feeder line has suggested that the transmission line with different length as showed in figure 5.1. There are four IEDs connected to the setup of this design. Every feeder has an IED and the fourth IED has connected to the transformer branch.

The Arc sensor has put in to the substation model. The location of the arc has selected in a manner where the most probable arc flash light can be ignite. The locations are in the tranformer main line, on the bus bar, inside the cubicles of the feeder. All three cubicle are three different boxes and each have a arc sensor inside of the box. The seperate arc sensor in ecah boxes are help to identify the arc flash in more better way. In the fault location 03 is not possible to put the arc sensor. The feeder line have long length can not able to cover with arc sensor. The model substation that have presented in the figure 5.1 is equiped with IEC 61850. The physical IEDs have devided in to two logical devices as per requirment in this experimental setup according to the IEC 61850 standard. The logical dividation has used due to shartage of physical IED. There are two physical IED but the substation model required four IEDs. So the logical IED has used as the mimic model of physical device into four IEDs. Reverse Interlocking scheme has used for the purpose of substation model design in figure 5.1

The communication between the IEDs have done through the process bus. The information which gathered from diffent part of the network in substation will be digitized and transmit. The protocol that follows for transmitting the data is unidirectional multidrop point-to-point fixed link carrying and configurable data set. The configurable data set has transport the data on the basis of multi-cast basis from a certain publisher to multiple subscriber. The IEDs has configured before it has coneected to the process bus in the substation model. The application software that need to install in the computer and import the SCL file from the IED. It will help to know the engineer about the current IED settings. According to the design requirement of the substation the SCL file will be configure and send it back to IED. The substation configuration language file helps to reveal the information to the configurator engineer. It does not necessary that the IED will be connected during the configuration process.

