American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-13, Issue-11, pp-65-75
www.ajer.org
Research Paper Open Access

Over Current Relay Coordination in a Chiller Motor Control Center (Case Study: Salvation Ministries Cathedral)

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Abstract
Effective coordination of protective devices is essential for maintaining the safety and reliability of electrical systems, especially in large facilities like cathedrals where cooling demands can fluctuate widely. Overcurrent relay coordination is a critical aspect of power system protection, ensuring that protective devices operate selectively and reliably during fault situations. The protection of motors within Motor Control Centers (MCCs) is especially important in industrial settings, as motors are integral to the operation. This research focuses on the optimal coordination of overcurrent relays in the chiller motor control center at the Salvation Ministries Cathedral project. The study examines the current relay settings and operational parameters, using simulation tools to evaluate system performance under different fault scenarios. For this undergraduate project, ETAP software was used to design the Single Line Diagram (SLD) of the MCC network, define equipment parameters, perform load flow and short circuit analyses, and conduct a protection coordination study. Manual calculations for the relay Time Multiplier Settings (TMS) and pickup settings were made, and the results were input into the relay properties in ETAP. Upon simulating fault conditions, it was observed that the relay sequence of operation was properly coordinated when faults were introduced at various points, including CH01, CH05, and LVBUS1&2, after inputting the calculated values for pickup and TMS. In conclusion, the protection of the Chiller Motor Control Center network is ensured in the event of a fault, regardless of the fault's location, through comprehensive fault analysis and protection coordination.
Keywords: *MCC, Chiller, HVAC, Relay Coordination, ETAP, Time Current Curve Fitting, Time Multiplier Setting, Pickup Current.*

Date of Submission: 09-11-2024 Date of acceptance: 21-11-2024

I. INTRODUCTION

Power system protection is a key area within electrical power engineering, aimed at continuously monitoring the power system to ensure a steady supply of electricity without causing harm to equipment. As power systems evolve, safeguarding them has become increasingly important. While engineers work to design systems that can withstand any potential failure, it is clear that creating a completely failure-proof system is impossible. This highlights the importance of protection systems and protective relays. In electrical engineering, a protective relay is an advanced electromechanical device that monitors the operational conditions of an electrical circuit and triggers circuit breakers when a fault is detected. Designing effective protective relays requires a deep understanding of fault characteristics. Therefore, protection engineers must have a thorough knowledge of the tripping behavior of different types of relays. Statistical data shows that many relay activations are due to incorrect or inadequate settings, rather than actual faults. [1]

The main objective of power system protection is to quickly identify faults and eliminate them, aiming to isolate only the faulty component or the smallest possible group of components when possible[2]Since the primary protection system may fail due to issues like relay or breaker malfunctions, backup protection mechanisms must be engaged, either within the same station or across adjacent lines. These backups are activated with time delays that meet the selectivity criteria. The process of establishing the appropriate time delays for all backup relays is referred to as coordinating the protection system.[3]

CHILLER

A chiller is a mechanical device used in commercial HVAC systems to cool indoor air. Essentially, it works by transferring heat from the interior of a building to an external location. This heat can originate from several sources, such as solar radiation hitting the building's exterior, or from the heat generated by the building's occupants and the equipment they use, which can increase the indoor temperature.[4]

A chiller is a device that removes heat from a liquid using either a vapor-compression or absorption refrigeration cycle. In a vapor-compression chiller, a refrigerant acts as the working fluid. There are various refrigerant options to choose from, and selecting the right one involves matching the chiller's application, cooling temperature requirements, and the refrigerant's thermal properties.

Chillers transfer heat away from a space that requires climate control much like a traditional split system or package unit does, but they use water (or a water solution) to do so instead of air.

Air-conditioning is the largest consumer of energy worldwide, with similar patterns of energy use observed in cities across tropical and subtropical regions. As urbanization and economic growth continue globally, the demand for air-conditioning is expected to rise. Consequently, energy-efficient air-conditioning systems present significant potential for both energy savings and reducing carbon emissions, making them a key focus in the building sector. In a central heating, ventilation, and air-conditioning (HVAC) system, chillers are crucial components, as they provide the necessary cooling and account for the majority of electricity consumption. The market offers various types of chillers, including conventional vapor-compression chillers, oil-free chillers, absorption chillers, and adsorption chillers, each with its own distinct features, advantages, and limitations.

The choice of chiller type depends on the specific site conditions and requirements, as some chillers may be more suitable than others for particular applications. This paper will explore the cooling mechanisms, characteristics, energy efficiency, environmental impact, and costs of each chiller type. The technical insights provided will help guide the selection of chillers in HVAC system design, leading to significant energy savings, reduced carbon emissions, and cost reductions.

Types of Chiller system

There are two types of chillers: water-cooled and air-cooled.

