Protection systems in power distribution systems in Data Centres in the UK

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ABSTRACT

A well-designed protection system in a power distribution system ensures the continuity of power delivery. Even though this can't prevent a fault, which can lead to a catastrophic situation when the protection will not operate correctly, therefore, protection devices must be correctly selected and installed to avoid these consequences. The power system in a data centre is constructed of prominent features like generators, power supply cables, high and low-voltage transformers, and UPSs with a battery backup system and protection system.

Researchers have looked at the problems in terms of faults inside a UPS system which is about protecting the UPS unit itself rather than the power distribution system within the Data Centre. If the fault occurs inside the UPS unit, then internal protection will shut down the faulty unit, and a redundant UPS N+1 will turn on. Operation of the UPS system with "in use" redundancy of the UPS is a critical moment for power delivery security. If the redundant UPS is lost, power backup is lost, so engineers must do repairs quickly. I concentrated on the protection system within the power distribution network in a data centre, not internally to a UPS.

The thesis presents the coordination of a protection system with the help of using the ETAP 21 software. The designed power system level is 11kV/400V AC with 50Hz frequency and a capacity of up to 8MW connected to two different DNO grid power networks. The power distribution system includes a backup system to ensure continuity of supply when both DNOs supplies have outages. The simulated protection coordination into randomly selected equipment, line or busbar under the fault condition will show the sequence of the operation. The primary protection has been designed to operate first as it is closer to the fault. However, when it fails to operate, then backup devices in the sequence must operate to isolate the faulty equipment.

Protection elements like fuses and circuit breakers are not designed to prevent the fault. The protection, however, senses and operates fast to limit the fault current severity that causes damage to the equipment and increases the system's safety. An integrated part of achieving those is selecting appropriately rated protection devices and switchgear and performing a protection study. Regular maintenance is essential to correctly working the power system and the protection.

Acknowledgements

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Contents

ABBREVIATIONS

AC: Alternating Current

ANSI: American National Standard Institute

ATS: Automatic Transfer Switch

DC: Direct Current

C: Current

CT: Current Transformer

DNO: Distribution Network Operator

ETAP: Software

Gen: Generators

IDMT – Inverse Definite Minimum Time

HV – High Voltage

IEC: International Electrotechnical Commission

LV: Low Voltage

LVPCB: Low Voltage Power Circuit Breaker

MCCB: Moulded Case Circuit Breaker

MV: Medium Voltage

NER: Neutral Earth Resistor

PCB: Power Circuit Breaker

RMS: Root Mean Square

TX: Transformer

UPS: Uninterruptible Power Supply

V: Volt

VT: Voltage Transformer

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Chapter 1 Introduction

1.1 Introduction to Power Systems in Data Centre

An 11kV/400V AC power system is a commonly used power system in Data Centres, in the small and medium industries in a secondary distribution network, and as a power system in financial institutions and hospitals.

The research is on protection coordination in 11kV/400V Alternating Current (AC) power systems, presents study cases and shows the results. The protection study concentrates on aspects like the selectivity of the protection device, which refers to the isolation of the faulty part of the power system from the rest of a network as well as the sensitivity of the device that avoids the nuisances tripping when it is wrongly selected to make coordination effective and reliable to maintain an uninterrupted power delivery to data racks during local short circuit faults with the help of use the current version of ETAP 21 software.

A power network has been developed with time and was initially formed in redial. Nowadays, power networks are mainly formed in mesh for more excellent reliability and security of supply. The radial form of power system differs from the mesh as it is formed of one power source with one or several load sides compared to the mesh that is formed in a loop connected to more than one source of power generation with number of loads. The network formed in a mesh is more reliable as when the loop is open or a power generation is lost then power is still supplied to the loads using other connected power generation sources. The power system created in redial is straightforward in design, construction, and operation as it requires fewer cables and less equipment to be maintained. A mesh power network has many disadvantages, being more expensive in construction as it requires more elements, cables, and equipment and therefore, the cost of build and maintenance is higher.

A new power distribution system utilised in industrial or commercial new premises is connected to the main power network, also called a “GRID”. A DNO issuing to the designer “Grid infeed parameters” says that the maximum capacity available at the point of new connection and the purpose of the new power system must be economically justified [1].

Also, the protection system in interconnected or mesh type is more complex and nowadays more digital. However, an interconnected or mesh power distribution system is more reliable, can take more load and voltage drop is much less, almost negligible [2]. Protection systems and coordination are used in both power AC and DC types, and any power system must be protected against the consequences of faults to prevent catastrophic results.

1.2 Thesis Aim and Objectives

This project aims to design a preferable AC power distribution system used in Data Centres in the UK having a power backup system to ensure power continuity as well as present protection coordination that is highly reliable, sensitive, and selective in 11kV/400V AC power distribution system to minimise the impact of Symmetrical and Unsymmetrical short circuit faults with the help of the ETAP 21 software. The objectives are:

1. Compare environmentally and conventional power systems in Data Centres
2. Present a load demand and share trends in Data Centre
3. Review elements and protection devices of an electrical power system
4. Construct a power distribution system of 11kV/400 AC
5. Apply the ETAP 21 software features
6. Cases study simulations using various fault scenarios

.3 Structure of the Thesis

This thesis is structured into five chapters and starts with an introduction talking about the importance of a protection system in the electrical power system in the Data Centre. An integral part of the introduction chapter is the aim and objectives and the thesis's structure. I have also added "Brainstorming" as a chosen creative thinking technique and discussed its importance.

Chapter 2 is a literature review presenting two types of Data Centres's power systems one is environmentally friendly, utilising renewable resources, and the second is not ecologically friendly, relying on the DNO grid. Both systems have an infeed power with a diesel backup generation system. It also covers a power share and demand per data rack within Data Centre and discusses the main power distribution system elements.

Chapter 3 illustrates the calculation methodology and power source parameters.

Chapter 4 is the proposed network design and case study of the power system in the Data Centre. The power network consists of two double grids in feeds supplied from two different DNOs to maximise power delivery and limit the risk of power interruption. An integrated design part is a diesel generator as the backup system configured in N+1 redundancy. The N+1 means that there is an additional independent backup of a component when the necessary component that is required to run the system fails.

The power system uses 11kV/400V step-down transformers connected on the primary side to MV and on the secondary side to LV switchboards, from where power is distributed to mechanical and electrical loads. The case study covers the work of three simulations performed in the proposed power distribution. The simulation will show protection coordination in faulty bus bars or cables on LV and MV sides. Protection devices isolate a defective part of the system to ensure power delivery continuity supplied from another aspect. On the LV side, ATS automatically transfer power in lack of the power supply feeds from another power source to cover the demand.

Chapter 5 is the place of the conclusion and future work needed based on this thesis topic.

A complete list of references is listed at the end of the thesis. Appendices cover all data sheets of equipment used to design this power distribution system as well as the DNO source of the grid information.

1.4 Chosen Creativity Thinking Technique

The chosen creative thinking technique is the "Brainstorming method", which is an effective method that will help me to manage the project.

The "Brainstorming" method Fig.1.1 is an excellent tool for quickly and effectively exchanging thoughts and perceptions of the problem. Brainstorming intends to use collective thinking, involving people listening to and capturing ideas based on other solutions. Requires freewheeling discussion in which people in conversation about a problem express their thoughts and share their diverse knowledge. The figure below shows the cycle of the Brainstorm and the resources involved in intellectual thinking and the interaction between them.

To brainstorm, use boards or large paper sheets to store all the ideas. To record the ideas write them down. This form allows you to look from the perspective of ideas, for example, that combining two ideas solves the problem.

The main challenge is to follow the basic rules of brainstorming:

- As many ideas as possible should be on the board, even the morazy" ones.
- Gather anyone you think can contribute.
- Do not judge what has been said (time for it will come later).
- You should listen carefully and refine the ideas of others. Borrowing ideas and modifying and improving people's thoughts are the most desirable.
- Reflect on the opinions of others and use the most of it
- Solutions should be drawn if possible because it stimulates creativity.

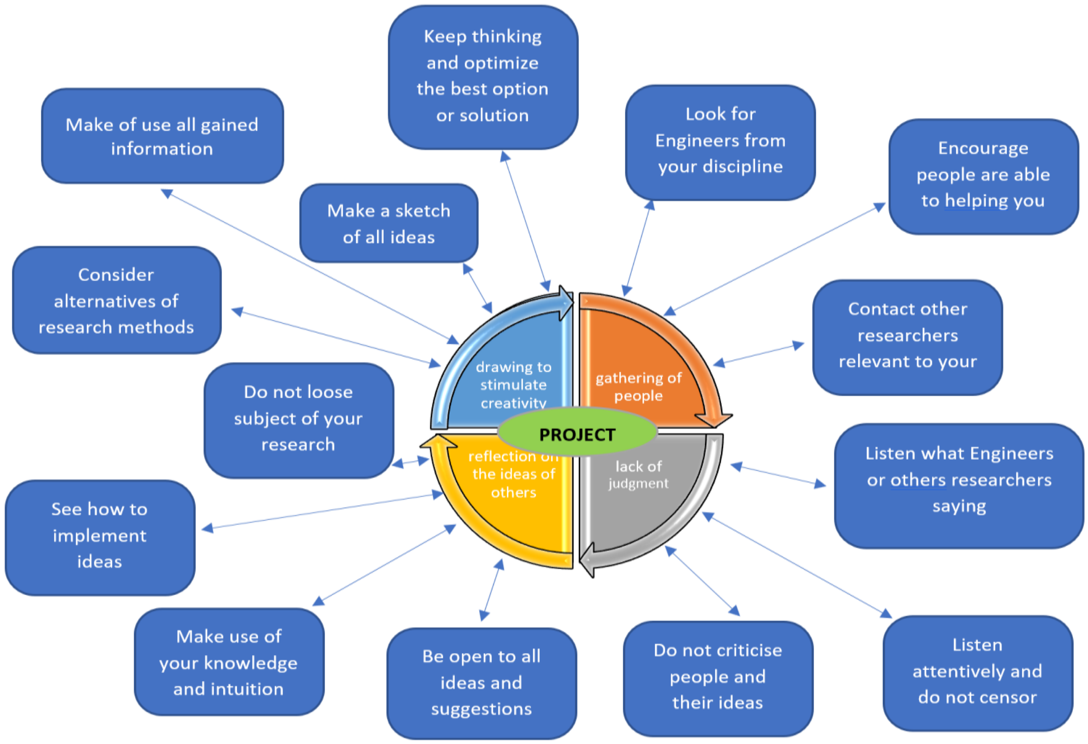


Figure 1.1. *Brainstorming Method*

Chapter 2 Literature Review

2.1 Introduction

Power systems in construction are different in terms of power supply security and are divided into groups based on power delivery priority and premisses power supply backup. The first group where uninterrupted power must be delivered are hospitals, financial services, government, and military infrastructure, where power interruption can cost people's lives or cause national security failure. Data centres are this group where the power supply ensures the uninterrupted operation of data IT equipment. The cost of losing IT data is extremely high, and the data centre must pay the client and the commercial business reliability, which can be easily lost. So, a reliable power system, including a well-designed and installed protection system is the core of power supply security.

Protection is divided into devices and the system. A protection device is an element designed to break the fault condition circuit. The protection system is built on multiple devices that coordinate according to a protection design. The very first type of protection in the power system is a fuse. The fuse is a simple construction device, developed to a more sophisticated form that can provide a very fast disconnection time of less than half of a cycle. With time a circuit breaker device and relay device have been developed too, and their significant advantage over the fuse is that relay. Circuit breaker can easily be reset, and the fuse must be replaced after operation. Circuit breakers and/or relays can be reset even easier to utilise in Power Management System (PMS) and Building Management System (BMS) systems.

The very beginning of relays started with an electromechanical relay using an electromagnetic coil to rotate a disk. This rotating disk is to adjust a time delay and is still in use, as the technology has developed, a solid-state relay was proposed, which, compared to the electromechanical relay, does not have a moving part and is considered a better option for relaying. Nowadays, a digital relay is the most popular in power protection systems. Digital relay and solid-state combine more than one function named a Multifunction Relay. This type of relay has all the functions of overcurrent relay, distance relay, directional relay and so on. This main benefit is that it takes less space than using each relay with its function, which gives greater flexibility and reduces the space needed. A reliable well-designed power system in Data Centre plays a crucial role in the whole business because it delivers uninterruptable power into data racks where all data are stored and cooling systems that cool down the data halls.

It is essential for the data business to keep the power system always working 24 hours, seven days a week, 365 days a year [3]. For that reason, every Data Centre employs a maintenance team which works 24/7 for 365 days a year to monitor the entire system. The power system in Data Centre supplies not only power to the data racks but also to a chiller water system responsible for cooling the heat generated by data racks, and it is no less important than the main power supply system.

Power systems used in Data Centres are divided into three types of systems Alternating Current (AC), Direct Current (DC) power systems and a mixture of AC and DC. Each of those systems has its advantages and disadvantages however, which should be used depends on Data Centre owner preferences [1]. A comparison of the two systems and justification, which is overall better, is outside this research and can be a subject for further analysis.

The choice of which power system is preferred is in line with typically for the industry type of the power system or with the power system is already implemented and utilised in a Data Centre managed by the same owner. The reason is to make all power systems on every site alike. This approach gives owners more flexibility in the security of maintenance and cost efficiency as all the Data Centres have the same equipment installed and are similar in design, and it helps more efficient way to manage the Total Facility Management (TFM) of the entire network of Data Centres spread across the whole.

During the research, a research paper has brought to my attention in terms of utilising in Data Centres as a renewable resource as an alternative source of power for cheaper use of energy to make Data centres more efficient and cost-effective [1].

However, based on Equinix's statement as the owner of Data Centres worldwide, the idea of utilising renewable energy resources has yet to be implemented in the UK. One of the reasons is to challenge DC-generated power systems in Data Centre that require lots of space to install the Solar PVs and/or wind turbines and will become more complex that might not be cost-effective in the long term because all the equipment requires not only maintenance and repair, but also after time of exploration, it must be decommissioned removed and utilised.

2.2: Power distribution system in Data Centres:

The design of the DC power system will include a mixture of AC and DC power systems and the primary power system supplied from the 11kV AC power grid, then stepped down to 400V via a step-down transformer. Then an installed AC/DC rectifier provides the power to data racks in data halls via low-voltage DC Power Distribution Units (PDU) [4]. At this point, it is good to mention that the cooling system works using AC power, so the power system would have to be split after the transformer to provide the AC for the cooling system, the power system, and the rectifier. The backup system will be constructed of Uninterruptible Power System (UPS) with a battery system and 2MV High Voltage diesel generators grounded via Neutral Earth Resistor (NER) directly connected to the main 11kV switchboard.

As mentioned earlier, the protection system and coordination must be correctly designed and carried out as a so-called "protection discrimination study" to meet the design requirements. Protection itself is not to prevent the fault; it is to detect the fault and disconnect in the required time to limit short circuit fault duration. Any fault and duration cause damage to the equipment installed within the network [5]. To limit the severity of the fault, a reliable, highly sensitive and selective protection system is crucial.

A protection system does not always require coordination, and it can be found in the isolated type of power system where the power circuit is composed of a single source of power, a single power cable and a load. In this type of power system, if a fault occurs, the protection device will operate and disconnect the load. In such a situation, the protection device protects the cable from melting down and the generator from being destroyed.

Protection coordination is used if the power system is constructed of a minimum of two power sources and a minimum of two loads but supplied from two different bus bars or in a power system formed in a ring or mesh. As soon as the protection system has at least two protection devices, protection coordination should be considered, and a discrimination study shall be performed to achieve coordination. The coordination can be done between a fuse and a circuit breaker, between two or more circuit/power breakers, and between relays and fuses and so on. In high-voltage power systems, the protection system is constructed of relays that operate High Voltage (HV) circuit breakers and/or fuses.

What does cause the protection system to operate? This happens by some natural incidents caused by lightning, ice, wind or even an earthquake, a human factor or by the equipment itself when insulation in a power transformer breaks (Heat = I2 R).

Before the protection study begins, an engineer must obtain basic information like power source voltage level, voltage angle and frequency to calculate prospective fault current at each point of the system. Power system equipment and load impedances must be known before to do this. Protection study in MV is technically similar compared to LV power systems. The difference is that in the MV systems, protection coordination is mainly between relays, fuses, and relays compared to the LV systems, where no relay coordination takes placeCircuit Breakers (MCCB) and Power Breakers (PB) have a built-in tripping unit where the settings can be adjusted to the required values. Further a tripping unit is briefly discussed in the low voltage circuit breaker section.

2.2.1 Environmentally friendly power distribution system in Data Centre

To construct an environmentally friendly Data Centre utilising renewable resources like a wind turbine, PV solar or tidal must be used as a source of energy [6]. However, the main problem with renewable resources is that they are an unreliable energy source; data centres must rely on more than just them but can be treated as an additional power supply. It is still common practice to rely on gas or coal as a main power plant to supply energy to the power system network. An example of a modern Data Centre is shown below in Fig. 2.1, using either fossil fuel energy sources or renewable energy interchangeably. To make the Data Centre more efficient, a system REDUX switches between energy sources according to the workload requirements. This power management system, REDUX, maintains a good balance between money and the energy system's efficiency [7]. However, every Data Centre has its generation plant running on diesel to ensure uninterrupted backup power supply to data server racks. A UPS power system installed in power switching rooms is responsible for continuing supply to the system for a short period of time using a battery system until generators are ready. The UPS system improves the power factor to almost unity, clears all noises circulating in the electrical power system and provides a stable voltage level. The reason to install the UPS in the Data Centre [8] has been justified as the installation cost is very high, and it must be profitable for the "return of investment" will also pay it's off. The justification of UPS equipment installation was based on Mean Time Between Failures (MTBF) vs Mean Time To Recovery (MTTR). This comparison refers to numbers of MTBF and, say, 100,000 in 10 years versus damages estimation caused by the time of the outage. An Interruption in power delivery cost paid to some important client of the Data Centre could reach £100.000 per minute. So, based on the information of the power interruption cost level, we can see that paying to Data Centre's clients is enough to make a reasonable decision to install a UPS system.

Another crucial factor is that the power delivered to data racks must be kept from being interrupted. Otherwise, all data are lost.

The current UPS system operates on a PWM type of converter, and the reason that is it is not complex and bulky. The UPSs systems are formed of power converters like rectifiers converting AC to DC, Inverters converting DC to AC and voltage boost, which principle is based on the buck-boost converter. Voltage boost is a compulsory module in UPS because it is responsible for boosting voltage supply from batteries, as the battery system is designed to deliver 600V. Then voltage boost increases the voltage to 720V to keep the requirement of power level supply of, e.g., 800kW. The UPS system is mainly constructed in N+1; however, the 2N system is more reliable as 2N means we have one more UPS system that includes a battery system available to operate in the event of a fault. This option is more expensive but always depends on the client's requirements.

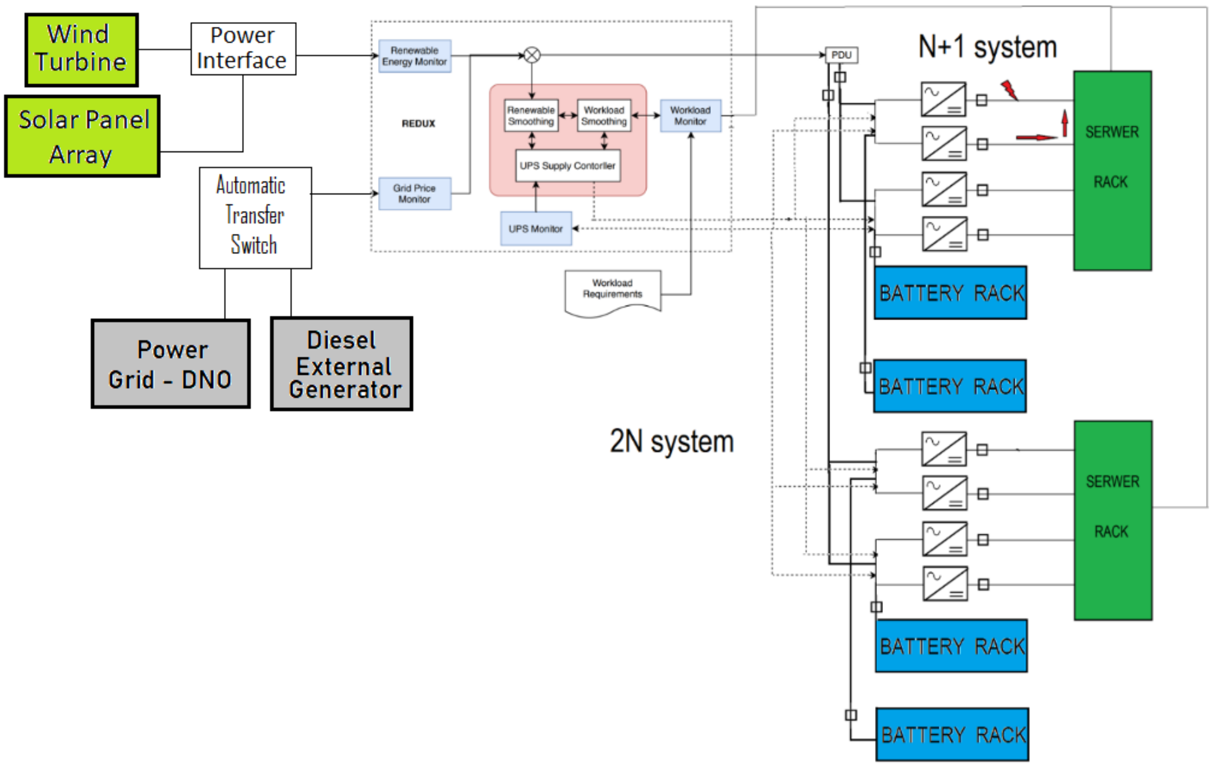


Figure 1.1. *Environmentally friendly power distribution system*

2.2.2 Conventional power distribution system in Data Centre

Conventional Data Centre power supply is a commonly used power system in Data Centres Fig.2.2. The reason that is an environmentally friendly source of energy is an unreliable source of energy that is widely documented by researchers. Renewable energy sources require additional space, and in some cases like the Solar PV requires a vast area which is only sometimes available next to Data Centre, especially in the UK. Another problem is the cost of the maintenance of the renewable resources. Based on all the factors and research done on Data Centres location the present below distribution network that is the preferable power system for Data Centres. Each power network might differ in some design, details but the power system core is the same and consist of the four main elements:

1. Main power supply at 11kV typical 2N+2 configuration. Two independent DNO operators supplying the power. Each of the DNO operators gives two 11kV feeds, to provide a very high-level security of power the delivery.