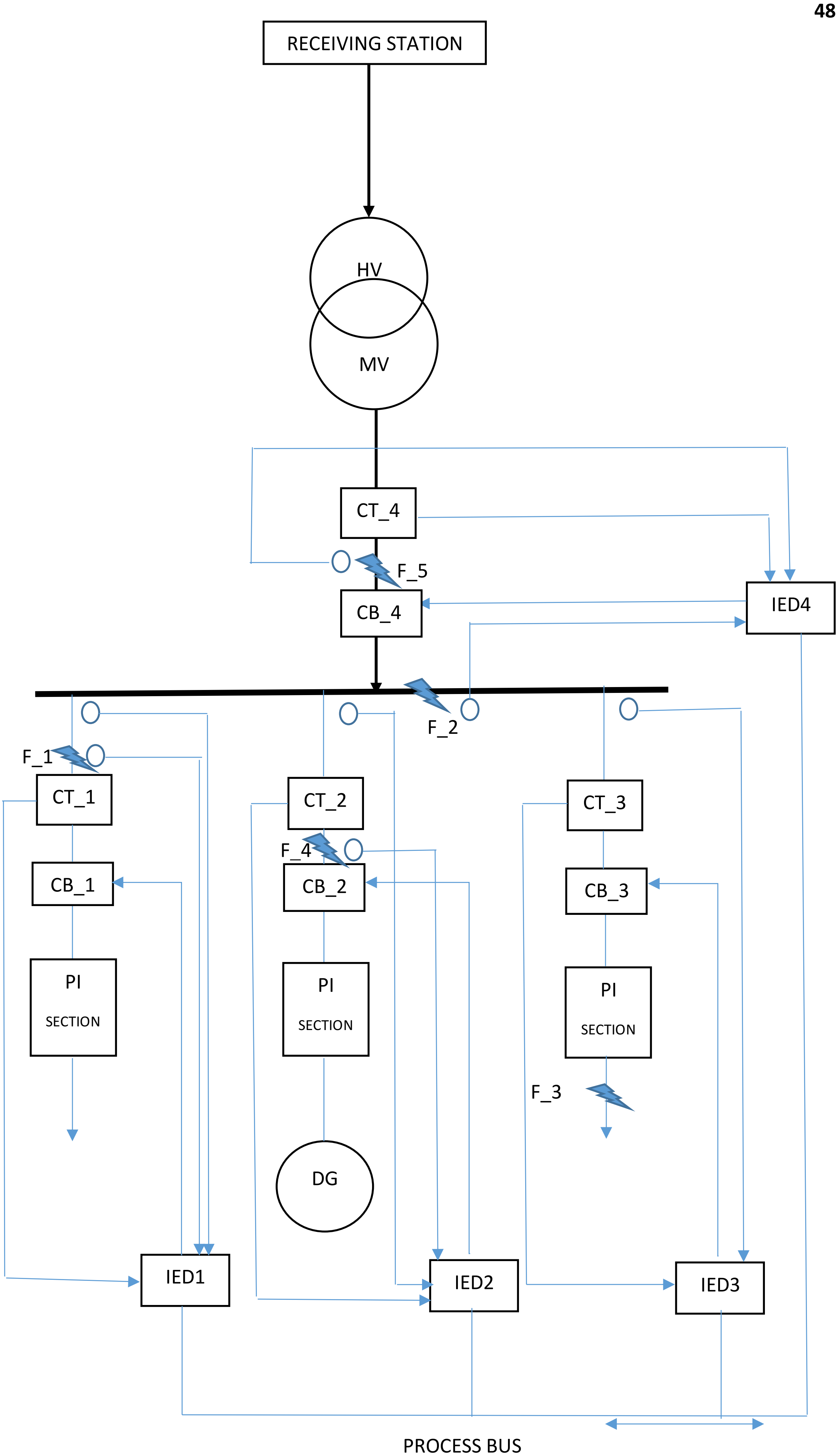


Figure 5.1 Research Module

## 5.2 Defining the Settings of VAMP 300 IED

The IEDs are used for this thesis research model need to be setup as per required order. There are different matrix availabe for defing the arc sensor, input, output and other relevent settings.

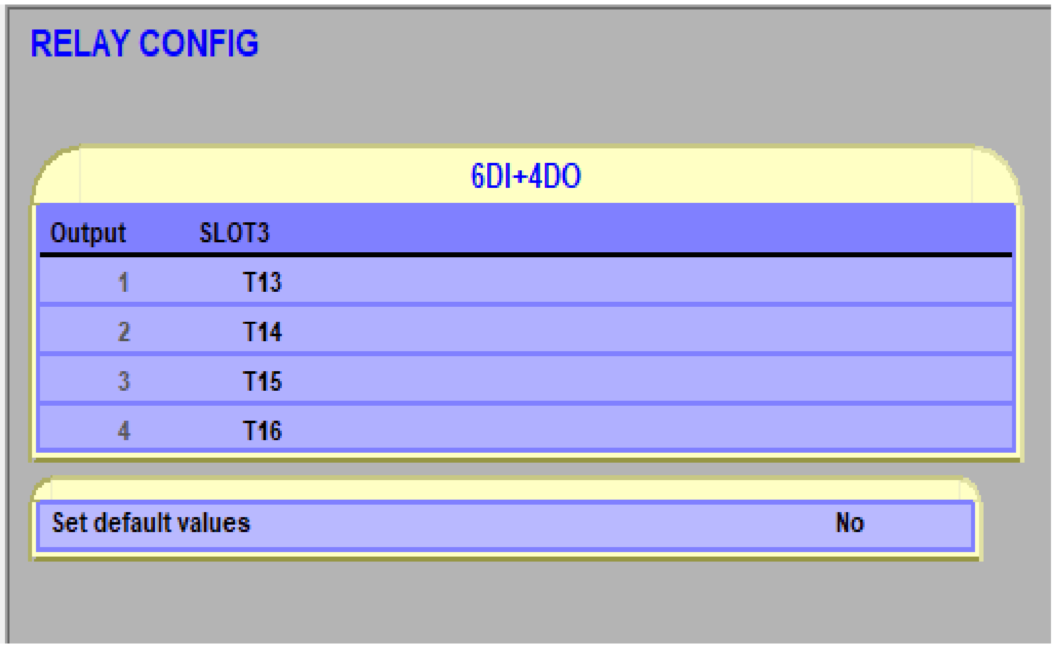


Figure 5.2 Relay output slot for tripping

In the figure 5.2 it has defined the output slot for providing the tripping command to the breaker connected with the rlay. The IED under experiment has Six (06) input slot and four (04) output slot.