- *air-cooled chiller* works a bit like a radiator that cools an automobile engine. It works by using a fan to blow air across tubes filled with refrigerant liquid. This carries the heat away.

Air-cooled chillers are commonly used in small to medium-sized commercial properties. These systems perform most efficiently when ambient temperatures are below 95°F.

They are generally easier to install and tend to be less expensive compared to other types of chillers. However, because they are often installed on rooftops, air-cooled chillers may have a shorter lifespan than other options. Exposure to weather elements such as rain, snow, and wind can lead to potential damage or blockages, reducing their durability.

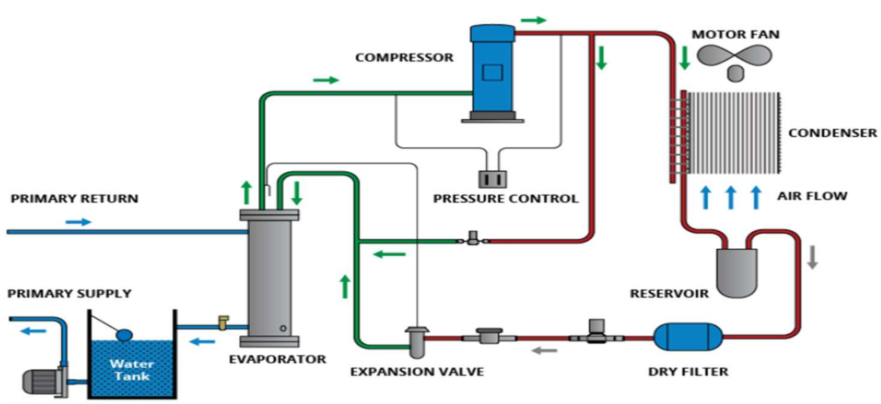

Fig 1: Diagram of an Air-cooled chiller system

- *Water-cooled* types of chillers work in much the same way as air-cooled chillers. However, instead of blowing air across tubes of refrigerant, water-cooled chillers transfer heat in a two-step process.

In a water-cooled chiller system, heat is first transferred from the vapor to the water in the condenser. The heated water is then pumped to a cooling tower, where the heat is dissipated into the air, often with the help of a fan to enhance heat removal.
Water-cooled chillers are commonly used in commercial settings where a reliable water supply is available. Unlike air-cooled chillers, water-cooled systems are less affected by changes in ambient air temperature, making them a more efficient option for medium- to large-sized commercial buildings.
Water-cooled chillers often reside in a basement. Because they're protected from the elements, water-cooled chillers tend to have a longer lifespan. However, they're more complex and usually have higher installation and maintenance costs.

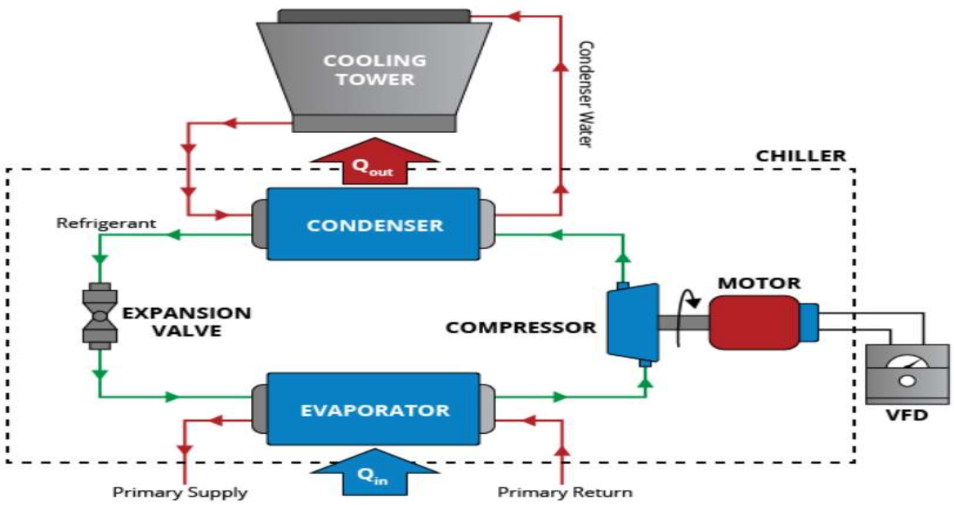

Fig 2: Diagram of a Water-cooled Chiller system

Basic Chiller Components
The central chiller components include the following:
i. *Compressor*
Compressor is the most important component in a chiller. It is similar to the heart in our blood circulation system. The compressor accounts for most of the electricity consumed by the entire air-conditioning system. There are different types of compressors available in the industry, including scroll, reciprocating, screw and centrifugal compressors. Based on the initial costs and operating costs, each compressor type has a favourable range of cooling capacity.