2. The backup power supply is provided by a UPS online systems N+1 configuration, reassuring power continuity after the main power is lost. This UPS system can deliver power for 8-10min. During this time, the backup generator N+1 configuration must start, synchronised and be ready to supply the power, keeping the power distribution system energised and covering the total power demand in required by the Data Centre. The uninterruptible power supply is also responsible for eliminates harmonics and increasing the power factor. The UPS system is connected to a battery system, the voltage and current parameters are determined by load level requirements. The UPS on the supply side is connected to the main low voltage switchboard and on the feeder side to the so-called mechanical switchboard to which all critical loads are connected. Critical loads are mainly data rack, fire alarms, Very Early Smoke Detector Alarm, midst/extinguishing system, and cooling system. Lighting and socked power are not critical loads.
3. Within a power system distribution are step-down power transformers n+1 stepping voltage to the low voltage level at 400V. Transformers are connected to a high-voltage switchboards. Transformers are in Delta-Star configuration with 11kV on the primary and 400V on the secondary side. The Star connection is on the secondary side because a neutral cable is established to provide a voltage level at 230V between Line and Neural.
4. Typical power system in Data Centre has two main voltage levels, 11kV and 400V, and based on these two types of voltage rating, different switchboard ratings are required. Those switchboards are HV switchboard and LV switchboard. It is essential to mention that the high voltage side provides a lower level of short circuit current compared to a low voltage level switchboard, which can deliver higher short circuit current in case of fault current.

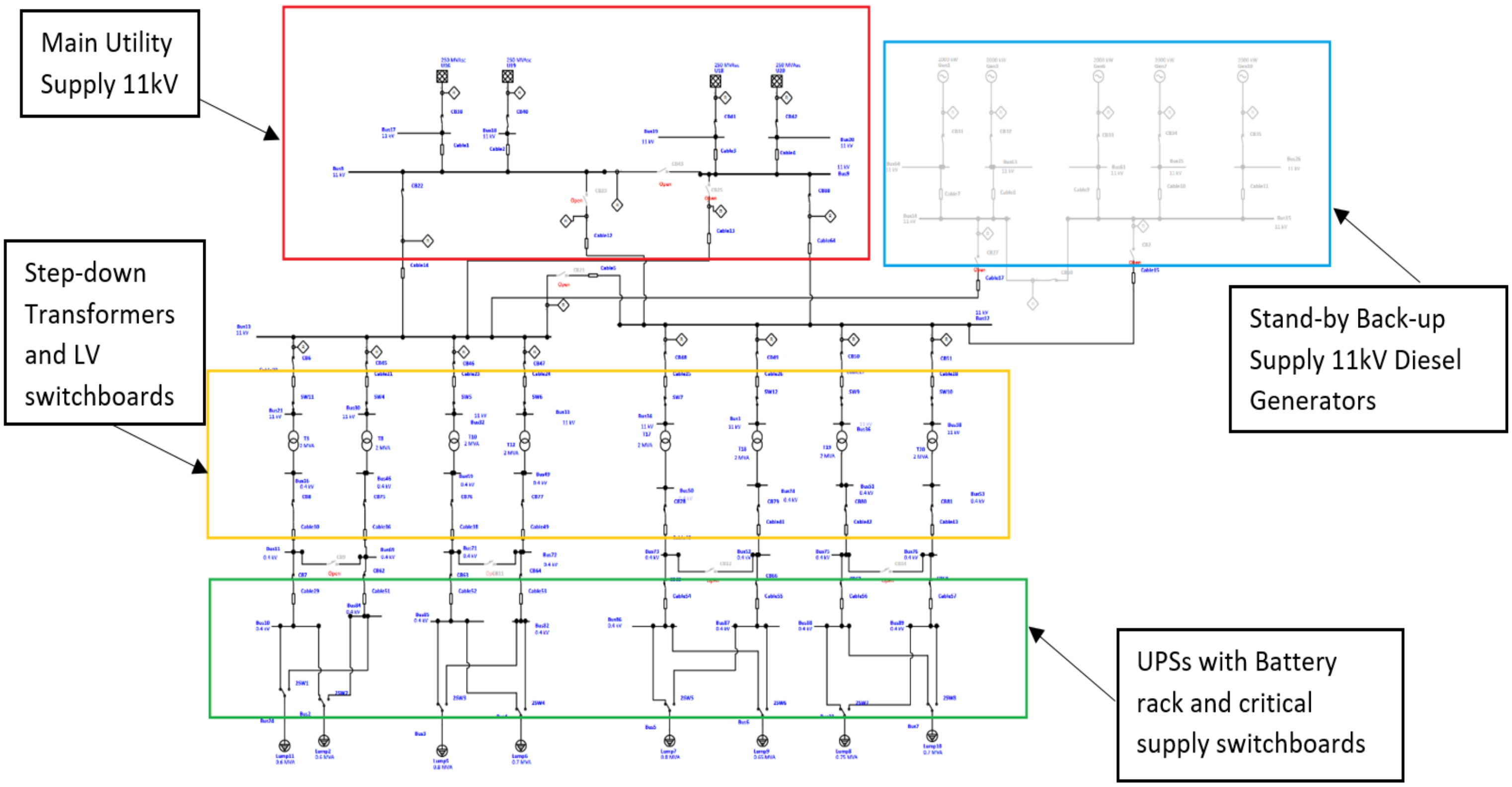


***Figure 2.2**. Conventional power distribution system in Data Centre*

2.3 Main Elements of Power System Distribution in Data Centre

2.3.1 Main Utility Supply

The main power supply is taken from the Distribution Network Operator (DNO), which is a utility company responsible for the delivery and secure demand of every power user. Power-user can be an industrial, e.g., National railway operator, commercial hospital and/or Data Centre and domestic to where power is supplied. Security power supply level is different and depends on the type of user. Utility always issues to clients before they start to build new projects a so-called "Grid infeed data" that is telling what the maximum demand that can be covered by DNO, power grid fault level, network positive and zero sequence impedances is. Priority is always given to hospitals, Data Centres, railway networks, Government, and secret services, which must secure power supply interruption. However, outages happen, and a power backup system is installed to avoid power supply disruption to critical users.

2.3.2 Main Stand-by Generators

A standby generation power system is responsible for delivering power to the internal power distribution system to cover the demand. Commonly used generators are diesel low voltage or medium voltage connected to the system and staying in the standby position. When the main power is lost, the generators start, synchronising required when more than one generator are which takes from a couple to several seconds and as soon as generators are ready circuit breaker will close making the connection with the power system to supply the power.

2.3.3 Transformers

Transformers are connected between medium- and low-voltage power system equipment to step down the voltage level to 3-phase low voltage, mainly 400V.
The transformer type and data chosen for this project are based on factors like power level of data storage required, the purpose of a transformer, the working transformer environment, the voltage level on the primary and secondary sides and the grounding system.
The transformer will be connected in redial to the load, and the load is around 40-45% of the size of the transformer.

It is more secure in terms of better load sharing to install more numbers of transformers than just one or two big transformers. The more oversized transformer has a more significant loss in both the no-load state caused by winding magnetising and the load state. It is also better to install more numbers of transformers because in case a transformer needs to be de-energised for, e.g., maintenance purposes, then another transformer will be capable of supplying power. A transformer working environment is a room in inside a building with a cooling system to keep room ambient temperature between 20-25°C. A dry transformer is more straightforward to cool down than an oil-filled transformer, as the transformer's efficiency drops with increased temperature. The power system on the primary side is connected to an 11kV 50Hz system. The power system requires a 400AC voltage level with a grounding system on the secondary side, so the transformer configuration must be a step-down delta star. However, this type has a phase shift of 30°, but the transformer is in a redial connection, so it is no need to care about the voltage shift. Otherwise, the phase shift would have to be adjusted to all transformers connected in parallel, and this is not the case. The transformer must be protected against thermal damage, so a transformer damage curve is required to be obtained by the manufacturer. The thermal damage curve of the transformer was taken from IEEE Guide for Dry-Type Transformer Through-Fault Current Duration. The size of the transformer used in this project is 2000kVA, so based on the above guidance protection curve reference is in "Figure II". The curve is based on the maximum magnitude of a 3-phase symmetrical short circuit current, the magnitude not exceeding 25 times of the total load current for a duration of 2s. The Short Circuit Current is derived based on transformer impedance plus power system impedance specified by the user.

2.3.4 Uninterruptible Power System

2.3.4.1 “On-Line” Uninterruptible Power System

The backup power system plays a crucial role in power security and continuity and is divided into two separate systems. One backup power system is an Uninterruptable Power System (UPS) with battery backup. The commonly used UPS system in Data Centre is an “online” system Fig. 2.3 in which there is no interruption in case of loss of power, as the power is continuously flowing through the UPS in normal operation. UPS system is constructed from power electronics converters that convert power from AC to DC and from DC to AC. During the conversion, built-in filters clean any power noises within the power system and improve the power factor up to 0.99, which is almost a unity. The system is set up in n+1 configuration, always having one more in case of fault. The second backup system is the diesel generator system. This system is constructed from fuel operating generators connected in parallel and controlled by the control system. Capacity is significant enough to cover a total power demand [9]. It was found that the main types of UPS systems are “Online” and “Off-line”. There is a big difference between those two systems. The online system is in operation during the work, which means the power is passing through the rectifier, which is rectified to DC voltage charging the battery and then is entering to an inverter were inverted into AC voltage. During this process, power noises are reduced, and the power factor will improve. This system has a massive advantage in terms of power security because when the power is lost, the system automatically takes energy from batteries, providing “zero” power continuity disruption [10].

“On-Line”

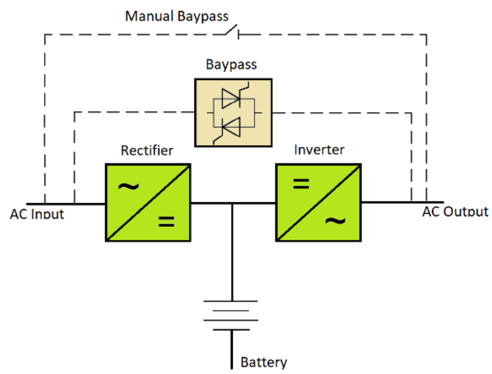


Figure 2.3. *UPS "On-Line" system*

2.3.4.2 “Off-Line” Uninterruptible Power System in AC power systems

The main difference between “On-line” and “Off-line” UPS systems is that “Off-line” UPS Fig. 2.4 does not operate continuously and is in standby mode ready to deliver power if voltage drops to a predetermined voltage level however it filters noises and improves power factor. It is a crucial difference between those two UPS systems in Data Centres power systems and as mentioned above power security is the priority and for that reason, the “Off-line” UPS system is not used.

“Off-Line”

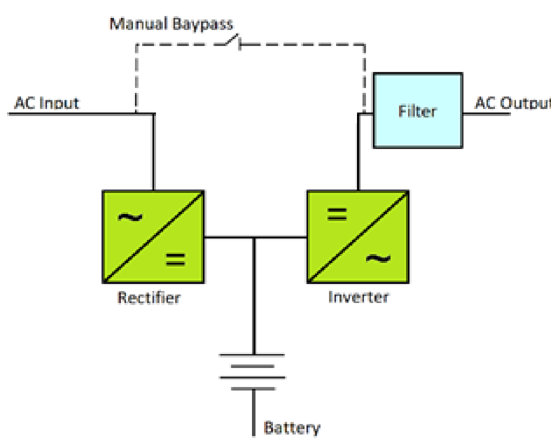


Figure 2.4. *UPS "Off-Line" system*

2.4 Power demand in the UK and world average Power Share in Data Centres

2.4.1 Size of Typical Data Centre

The typical size of the Data Centre in the UK is 1,510m² just for IT space and a max of 2.7MW based on Equinix Data Centre in Slough. The system is designed in 2N UPS with a backup battery system, an N+1 generator backup system, and the cooling system with an efficiency of 20kW per rack [11].

2.4.2 Average Power Share in Data Centre

The power in Data Centre is shared between the cooling and power system, data servers, storage drivers and network. Looking at data provided by Lawrence Berkeley National Laboratory on 22/06/2016 [12], they are saying that in 2014 total power consumption in the U.S. was around 68 billion kWh/y where the cooling and power system consuming 43% of the total power dement, servers 43%, storage drivers 11% and network 3%.

2.4.3 Size of Data Rack in Data Centre

Power consumption per data rack is determined by data rack density. Uptime Institute published on the 7th of December 2020 that the density of data racks is rising caused of the compute-intensive workload. The computer-intensive workload includes cryptocurrency, Artificial Intelligence, more sensors, software, connecting and exchanging data, etc. All of those require more space and storage, which is a challenge for the Data Centres industry. However, in a 2020 survey, Uptime Institute published that the overall average data rack density was below 10kW/rack with an installed 20kW capacity rack. The most common rack density was between 5-9kW/rack [12]. Another challenge to higher rack density is cooling capacity, as more data require a more efficient cooling system to deal with increasing data hall temperature.

A methodology for calculating the total average Data Centre power demand in the UK is based on the average number of halls in the Data Canter multiplied by the number of racks in one hall times the data rack average load demand. This project will use the average values obtained to justify the Data Canters power load demand.

2.5 Protection system in AC power systems

2.5.1 Purpose of protection system in AC power system

Protection plays a significant role in electrical power systems. The fault occurring to the system has been categorised according to types shown below [13]:

- Symmetrical is on three lines in a three-line system and three lines to earth in a 4-line system.
- Unsymmetrical, which is on any two lines in a 3-line system, any two lines to earth, or any one line to earth.

When a fault happens, protection will disconnect the faulty line and/or equipment from the system, allowing the rest of the network to operate as usual. Protection is used to protect any equipment within the power network like generators, bus bars, transformers cables/lines, power banks, capacitor banks, power correction banks, motors and so on.

Protection system devices

- LV and MV fuses
- LV and MV circuit breakers
- Current transformer
- Voltage transformer
- Relays
- Batteries
- Communication cable and system

Protection can be used as a single element, e.g., fuse or circuit breaker, commonly used in low voltage applications [14]. Protection in high voltage and extra high voltage power systems applications requires current and voltage transformers, relays, circuit breakers, battery tripping units and, in some cases, a communication system [15].

2.5.2 Medium and Low Voltage fuses

The fuse is constructed of quartz sand and a melting element. The fuse's inconvenience is that it is not a self-recovering feature and must be replaced after it operates. However, it can greatly limit the fault current significantly down to a very fast operating time. Medium voltage fuses in DC systems are commonly used in railway networks and renewable power systems like a wind turbine. In railway networks, the typical voltage range is between 1.9 – 4kV DC voltage. The general classification of fuses is shown in Fig. 2.5 below.

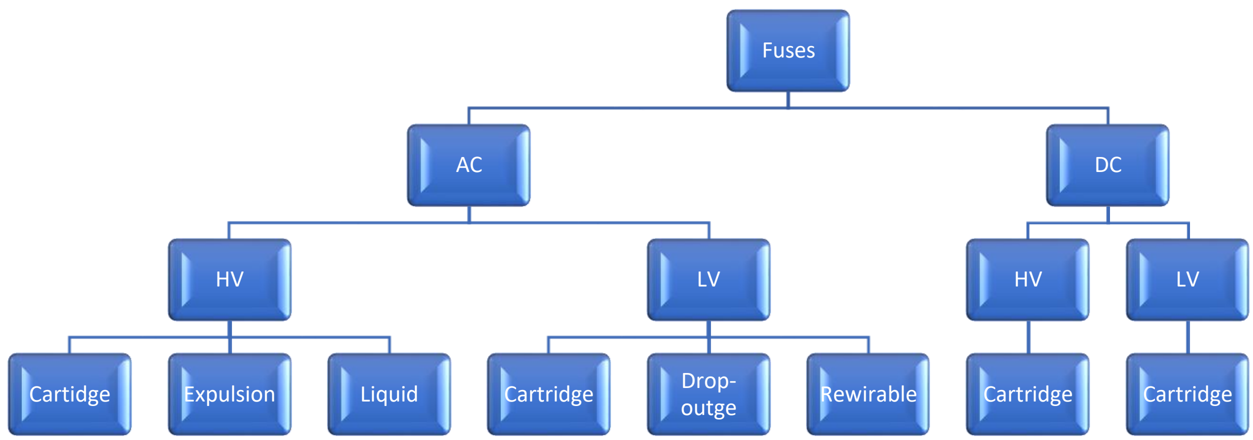


Figure 2.5. *General classification of fuses*

2.5.3 Medium and Low Voltage Circuit Breakers

Medium voltage circuit breakers a very much different to low voltage circuit breakers and require an operation, the presence of additional devices like current and voltage transformers and a relay. The current and voltage transformers are the eyes and ears of the relay, and the relay is the brain of the protection. The medium voltage circuit breakers are bigger than LV in size and are designed to break the high flow currents. Types of high voltage circuit breakers are Oil, Air blast and Vacuum.

Types of circuit breakers are divided based on arc extinguish principles when circuit breakers disconnect power. Oil immersed type simple causes insulation between contractors and extinguishes the arc. In the Air blast type, the high-pressure air is blasted on contactors to extinguish the arc. Vacuum-type circuit breaker provides an excellent insulation barrier for the arc that needs to be extinguished. The classification of Circuit Breakers is shown in Fig. 2.6 below.

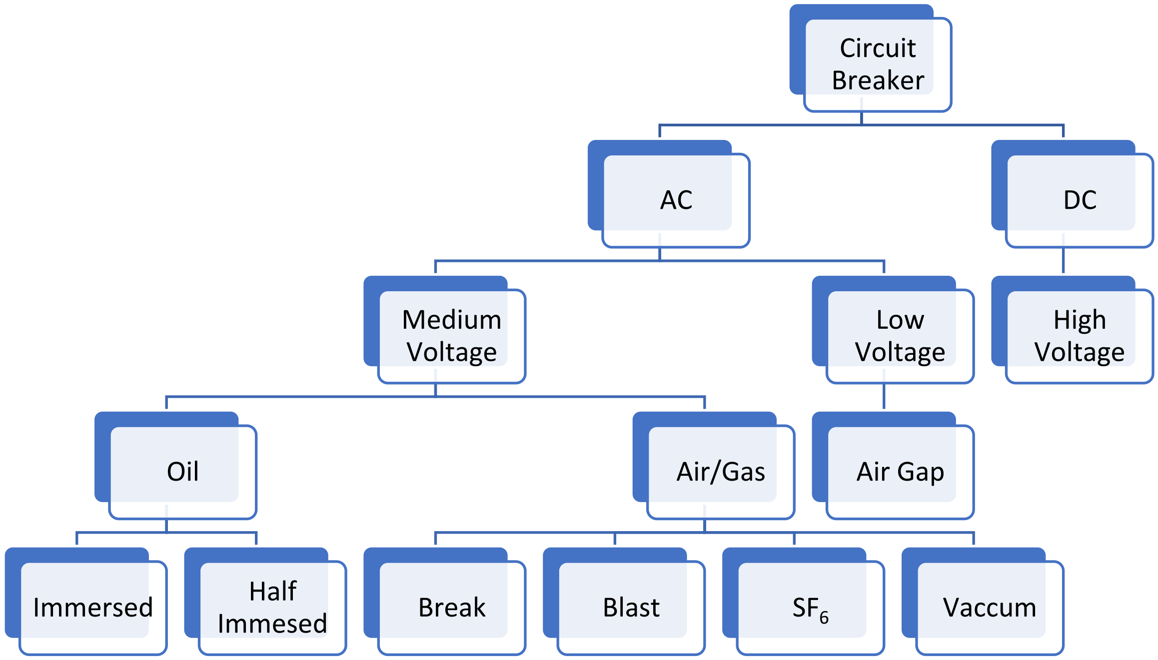


Figure 2.6. *General classification of circuit breaker*

2.5.3.1 Medium Voltage Circuit Breakers

A medium voltage circuit breaker does not operate in principle like a low voltage circuit breaker because the medium voltage circuit breaker requires a relay to trip the breaker. However, the relay is connected to current, and voltage transformers are installed in the same panel and need a 110V Battery Tripping Unit (BTU) to keep the relay powered [16] [14]. It is crucial that BTU has constant power because if BTU is lost, then the relay will not operate, and the circuit breaker will not operate too. So, for that reason, it is a common practice to connect two BTU units in parallel to secure the power supply to the relay. The BTU also has a battery built-in backup system.

MV switchboards are constructed of several single units. A typical MV switchboard is constructed of a busbar panel, MV circuit breakers, Busbar VT, and Load Bank units. Such configuration depends on a designed power system. A typical Data Centre has more than one income power supply connected by a Distribution Network Operator (DNO) to secure continuity of power supply. In such systems, the MV switchboard is built of several switchboard blocks interconnected.

In a medium range of voltage AC power systems, a protection study is required to achieve protection discrimination and is performed by engineers specialising in protection systems. Protection study also is conducted in low 400V systems in Data Centres and is called Low Voltage Protection Study.

2.5.3.2 Low Voltage Power Circuit Breakers and Moulded Case Circuit Breakers

In the 3-phase low voltage applications, typical circuit breakers are Moulded Case Circuit breakers (MCCB) and Power Circuit Breakers (PCB). PCBs MCCBs can be used as isolation circuit breakers that do not have an electronic control unit built in shown on Fig. 2.7. That sort of control unit makes PCBs and

MCCBs are fully adjustable protective devices that can be adjusted accordingly to discrimination study in protection design. Low voltage PCBs and MCCBs are available in different max current flow ratings and fault current breaking capacities. A Control unit is an element that can be installed in MCCBs and change the MCCB characteristic to a fully adjustable circuit breaker. Without the unit, an MCCB is playing the function of an isolator with total load braking capacity.