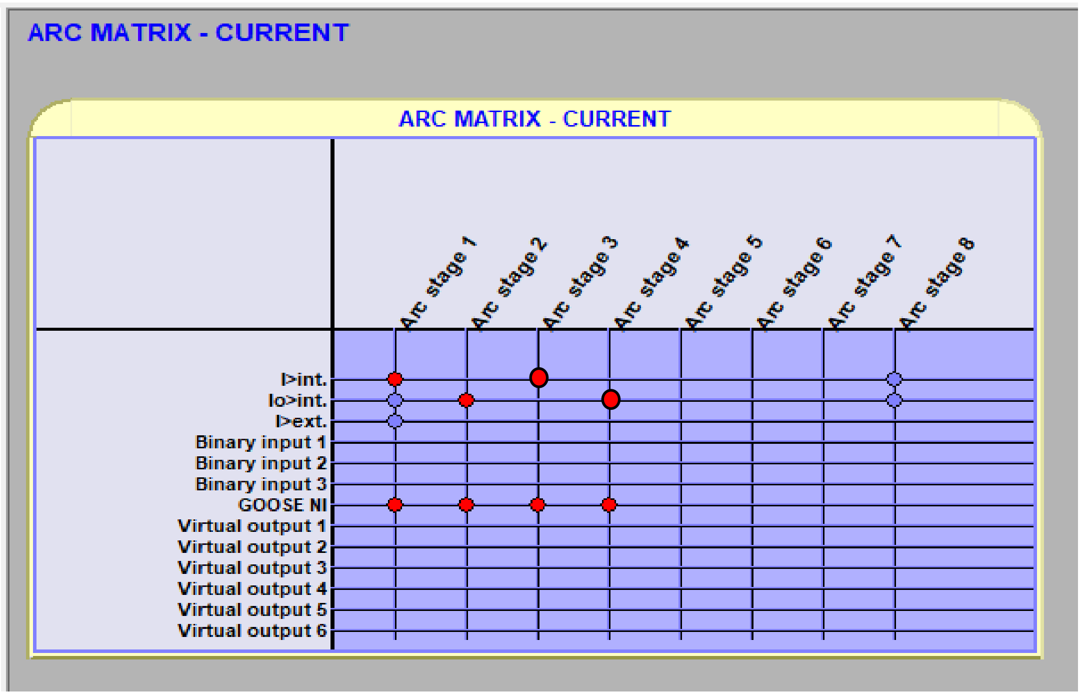


Figure 5.3 Arc Matrix- Current

The figure 5.3 shows Arc stages from 1 to 8 in horizontal axis and the fault current stage with binary input/ output shows in the vertical axis. The red dot means there are connection between two quatities from horizontal and vertical axis.

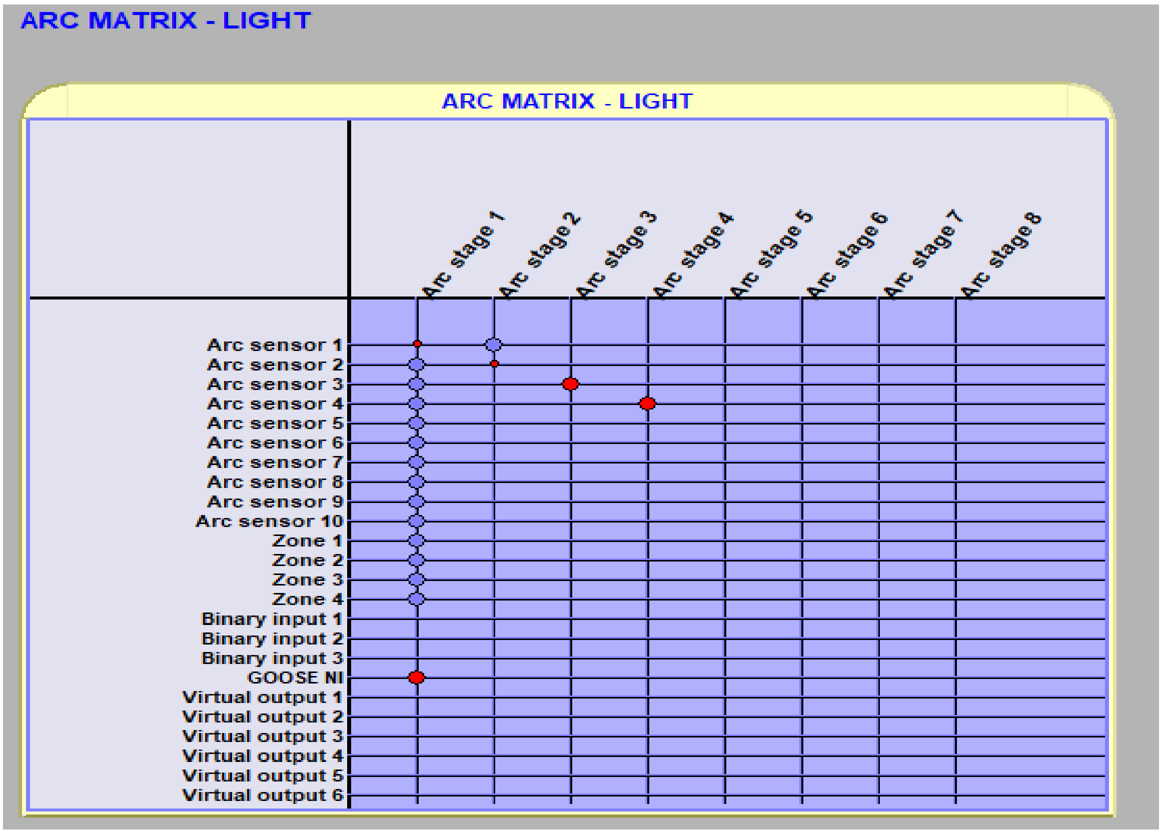


Figure 5.4 Arc Matrix - Light

The figure 5.4 has showed the arc matrix-light where arc light signals are linked(left column) are connected to the proper Arc stages with red dot points the connected point. So the sensor input will lit the light for different arc stages.