ii. *Condenser*
The function of a chiller condenser unit is to eliminate heat from the refrigerant being circulated through the chiller unit. This is achieved by circulating water between a cooling tower and the condenser for water-cooled variants or blowing cool air over condenser piping for air-cooled chiller units.
iii. *Evaporators*
An evaporator is placed between the expansion valve, and the condenser removes heat from any associated process into circulating refrigerant. This is then channeled to a cooling tower or air-cooled depending on the chiller configuration.
iv. *Thermal Expansion Valves*
Thermal expansion valves located between the compressor and the evaporator serve to expand refrigerant passing through them. This action diminishes the pressure and improves the heat elimination from the evaporator.
v. *Power Unit*
Every chiller incorporates a power unit that controls electrical energy flowing through the system. Power unit components usually include starters, power monitoring panels, and circuit breakers.
vi. *Control Panels*
Control panels serve to regulate the entire process of cooling operation. They usually integrate sensors, alarms, and display screens that allow operators to adjust system settings for optimal thermal control.

vii. *Water Boxes*
These devices may be mounted on either the chiller system evaporator or its water-cooled condenser. Their purpose is to conduct water flow effectively.

MOTOR CONTROL CENTER

A Motor Control Center (MCC) is a centralized system designed to control electric motors. It consists of several enclosed sections connected by a common power bus, with each section containing a combination starter. This starter includes a motor starter, fuses or a circuit breaker, and a power disconnect. An MCC may also include components such as push buttons, indicator lights, variable-frequency drives, programmable logic controllers (PLCs), and metering equipment. In some cases, the MCC may be integrated with the building's electrical service entrance. Typically found in large commercial or industrial facilities, MCCs manage multiple electric motors from a central location, often in a mechanical or electrical room. Before the advent of MCCs, preventive and corrective maintenance in production plants was carried out in a decentralized manner, leading to inefficiencies and delays in the production process. With MCCs, motors can be started or stopped with a single button, streamlining operations and saving valuable time in the production workflow. [5]

The MCC includes key components like contactors, fuses, circuit breakers, and overcurrent relays to protect and isolate motors from faults. This setup integrates a protection system into the MCC. The primary goal of the protection system is to quickly and effectively isolate any faulty part of the network, preventing additional damage and maintaining a continuous power supply to the unaffected areas of the system. [6]

OVERCURRENT RELAY COORDINATION

Overcurrent relays are utilized to safeguard motors and prevent damage caused by extended short circuit conditions. When a short circuit fault occurs, the overcurrent relays work alongside circuit breakers to trip and interrupt the circuit. [7]. Overcurrent relays are activated when the current flowing through them exceeds a predetermined threshold. If incorrectly configured, this result in frequent tripping, causing consistent disruption in plant operations and miscoordination. Hence, it is important to ensure proper relay coordination in a Chiller Motor Control Center.

Relay coordination involves strategically arranging and setting up relays to trip in a precise sequence, effectively isolating faults [8]. In order for relay coordination to be effective, it is crucial that the primary relay initiates before the back up relay, That is, the relay closer to the fault location must trip first. This requires careful selection of Pickup values and Time Dial Settings TDS for each relay, which can be calculated by adjusting the Time-Current Curve TCC.

The Time-Current Curve (TCC) displays the response time of overcurrent relays at different current levels and be adjusted to modify the Time Dial settings (TDS) and Pickup values. Time-Current curve (TCC) fitting involves shifting and adjusting the relay curve to change the pickup or time multiplier setting (TMS) values for proper relay coordination. [9]

In this research work, relay coordination including TCC fitting is performed utilizing the Electrical Transient Analyzer Program (ETAP).

II. MATERIALS AND METHODS

Materials gathered

1. Single Line Diagram SLD obtained from HVAC Chiller MCC Panel CHDP 1 and 2 designed by DESL for Salvation Ministry Cathedral Project.
2. Data obtained from the field
3. Personal computer
4. Software: AutoCAD, ETAP19.01

Existing Single Line Diagram of Salvation Ministries Cathedral MCC Network

The SLD shows the arrangement and interconnections between components in the Chiller MCC Network. From the SLD, a 3000MVAsc/11KV Public Utility supplied power to 2 x 2MVA 11/0.415KV power transformers, which supplies power to 0.415kV busbars (LVBUS-1 and LVBUS-2) which are coupled via a 3200A Bus coupler. LVBUS-1 and LVBUS-2 feeds three (3) 611.2kW and one (1) spare three phase HVAC Chiller loads each.