The Whole protection system is connected to Supervisory Control and Data Acquisition (SCADA) system, allowing the Total Facilities Management (TFM) Team to observe the system from the control room.

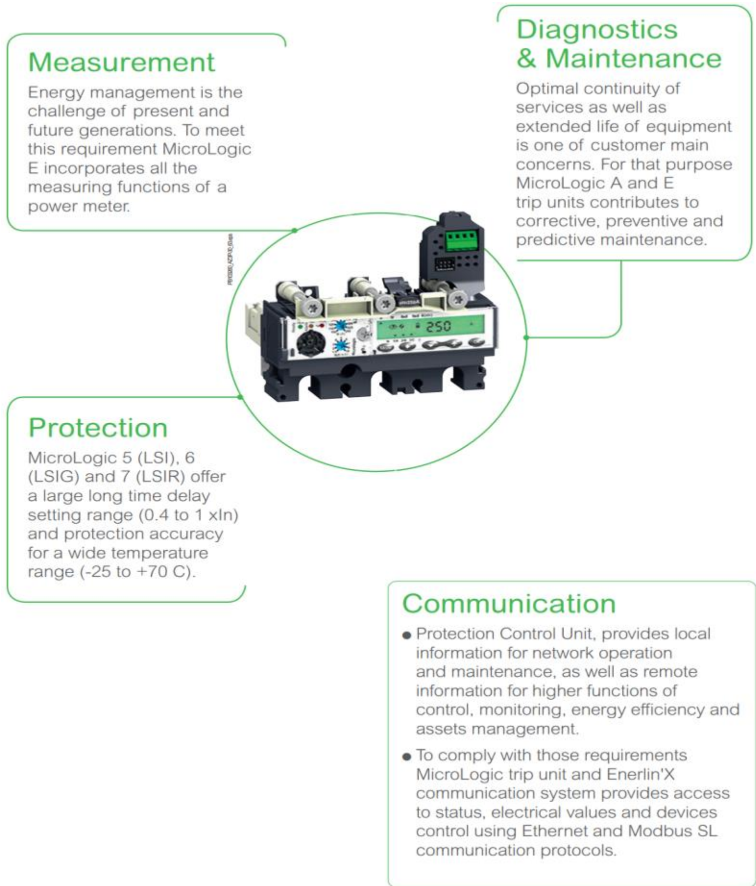


Figure 2.7. *Control unit of MCCB protection device - https://download.schneider-electric.com/files?p_enDocType=Catalog&p_File_Name=LVPED217032EN.pdf&p_Doc_Ref=LVPED217032EN – [Accessed 28/11/2021]*

2.5.3.3 Protection and Metering Current Transformers

A current transformer is a device that possesses the ability to convert a high current on the primary side to a lower magnitude on the secondary side Fig. 2.8. This transformation to low magnitude is required because the protection relays and meters would be destroyed by the load current and fault current level. Current Transformers (CT) are connected in series with the primary side. To achieve the high to low magnitude, ration a CT on the primary side has a small number of turns opposite to the secondary side, which has a large number. The ampere-turns (AT) relationship:

$$AT_{Primary} = Np * Ip$$

$$AT_{Secondary} = Ns * Is$$

$$So\ if\ AT_{Primary} = AT_{Secondary}\ then\ ratio\ is\ equal\ to\ 1$$

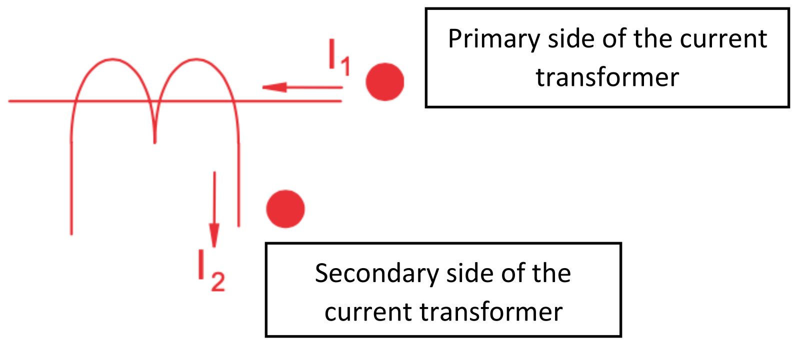


Figure 2.8. *Circuit breaker types of general classification*

2.5.3.3.1 Protection and Metering Current Transformers

To select the correct CT, we need to know factors like Ful Load Current (FLC). Next, the FLC must be increased by 20% compared to the manufacturer's current transformer size standards. The next factor is the accuracy value, as the higher accuracy CTs are used more for metering purposes. Another important piece of information is the fault current, as the CT must be able to withstand this value and the CT burden, which is the auxiliary stuff like cable resistance connected to the CT. The classification of CTs is shown on Fig. 2.9.

The most essential element of sizing the CT is a ratio:

$$\frac{N_s}{N_p} = \frac{I_p}{I_s}$$

If we select the secondary current as 5A, then the ratio of a CT can't exceed this value and must be in the relation of

$$CTratio = \frac{I_p}{I_s} = \frac{FLC}{5A}$$

Because on the market manufactured CTs are with standard ratios like, e.g., 100/5 = 20, an adjustment is required. Any selected CT must not exceed 20 x Full Load Current with an error of 10%.

2.5.3.4 Relay types and application in Medium and Hight Voltage applications

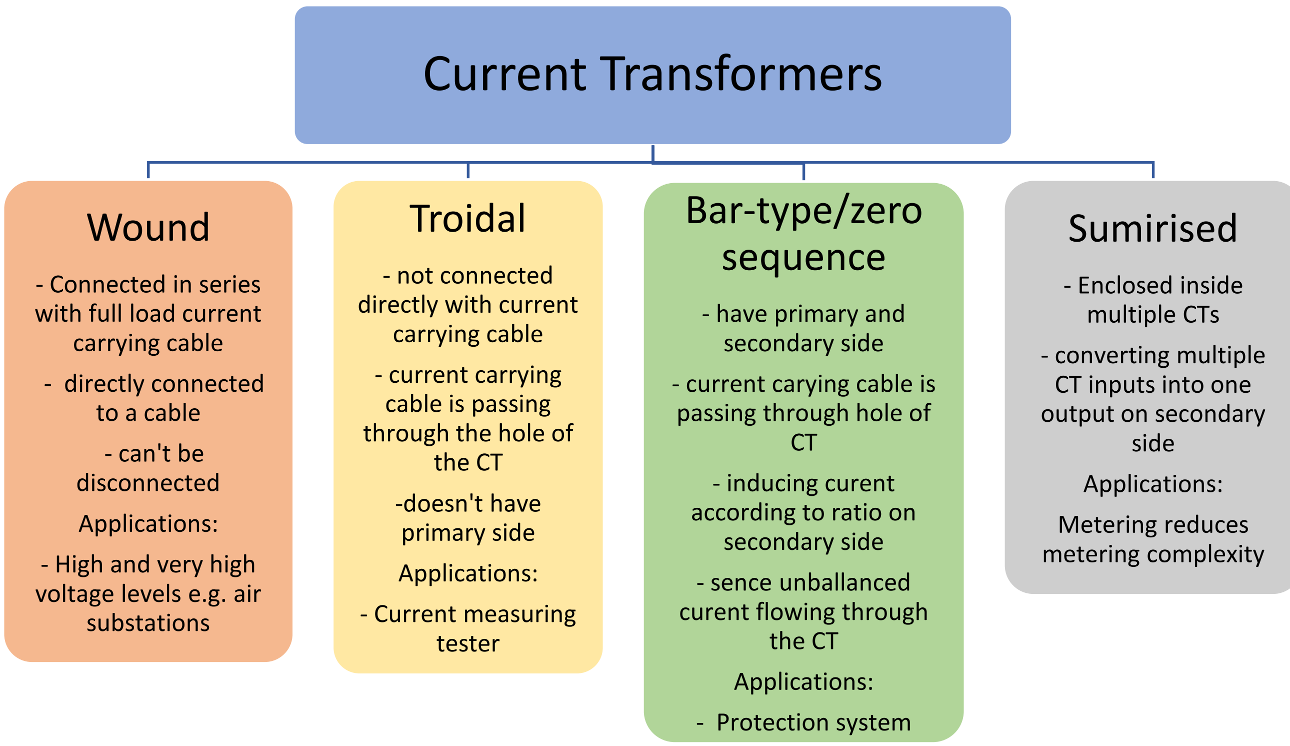
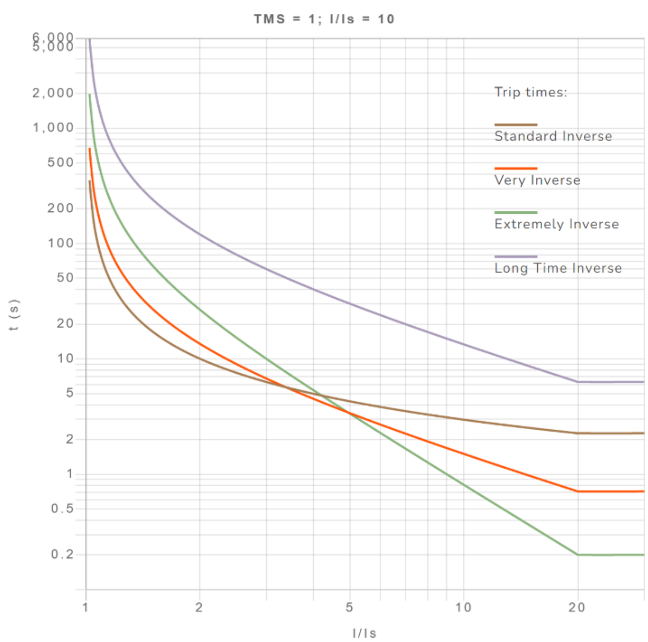


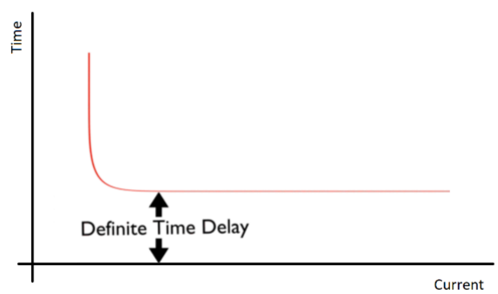
Figure 2.9. *Current transformers classification*

Relay is an electrical device used in the high and medium protection system application. When the relay detects a pick-up current is starting to operate and operates instantaneous or with time delay sending a signal to an MV or HV circuit breaker to operate. The relay operates based on the current and voltage transformers selection. The CT and VT transformer are the "eyes" of a relay and must be correctly selected and sized to be able to detect the designed fault current or the voltage level. It is also essential that during the selection and sizing of CTs and VTs, device tolerances are considered.

Selecting the correct type of relay from a mechanical, electronic, or digital range of relays is the first step to achieving the minimum operating time. The minimum operation time of the relay itself can not only be achieved by selecting the correct type of relay but also by selecting a fast-operating circuit breaker below 1ms. The electronic and digital relays have a wide range of "amp taps" that adjust the relay settings more precisely. Protection relay types and classifications are detailed in Appendix J and in tables Fig 2.11 and Fif.2.12 below.

A selection of a protection relay nowadays is very different from days when only mechanical relays were in use. Today's mainly used protection relay is a digital and multifunctional type of relay that combines more than one built-in function. An operating Time for the relay is set by the type of an operating curve like Standard Inverse, Very Inverse, Extremely Inverse, Long Time Inverse, Short Time Inverse, Inverse and Definite Time, and an example of the graph is presented below on Fig. 2.10.





b) Definite Time Delay curve

a) IDMT types of Relay operating curves

Figure 2.10. *IEC 60255 IDMT Relay operating curves.*

Approved equations to IEC standards:

Standard Inverse Time: $TMS = \frac{0.14}{M^{0.01}-1}$

Very Inverse Time: $TMS = \frac{13.1}{M \quad -1}$

Extremally Inverse Time: $TMS = \frac{80}{M^{2}-1}$

Long Time Inverse Time: $TMS = \frac{120}{M \quad -1}$

Short Time Inverse Time: $TMS = \frac{0.05}{M^{0.04}-1}$

Inverse Time: $TMS = \frac{9.4}{M^{0.7}-1}$

Definite Time: This is the actual time to which relay is set e.g., relay curve D6 is telling that Definite Time is 6 seconds for TMS set to 1. If TMS is set to 0.3 then Definite Time will be $DT = 6 * 0.3$ which is 1.8s.

Calculating the Time Multiplier Setting formula:

$$TMS = \frac{Reguired\ Relay\ Operating\ Time}{Time\ to\ Operate\ With\ a\ TMS\ of\ 1.0}$$

Calculating the Plug Setting Multiplier formula:

$$PSM = \frac{Minimum\ Fault\ Time}{CT\ Ratio}$$

Important Protections for Individual Units					
Units	**Type of Protection**	**ANSI Codes**	**Causes**	**Effect**	**Protection Scheme**
TRANSFORMER	Protection against overload	58	Increased power on secondary side of transformer	Transformer Overheating	Thermal image relay (keeping track of temperature) / over current relay
	Over-current protection	50/51	Phase and ground faults	Over current can cause damage to windings	Over-current relays
	Earth Fault protection (Stator & Rotor)	50N/51N	Poor insulation, direct connection to earth	Causes current imbalances in the system	Over-current relays with neutral module
	Differential protection	87	Internal faults within the protected zone	Internal faults can be short circuits, or earth faults, or overloading which can cause damage to transformer windings	Differential protection with CTs on each side of transformer (Unit Protection)
	Directional protection (Phase and Neutral)	67/67N	Fault in nearby (parallel) feeder/bay causing tripping in the healthier feeder/bay due to poor selectivity of the relay	Tripping of additional feeders, thus pushing the system towards larger outages	Directional Over-current relay detects the direction of current flows in to and flow out from the protected unit. A trip signal will be sent to breakers if direction of flow-in and flow-out current are not the same
	Breaker Failure protection	50 BF	Breaker malfunctioning	Unable to isolate faulty equipment due to tripping failures (longer existence of fault currents, thus more damage to equipment)	Breaker failure relay which operates with its algorithm to try to open the breaker, otherwise it sends trip command to nearby breakers to isolate the faulted equipment to stop feeding fault currents

Table 2.11. *Protection Relay classification*

Important Protections for Individual Units					
Units	**Type of Protection**	**ANSI Codes**	**Causes**	**Effect**	**Protection Scheme**
LOAD	Protection against overload	49	Increase of load torque, or decrease in the motor torque due to busbar voltage or decrease in DC Field current (Synchronous motors)	High currents drawn by the motor affects insulation, and thus reduces the machines life expectancy	Thermal image relay (keeping track of temperature and has a thermal time constant) / over-current relay
	Short circuit	50/51	Phase to phase short circuit in the winding , at the motor terminals or between cables	Destroy the machine due to over-heating and electro-dynamic forces created by the high currents	Over-current relay with a preset value which sends a trip signal if the current exceeds its preset value
	Earth fault protection	50N/51N	Machine insulation damage	Results in a fault current that flows from windings to earth via stator laminations	Over-current relays with neutral module
	Number of starts supervision	66	If the operator (or by automatic function) tries to switch on the motor more than an specific number of times within a specific time-interval	The thermal state of the machine changes when a number of starts occur. Adequate cooling of machine is required before the machine is given another start, otherwise the life expectancy of the machine will decrease due to insulation deterioration	Notching or jogging relay that uses a counter to control the number of starts within a certain time. They take into account the machine thermal state and do not allow any further starts if the machine has already attained specific starts within a specific time
	Under voltage protection	27	System disturbance or load increase	Under voltage results in over-currents which can damage insulation	Under voltage relay with pre-defined voltage limits defined in the relay's settings
	Loss of synchronism (synchronous machines only)	55	Increase in load causes a decrease in the busbar voltage, or due to decrease in the field current that causes the motor torque to decrease	Damage occurs to the dampers and rotor windings due to loss of synchronism	Power factor relay that responds to the change in power factor that occurs when there is pole slipping (weakening of synchronizing torque to maintain synchronism under the same load)
	Protection against unbalanced loads	46	Sudden loss or connection of heavy loads or poor distribution of loads	Gives rise to negative sequence components (tries to rotate rotor in reverse direction) causing heavy currents in the rotor causing damages	Negative sequence over current relay (unsymmetrical loads will give rise to negative sequence components)

***Table 2.12**. Protection Relay classification*

2.6 Summary

In this chapter several papers have been reviewed which shows the importance of review of the literature related to the types of a power system construction, feature and protection device types and classifications. During this review I have proved that depending on the personal circumstances like location of the Data Centre and sensitivity of a reliable source of power determinates the use of renewal resources can be implemented in the power system design as an alternative source of power.

The literature review discusses the differences between the available equipment, possible solutions and the types of the protection devices available on the market. It concludes why it is important to choose the right option for the designed in Data Centre power distribution system to provide its reliability.

In the chapter 3 the calculation methodology presents the parameters of the predicted short circuit current, the equipment and cable impedances, the maximum load current needed to perform a protection study. The protection study itself is outside of this work, however, it is a common practice at the design stage of the power system to do it.

Chapter 3 Calculations Methodology

3.1 Introduction

In this chapter a calculation methodology is presented to show what are the power source data, how power source impedance is calculated, short circuit current on the primary and secondary side of the transformer, cable impedances including the generator full load current and short circuit current.

3.2 Power Source Short Circuit Current, Impedances, Full Load Current

The following data was obtained from the DNO which illustrates the power sources parameters required to start the design the power system. Those parameters limit the size of the power system in Mega Watts (MW) that can be design, providing the voltage level, Short Circuit Current level, and impedance ratio. Based on the DNO parameters the designer can calculate power system impedances values. This is shown below in A and B figures.

SCC = 7kA (3.1) DNO Power System source data

X/R ratio = 3.2

Primary voltage = 11kV

Short Circuit Current (SCC):

$kVA_{Source} = \sqrt{3} * kV_{L-L} * SCC_{Source}$ (3.2) The max MVA of the Power Source

$kVA_{Source} = \sqrt{3} * 11 * 7000$

$MVA_{Source} = 133.368$

$Z_{Source} = \sqrt{(R_1^2 + X_1^2)}$ (3.3) The Power Source Impedances

$Z_{Source} = \sqrt{(22.41_1^2 + 71.61_1^2)}$

$Z_{Source} = 75.03$

$tan^{-1}(\frac{X}{R}))$

$tan^{-1}(3.2) = 72.65$

$R_1 = Z_{Source} * cos\Theta \rightarrow (\cos 72.65 = 0.2982);$

$R_1 = 75.03 * 0.2982 = 22.37$

$X_1 = Z_{Source} * sin\Theta \rightarrow (sin\Theta = sin72.65 = 0.2982);$

$X_1 = 75.03 * 0.9545 = 71.61$

3.3 Transformer Short Circuit Current and Full Load Current

The following calculations illustrate the calculation methodology in terms to obtain Full Load Current (FLC) of the transformer and the Short Circuit Current (SCC) on the primary and secondary side of the transformer shown in figures A to D. This information is required to calculate the current levels for the relay not to operate. The relay must be sensitive adjusted and operate above the FLC current value which will be recognised by the relay as so called "pickup value" from which the relay starts to operate. The above is one of the reasons why the Short Circuit Current is calculated. Another reason why the SCC is calculated is to know what the maximum current level is expected during the fault condition in terms of install the equipment that can withstand a severity of the SCC. The basic transformer information is provided by the manufacture.

Transformer data that are obtained from the manufacture are required to perform the power system design and protection study.

$V_{Primary}$ = 11000A, P = 2000KVA, (3.4) Transformer Data

Z_{TX} = 6%, $V_{secondary}$ = 400/230

The transformer full load current allows to know what the current full load is that will pass through a transformer before protection operates. This is important factor because wrongly calculated value will cause the nuisance tripping.

$$FLC_{Prim} = \frac{MVA}{(\sqrt{3} * V_{Prim})}$$ (3.5) Transformer FLC primary side

$$FLC_{Prim} = \frac{250000}{(\sqrt{3} * 11)}$$

$$FLC_{Prim} = 13.12kA$$

The value of the short circuit current tells the designer what the predicted maximum current on the primary side of the transformer is in the event of fault to install a protection to transformer against damage.

$SCC_{Prim} = \frac{FLC_{Prim}*100}{\%Z_{TX}*\sqrt{3}*V_{Prim}}$ (3.6) Transformer max SCC primary side

$$SCC_{Prim} = \frac{2000kA * 100}{6 * \sqrt{3} * 11kA}$$

$$SCC_{Prim} = 1749.55kA$$

The transformer full load current tells us what the current full load of the transformer before protection operates. This is important factor because wrongly calculated value will cause the nuisance tripping as it is difference between max full load current from min short circuit current that causes protection device to operate.

$FLC_{Sec} = \frac{TX_{rating}}{(\sqrt{3} * V_{Sec})}$ (3.7) Transformer FLC secondary side

$$FLC_{Sec} = \frac{2000}{(\sqrt{3} * 0.4)}$$

$$FLC_{Sec} = 2887kA$$

The value of the short circuit current tells the designer what the predicted maximum current on the secondary side of the transformer during the fault is to protect transformer against damage by the selection of the correct protection device.

$SCC_{Sec} = \frac{FLC_{Sec}*100}{\%Z_{TX}}$ (3.8) Transformer max SCC on secondary side

$$SCC_{Sec} = \frac{2887 * 100}{6\%}$$

$$SCC_{Sec} = \frac{2887}{0.06}$$

$$SCC_{Sec} = 48116kA$$

3.4 Cable Impedances and Full Load Current

A medium voltage cable that has insulation rated between 1000V to 36,000V and is standardised by British Standards (BS) BS6622/BS7835/ and International Electrotechnical Commission (IEC) under IEC 60502-2, 60909 [17]. This standard regulates single and multi-core cables, the armoured and the un-armoured, and testing cable scope. The MV cable is more complex in construction than the LV cable, and in higher voltage applications, the high voltage pressure is on the outer part of the cable/insulation.

The standardisations of BS7671 refer to single and multi-core armoured and un-armoured cables and the testing procedure. In the design process, the cables are chosen using design current, voltage drop factors, working cable environment, ambient temperature, and the installation system.