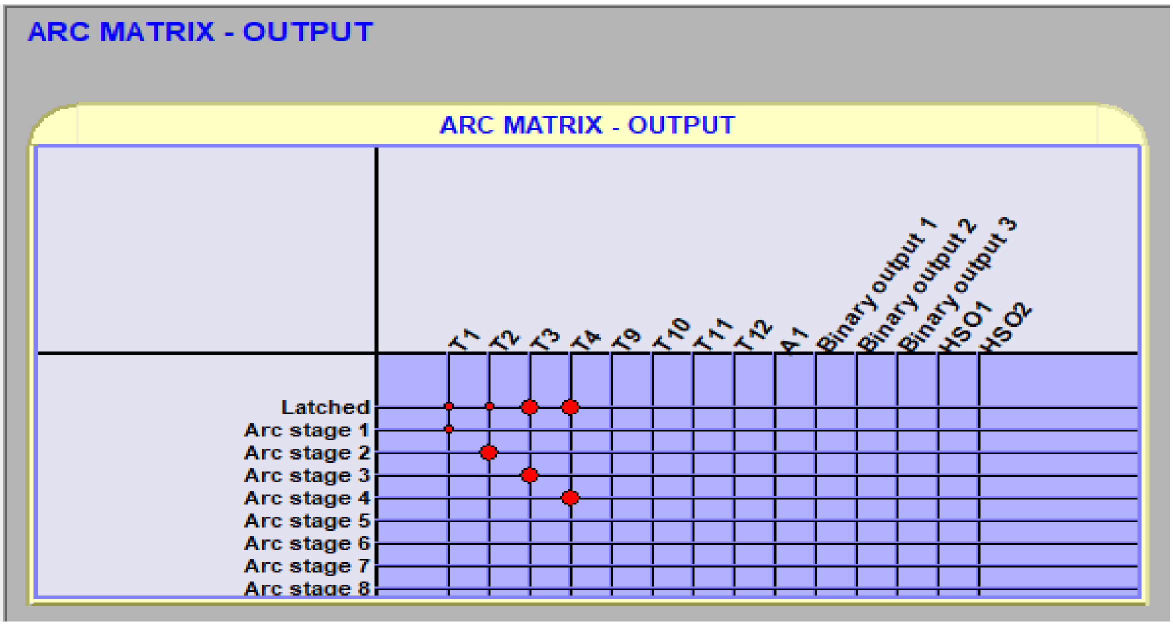


Figure 5.5 Arc Matrix output

The figure 5.5 arc matrix output has got the input from arc stages and output has connected with the tripping terminal (T1 to T4). If the figure 5.3 and 5.4 are compare than it can be seen that the horizontal axis has the arc stages. These arc stages act as input in the figure 5.5 and output are denoted as tripping command due to the arc flash.

## 5.3 Working Process of Research Module

According to the figure 5.1 there are five fault locations. These faults are three phase to ground faults. Amoung these five faults three faults are in the feeder, one is on the transformer side and the other is on the bus bar. Five fault locations have assigned by F_1, F_2, F_3, F_4 and F_5. During these faults are happening different phenomena has occured. In the location of F_1 has situated on feeder than CT_1 has measured higher current than the normal level. The CB_1 has tripped for protecting the feeder. The CB_1 has issued a GOOSE message for IED_2 and IED_4. The GOOSE message has put in to the process bus that can be read by IED_2 and IED_4. IED_2 has controlled the feeder with DG. It is important to continue the power supply by the DG towards the feeder and connected load. The IED_4 has played a vital role in this experimantal setup. The main line from the receving station has connected to the bus bar that works as main power supplier for the feeder and its coneected loads. If this intercommunication does not stablished, there will be symphathetic tripping will happen. In the figure 5.1 there is fault location F_1 and corresponding circuit breaker CB_1 take the resposibility for trriping on the basis of the decision of IED_1. The neighbouring branch there are circuit breaker CB_2, IED_2 and CT_2. A distributed generation (DG) unit is also connected to that feeder. As the fault has occured in the location F_1 than the DG unit will also contributes the fault circuit current towards that location. As a result feeder with DG unit will shutdown due to the decison has taken by the IED_2. The description of the scenario has depicted in the Figure 5.6. An arc sensor has set up, which will detec the arc flash light and send the indication to the IED_1. IED_4 also need to know the block message that IED_1 has decided for tripping as the figure 5.6 also refering the process.