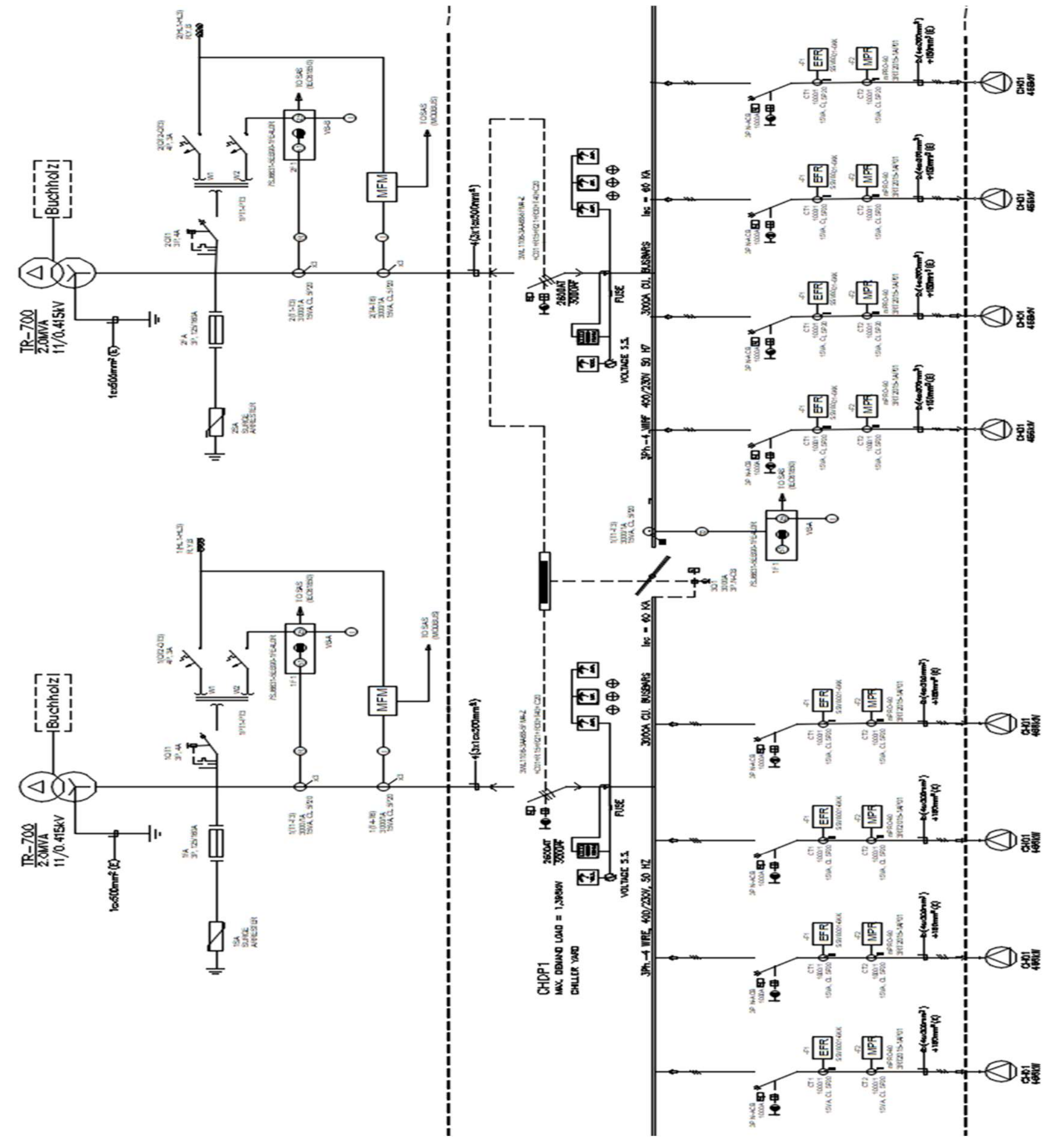

Fig 3: AutoCAD Presentation of the single line diagram of CHDP 1 & 2 MCC Panel Network at SMCP

Table 1; Equipment Specification and Values of MCC Network

DESCRIPTION	RATING
Public Utility	3000MVAsc/11kV
Siemens 12-3AF-16 HVCB	630A/16kA/12kV x 3
Transformer, TR-703	2MVA 11/0.415KV
Transformer, TR-704	2MVA 11/0.415KV
Schneider MVS32-N	3200A/42kA/0.69kV x 3
Schneider MVS10-H	1000A/65kA/0.69kV x 8
HVAC CHILLERS CONNECTED ON LVBUS-1	
Chiller, CH-01	611.2KW/0.415KV
Chiller, CH-02	611.2KW/0.415KV
Chiller, CH-03	611.2KW/0.415KV
Chiller, CH-04 (Spare)	611.2KW/0.415KV
HVAC CHILLERS CONNECTED ON LVBUS-2	
Chiller, CH-05	611.2KW/0.415KV
Chiller, CH-06	611.2KW/0.415KV
Chiller, CH-07	611.2KW/0.415KV
Chiller, CH-08 (Spare)	611.2KW/0.415KV

Methods used

ETAP software was utilized to perform load flow analysis, employing the Newton-Raphson technique, as well as short circuit analysis and protection coordination. Utilizing the results obtained from the load flow and short circuit analysis, manual calculations were carried out to determine relay settings (TDS and Pickup).