The rating of the cable installed on the MV side must be min 11kV with screening, and this is due to eliminating stress on the insulation. Conductor size depends on Full Load Current (FLC) and voltage drop. However, the voltage drop is determined by conductor resistance, reactance, and cable length.

The cable impedance calculation is required to evaluate the short circuit current to make sure the protection device will operate in the required time. The calculated total short circuit current includes all the equipment impedances.

Length – 40m = 0.040KM, R = 0.196Ω/KM, (3.9) Data Sheet

X = 0.096Ω/KM

$Z = \sqrt{R^2 + X^2}$ (3.) Cable impedance calculation

$Z = \sqrt{0.196^2 + 0.096^2}$

$Z = 0.2182$Ω/KM

$Z = 0.2182 * 0.040$

$Z = 0.0008729\Omega$

3.5 Generator Full Load Current and Short Circuit Current

The following calculations illustrate the calculation methodology in terms to obtain Full Load Current (FLC) and the Short Circuit Current (SCC) shown in figures A and B. The FLC value is required to know the current levels to ensure the protection will not operate. The SCC value is calculated not only for to calculate protection's "pickup" current level from which the relay will start to operate but also to install the equipment that can withstand the SCC level. The basic transformer information is provided by the manufacture.

- P = 2000MW/2500kVA (5.1) Generator manufacture data
- V = 11kV
- PF = 0.8
- Subransient Xd'' = 11.5
- Generator Time Constants (manufacture data):
- Td'' – Sub-transient in seconds = 19ms
- Td' – Transient in seconds = 311ms
- Ta - Armature in seconds = 34ms
- If - Field current (typical 1 – 3 Ifg) = 3
- Ifg – Field current at load = 0 and at rated voltage (typical 1p.u.) = 1

The full load current calculation of the generator in the principles does differ from the calculation of the other power system elements.

$$\frac{kVA}{\sqrt{3} * kV_{L-L}}$$ (5.2) Calculation of max FLC

$$\frac{2500}{(\sqrt{3} * 11)} = 131A$$

The value of the short circuit current tells the designer what the predicted maximum current to protect the generator winding against damage the protection is installed on primary side as well as on secondary side during the fault condition.

$$\frac{(FLC * 100)}{Xd''}$$ (5.3) Calculation of mas SCC

$$\frac{(131 * 100)}{11.5} = 1139A$$

3.6 Summary

This chapter presents the main power source data that are obtained from the DNO, the equipment manufacturers datasheet and cable impedance in terms of performing power system design and protection study. During the power system design, the designer must calculate SSC and FLC as the protection engineer's basic values to ensure that the protection devices will operate in the required time and avoid nuisance tripping. The nuisance tripping is an effect of misunderstanding the difference between fill load current and minimum short circuit current. The difference is minimal however the calculation must include the difference.

All the calculations utilised the commonly used in power system calculation basic formulas.

The chapter 4 presents the proposed power system network design and four case studies performed on the high-voltage and low-voltage side of the system.

Chapter 4. Proposed Network Design and Case Study

4.1 Proposed Power Distribution System in Data Centre

The figure 4.1 illustrates the proposed power distribution system in a typical Data Centre. The figure contains 4 DNOs supplies connected to two independent upstream network 11kV buses to increase the security of continuity of the power supply. The second level of 11kV busses are connected to the DNOs upstream busses and to the 5 numbers of 11kV diesel generators as a power supply back-up system. Those 5 generators can deliver max 10 MW of power, however because of the configuration in the N+1 the, only four generators will operate as the backup because one generator is redundant. In case of loss, all two DNOs supply the generators will turn on and synchronised and as soon as the synchronisation is achieved, the circuit breaker will close, and power is supplied to the network. All this will take approximately 20- 30 seconds.

The installed 3-phase 11kV voltage cables connect the busses via medium voltage circuit breakers. Because the system is supplied from two different upstream networks permanently connected the designed system must keep this separation. This separation is ensured by “Normal Open” condition of the circuit breaker that can be closed when one on the DNO supply is not available. The protection system at the 11kV voltage level is configured according to the design requirement standards and consists of a relay and medium voltage circuit breaker where the relay controls the operation of the circuit breaker.

Further downstream 7 numbers of transformers are connected between 11kV and 400V busses via MV cable upstream and LV cable downstream. All the transformers are of the size of 11kV/400V 2MVA. Each transformer has a single 11kV supply and covers a power demand of max 1 MVA. However, each of transformer is capable of covering the supply-demand of two 2MVA loads. The configuration of working independently from each other covers only 50% of its power demand capability, allowing the transformer to be shut down for periodic maintenance. Another benefit of this is when a fault current occurs to the transformer or any equipment associated with the transformer, then the adjacent transformer that is linked to it vie a “Normal Open” low voltage circuit breaker is capable of supplying the power to more than one number of loads with the maximum of 1MVA power demand.

All the loads are supplied from local low-voltage switchboards to which the transformer is connected. Then from this switchboard panel low voltage cables are connected to the UPS. The UPS system consists of 3 numbers of 1MVA UPS in configuration N+1 is connected between the transformer's switchboard and the load switchboard. The UPS has its own built-in protection that shuts down the UPS in case of an internal fault. The installed UPSs are the "on-line" types of the UPS system and has an installed battery system via DC protection distribution panels with the DC protection fuses. The installed battery system is to supply the power to the power supply. Via UPS. The installed battery system is powerful enough to supply power for about 8 minutes and which is enough for the generators to start supplying power to the system.

The data racks are connected to AC Power Distribution Units (PDU) incorporated in protection devices protecting supply cable to the data racks.

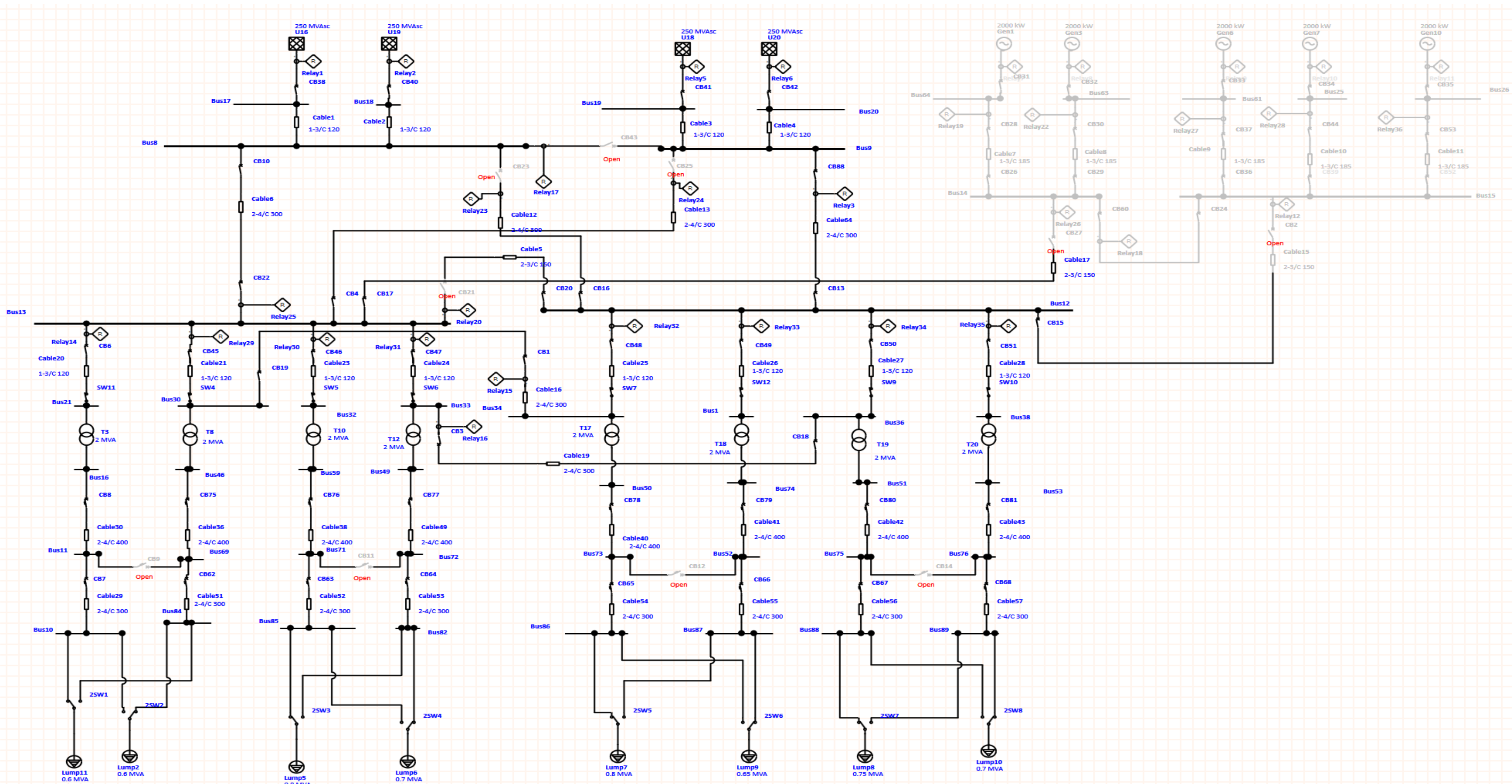


Figure 4.1. *Proposed power distribution system in Data Centre*

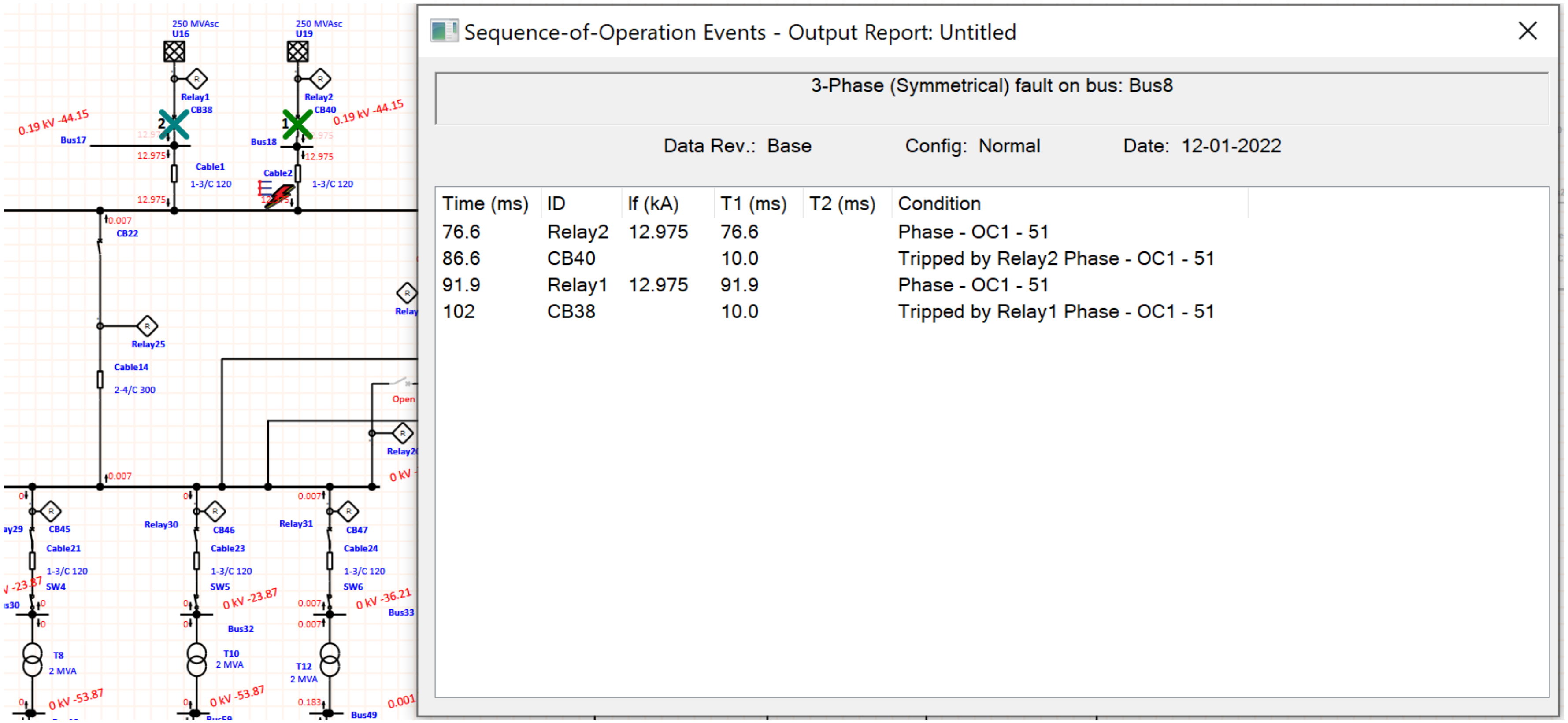
4.2 Protection Coordination according to IEC standards in Proposed Power Distribution System in Data Centre – case studies

4.2.1 Case Study 1 Protection coordination on 11kV bus bar.

The purpose of this case study is to look at a part of the network which includes eight distribution 11kV/400V transformers on Fig. 4.2. In this case study, if the 11kV bus becomes faulty, both upstream relays will send the signal to the associated circuit breakers to disconnect the power to the transformers. The power, in this case, will be handled by the second section of the DNO supply. In this case study, there are two relays however, only two upstream relays will operate to isolate the power in case there is a fault on the busbar.

The output report in Fig. 4.3 shows the relay and circuit breaker's operation sequence. At the short circuit current of 12.975 kA the relay 2 operation time is 76.6 ms, and the associated circuit breaker CB40 is 10ms, which is extremely fast below 100ms. The relay 1 operation time compared to relay 2 is longer and is 91.9 ms. The difference of 15.3 ms between the operation time of relays 2 and 1 is because relay 2 is closer to the fault causing relay 2 to operate first. The operation time discrepancy can also be caused by manufacturers in production components differences of a relay, and it is impossible to achieve two precisely the same relays that can deliver the same operation time.

On the graph, we can see that cable protection has been achieved as well as the buss bar by clearing the faulty bus bar within 102ms. In this situation, the power is supplied from the second DNOs supply. The miscoordination shown on the graph is irrelevant to the presented scenario because the main aim is to disconnect the faulty bus bar quickly from the rest of the network.



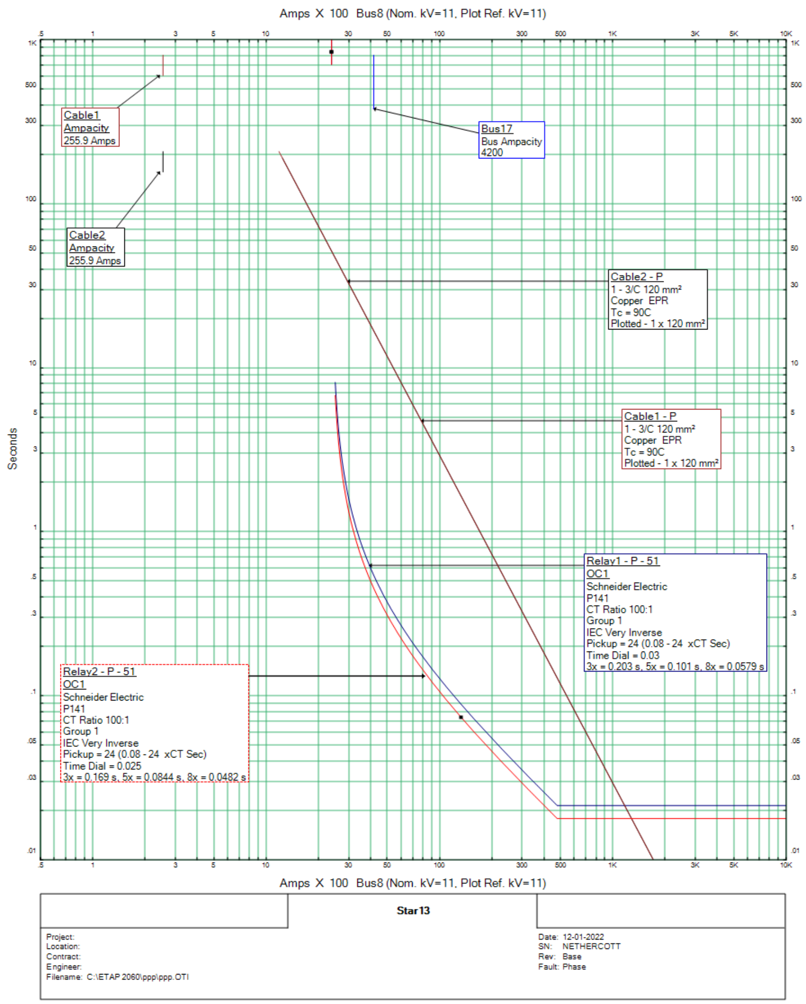
Sequence-of-Operation Events - Output Report: Untitled

3-Phase (Symmetrical) fault on bus: Bus8

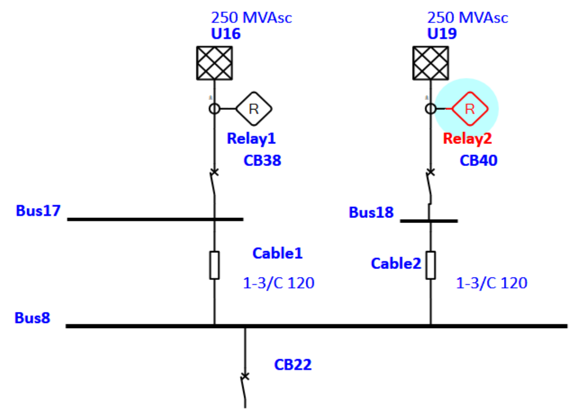
Data Rev.: Base Config: Normal Date: 12-01-2022

Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
76.6	Relay2	12.975	76.6		Phase - OC1 - 51
86.6	CB40		10.0		Tripped by Relay2 Phase - OC1 - 51
91.9	Relay1	12.975	91.9		Phase - OC1 - 51
102	CB38		10.0		Tripped by Relay1 Phase - OC1 - 51

Figure 4.2. *Sequence of protection operation*



a) Devices Time Current Curves under the fault simulation



a) Devices under the fault simulation

Figure 4.3. *The time current curve and protection devices operation under fault simulation*

4.2.2 Case study 2 Protection coordination on 400V bus bar in normal operation with open CB between two separate transformer feeders.

In this case study graphically presented on Fig. 4.4 the fault of 21.488kA happened on the low voltage side of the transformer TX3. The fault that occurred to the Bus10 caused the low voltage circuit breaker CB7 to operate and clear the fault within 80ms after 120ms, the circuit breaker CB8 opened too. The reason for setting both CBs to operate is to ensure the disconnection of the faulty part of the installation from the TX3 in terms of protecting the transformer from damage. The CB7 also is in coordination with CB9 and CB75 in another scenario.

On the graph in Fig. 4.5, we can see that the equipment is well protected by the coordination and protection has been achieved. In this situation, the power supply is continued as the CB9 installed to the link between TX3 and TX8 further down of the single supply will close. The miscoordination shown on the graph is irrelevant to the presented scenario because the main aim is to disconnect the faulty bus bar quickly from the rest of the network.