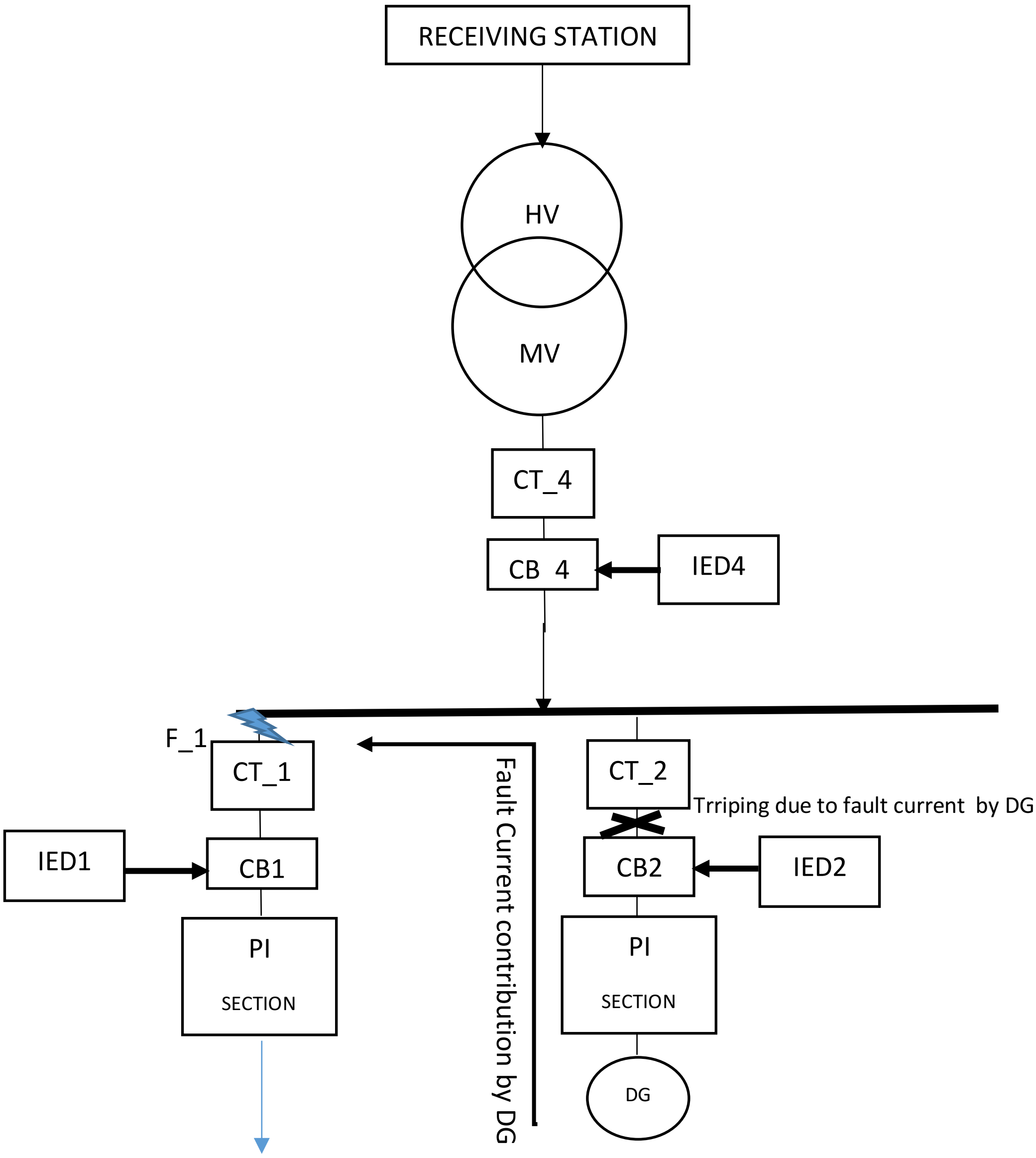


Figure 5.6 Symphatetic Tripping for location F_1

In the location F_2 during the fault on the bus bar there will be different situation will happend. IED_4 is resposible for take care of the bus bar main supply feeder. In the bus bar there are two source for power supply. One source is the supply from recceiving station via the HV to MV transformer and the another source is the distributed generation (DG) unit (see figure 5.1). The IED_4 has tripped itself . As a result the main power supplier has disconnected from the fault location F_2. But the DG from the feeder 02 will provide the current towards the location F_2. So the fault in F_2 will not yet be cleared after the tripping of IED_4. The IED_2 will be trip and disconnect the DG until the fault has removed by itself or manual process. If the fault on the location F_2 has disappeared by itself than IED_2 will use its autoreclosing features and connect the DG to the Bus bar. Autoreclosing of DG unit is possible when all synchronization works properly. If the IED_4 is not use it's auto-reclosing feature by itself than the power supply towards the three feeders will not become in normal situation. The DG can supply the power towards the other feeders. The current will flow towards other two feeders.