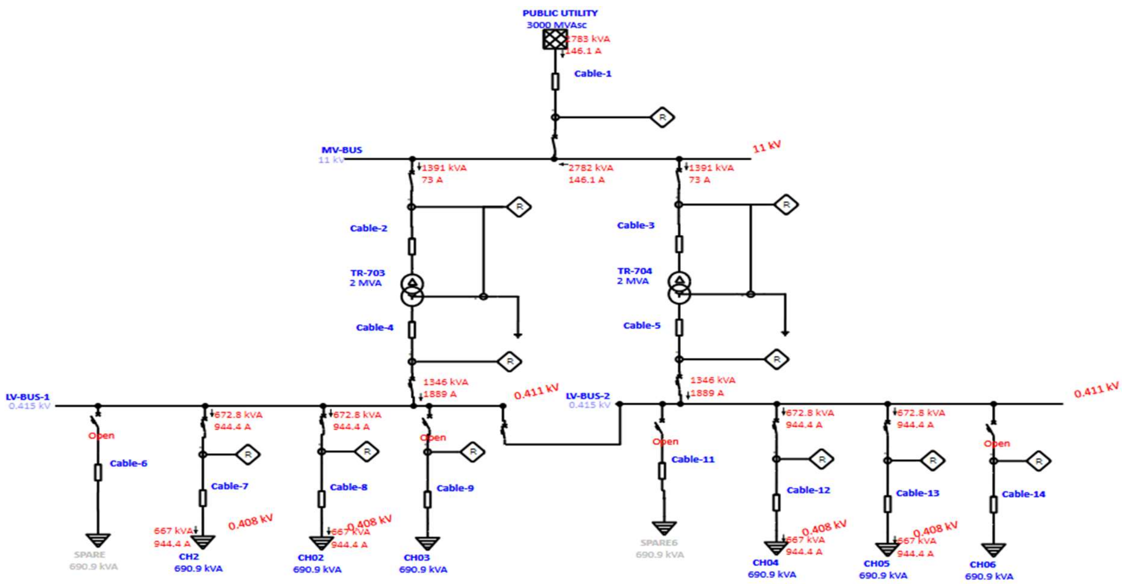

Fig4: Load Flow Analysis of MCC Network

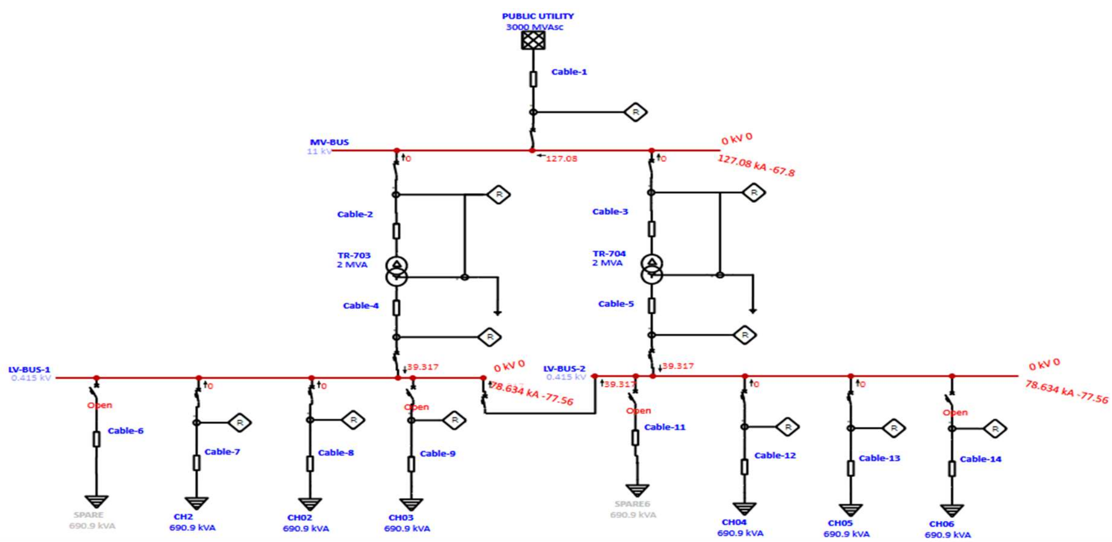

Fig5: Short Circuit Analysis of MCC Network

Manual Calculations Of Relay Settings

Pickup Current $= 110\% \times Full\ Load\ Current\ (FLA)$

Pickup Current in Relay $= \frac{110\% \times FLA}{CT\ Ratio}$

Relay Operating Time, t $= \frac{\alpha \times TMS}{(PSM)^{\beta} - 1}$

TMS $= \frac{t\left[(PSM)^{\beta} - 1\right]}{\alpha}$

PSM $= \frac{I_F}{I_P} = \frac{Fault\ Current}{Pickup\ Cuirrent}$

time= Constant

β= Constant
I_F= Fault Current in relay
I_P= Relay Pick up current
t= Relay operating
From the equation above two constant values α and β are seen. These constant values depend on the relay curve type. Different relay curve types are available on ETAP relay properties. The values for α and β are shown for different curve types on table 2