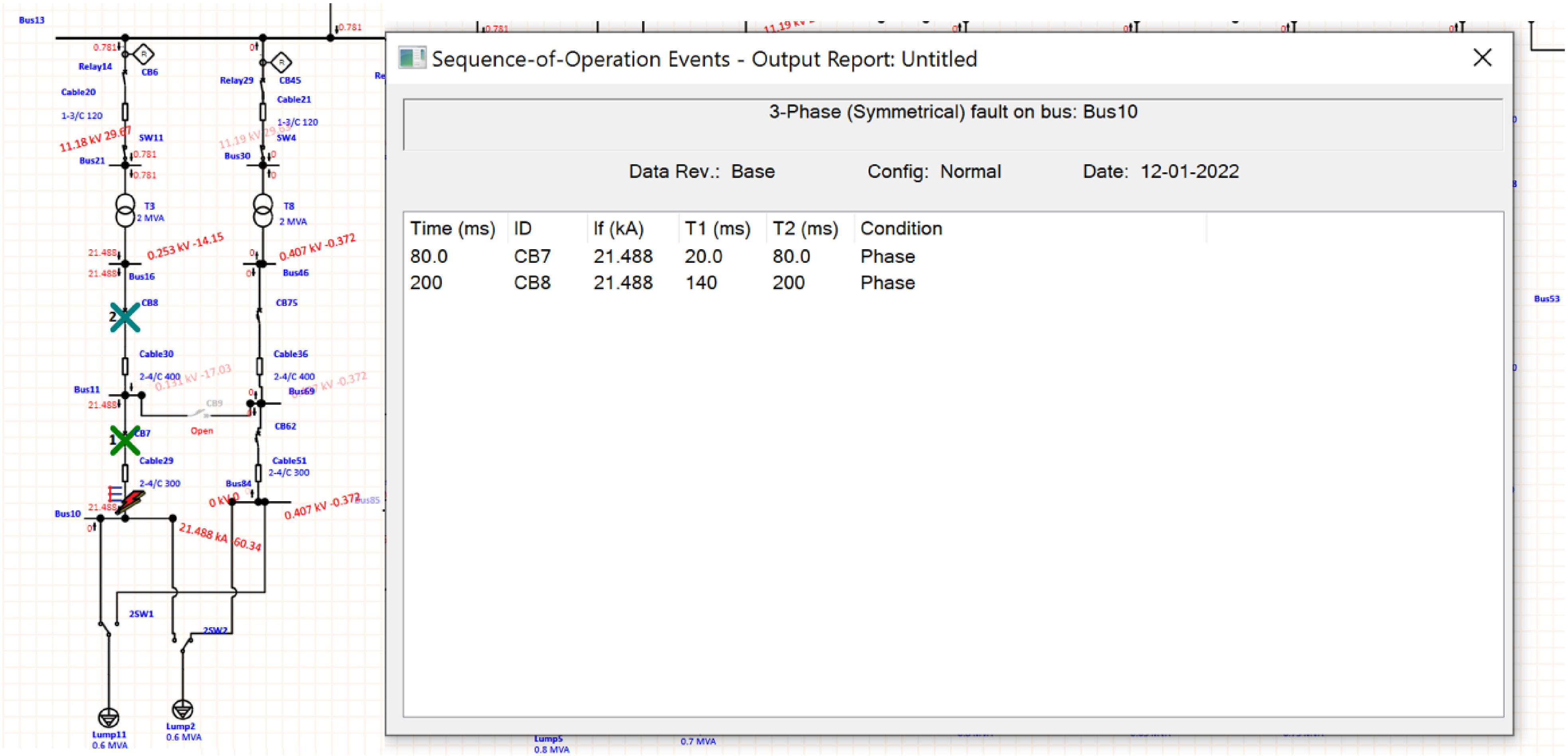
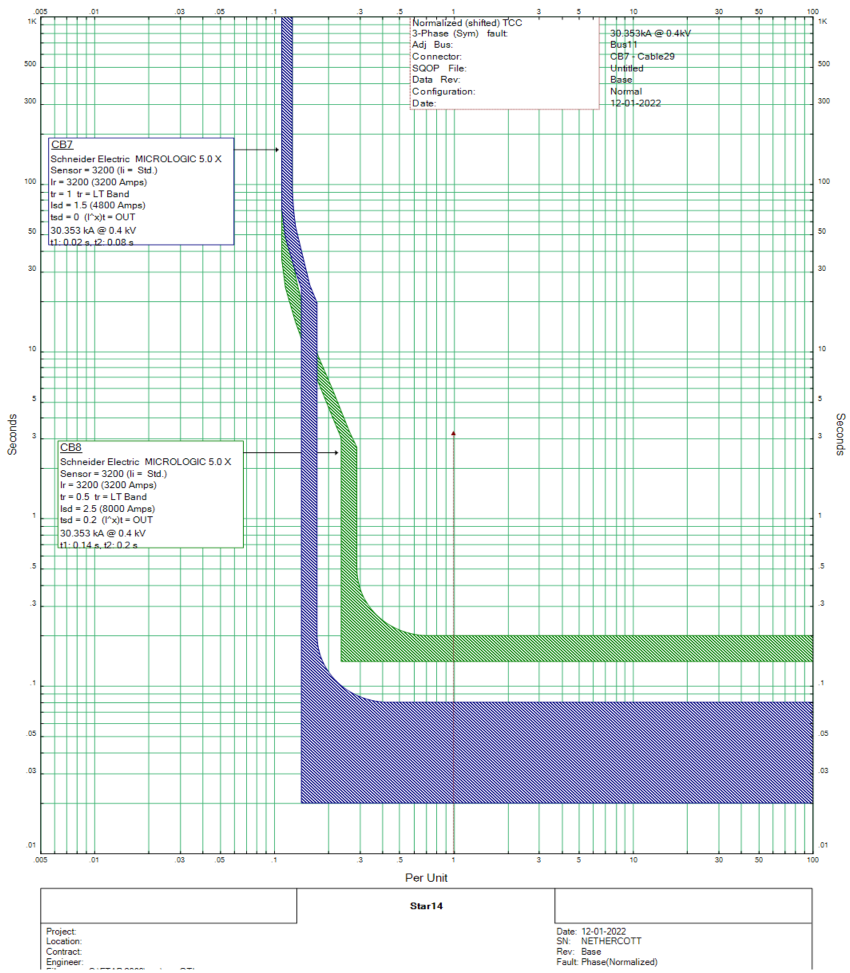
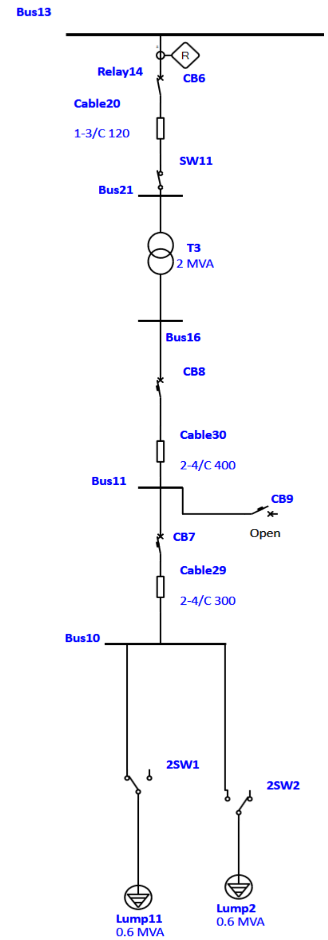


__Figure 4.4.__ The sequence of protection operation



b) Devices Time Current Curves under the fault simulation



a) Devices under the fault simulation

Figure 4.5. *The time current curve and protection devices operation under fault simulation*

4.2.3 Case study 3 Protection coordination on 400V cable in fault condition in with closed CB feeding from another transformer when primary transformer is de-energised for maintenance purpose Fig. 4.6.

This case study is the sequence of the operation of the protection devices CB7, CB9 and CB75. The fault of 30.36kA appeared on the low voltage side to cable 29 supplied from a transformer TX8. This scenario is an example of the critical moment when the data rack relies on one supply only due to shut down of the TX3 transformer for maintenance.

In this situation, the fault causes the low voltage circuit breaker CB7 to operate and clear the fault within 80ms, because the fault has not been cleared within 80ms, then the CB9 operates too. The CB75 is the backup of those two that have cleared the fault.

The reason for setting this sequence of operation of all the CBs is to ensure the disconnection of the faulty part of the installation from the TX3 in terms of protecting the transformer from damage. The CB7 also is in coordination with CB9 and CB75 in another scenario.

On the graph in Fig. 4.7, we can see that the equipment is well protected by the coordination and protection has been achieved. In this situation, the power supply is continued as the CB9 installed to the link between TX3 and TX8 further down of the single supply will close. The miscoordination shown on the graph is irrelevant to the presented scenario because the main aim is to disconnect the faulty bus bar quickly from the rest of the network.

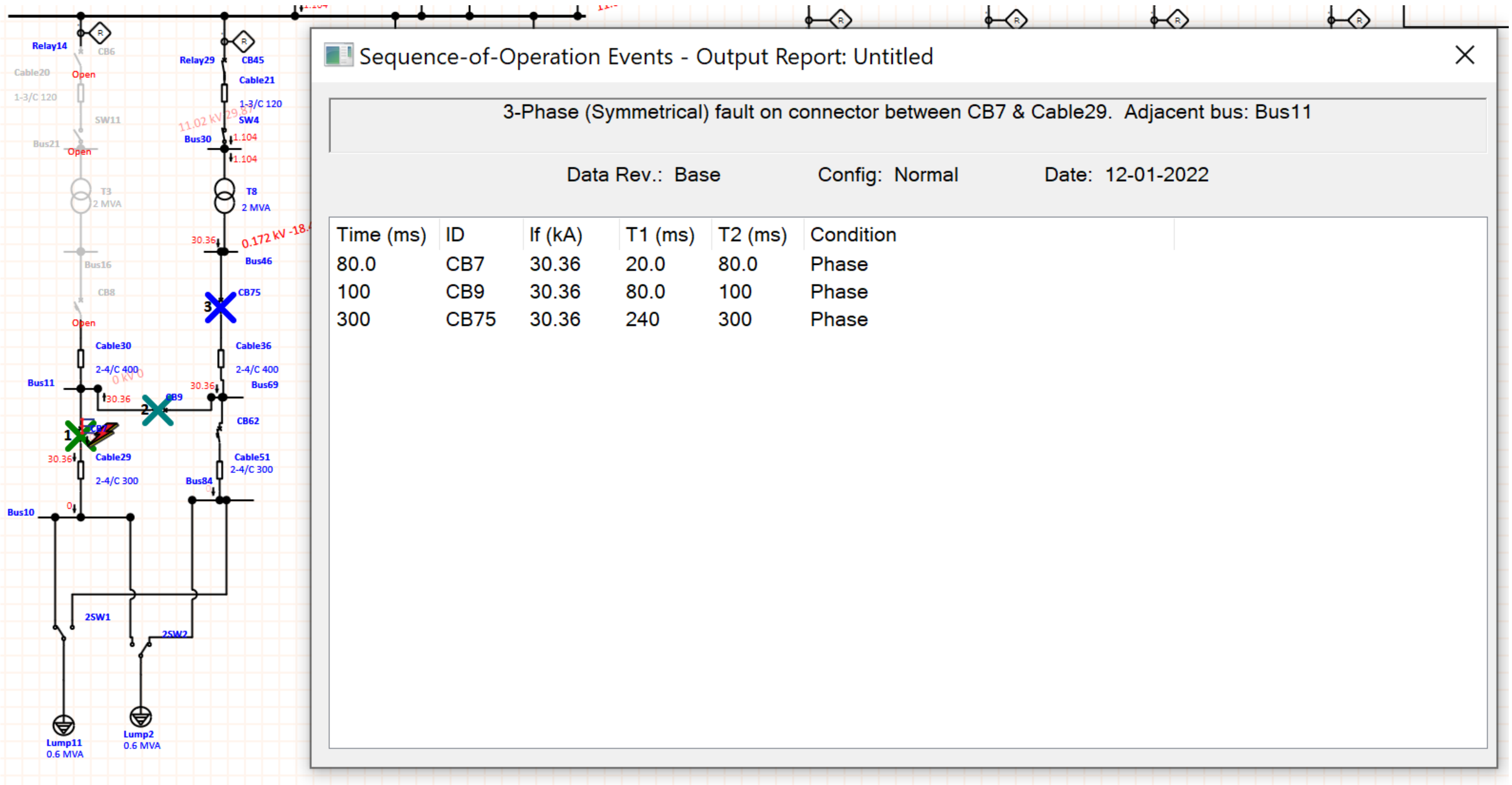
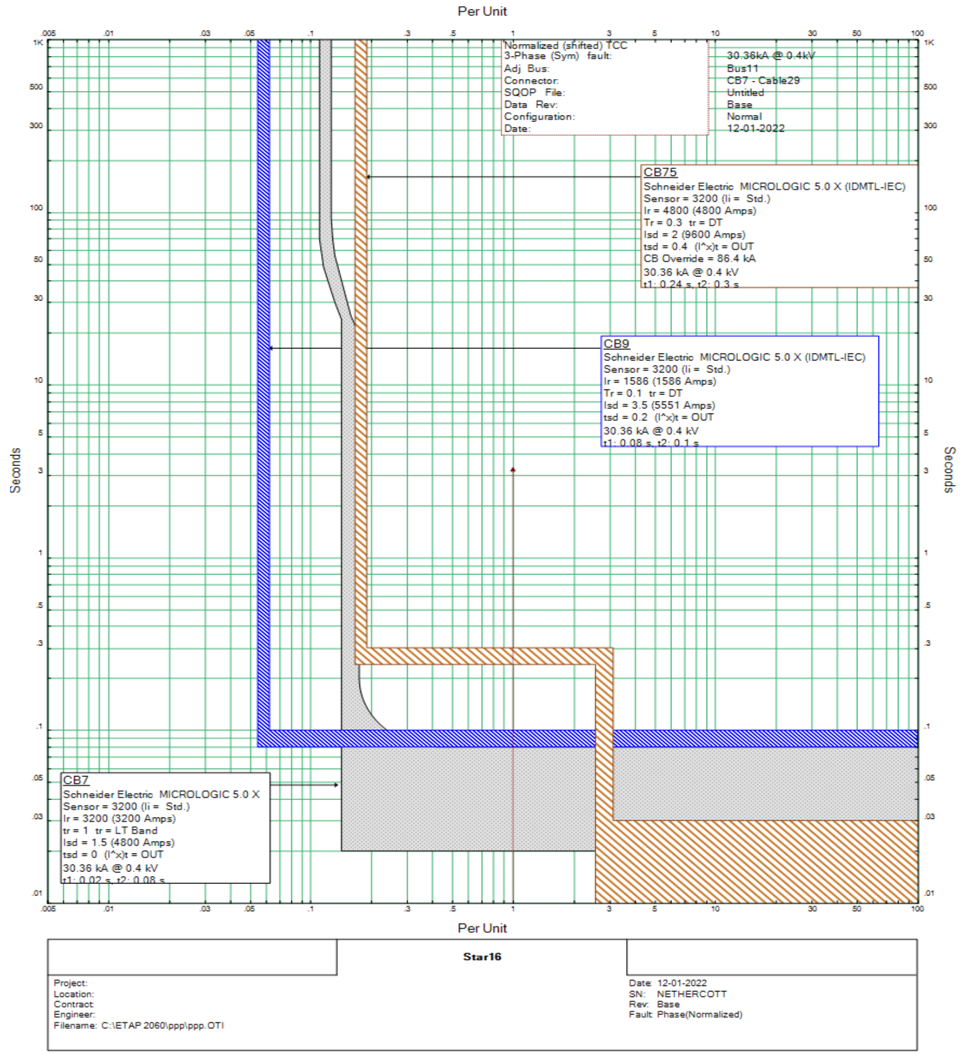
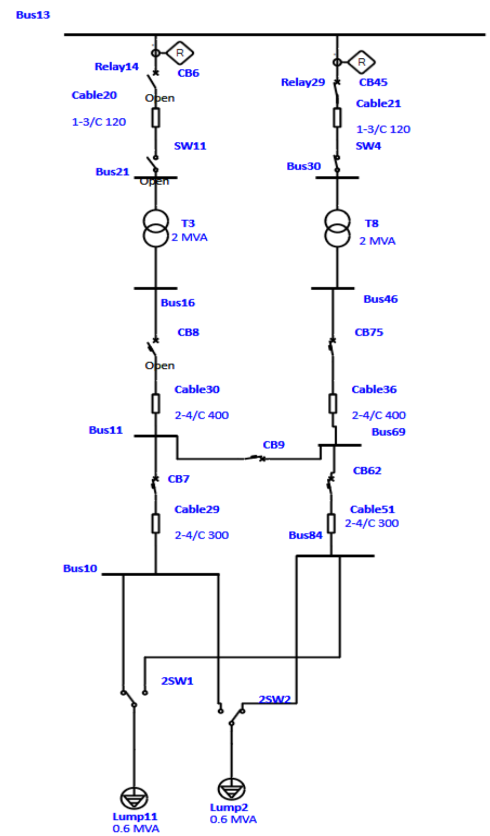


__Figure 4.6.__ The sequence of protection operation





a) Devices under the fault simulation

b) Devices Time Current Curves under the fault simulation

Figure 4.7. *The time current curve and protection devices operation under fault simulation*

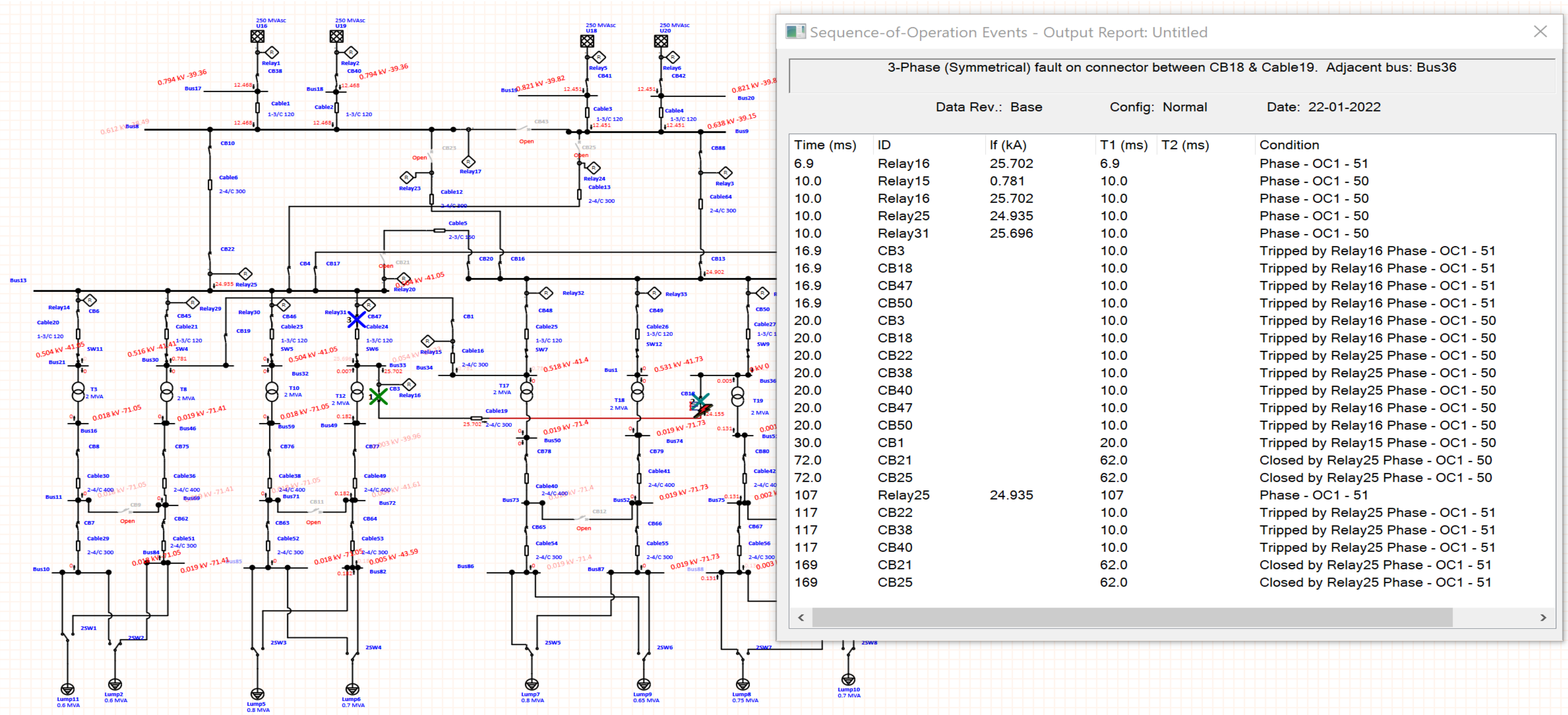
4.2.4 Case study 4 Protection coordination on 11kV cable in fault condition in normal operation state.

The purpose of case study shown in Fig. 4.8 is to look at a part of the network which includes 11kV/400V cables interconnected to provide bypass of the supply at 11kV voltage level. In this case study, if the 11kV cable becomes fault condition then relays 16, 15,25 and 31 will operate in the required sequence and send the signal to the assigned to the relay's circuit breakers to clear the fault. The power, in this case, will be supplied from the upstream bus bars anyway. This interconnected cable is live and does not play a crucial role during normal operation. This will change when one of the upstream bus bars is in fault so the power without interruption is transferred through cable 29 to the transformers.

The output report shows the relay and circuit breaker's operation sequence. At the short circuit current at relay 16 is at 25.702 kA, at relay 15 is 0.781 kA, at relay 25 is 24.935kA and at relay 31 is 25.695kA. The disconnection times are various and are shown on the output report below. The sequence of the operation of the relays shows that relay 16 opens all the breakers assigned to it. If relay 16 fails to operate, then relays 15 and 31 open the required circuit breakers.

The operation time discrepancy can also be caused by manufacturers in production components differences of a relay, and it is impossible to achieve two precisely the same relays that can deliver the same operation time.

In the graph in Fig. 4.9, we can see that cable protection has been achieved as well as the buss bar by clearing the faulty bus bar within 102ms. In this situation, the power is supplied from the second DNOs supply. The miscoordination shown on the graph is irrelevant to the presented scenario because the main aim is to disconnect the faulty bus bar quickly from the rest of the network.