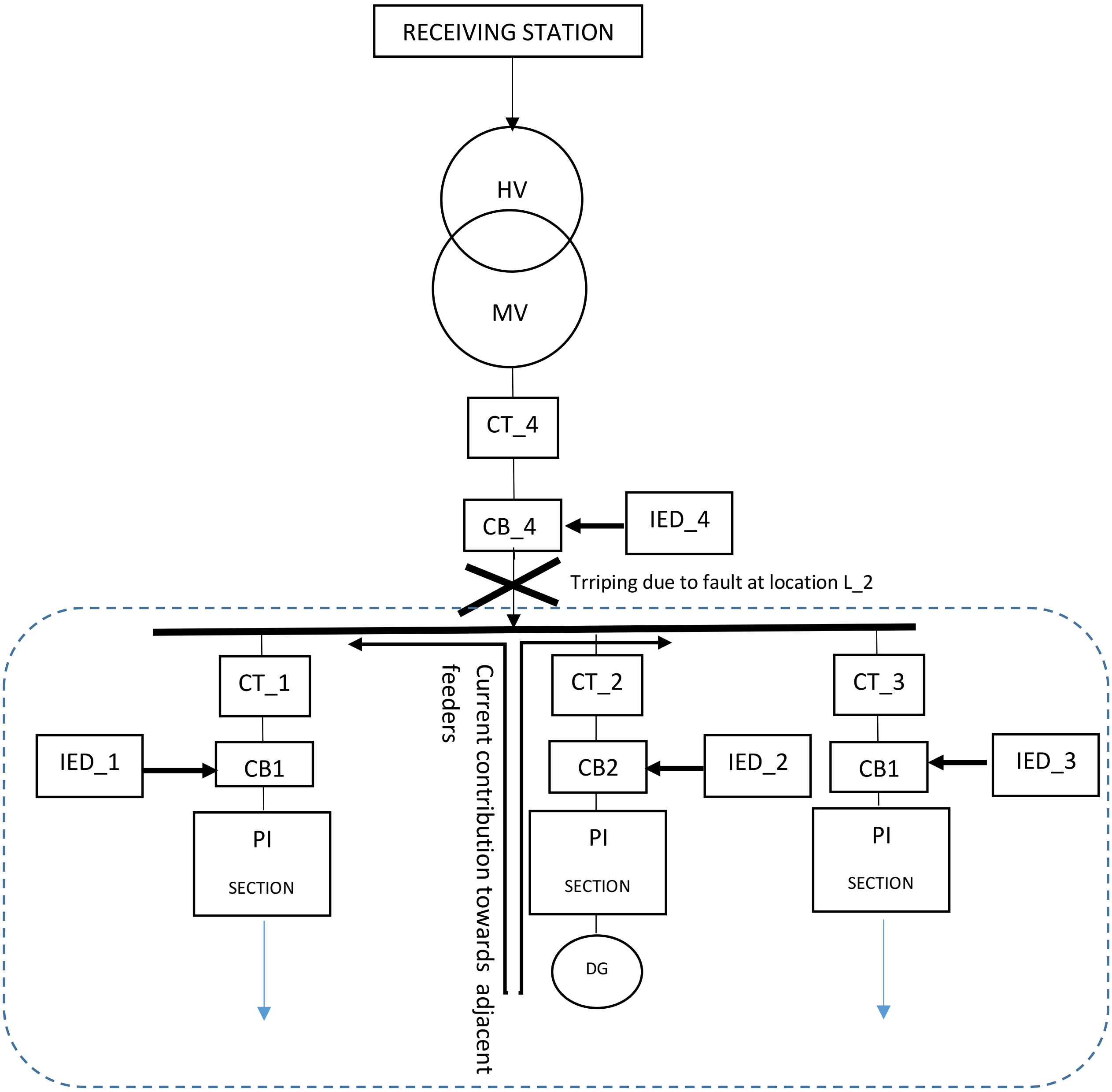


Figure 5.7 Fault at location F_2

The situation has depicted in the figure 5.7. This scenario has created an islanding operation with DG among three feeders and bus bar. The dotted line box has shown in figure 5.3 indicate about the islanding zone. In this scenario there are two IEDs (IED_2 and IED_4) have gone under tripping condition. The DG unit should be disconnected until the fault F_2 has not goes away. When the IED_4 goes under tripping situation than it will generate a message for IED_2 and put it on the process bus. This fault could be solved by using certain time period (1-2 seconds) disconnection of DG without trriping IED_2. Because there is also possibility for supplying the fault current towards the location of F_2. The IED_2 does not need to open the CB_2 because when the fault elimination has done and islanding operation has started then connecting load again takes extra time. Also there is another soultion by regulating the capacity of DG production. When the blocking signal has received by IED_2 from IED_4, it can send an acknowledgement to the DG regulator that will assit to reduce the production of power for a certain time limit. The DG could be a wind turbine or solar powered unit. The speed of turbine and partial shedding of solar power unit can be controlled.

If the bus bar has arrangement with sectionalization or double busbar arrangement in the figure 5.7 then the solution will take in to account with the features of busbar. For more details on this bus bar please check article 1.4. The absence of sectionalized bus bar or double bus bar concept then both IED_2 and IED_4 need to be shut down. Because IED_4 is resposible for disconnecting the main power supplier source from receiving station and IED_2 is also disconnecting the supply of the distributed generation unit. The main power source from receving station and the distributed generation could resposible for providing the fault current to the location on the bus bar fault location F_2. The faullt location F_3 is happen outside of the substation. In the figure 5.1 it has shown that the fault is happen after the PI section. IED_3 will take the initiative for the tripping as the CT_3 has recorded the higher flow of fault current. The IED_3 will issue a block signal for the IED_2 and IED_4. Those two IEDs not required to trip by itsself. The IED_2 will need to concern about the tripping because the CT_2 will also record the higher flow of current. There will also have possibility to occure the sympethetic tripping. Due to high demand of current towards the fault location of F_3.

The Fault location F_4 is situated between the CB_2 and CT_2 (see figure 5.1). The fault location is feed by DG and the main supply from bus bar. CT_2 can able to record the high flow of current in very short possible time. As both sources have supplied extra amount of current for short circuit fault demand. IED_2 will trip and send block message for IED_4 on the process Bus. So IED_4 will check the current level. If the situation has requires than IED_4 will trip and eliminate the fault current from the system.