Table 2: IEC Constants Values for Relay Curve types

Curve Type	A	B
Standard Inverse	0.14	0.02
Very Inverse	13.5	1.0
Extremely Inverse	80.0	2.0
Long-time Inverse	120.0	1.0

For the purpose of this work the very inverse relay curve type is used throughout.
Using formulas stated above, the relay setting values for (PSM, Pickup and TMS) were calculated as seen in table 3 below. The values of Operating Time t (s) and CT ratio were selected while fault current values were gotten the short circuit analysis conducted in ETAP

Table 3. Relay setting Values

Relays	Selected CT Ratio (A)	Fault current I_F (A)	Pick-up Current, I_P (A)	Pickup in relay	PSM	t(secs)	TSM
Relay-1	300/1	1325	255.09	0.85	5.19	1.6	0.496
Relay-2 &3	300/1	546	115.5	0.38	4.73	1.2	0.332
Relay-4 & 5	3200/1	15269.4	3060.2	0.95	4.99	0.8	0.236
Relays (7-14) protecting 611.2KW Chillers	1000/1	5345	1057.3	1.06	5.05	0.5	0.150

The pickup and TMS (Time Dial) values for the respective relays are inputted into the relay property dialogue box on ETAP. After the insertion of bolted fault various buses on ETAP the following relay sequence of operation were observed as shown in figures 6-9.

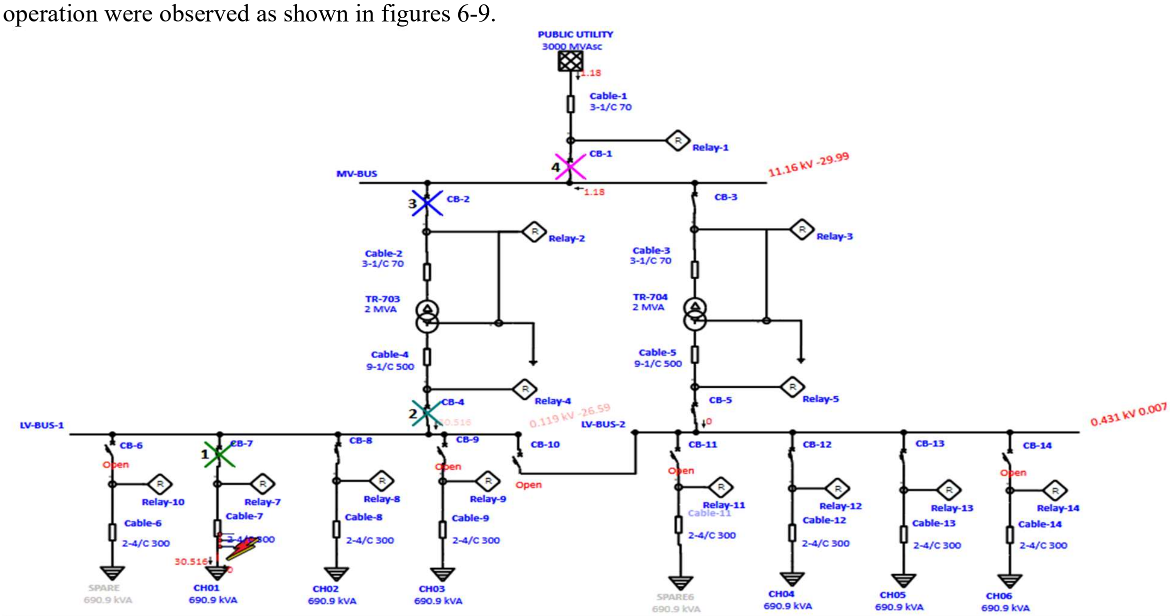

Fig 6: Relay Sequence of Operation with fault insertion on CH-01 (611.2KW) after inputting Calculated Pickup and TMS values