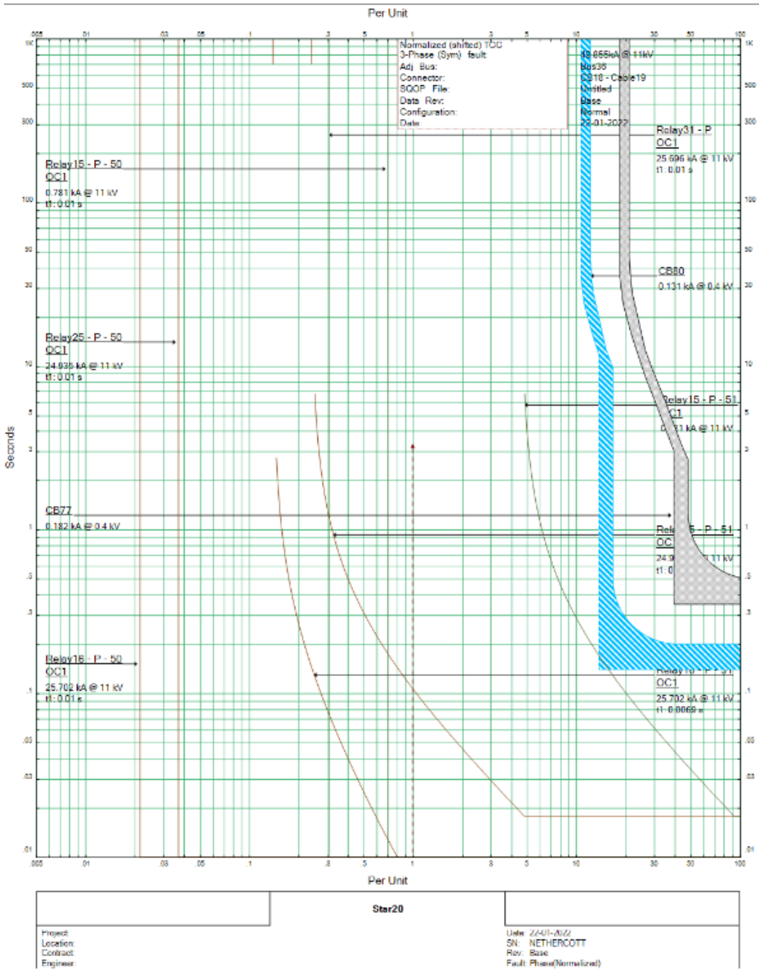
Sequence-of-Operation Events - Output Report: Untitled

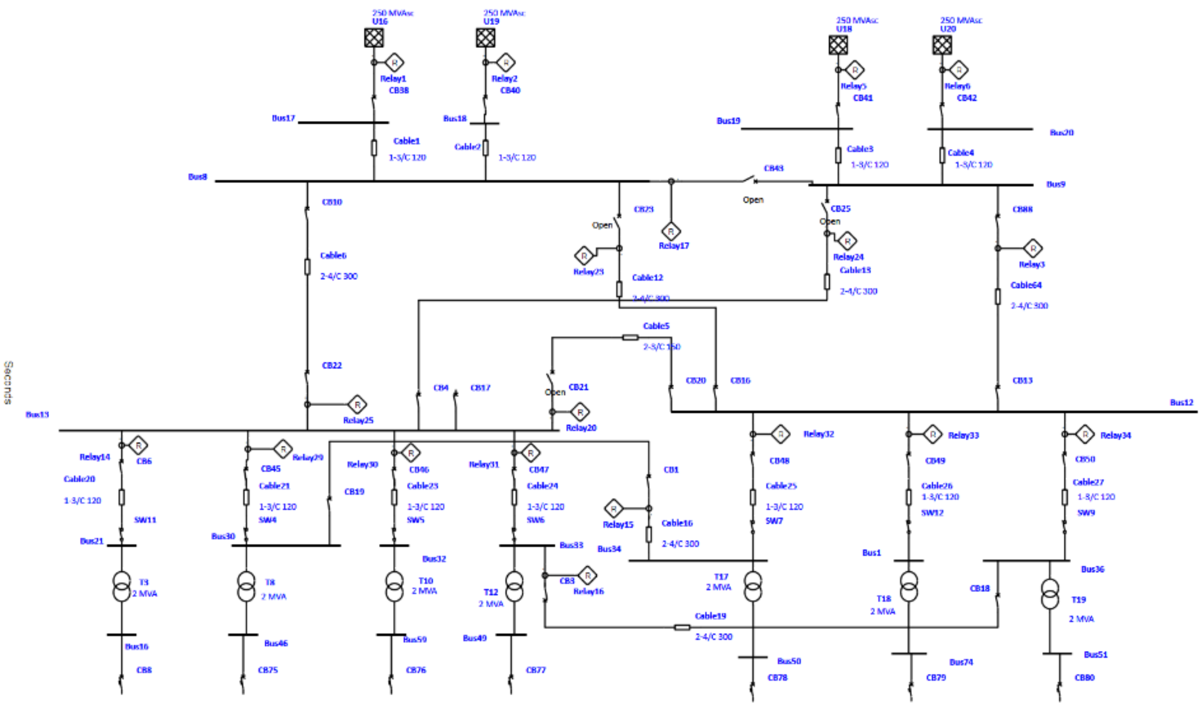
3-Phase (Symmetrical) fault on connector between CB18 & Cable19. Adjacent bus: Bus36

Data Rev.: Base Config: Normal Date: 22-01-2022

Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
6.9	Relay16	25.702	6.9		Phase - OC1 - 51
10.0	Relay15	0.781	10.0		Phase - OC1 - 50
10.0	Relay16	25.702	10.0		Phase - OC1 - 50
10.0	Relay25	24.935	10.0		Phase - OC1 - 50
10.0	Relay31	25.696	10.0		Phase - OC1 - 50
16.9	CB3		10.0		Tripped by Relay16 Phase - OC1 - 51
16.9	CB18		10.0		Tripped by Relay16 Phase - OC1 - 51
16.9	CB47		10.0		Tripped by Relay16 Phase - OC1 - 51
16.9	CB50		10.0		Tripped by Relay16 Phase - OC1 - 51
20.0	CB3		10.0		Tripped by Relay16 Phase - OC1 - 50
20.0	CB18		10.0		Tripped by Relay16 Phase - OC1 - 50
20.0	CB22		10.0		Tripped by Relay25 Phase - OC1 - 50
20.0	CB38		10.0		Tripped by Relay25 Phase - OC1 - 50
20.0	CB40		10.0		Tripped by Relay25 Phase - OC1 - 50
20.0	CB47		10.0		Tripped by Relay16 Phase - OC1 - 50
20.0	CB50		10.0		Tripped by Relay16 Phase - OC1 - 50
30.0	CB1		20.0		Tripped by Relay15 Phase - OC1 - 50
72.0	CB21		62.0		Closed by Relay25 Phase - OC1 - 50
72.0	CB25		62.0		Closed by Relay25 Phase - OC1 - 50
107	Relay25	24.935	107		Phase - OC1 - 51
117	CB22		10.0		Tripped by Relay25 Phase - OC1 - 51
117	CB38		10.0		Tripped by Relay25 Phase - OC1 - 51
117	CB40		10.0		Tripped by Relay25 Phase - OC1 - 51
169	CB21		62.0		Closed by Relay25 Phase - OC1 - 51
169	CB25		62.0		Closed by Relay25 Phase - OC1 - 51

Figure 4.8. *The sequence of protection operation*





a) Devices under the fault simulation

b) Devices Time Current Curves under the fault simulation

Figure 4.9. *The time current curve and protection devices operation under fault simulation*

4.3 Summary

The intention of presenting case studies was to show the operation of the protection devices during various scenarios of fault conditions in the designed 11kV/400V power distribution network in the Data Centre. The protection devices data used in Case studies 4.2.2 and 4.2.3 shall operate in the required by BS7671 regulation time of 400ms. In Case study 4.2.2, applied protection cleared the fault within 120ms which is faster than the required value. Like this, in case study 4.2.3, the faulty part of the system was isolated within 300ms.

Case studies 4.2.1 and 4.2.4 related to the high voltage part of the distribution system of the network prove that the protection isolates the faulty element below the required by IEC regulations 200ms disconnection time. In case study 4.2.1, the disconnection time was limited to 102ms and in case study 4.2.4 the max disconnection time of the faulty system was 169ms.

All these four case studies have proven protection devices' sensitivity and selectivity. Protection has detected the fault condition and has responded correctly by operating below the required time and it is highly selective because isolating the faulty part of the power system keeps the rest of the power system in uninterrupted operation and continues supplying power to data racks

Chapter 5 Conclusion and Future Work

5.1 Conclusion

This research compares environmentally and not environmentally friendly Data Centres to show a preferred distribution power system used in Data Centres in the UK. The work has discussed that no environmentally friendly type of Data Centre is preferred to be used in the UK. The reason is that renewable resources are not a reliable energy source and are more costly, including maintenance. Additionally, to that the renewable source of energy requires more space, e.g., a big space for the solar panels, to be installed to achieve significant power output to be able to cover the Data Centres load demand and, in this case, would be an 8MW. A Data Centre require a highly reliable power source, a simple in construction power distribution system and equipment and maintenance running 24/7 to ensure that data racks are receiving uninterruptable power flow. This can only be achieved using a reliable connection to the power grid with a diesel generator backup and an “In-line” UPS system.

The main subject of this thesis is the protection coordination in the preferable power distribution system used in Data Centre and the power distribution system size is 11kV/400V AC. The project has several protection coordination simulations performed on the MV and LV sides of the power system by creating a simulated short circuit fault. To ensure the correct size of equipment is selected correctly, I had to calculate the step-down transformer size that is able to cover power demand in both circumstances working as normal and when one transformer has been disconnected, and power is transferred to another load via interconnecting path. Also, the size of the cable on the MV and LV sides was a challenge, as the voltage drop and current carrying capacity of the cable must be considered when doing the sizing. All protection components’ segregation and adjustment are required to analyse to operate correctly and be highly selective and fast. In the case study, I have presented that protection coordination has been achieved in several fault simulations on all voltage levels. I had to consider disconnection time and protection device coordination when the circuit breaker that usually is open will close to provide the power supply using another source.

The software I have used has some limitations, like a max of 50 Bus Bars and UPS analyse, so for that reason, this work does not consider UPS fault analyse to show the total capability of the software.

5.2 Future Work

Protection coordination in this thesis is limited to power supplied from the grid and does not consider protection coordination in case of loss of main power Fig. 5.1. This subject is for future work to consider protection coordination in an 11kV/400V 50Hz power distribution system supplied by a diesel generator working as the backup system earthed via Neutral Earth Resistor. The investigation should show that protection detects loss of main power, operation of the UPS system taking power from the battery backup system until generators are synchronised, and closed-circuit breaker to allow energy to be supplied to the system.

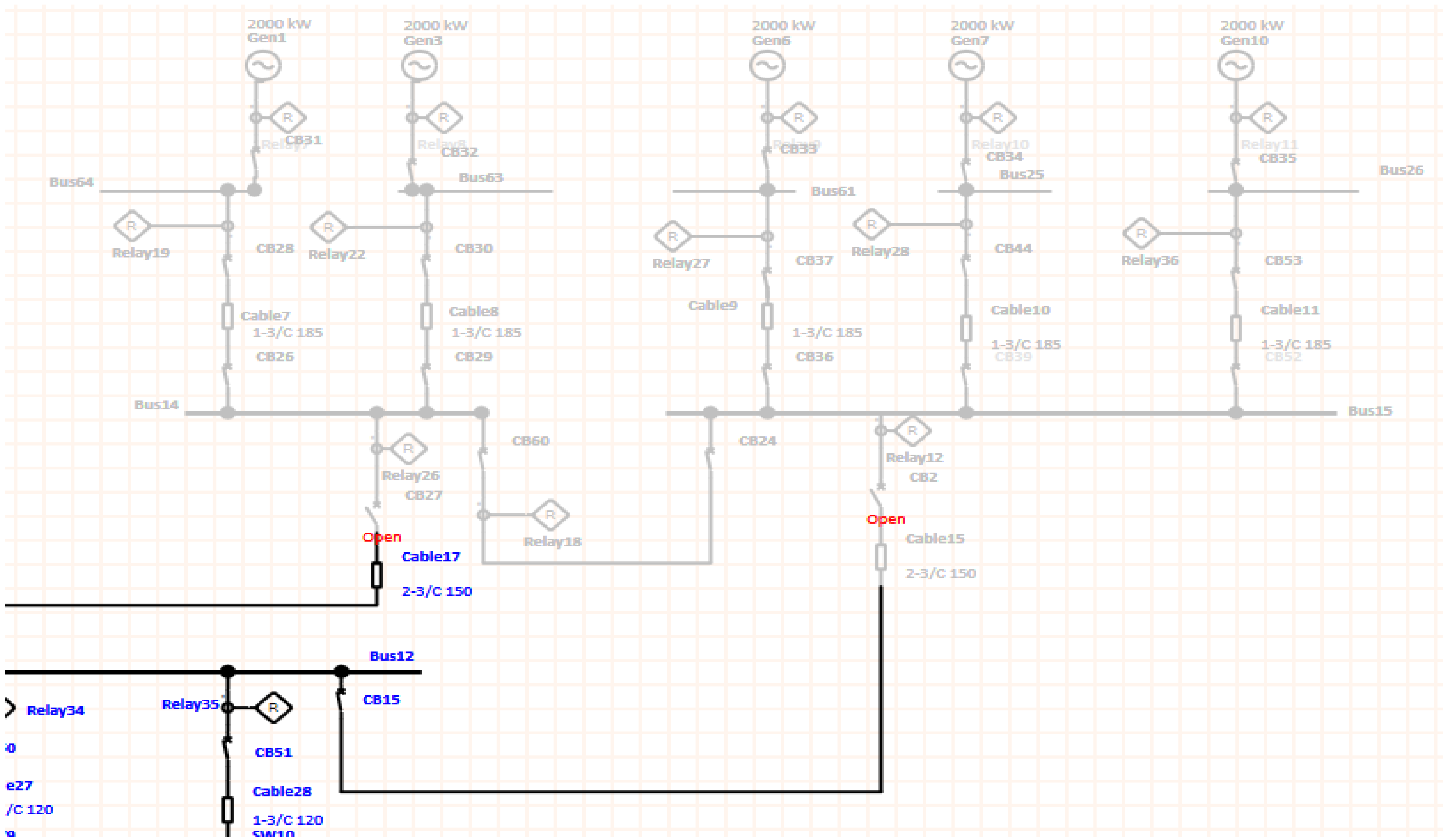


Figure 5.1. *The future work generator back-up system*

However, the main challenge is to present protection coordination on short circuit current fault in the back-up generator system that disconnects faulty generator without causing the whole back-up system to shut down, as well as fault current not damaging the generator's alternator. A Neutral Earth Resistor is used to limit the high current flows through an alternator and could cause damage to it. The size of the resistor must be calculated, but generator manufacture data gives the required information for max current flow.

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Appendices

Appendix A: Utility Company Data

Fault levels, source impedance values and Fault Clearance times for

UK Power Networks

				Fault Level @11kV (kA)		Impedance values in % on 100MVA					
Sub no	Condition	Impedance Type	3ph	Peak	1ph-E	R1	X1	R2	X2	R0	X0
66482	Normal	Transient	7		5.4	22.41	71.61	22.41	71.61	39.61	135.42
66482	Normal	Sub-transient	8.5	16	6	22.4	57.21	22.4	57.21	39.61	135.42
66482	Minimum - 2 circuit outage	Transient	5.3		4.1	42.76	88.88	42.76	88.88	120.57	143.78
66482	Minimum - 2 circuit outage	Sub-transient	6.1	10.3	4.4	42.75	74.48	42.75	74.48	120.57	143.78

HV Services Settings			
OC		EF	
Pickup	450A	Pickup	150A
TMS / Time	0.15	TMS / Time	0.15
Curve	SI	Curve	SI

Comments:

Those figures do not account for any distributed generation.

Fault Levels and network parameters may change overtime due to changes in the network structure.

All the 11kV switchgears shall be rated to a fault level of 250MVA, at least.

Appendix B: Data Centre Overview

Site brochure | Slough 3 Data Center

Secure and flexible space built to your specifications

Your requirements are the most important aspect of our service offering. You choose, we deliver. Whether you select a building shell which you configure yourself, or we construct it according to your specifications, or even if you want to rent a single rack in our shared environment, we can accommodate your needs. We will also ensure the space is highly available through our years of engineering critical data centers while maintaining high levels of security to keep your infrastructure and data safe.

Overview of our main product offerings:

Fully-fitted	Colocation Rack Carrier Rack
	Dedicated Cage
	Dedicated Suite
Supporting products and services	Multi Service Interconnection Platform*
	Cross Connect
	Remote Hands

*Enabling internet bandwidth, access to major cloud providers and connectivity between other NTT data centers

Infrastructure

Data center space

- 1,510 m^2 of IT space
- flexible colocation deployments: single rack colocation, cages, suites, turnkey build to suites, shell and core solutions
- ancillary spaces (offices, storages, and pre-installation rooms) available
- common areas such as meeting rooms, and catering area

Cooling

- primary cooling infrastructure, centrally managed and linked to BMS
- room air conditioning units
- regulated humidity
- 1.5 m clear false ceiling void for hot-air return to Air Handling Units (AHU)
- contained hot aisle or chimney rack design for high efficiency cooling up to 20 kW per rack

Power

- dual dedicated 11,000V (HV) grid connections (2N)
- maximum client IT load of 2.7 MW
- dedicated 2N redundant HV substations on-site
- minimum 2N (UPS) with battery back-up
- N+1 back-up generators
- refuelling contracts to ensure timely replacement

Fire protection

- physical fire protection in hosting suites and in all plant areas
- fully addressable fire detection system with Very Early Smoke Detection Apparatus (VESDA)
- gas suppression systems to technical areas
- fire detection and suppression systems interconnected to central BMS

Security

- 24/7 on-site security
- 3.6 m SEAP certified security fence with electrified topper
- secure crash-rated vehicle trap access to loading area
- PAS68 certified anti ram-raid barriers throughout site perimeter
- blast proof and anti-intruder shielded external windows
- steel security doors
- external and internal IP CCTV system
- proximity cards to authorize access levels including man trap access
- biometric identification

Connectivity

- carrier- and cloud-neutral
- carrier mix from global tier 1 supplier to regional supplier
- connectivity to the major carrier hubs in Docklands
- redundant Carrier-Meet-Me-Rooms
- redundant cabling infrastructure with diverse paths
- Pre-Cabling to support fast Cross Connect deployments
- high-performance internet access
- inter data center connectivity between NTT data centers for geo-redundant solutions
- Multi Service Interconnection Platform to connect our clients to major cloud service providers such as Amazon Web Services, Microsoft Azure, and Google Cloud Platform

Appendix C: MV Protection Data

Bringing simplicity and high reliability to your applications
GenieEvo is a compact indoor Medium Voltage switchgear assembly. A fixed circuit breaker and 3-position disconnector, combined with solid insulation technology, makes it a simple and highly reliable solution.
It complies with IEC and BS standards.

PE90208

Main characteristics

- Compartmented design
- LSC2A-PM
- Rated voltage: 13.8 kV
- Solid insulated single busbar
- Fixed (demountable) circuit breaker: Evolis
- Resin encapsulated busbars and disconnector are virtually insensitive to ambient conditions
- Internal arc classification: AF(LR) up to 25 kA 1 s
- Protection and control devices: Sepam, MiCOM, VAMP arc flash or GemControl

Key applications

Utilities - Industry - Infrastructure - Building
(please see page 12 for more details)

+

Peace of mind
Energy availability
Safety

Technical characteristics

Rated voltage				
		Ur	(kV)	**13.8**
Rated insulation level				
Power frequency withstand voltage 50 Hz - 1 min		**Ud**	(kV rms)	38
Lightning impulse withstand voltage 1.2/50 µs		**Up**	(kV peak)	95
Rated normal current and maximum short time withstand current				
Rated peak current			(kA)	67.5
Short time withstand current	Ik max.	**Ik/tk**	(kA/3 s)	25
Rated current	Ir max. busbar	**Ir**	(A)	630
				1250
				2500 (1)
Rated current	Ir CB	**Ir**	(A)	200
				630
				1250
				2500 (1)
Internal arc classification (maximum value I_A and t_A)				
			(kA/1 s)	25
			IAC	AF - AFLR
Degree of protection				
External enclosure		Standard		IP3X
		Option		IP4X

(1) 2500 A available on request.

Appendix D: Power Breaker Data sheet

Product data sheet

Specifications

Circuit breaker Masterpact MTZ2 32H1, 3200 A, 4P fixed, without Micrologic

LV848087

Main

Range	Masterpact
Product name	Masterpact MTZ2
Device short name	MTZ2 32 H1
Product or component type	Circuit breaker
Device application	Protection
Poles description	4P
Neutral position	Left
Network type	AC
Network frequency	50/60 Hz
Breaking capacity code	H1
Suitability for isolation	Yes conforming to IEC 60947-2
Selectivity category	Category B

Complementary

Control type	Push-button
Mounting mode	Fixed
Mounting support	Base plate Rails
[In] rated current	3200 A at 40 °C
[Ui] rated insulation voltage	1000 V AC 50/60 Hz conforming to IEC 60947-2
[Uimp] rated impulse withstand voltage	12 kV conforming to IEC 60947-2
[Icm] rated short-circuit making capacity	145 kA 220/415 V AC at 50/60 Hz 145 kA 440 V AC at 50/60 Hz 145 kA 500/525 V AC at 50/60 Hz 145 kA 660/690 V AC at 50/60 Hz
[Ue] rated operational voltage	690 V AC 50/60 Hz conforming to IEC 60947-2
Circuit breaker CT rating	3200 A
Performance level	66 kA Icu at 220/415 V AC 50/60 Hz conforming to IEC 60947-2 66 kA Icu at 440 V AC 50/60 Hz conforming to IEC 60947-2 66 kA Icu at 500/525 V AC 50/60 Hz conforming to IEC 60947-2 66 kA Icu at 660/690 V AC 50/60 Hz conforming to IEC 60947-2
[Ics] rated service breaking capacity	66 kA at 220/415 V AC 50/60 Hz conforming to IEC 60947-2 66 kA at 440 V AC 50/60 Hz conforming to IEC 60947-2 66 kA at 500/525 V AC 50/60 Hz conforming to IEC 60947-2

	66 kA at 660/690 V AC 50/60 Hz conforming to IEC 60947-2
Mechanical durability	20000 cycles with periodic preventive maintenance conforming to IEC 60947-2
Electrical durability	AC-3: 6000 cycles 440/690 V AC 50/60 Hz conforming to IEC 60947-3 2500 cycles 690 V AC 50/60 Hz conforming to IEC 60947-2 5000 cycles 440 V AC 50/60 Hz conforming to IEC 60947-2 AC-23A: 2500 cycles 690 V AC 50/60 Hz conforming to IEC 60947-3 AC-23A: 5000 cycles 440 V AC 50/60 Hz conforming to IEC 60947-3
Connection pitch	115 mm
[Icw] rated short-time withstand current	66 kA 0.5 s conforming to IEC 60947-2 66 kA 1 s conforming to IEC 60947-2 66 kA 3 s conforming to IEC 60947-2
Maximum breaking time	25 ms
Maximum closing response time	70 ms
Height	352 mm
Width	537 mm
Depth	300 mm

Environment

Standards	IEC 60364-8-1 IEC 60947-2
Product certifications	ASTA
Pollution degree	3 conforming to IEC 60947-1
Ambient air temperature for operation	-25…70 °C
Ambient air temperature for storage	-40…85 °C

Packing Units

Unit Type of Package 1	PCE
Number of Units in Package 1	1
Package 1 Weight	47.252 kg
Package 1 Height	30.5 cm
Package 1 width	29.5 cm
Package 1 Length	49.5 cm

Offer Sustainability

Sustainable offer status	Green Premium product
REACh Regulation	REACh Declaration
EU RoHS Directive	Compliant EU RoHS Declaration
Mercury free	Yes
RoHS exemption information	Yes
China RoHS Regulation	China RoHS declaration Product out of China RoHS scope. Substance declaration for your information
Environmental Disclosure	Product Environmental Profile
Circularity Profile	End of Life Information
PVC free	Yes
California proposition 65	WARNING: This product can expose you to chemicals including: DINP, which is known to the State of California to cause cancer, and DIDP, which is known to the State of California to cause birth defects or other reproductive harm. For more information go to www.P65Warnings.ca.gov