The fifth fault location is situated next to the tranformer and between CB_4, CT_4 (see the figure 5.1). IED_4 will take the decision for tripping, when the CT_4 has recorded the higher amount of current compare to normal situation. IED_4 will issue a blocking signal to IED_2 because there is a DG connected with the feeder. So the CT_2 will recorde higher amount of current than the normal situation. As the main power supply from the receiving station has shutdown due to the fault location F_5 there could be a islanding operation will started automatically. The DG unit start supply to other feeders. On the basis of load demand the power will distributed rationally.

# 6. Conclusion and Future work

## 6.1 Research Philosophy

The research work for thesis has aimed to implement the theoretical framework. It helps to understand the main idea of theoretical concept. The research work includes the creative work progress with an organized approach. It could be an analysis that increases the idea on the ground of a basic. The previous knowledge is an important catalyst for the research path progress. The result of new work has established facts and reaffirm to the former work. The new result of a research work could be able to give solution for new or present problem. It might support the theorems that has used in the contemporary or develop the theorem from its present condition. The implementation phase of the research has required physical instrumental arrangement. The instrument selection from it's own variation has played a vital role. The expected results from the experimental setup could be depends on the proper experimental procedure and calibration.

From the perspective of the safety it is important to design a plan to secure the substation from unexpected hazard. To provide a qualitative service to the consumer manintaing a good protection system for the power system is important. The thesis deals with the discussion on the different kind of bus bar which provides operational oppertunity for the substation design arena. Different protection scheme has discussed with a brief idea. The arc has produced and causes damage for the power system. This topics has discussed with proper context for the main scope of the thesis. Internal communication between the protecting device with proper message exchange has realized the substation protection goal. Differnt fault and location can change the perpective of the protection idea planning. The study of the thesis has made on the basis of modern technological idea. These idea could need more assesment to implement in different situation.

## 6.2 Accomplishment of Thesis objective

The goal that has set in the introduction chapter art 1.5 fulfilled. The study has done on the differnt types of bus bar in the art 1.4, the arc sensor has studied in the art 3.7. Feeder and cubicle have studied in simulteneous chapter also. The IEC 61850 system bus has studied and discussed in a detail menner is the chapter 4. The arc flash charecterists and related issues have disccused in chapter 3. The IEC 61850 protocol has selected for the purpose of communication between protection equipments discussed in chapter 4 as well. The idea of laboratory experiment has required a substaion model. The substation model has given in the chapter 5. The complete idea about the implementation of the protection scheme with communication prtocol have depicted in a detail menner. The proposed idea of the chapter 05 is fufilled the one of the important reserach goal of this thesis.