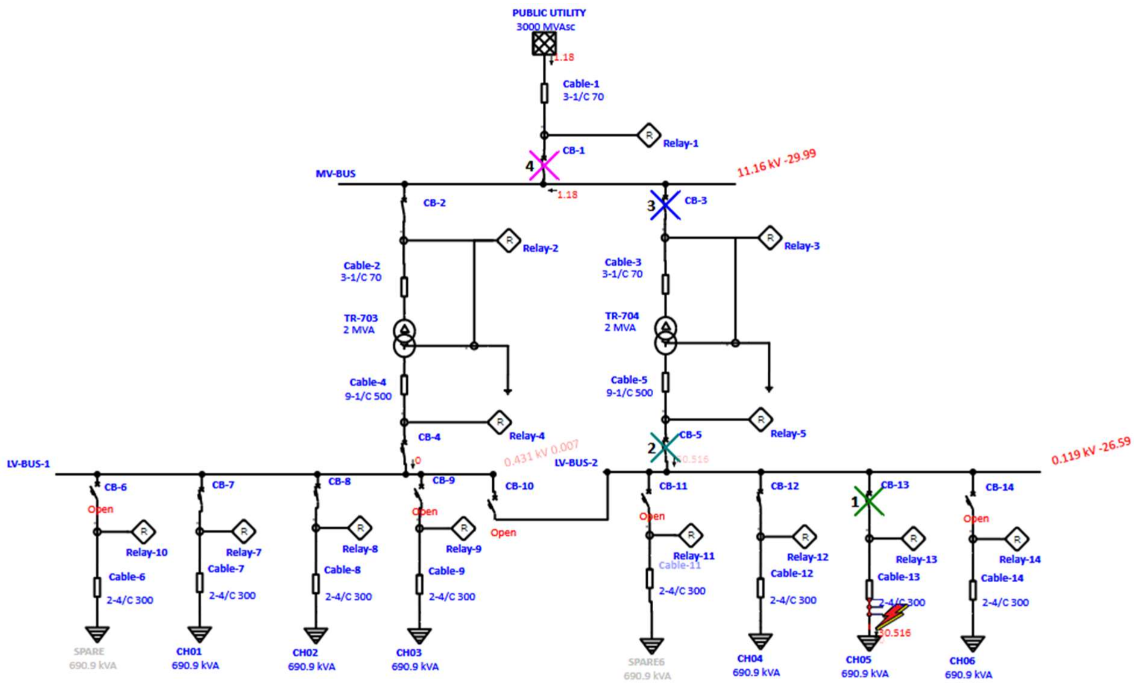

Fig 7: Relay Sequence of Operation with fault insertion on CH05 (611.2KW) after inputting calculated Pickup and TMS values

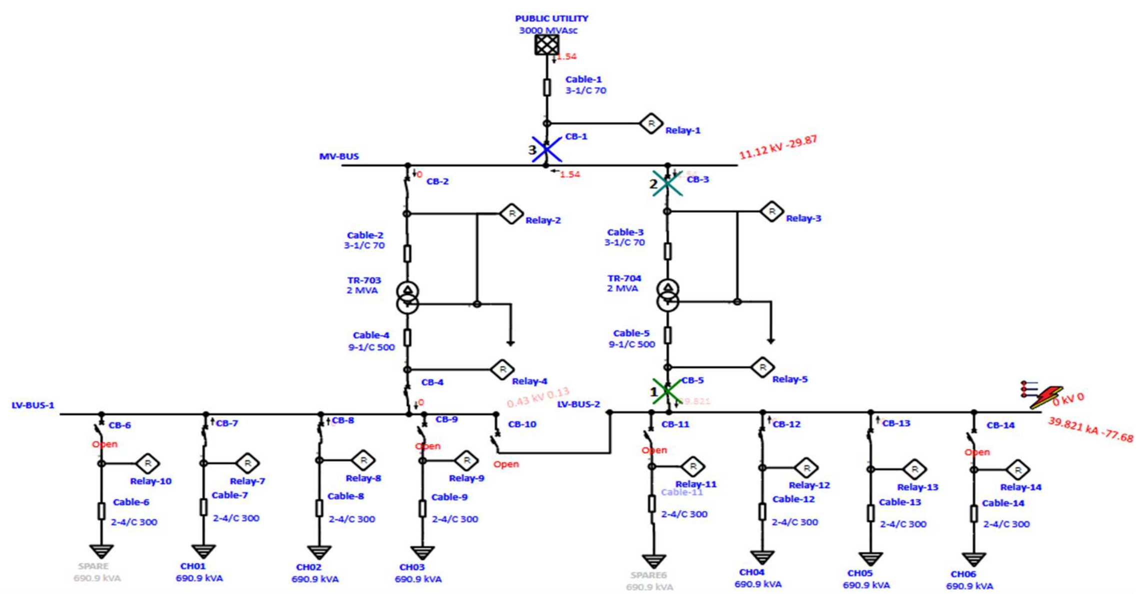

Fig 8: Relay Sequence of Operation with fault insertion on LV-BUS-2 after inputting Calculated Pickup and TMS values