Appendix E: MCCB Data Sheet

Product datasheet
Characteristics

LV432893

circuit breaker Compact NSX630N - Micrologic 2.3 - 630 A - 3 poles 3d

Main

Product or component type	Circuit breaker
Device short name	Compact NSX630N
Circuit breaker application	Distribution
Poles description	3P
Protected poles description	3t
Network type	AC
Network frequency	50/60 Hz
[In] rated current	630 A (40 °C)
[Ui] rated insulation voltage	800 V AC 50/60 Hz
[Uimp] rated impulse withstand voltage	8 kV
[Ue] rated operational voltage	690 V AC 50/60 Hz
Breaking capacity code	N
Breaking capacity	20 kA at 600 V AC 50/60 Hz conforming to NEMA AB1 20 kA at 600 V AC 50/60 Hz conforming to UL 508 42 kA at 480 V AC 50/60 Hz conforming to NEMA AB1 50 kA at 480 V AC 50/60 Hz conforming to UL 508 85 kA at 240 V AC 50/60 Hz conforming to NEMA AB1 85 kA at 240 V AC 50/60 Hz conforming to UL 508 Icu 10 kA at 660/690 V AC 50/60 Hz conforming to IEC 60947-2 Icu 22 kA at 525 V AC 50/60 Hz conforming to IEC 60947-2 Icu 30 kA at 500 V AC 50/60 Hz conforming to IEC 60947-2 Icu 42 kA at 440 V AC 50/60 Hz conforming to IEC 60947-2 Icu 50 kA at 380/415 V AC 50/60 Hz conforming to IEC 60947-2 Icu 85 kA at 220/240 V AC 50/60 Hz conforming to IEC 60947-2
[Ics] rated service breaking capacity	Ics 10 kA 660/690 V AC 50/60 Hz conforming to IEC 60947-2 Ics 11 kA 525 V AC 50/60 Hz conforming to IEC 60947-2 Ics 30 kA 500 V AC 50/60 Hz conforming to IEC 60947-2 Ics 42 kA 440 V AC 50/60 Hz conforming to IEC 60947-2 Ics 50 kA 380/415 V AC 50/60 Hz conforming to IEC 60947-2 Ics 85 kA 220/240 V AC 50/60 Hz conforming to IEC 60947-2
Suitability for isolation	Yes conforming to EN 60947-2 Yes conforming to IEC 60947-2
Utilisation category	Category A
Trip unit name	Micrologic 2.3
Trip unit technology	Electronic
Trip unit protection functions	LSoI
Trip unit rating	630 A (40 °C)
Protection type	Instantaneous short-circuit protection Overload protection (long time) Short time short-circuit protection
Pollution degree	3 conforming to IEC 60664-1

Complementary

Control type	Toggle
Mounting mode	Fixed
Mounting support	Backplate
Upside connection	Front
Downside connection	Front
Mechanical durability	15000 cycles
Electrical durability	2000 cycles 690 V In conforming to IEC 60947-2 4000 cycles 440 V In conforming to IEC 60947-2 6000 cycles 690 V In/2 conforming to IEC 60947-2 8000 cycles 440 V In/2 conforming to IEC 60947-2
Connection pitch	45 mm
Local signalling	LED 105 % Ir LED 90 % Ir LED ready
Long time pick-up adjstment type Ir	Adjustable 9 settings
Long time pick-up adjustment range	0.9...1 x Io
Long time delay adjustment type	Fixed
[tr] long-time delay adjustment	16 s 6 x Ir
Thermal memory	20 minutes before and after tripping
Short-time pick-up adjustment type Isd	Adjustable 9 settings
[Isd] short-time pick-up adjustment range	1.5...10 x Ir
Short-time delay adjustment type	Fixed
Instantaneous pick-up adjustment type Ii	Fixed
Instantaneous pick-up adjustment range	6900 A
Height	255 mm
Width	140 mm
Depth	110 mm
Product weight	6.2 kg

Environment

Electrical shock protection class	Class II
Standards	EN 60947-2 IEC 60947-2 NEMA AB1 UL 508
Product certifications	CSA UL
IP degree of protection	IP40 conforming to IEC 60529
IK degree of protection	IK07 conforming to IEC 62262
Ambient air temperature for operation	-35...70 °C
Ambient air temperature for storage	-55...85 °C

Offer Sustainability

Sustainable offer status	Green Premium product
RoHS	Compliant - since 0839 - Schneider Electric declaration of conformity
REACh	Reference not containing SVHC above the threshold
Product environmental profile	Available
Product end of life instructions	Need no specific recycling operations

Appendix F: Metering CTs Data Sheet

PB118085

Presentation of commercial reference numbers

MET SE CT X XX XXX

- X: 1 = 1 Amp, 5 = 5 Amp, R = Rogowski
- XX: 2 letters = Form Factor
- XXX: Last 3 digits = primary rating/10

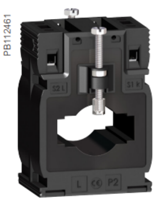
Examples:

METSECT5CC008 = 5 A secondary, Cables only, 75 A primary
METSECT5MC080 = 5 A secondary, mixed for cables and bars, 800 A primary
METSECTR30500 = Rogowski CT, 300 mm length, 96 mm diameter 50 A to 5000 A

PB112446

METSECT5CC●●●

PB112461



METSECT5MB●●●

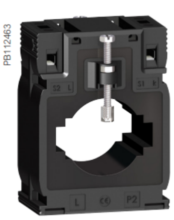
PB112460

METSECT5MA●●●

PB112462

METSECT5MC●●●

PB112463



METSECT5MD●●●

Type C - solid core current transformer (cable profile)

Internal profile type	Cables (mm)	Bars (mm)	Rating Ip/5 A (A)	Commercial ref number
CC				
FF CC	**Ø21**	-	40	**METSECT5CC004**
			50	**METSECT5CC005**
			60	**METSECT5CC006**
			75	**METSECT5CC008**
			100	**METSECT5CC010**
			125	**METSECT5CC013**
			150	**METSECT5CC015**
			200	**METSECT5CC020**
			250	**METSECT5CC025**

Type M - current transformers (mixed: cable/bar profile)

Internal profile type	Cables (mm)	Bars (mm)	Rating Ip/5 A (A)	Commercial ref number
MB				
FF MB	**Ø26**	**12 x 40** **15 x 32**	250	**METSECT5MB025**
			300	**METSECT5MB030**
			400	**METSECT5MB040**
MA				
FF MA	**Ø27**	**10 x 32** **15 x 25**	150	**METSECT5MA015**
			200	**METSECT5MA020**
			250	**METSECT5MA025**
			300	**METSECT5MA030**
			400	**METSECT5MA040**
MC				
FF MC	**Ø32**	**10 x 40** **20 x 32** **25 x 25**	250	**METSECT5MC025**
			300	**METSECT5MC030**
			400	**METSECT5MC040**
			500	**METSECT5MC050**
			600	**METSECT5MC060**
			800	**METSECT5MC080**
MD				
FF MD	**Ø40**	**12 x 50** **20 x 40**	500	**METSECT5MD050**
			600	**METSECT5MD060**
			800	**METSECT5MD080**

See your Schneider Electric representative for complete ordering information.

Appendix G: Power Transformer Data Sheet

Transformer:

IEEE Std C57.12.59-2015
IEEE Guide for Dry-Type Transformer Through-Fault Current Duration

Table 1—Transformer categories

Category (see NOTE 1)	Single-phase (kVA) (see NOTE 2)	Three-phase (kVA) (see NOTE 2)	Reference protection curves
I	1–500	15–500	Figure 1
II	501–1667	501–5000	Figure 2
III	1668 – 10 000	5001 – 30 000	Figure 3

NOTE 1— Category I include autotransformers of 500 kVA or less (equivalent two winding) even through nameplate kVA may exceed 500 kVA.

NOTE 2— All kVA ratings are minimum nameplate kVA for the principal winding.

IEEE Std C57.12.59-2015
IEEE Guide for Dry-Type Transformer Through-Fault Current Duration

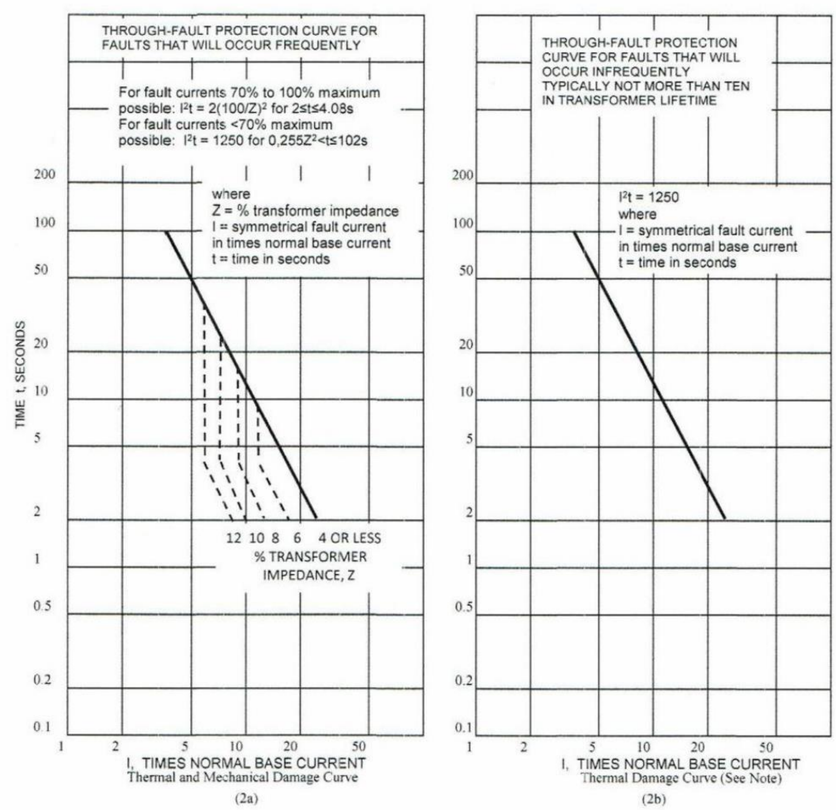


Figure 2—Category II transformers

TRIHAL 2000kVA 13,2kV/420V 17,5kV IP00 TIER2

TRI200017K2A3YEB1

Main

Product range	Trihal
Product or component type	Transformer
Transformer type	Dry type transformer
Network type	AC
Type of installation	Indoor
Maximum altitude	1000 m
Cooling mode	AN (air natural)
Winding material	Aluminium
Insulation material	Pre-impregnated (LV) Cast resin (HV)
Degree of protection	IP00
Mounting mode	Ground mounted

Complementary

Phase	3 phases
Rated power	2000 kVA
Rated frequency	50 Hz
Rated primary voltage	13.2 kV
Secondary voltage (at no-load)	No load: No load: 420 V
Insulation voltage to industrial frequency (50 Hz 1 mn)	17.5 kV AC primary 1.1 kV AC secondary
Rated insulation level	Primary circuit: 38 kV AC Secondary circuit: 10 kV AC
Lighting impulse whistand voltage (BIL) , 1.2/50 µs	95 kV
Vector group	Dyn11
HV tappings (off circuit)	+/- 4 x 2.5 %
Short circuit impedance	6 %
No-load losses	2340 W
Load losses at 75°C/120 °C	16000 W at 120 °C
Temperature rise of windings	100 K

Thermal class	F
Sound power level	55 dB at 1 m
Electrical connection	Cable high voltage connection Cable low voltage connection
Protective relay	protection relay T-154
Height	2150 mm
Width	1230 mm
Length	1900 mm
Total weight	4337 kg

Environment

Ambient air temperature for operation	-25…40 °C for C2
Ambient air temperature for storage	-50…40 °C C4
Environmental certification	0…95 % (E4)
Fire certificate	F1
Standards	UNE 21538-1:2018
Corrosion category	C4

Appendix H: MV Cable Data Sheet

MEDIUM VOLTAGE CABLES

Copper 6.35/11kV – Three core heavy duty screened armoured

Application

Electricity distribution network cable typically used as primary supply to Commercial, Industrial and urban residential networks. Suitable for high fault level systems rated up to 10kA/1sec. Higher fault current rated constructions are available on request.

Approvals

Approved by all major power Utilities and industrial customers in Australia.

Behaviour in flame and fire:

PVC or LSOH outer sheath exceeds the requirements of IEC 60332-1.

Temperature range

Minimum installation temperature: 0 °C
Maximum operating temperature: +90 °C
Minimum operating temperature: -25 °C

Minimum bending radius

Installed cables:	12D (PVC only) 15D (HDPE)
During installation:	18D (PVC only) 25D (HDPE)

Resistance to

Chemical exposure:	Accidental
Mechanical impact:	Heavy (Armoured)
Water exposure:	XLPE – Spray EPR – Immersion/Temporary coverage
Solar radiation and weather exposure:	Suitable for direct exposure.

Cable design

Conductor:
Plain circular compacted copper

Conductor screen:
Extruded semi-conductive compound, bonded to the insulation and applied in the same operations as the insulation.

Insulation:
Cross Linked Polyethylene (XLPE) – standard
Ethylene Propylene Rubber (EPR) – alternative

Insulation screen:
Extruded, semi-conductive compound

Metallic screen:
Plain annealed copper wire: nominal 10kA for 1 second. See table next page.

Armouring:
Galvanised steel wires

Sheath:
Black 5V-90 polyvinyl chloride (PVC) – standard
Orange 5V-90 PVC inner plus black high density polyethylene (HDPE) outer – alternative
Low smoke zero halogen (LSOH) – alternative

Installation conditions

In free air
In duct
In trench
In ground

Physical & electrical characteristics

Copper 6.35/11kV – Three core heavy duty screened armoured										
Product code: 3CCUX11HDA										
Nominal conductor area mm²		25	35	50	70	95	120	150	185	240
Nominal conductor diameter mm		6.1	7.0	8.2	9.8	11.5	12.9	14.3	16.1	18.2
Nominal insulation thickness mm		3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4
Approx cable diameter mm		51.3	53.7	56.3	60.4	64.4	67.9	71.3	76.7	82.1
Approx mass kg/100m		430	495	560	675	795	890	995	1220	1440
Max pulling tension on conductors kN		5.3	7.4	11	15	20	25	25	25	25
Max pulling tension on stocking grip kN		5.3	7.4	11	13	15	16	18	21	24
Max pulling tension on amour wires kN		11	12	13	15	17	19	21	24	25
Min bending radius* during installation mm		920	970	1010	1090	1160	1220	1280	1380	1480
Min bending radius* set in position mm		620	640	680	720	770	810	860	920	980
Max conductor resistance, dc @ 20°C Ohm/km		0.727	0.524	0.387	0.268	0.193	0.153	0.124	0.0991	0.0754
Conductor resistance, ac @ 90°C & 50 Hz Ohm/km		0.927	0.668	0.494	0.342	0.247	0.196	0.159	0.128	0.0984
Inductance mH/km		0.415	0.397	0.379	0.350	0.333	0.319	0.310	0.300	0.290
Inductive reactance, @ 50Hz Ohm/km		0.130	0.125	0.119	0.110	0.105	0.100	0.0973	0.0942	0.0910
Zero seq. impedance @ 20°C & 50 Hz Ohm/km		3.07+ j0.0836	2.16+ j0.0781	1.56+ j0.0726	1.11+ j0.0635	1.03+ j0.0585	0.995+ j0.0543	0.966+ j0.0515	0.941+ j0.0485	0.917+ j0.0454
Capacitance, phase to earth µF/km		0.212	0.231	0.255	0.290	0.325	0.354	0.383	0.419	0.465
Min insulation resistance @ 20°C MOhm.km		12,000	11,000	10,000	8,900	7,900	7,200	6,600	6,000	5,400
Electric stress at conductor screen kV/mm		2.64	2.56	2.49	2.40	2.33	2.29	2.25	2.22	2.18
Charging current @ rated voltage & 50 Hz A/phase/km		0.422	0.461	0.509	0.578	0.648	0.706	0.764	0.837	0.927
Short circuit rating	Phase conductor kA, 1 sec	3.6	5.0	7.2	10.0	13.6	17.2	21.5	26.5	34.3
	Metallic screen kA, 1 sec	3.5	5.1	7.1	10	10	10	10	10	10
Contin-uous current rating	In ground, direct buried A	135	165	195	245	290	330	370	410	475
	In ground, in singleway ducts A	120	145	170	205	245	280	310	350	410
	In free air, unenclosed & spaced from wall A	135	165	195	245	295	345	385	440	520

The cables described in this technical manual are designed to be used for the supply of electrical energy in fixed applications up to the rated voltages at a nominal power frequency between 49Hz and 61Hz. All values in this catalogue are for XLPE cables only. *Increased radius required for HDPE and nylon incorporating designs.

T: 01642 241133
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BS7835 11KV LSZH 3 CORE COPPER SCREENED CABLE - DIMENSIONS

CCC CODE	CONDUCTOR SIZE (MM^2)	STRANDING (MM)	NO OF CORES	WEIGHT (KG/KM)	OVERALL DIAMETER (MM)			NYLON CLEAT SIZE
					UNDER ARMOUR	OVER ARMOUR	OVERALL MM	
10302RD	35	19/1.53	3	4501	41.6	46.6	51.6	TC9
10304RD	50	19/1.78	3	5117	44.4	49.4	54.6	TC9
10306RD	70	19/2.14	3	6032	48.1	53.1	58.5	TC9
10308RD	95	19/2.52	3	7163	52	57	62.6	TC10
10310RD	120	37/2.03	3	3216	55.6	60.6	66.6	TC11
10312RD	150	37/2.25	3	9292	58.6	63.6	69.8	TC11
10314RD	185	37/2.52	3	10726	62.7	67.7	74.1	TC12
10316RD	240	61/2.25	3	13763	68.1	74.4	81.2	TC14
10318RD	300	61/2.52	3	16077	73.5	79.8	87	TC14
10320RD	400	70/3.15	3	19124	78.3	84.6	92.2	TC15

BS7835 11KV LSZH 3 CORE COPPER SCREENED CABLE– ELECTRICAL CHARACTERISTICS

CONDUCTOR SIZE	MAXIMUM CONDUCTOR DC RESISTANCE AT (20ºC Ω/Km)	CONDUCTOR AC RESISTANCE AT MAX OPERATING TEMERATURE AND 50HZ (20ºC Ω/KM)	CAPACITANCE mF/Km	CHARGING CURRENT (A/Km)	DIELECTRIC LOSSES (W/Km)	RSISTANCE AT 50HZ (Ω/KM)	CONDUCTOR S.C.C FOR 1 SEC (KA)	SCREEN S.C.C FOR 1 SEC (KA)	CURRENT RATING		
									LAID IN GROUND A	LAID IN DUCT A	LAID IN FREE AIR A
35	0.524	0.670	0.22	0.360	5.80	0.110	5.01	1.29	178	162	173
50	0.387	0.494	0.316	0.525	13.33	0.109	7.15	0.8	214	170	228
70	0.268	0.342	0.363	0.605	15.35	0.102	10.01	0.9	263	211	285
95	0.193	0.247	0.398	0.662	16.81	0.099	13.585	1	313	253	342
120	0.153	0.196	0.435	0.723	18.37	0.096	17.16	1.1	354	286	392
150	0.124	0.159	0.477	0.793	20.15	0.092	21.45	1.2	397	321	444
185	0.0991	0.128	0.516	0.859	21.81	0.089	26.455	1.2	446	365	504
240	0.0754	0.098	0.579	0.964	24.47	0.086	34.32	1.4	511	421	589
300	0.0601	0.078	0.642	1.068	27.13	0.084	42.9	1.5	569	474	667
400	0.047	0.062	0.71	1.181	30.00	0.081	57.2	1.6	634	532	754

ELECTRICAL DATA:

Maximum conductor operating temperature:	90°C
Maximum screen operating temperature:	80°C
Maximum conductor temperature during S.C:	250°C

LAYING CONDITIONS AT TREFOIL FORMATION ARE AS BELOW:

Soil thermal resistivity:	120˚C. Cm/Watt
Burial depth:	0.5m
Ground temperature:	15°C
Air temperature:	25°C
Frequency:	50Hz

Appendix I: LV Cable Data Sheet

CLEVELAND CABLE COMPANY
A WORLD POWER IN CABLE SUPPLY

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BS6724 LSZH MULTICORE MAINS & CONTROL (25 - 400MM)

APPLICATION

Used in power networks, indoor, outdoor, underground. Can be used in cable ducting for installation where fire, smoke emissions and toxic fumes create a potential threat to life and equipment.