## 6.3 Future Work Aspect

The protection concept and planning should be implemented with more developed idea. The idea of research in this thesis has moved forward with the progressive time frame. The previous implemented work in a real-time project for research can be altered with additional implemented demo and laboratory work. It will be expected that the alteration of the established research work might be required more rigorous implementation design. In this thesis it has been tried to study and implemented an idea that could be helps further progress of the future development. There are differnt topology for designing a substaion in a power system. In differnt geographical location there are differnt number of consumer, business scenario, netural environment and also availabilty of resources. So the idea that take into account for designing the substation perspective in this thesis could not be adjust with all realtime scenario. The basic implementation of a scientific law is also helped to motivate the learner to think the idea in a deep level. From the power system protection point of view it has focused to follow the basic idea of fault effect is abated in the medium voltage bus bar level in the thesis. The created idea for understanding the scientific law influence the learner to move forward on the path of subjective knowledge. So in the future timeline segment, the basic idea of busbar protection will helps the learner for surfing on the ocean of substation switchgear knowledge. Consequently there could be new type of implemantation on the basis of same power system protection theory, will appear on the horizon of bus bar protection as well as substation protection arena. For being a researcher to design a research methodology for basic implementation of an established theory plays an important role. So taking into consideration of basic idea of the thesis has tried to clear the concept of busbar protection scheme using IEDs with a designed reserach module. The reserach module could be developed to increase the relaiablity of the substation protection in future.

## 6.4 Conclusion

The thesis has focused on the busbar protection. It has also consider the communication between IEDs. It is a significant discussion topic for the establish of a busbar and provide a quality ful service to the customer. It has tries to added the real scenario of the fault situation as well as communication on the basis of IEC 61850. From the part of final word of this thesis tries to depict the total protection scenario and as a part of solution of IEDs implementation usig the GOOSE message.

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# Appendix 1

Complete description of Circuit Breaker (XCBR) Logical Node in IEC 61850-7-4. Source: ([28][29])

| XCBR Class | | | | |
|---|---|---|---|---|
| DATA NAME | COMMON DATA CLASS | DESCRIPTION | T | MANDATORY/ OPTIONAL |
| LNName | Secure | Shall be inherited from logical node class | | |
| DATA | | | | |
| Common Logical Node Information | | | | |
| | | LN shall be inherited all mandatory data from logical node class | | Mandatory |
| Loc | SPS | Local operation (Local means without substation automation communication, hardwired direct control) | | Mandatory |
| EE Health | INS | External equipment health | | Optional |
| EE Name | DPL | External equipment name plate | | Optional |
| OpCnt | INS | Operation counter | | Mandatory |
| Controls | | | | |
| POS | DPC | Switch Position | | Mandatory |
| BlkOpn | SPC | Block Opening | | Mandatory |
| BlkCls | SPC | Block Closing | | Mandatory |
| ChaMotEna | SPC | Charger Motor Enabled | | Optional |
| Metered Value | | | | |
| SumSwARs | BCR | Sum o switched Amperes, resettable | | Optional |
| Status Information | | | | |
| CBOpCap | INS | Circuit breaker operating capability | | Mandatory |
| POWcap | INS | Point on wave switching capability | | Optional |
| MaxOpCap | INS | Circuit barker operating capability when fully charged | | Optional |

# Appendix 2

Anatomy of Single Point Status (SPS) Common Data class in IEC 61850. Source: ([28][29])

| SPS Class | | | | | |
|---|---|---|---|---|---|
| Attribute Name | Attribute Type | Functional Constrain | TRGOP | Value/ Value Range | Mandatory/ Optional |
| Data Name | | Inherited from Data class | | | |
| Data Attribute | | | | | |
| Status | | | | | |
| StVal | BOOLEN | ST | Dchg | True\|False | Mandatory |
| Q | Quality | ST | Qchg | | Mandatory |
| T | TimeStamp | ST | | | Mandatory |
| Substitution | | | | | |
| subEna | BOOLEN | SV | | | Pic SUBST |
| subVal | BOOLEN | SV | | True\|False | Pic SUBST |
| subQ | Quality | SV | | | Pic SUBST |
| subID | Visible String 64 | SV | | | Pic SUBST |
| Configuration, description and extension | | | | | |
| d | Visible String 255 | DC | | Text | Optional |
| du | Unicode String 255 | DC | | | Optional |
| cdcns | Visible String 255 | EX | | | AC_DLNDA_M |
| cdcName | Visible String 255 | EX | | | AC_DLNDA_M |
| dataNs | Visible String 255 | EX | | | AC_DLN_M |