CABLE STANDARDS

BS6724, Acid gas emission to BS EN 50267 (IEC 60754-1)

Smoke emission to BS EN 50268 (IEC 61034)

Flame propagation: IEC 60332-1, IEC60332-3, BS EN 50265, Category C; BS EN 50266

BASEC Approved (*see notes)

CONSTRUCTION

Conductor: Plain Annealed Stranded Copper Conductors

Insulation: Cross Link Polyethylene (XLPE)

Bedding: LSZH

Armouring: Galvanised Steel Wire Armour

Sheath: Low Smoke and Zero Halogen

Sheath Colour: Black

THE FOLLOWING CABLES ARE MANUFACTURED TO IEC 60502-1 AND ARE NOT COVERED BY BASEC

5 CORE 95MM²

5 CORE 120MM²

5 CORE 150MM²

5 CORE 185MM²

5 CORE 240MM²

CHARACTERISTICS

Voltage Rating: 600/1000 Volts

Temperature Limits: -25°C to +90°C

Minimum Bending Radius:
As per cable manufacturer datasheet

CORE IDENTIFICATION

2 Core: Brown Blue
3 Core: Brown Black Grey
3 Core: Brown Blue G/Y (up to 35mm²)
4 Core: Brown Black Grey Blue
5 Core and above: up to 6mm² 8 White**

Also available as - Brown Black Grey Blue G/Y

Should not be installed at temperatures below 0°C or above +40°C

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BS6724 LSZH MULTICORE MAINS & CONTROL (25 - 400MM) – DIMENSIONS

CCC CODE	CONDUCTOR SIZE (MM^2)	STRANDING (MM)	NO OF CORES	WEIGHT (KG/KM)	OVERALL DIAMETER (MM)	GLAND SIZE (MM) ALI (MM)	CLEAT SIZE
LSF2X25	25	7/2.14	2	1050	20.00	25	0.8
LSF3X25**	25	7/2.14*	3	1500	23.00	25	1.0
LSF4X25	25	7/2.14	4	1800	25.00	32	1.0
LSF5X25	25	7/2.14	5	2200	29.00	32	1.2
LSF2X35	35	7/2.52	2	1400	22.00	25	0.9
LSF3X35**	35	7/2.52	3	1800	26.00	32	1.1
LSF4X35	35	7/2.52	4	2200	28.00	32	1.2
LSF5X35	35	7/2.52	5	2800	33.00	40	1.4
LSF2X50	50	19/1.78	2	1750	25.00	32	1.0
LSF3X50	50	19/1.78	3	2250	28.00	32	1.2
LSF4X50	50	19/1.78	4	2850	31.00	32	1.4
LSF5X50	50	19/1.78	5	3850	38.00	40	1.6
LSF2X70	70	19/2.14	2	2200	28.00	32	1.2
LSF3X70	70	19/2.14	3	3000	32.00	32	1.4
LSF4X70	70	19/2.14	4	4100	37.00	40	1.6
LSF5X70	70	19/2.14	5	5100	43.00	50S	1.8
LSF2X95	95	19/2.52	2	3000	32.00	32	1.4
LSF3X95	95	19/2.52	3	4150	37.00	40	1.6
LSF4X95	95	19/2.52	4	5200	40.00	50S	1.6
LSF5X95	95	19/2.52	5	7700	52.00	50	TC9
LSF2X120	120	37/2.03	2	3600	35.00	40	1.4
LSF3X120	120	37/2.03	3	4950	40.00	50S	1.6
LSF4X120	120	37/2.03	4	6700	46.00	50	2.0
LSF5X120	120	37/2.03	5	9030	56.70	63S	TC9
LSF2X150	150	37/2.25	2	4250	37.00	40	1.6
LSF3X150	150	37/2.25	3	6300	45.00	50S	1.8
LSF4X150	150	37/2.25	4	7900	49.00	50	2.0
LSF5X150	150	37/2.25	5	10752	64.31	63	TC11
LSF2X185	185	37/2.52	2	5500	43.00	50S	1.8
LSF3X185	185	37/2.52	3	7650	49.00	50	2.0
LSF4X185	185	37/2.52	4	9650	55.00	63S	TC9
LSF5X185	185	37/2.52	5	11765	64.60	75S	TC11
LSF2X240	240	61/2.25	2	6300	48.00	50	2.0
LSF3X240	240	61/2.25	3	9650	56.00	63S	TC9
LSF4X240	240	61/2.25	4	12400	62.00	63	TC10
LSF5X240	240	61/2.25	5	15000	73.80	75	TC12
LSF2X300	300	61/2.52	2	8200	50.00	50	2.0
LSF3X300	300	61/2.52	3	11550	59.00	63	TC10
LSF4X300	300	61/2.52	4	14800	66.00	75S	TC11
LSF3X400	400	61/2.85	3	14350	65.00	75S	TC11
LSF4X400	400	61/2.85	4	19300	76.60	75	TC14

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BS6724 LSZH MULTICORE MAINS & CONTROL (25 - 400MM) – CARRYING CAPACITY (AMPERES)

CONDUCTOR CROSS – SECTIONAL AREA MM²	REFERENCE METHOD C (CLIPPED DIRECT)		REFERENCE METHOD E (IN FREE AIR OR ON A PERFORATED CABLE TRAY, HORIZONTAL OR VERTICAL)		REFERENCE METHOD D (DIRECT IN GROUND OR IN DUCTING IN GROUND, IN OR AROUND BUILDINGS)	
	1 TWO CORE CABLE SINGLE-PHASE AC OR DC	1 THREE OR 1 FOUR CORE CABLE THREE-PHASE AC	1 TWO CORE CABLE SINGLE-PHASE AC OR DC	1 THREE OR 1 FOUR CORE CABLE THREE-PHASE AC	1 TWO CORE CABLE SINGLE-PHASE AC OR DC	1 THREE OR 1 FOUR CORE CABLE THREE-PHASE AC
25	146	124	152	131	116	96
35	180	154	188	162	139	115
50	219	187	228	197	164	135
70	279	238	291	251	203	167
95	338	289	354	304	239	197
120	392	335	410	353	271	223
150	451	386	472	406	306	251
185	515	441	539	463	343	281
240	607	520	636	546	395	324
300	698	599	732	628	446	365
400	787	673	847	728	-	-

THE ABOVE IS IN ACCORDANCE WITH 18TH EDITION OF IET WIRING REGULATIONS

BS6724 LSZH MULTICORE MAINS & CONTROL (25-400MM) - VOLTAGE DROP

NOMINAL CROSS SECTIONAL AREA MM²	TWO CORE CABLE DC	TWO CORE CABLE SINGLE-PHASE AC mV/A/m			THREE OR FOUR CORE CABLE THREE-PHASE AC mV/A/m		
		R	X	Z	R	X	Z
25	1.85	1.85	0.160	1.900	1.600	0.140	1.650
35	1.35	1.35	0.155	0.350	1.150	0.135	1.150
50	0.98	0.99	0.155	1.000	0.860	0.135	0.870
70	0.67	0.67	0.150	0.690	0.590	0.130	0.600
95	0.49	0.50	0.150	0.520	0.430	0.130	0.450
120	0.39	0.40	0.145	0.420	0.340	0.130	0.370
150	0.31	0.32	0.145	0.350	0.280	0.125	0.300
185	0.25	0.26	0.145	0.290	0.220	0.125	0.260
240	0.195	0.20	0.140	0.240	0.175	0.125	0.210
300	0.155	0.16	0.140	0.210	0.140	0.120	0.185
400	0.12	0.13	0.140	0.190	0.115	0.120	0.165

THE ABOVE IS IN ACCORDANCE WITH 18TH EDITION OF IET WIRING REGULATIONS

CONDUCTOR OPERATING TEMPERATURE: 90°C

R = RESISTIVE COMPONENT
X = REACTIVE COMPONENT
Z = IMPEDANCE VALUE

BS 6724 1kV

LSOH Copper Conductor Armoured Cable. BS 6724. 600/1000 V

Prysmian BS 6724 is a Low Smoke, Zero Halogen (LSOH®) industrial wiring cable for interconnection of systems, control circuitry and power circuits

KEY APPLICATIONS

Designed primarily for clipped directly to a surface, on tray, in basket or in free air. These cables can also be laid direct in ground or in ducts in free draining soil, or embedded in concrete

The design of Prysmian BS 6724 is particularly robust and is well suited to areas at risk of mechanical damage.

FEATURES AND BENEFITS

- Low Smoke, Zero Halogen (LSOH®)
- Manufactured under ISO 9001 Quality management systems
- Single core aluminium wire armour
- Multi core steel wire armour

STANDARDS

BS 6724	Construction Standard
BS EN 60332-1-2	Flame Propagation - Single Cable
BS EN 60332-3-24	Flame Propagation - Multiple (bunched) Cables - Category C
BS EN 61034-2	Smoke emission
BS EN 60754-1	Corrosive and acid gas

CONSTRUCTION

Conductor material	Copper
Conductor surface	Bare
Core insulation material	XLPE
Armouring/reinforcement	Wire
Armouring	Yes
Material inner sheath	Low smoke zero halogen
Material outer sheath	Low smoke zero halogen
Cable shape	Round

Prysmian

A Brand of Prysmian Group

APPLICATIONS PROPERTIES

Nominal voltage U0 [V]	600
Nominal voltage U [V]	1,000
Flame retardant	In accordance with BS EN 60332-3-24
Halogen free	Yes
Low smoke	Yes
Max. conductor temperature [°C]	90
Min. Operation temperature [°C]	-25
UV resistant	Yes
Outdoor installation	Yes
Min. Installation temperature [°C]	0
Max. Installation temperature [°C]	80
Underground installation	Yes
Bending radius (rule)	8D

COLOURS

Insulation:
Single Core: Brown or Blue;

Two Cores: Brown, Blue;

Three Cores: Brown, Black, Grey; Or, Brown, Blue, Green/Yellow;

Four Cores: Blue, Brown, Black, Grey;

Five Cores: Blue, Brown, Black, Grey, Green/Yellow;

7 to 37 Cores: White (with printed numbers);

Sheath:

Black

CURRENT RATINGS

Refer to table 4E3 and 4E4 of BS 7671 Requirements for Electrical Installations. IET Wiring Regulations

Note: Where a conductor operates at a temperature exceeding 70°C it shall be ascertained that the equipment connected to the conductor is suitable for the conductor operating temperature

CONTACT INFORMATION

Prysmian Cables & Systems Limited, Chickenhall Lane, Eastleigh, Hampshire, SO50 6YU, United Kingdom

uk.prysmiangroup.com

TECHNICAL DATA

Number of cores	Nominal cross section conductor [mm²]	Shape of conductor	Nominal diameter of armouring wire [mm]	Nominal diameter under armour [mm]	Nominal outer diameter [mm]	Cable weight [kg/km]	Conductor resistance at 20° C [Ohm/km]
1	150	Round	1.6	19.6	28	1,900	0.124
1	185	Round	1.6	22	30	2,300	0.0991
1	240	Round	1.6	24	32	2,900	0.0754
1	300	Round	1.6	27	35	3,500	0.0601
1	400	Round	2	31	40	4,500	0.047
1	500	Round	2	35	44	5,700	0.0366
1	630	Round	2	38	48	7,000	0.0283
1	800	Round	2.5	44	55	9,100	0.0221
1	1,000	Round	2.5	49	60	11,500	0.0176
2	1.5	Round	0.9	6.9	10.8	250	12.1
2	2.5	Round	0.9	8.2	12.2	315	7.41
2	4	Round	0.9	9.2	13.3	375	4.61
2	6	Round	0.9	10.4	14.4	450	3.08
2	10	Round	0.9	11.9	16.2	590	1.83
2	16	Round	1.25	14	19	890	1.15
2	25	Sector-shaped	1.25	15.8	22	1,150	0.727
2	35	Sector-shaped	1.6	17.2	24	1,450	0.524
2	50	Sector-shaped	1.6	21	28	1,900	0.387
2	70	Sector-shaped	1.6	23	30	2,400	0.268
2	95	Sector-shaped	2	25	32	3,100	0.193
2	120	Sector-shaped	2	28	36	3,700	0.153
2	150	Sector-shaped	2	30	39	4,500	0.124
2	185	Sector-shaped	2.5	34	43	5,700	0.0991
2	240	Sector-shaped	2.5	39	48	7,100	0.0754
2	300	Sector-shaped	2.5	43	53	8,500	0.0601
2	400	Sector-shaped	2.5	47	58	10,400	0.047
3	1.5	Round	0.9	7.4	11.2	270	12.1
3	2.5	Round	0.9	8.7	12.7	345	7.41
3	4	Round	0.9	9.9	13.9	425	4.61
3	6	Round	0.9	11.1	15.1	520	3.08
3	10	Round	1.25	12.8	17.7	800	1.83
3	16	Round	1.25	15	21	1,100	1.15
3	25	Round	1.6	19.2	26	1,700	0.727
3	35	Round	1.6	22	28	2,100	0.524
3	50	Sector-shaped	1.6	24	30	2,500	0.387

TECHNICAL DATA

Number of cores	Nominal cross section conductor [mm²]	Shape of conductor	Nominal diameter of armouring wire [mm]	Nominal diameter under armour [mm]	Nominal outer diameter [mm]	Cable weight [kg/km]	Conductor resistance at 20° C [Ohm/km]
3	70	Sector-shaped	1.6	26	33	3,100	0.268
3	95	Sector-shaped	2	29	37	4,200	0.193
3	120	Sector-shaped	2	32	40	5,100	0.153
3	150	Sector-shaped	2.5	36	45	6,400	0.124
3	185	Sector-shaped	2.5	40	49	7,700	0.0991
3	240	Sector-shaped	2.5	45	55	9,700	0.0754
3	300	Sector-shaped	2.5	49	59	11,700	0.0601
3	400	Sector-shaped	2.5	55	65	14,400	0.047
4	1.5	Round	0.9	8.1	11.9	305	12.1
4	2.5	Round	0.9	9.6	13.6	395	7.41
4	4	Round	0.9	10.9	14.9	495	4.61
4	6	Round	1.25	12.3	17.2	720	3.08
4	10	Round	1.25	14.1	19	940	1.83
4	16	Round	1.25	16.7	22	1,300	1.15
4	25	Round	1.6	22	28	2,100	0.727
4	35	Round	1.6	24	31	2,600	0.524
4	50	Sector-shaped	1.6	27	34	3,100	0.387
4	70	Sector-shaped	2	29	37	4,000	0.268
4	95	Sector-shaped	2	33	41	5,100	0.193
4	120	Sector-shaped	2.5	37	46	6,600	0.153
4	150	Sector-shaped	2.5	41	50	7,900	0.124
4	185	Sector-shaped	2.5	45	55	9,600	0.0991
4	240	Sector-shaped	2.5	51	61	12,100	0.0754
4	300	Sector-shaped	2.5	56	66	14,700	0.0601
4	400	Sector-shaped	3.15	63	75	19,100	0.047
5	1.5	Round	0.9	10.1	14.8	415	12.1
5	2.5	Round	0.9	11.5	16.1	500	7.41
5	4	Round	0.9	13	17.8	630	4.61
5	6	Round	1.25	14.8	21	900	3.08
5	10	Round	1.25	17.6	24	1,250	1.83
5	16	Round	1.6	19.9	27	1,750	1.15
5	25	Round	1.6	25	32	2,500	0.727
5	35	Round	1.6	27	34	3,000	0.524
7	1.5	Round	0.9	11	15.9	495	12.1
7	2.5	Round	0.9	12.9	17.6	620	7.41

Appendix J: ANSI Table

ANSI Standard Device Numbers & Common Acronyms

Suffixes	Description
_1	Positive-Sequence
_2	Negative-Sequence
A	Alarm, Auxiliary Power
AC	Alternating Current
AN	Anode
B	Bus, Battery, or Blower
BF	Breaker Failure
BK	Brake
BL	Block (Valve)
BP	Bypass
BT	Bus Tie
BU	Backup
C	Capacitor, Condenser, Compensator, Carrier Current, Case, or Compressor
CA	Cathode
CH	Check (Valve)
D	Discharge (Valve)
DC	Direct Current
DCB	Directional Comparison Blocking
DCUB	Directional Comparison Unblocking
DD	Disturbance Detector
DUTT	Direct Underreaching Transfer Trip
E	Exciter
F	Feeder, Field, Filament, Filter, or Fan
G	Ground or Generator
GC	Ground Check
H	Heater or Housing
L	Line or Logic
M	Motor or Metering
MOC	Mechanism Operated Contact
N	Neutral or Network
O	Over
P	Phase or Pump
PC	Phase Comparison
POTT	Pott: Permissive Overreaching Transfer Trip
PUTT	Putt: Permissive Underreaching Transfer Trip
R	Reactor, Rectifier, or Room
S	Synchronizing, Secondary, Strainer, Sump, or Suction (Valve)
SOTF	Switch On To Fault
T	Transformer or Thyratron
TD	Time Delay
TDC	Time-Delay Closing Contact
TDDO	Time Delayed Relay Coil Drop-Out

Suffixes	Description
TDO	Time-Delay Opening Contact
TDPU	Time Delayed Relay Coil Pickup
THD	Total Harmonic Distortion
TH	Transformer (High-Voltage Side)
TL	Transformer (Low-Voltage Side)
TM	Telemeter
TT	Transformer (Tertiary-Voltage Side)
U	Under or Unit
X	Auxiliary
Z	Impedance

Acronyms	Description
AFD	Arc Flash Detector
CLK	Clock or Timing Source
CLP	Cold Load Pickup
DDR	Dynamic Disturbance Recorder
DFR	Digital Fault Recorder
ENV	Environmental Data
HIZ	High Impedance Fault Detector
HMI	Human Machine Interface
HST	Historian
MET	Substation Metering
PDC	Phasor Data Concentrator
PMU	Phasor Measurement Unit
PQM	Power Quality Monitor
RIO	Remote Input/Output Device
RTD	Resistance Temperature Detector
RTU	Remote Terminal Unit / Data Concentrator
SER	Sequence of Events Recorder
TCM	Trip Circuit Monitor
VTFF	Vt Fuse Fail

ANSI Standard Device Numbers & Common Acronyms

Device No.	Description
1	Master Element
2	Time Delay Starting or Closing Relay
3	Checking or Interlocking Realy
4	Master Contactor
5	Stopping Device
6	Starting Circuit Breaker
7	Rate of Change Relay
8	Control Power Disconnecting Device
9	Reversing Device
10	Unit Sequence Switch
11	Multifunction Device
12	Overspeed Device/Protection
13	Synchronous-Speed Device
14	Underspeed Device
15	Speed or Frequency Matching Device
16	Communication Networking Device
17	Shunting or Discharge Switch
18	Accelerating or Decelerating Device
19	Motor Starter / Starting-to-Running Transition Contactor
20	Electrically-Operated Valve
21	Distance Relay
21G	Ground Distance
21P	Phase Distance
22	Equalizer Circuit Breaker
23	Temperature Control Device
24	Volts-per-Hertz Relay / Overfluxing
25	Synchronizing or Synchronism-Check Device
26	Apparatus Thermal Device
27	Undervoltage Relay
27P	Phase Undervoltage
27TN	Third Harmonic Neutral Undervoltage
27X	Auxiliary Undervoltage
27 AUX	Undervoltage Auxiliary Input
27/27X	Bus/Line Undervoltage
28	Flame Detector
29	Isolating Contactor
30	Annunciator Relay
31	Separate Excitation Device
32	Directional Power Relay
32L	Low Forward Power
32N	Wattmetric Zero-Sequence Directional
32P	Directional Power
32R	Reverse Power

Device No.	Description
33	Position Switch
34	Master Sequence Device
35	Brush-Operating or Slip-ring Short Circuiting Device
36	Polarity or Polarizing Voltage Device
37	Undercurrent or Underpower Relay
37P	Underpower
38	Bearing Protective Device / Bearing Rtd
39	Mechanical Condition Monitor
40	Field Relay / Loss of Excitation
41	Field Circuit Breaker
42	Running Circuit Breaker
43	Manual Transfer or Selector Device
44	Unit Sequence Starting Relay
45	Atmospheric Condition Monitor
46	Reverse-Phase or Phase Balance Current Relay or Stator Current Unbalance
47	Phase-Sequence or Phase Balance Voltage Relay
48	Incomplete Sequence Relay / Blocked Rotor
49	Machine or Transformer Thermal Relay / Thermal Overload
49RTD	RTD Biased Thermal Overload
50	Instantaneous Overcurrent Relay
50BF	Breaker Failure
50DD	Current Disturbance Detector
50G	Ground Instantaneous Overcurrent
50N	Neutral Instantaneous Overcurrent
50P	Phase Instantaneous Overcurrent
50_2	Negative Sequence Instantaneous Overcurrent
50/27	Accidental Energization
50/74	Ct Trouble
50/87	Instantaneous Differential
50EF	End Fault Protection
50IG	Isolated Ground Instantaneous Overcurrent
50LR	Acceleration Time
50NBF	Neutral Instantaneous Breaker Failure
50SG	Sensitive Ground Instantaneous Overcurrent
50SP	Split Phase Instantaneous Current
51	Ac Time Overcurrent Relay
51	Overload
51G	Ground Time Overcurrent
51N	Neutral Time Overcurrent
51P	Phase Time Overcurrent
51V	Voltage Restrained Time Overcurrent
51R	Locked / Stalled Rotor

Device No.	Description
51_2	Negative Sequence Time Overcurrent
52	Ac Circuit Breaker
53	Exciter or Dc Generator Relay
54	Turning Gear Engaging Device
55	Power Factor Relay
56	Field Application Relay
57	Short-Circuiting or Grounding Device
58	Rectification Failure Relay
59	Overvoltage Relay
59B	Bank Phase Overvoltage
59P	Phase Overvoltage
59N	Neutral Overvoltage
59NU	Neutral Voltage Unbalance
59P	Phase Overvoltage
59X	Auxiliary Overvoltage
59_2	Negative Sequence Overvoltage
60	Voltage or Current Balance Relay
60N	Neutral Current Unbalance
60P	Phase Current Unbalance
61	Density Switch or Sensor
62	Time-Delay Stopping or Opening Relay
63	Pressure Switch Detector
64	Ground Protective Relay
64F	Field Ground Protection
64S	Sub-harmonic Stator Ground Protection
64TN	100% Stator Ground
65	Governor
66	Notching or Jogging Device/Maximum Starting Rate/Starts Per Hour/Time Between Starts
67	Ac Directional Overcurrent Relay
67G	Ground Directional Overcurrent
67N	Neutral Directional Overcurrent
67P	Phase Directional Overcurrent
67SG	Sensitive Ground Directional Overcurrent
67_2	Negative Sequence Directional Overcurrent
68	Blocking Relay / Power Swing Blocking
69	Permissive Control Device
70	Rheostat
71	Liquid Switch
72	Dc Circuit Breaker
73	Load-Resistor Contactor
74	Alarm Relay
75	Position Changing Mechanism

Device No.	Description
76	Dc Overcurrent Relay
77	Telemetering Device
78	Phase Angle Measuring or Out-of-Step Protective Relay
78V	Loss of Mains
79	Ac Reclosing Relay / Auto Reclose
80	Liquid or Gas Flow Relay
81	Frequency Relay
81O	Over Frequency
81R	Rate-of-Change Frequency
81U	Under Frequency
82	Dc Reclosing Relay
83	Automatic Selective Control or Transfer Relay
84	Operating Mechanism
85	Carrier or Pilot-Wire Receiver Relay
86	Locking-Out Relay
87	Differential Protective Relay
87B	Bus Differential
87G	Generator Differential
87GT	Generator/Transformer Differential
87LG	Ground Line Current Differential
87S	Stator Differential
87S	Percent Differential
87L	Segregated Line Current Differential
87M	Motor Differential
87O	Overall Differential
87PC	Phase Comparison
87RGF	Restricted Ground Fault
87T	Transformer Differential
87V	Voltage Differential
88	Auxiliary Motor or Motor Generator
89	Line Switch
90	Regulating Device
91	Voltage Directional Relay
92	Voltage And Power Directional Relay
93	Field-Changing Contactor
94	Tripping or Trip-Free Relay
50/74	Ct Supervision
27/50	Accidental Generator Energization
27TN/59N	100% Stator Earth Fault