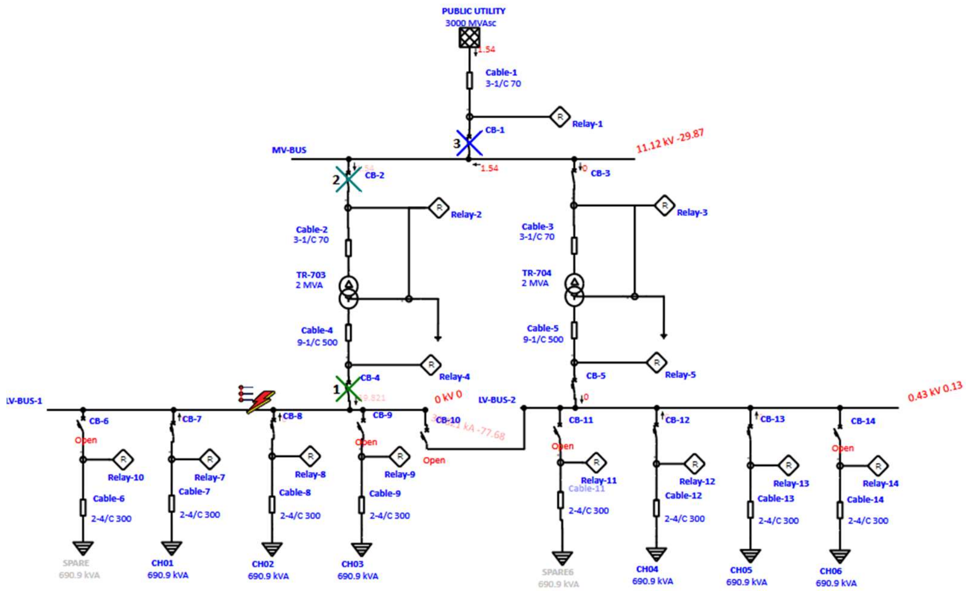

Fig. 9: Relay Sequence of Operation with fault insertion on LV-BUS-1 after inputting Calculated Pickup and TMS values

Time Current Characteristics (TCC) Curve Fitting

This is another way of protection coordination for a mis-coordinated system. In a situation where the relay sequence of operation is miscoordinated after inputting calculated pickup and TMS values, a star view is created showing a graph containing the characteristic curve of several relays in the network. The shifting or adjustment of these relay curves in order to change the Pickup or TMS values to ensure proper coordination of the relays is known as TCC curve fitting.

From Fig 6-9, it is seen that relay sequence of operation with fault insertion on various selected points are all coordinated. In a properly coordinated system the sequence of operation of the relays should be relays above the point of fault

Fig10 Shows the TCC curve for relay 1 to relay 14.

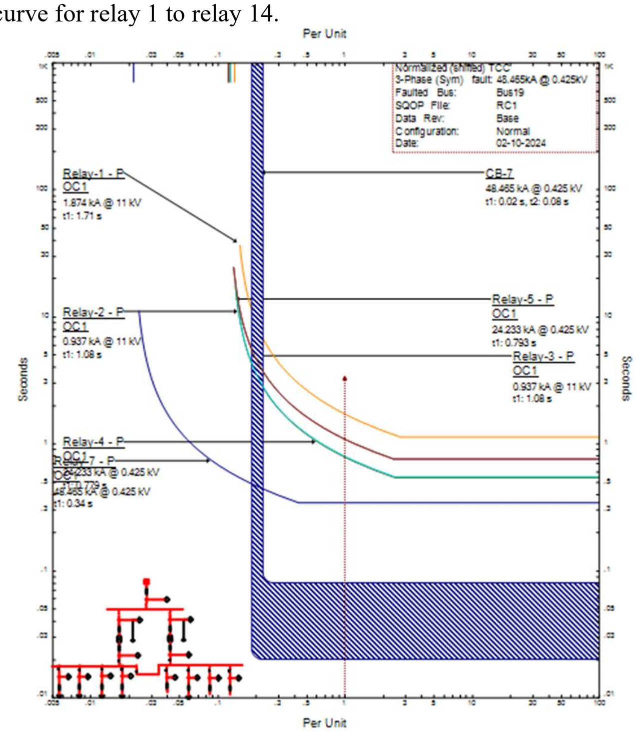

Fig10: TCC Curve with fault insertion on CH01 and the Bus Coupler kept Closed

III. RESULTS AND DISCUSSION

From Fig 6-9, it is seen that relay sequence of operation with fault insertion on various selected points are all coordinated for fault insertion on CH01, CH05 and LVBUS1&2respectively after the inputting the calculated values for pickup and TMS

Fault insertion on Chiller CH01

Though the relay coordination for fault insertion on CH01 shown in Fig6 is excellent, a critical look at the sequence of operation is still necessary. All the relays protecting the Chiller trip first between 340msec to 365msec. Followed by Relay-4 which tripped at 700msec. Next, Relay-2 and Relay-1 trips with a trip time of 971msec and 2,232msec respectively. The difference between the trip time of Relay-7 and Relay-4 is 360msec and 1,261msec between Relay-2 and Relay-1. The sequence of operation is correct and the time margin between the relays are satisfactory.

Sequence-of-Operation Events - Output Report: RC1

3-Phase (Symmetrical) fault on bus: Bus19

Data Rev.: Base Config: Normal Date: 10-10-2024

Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
340	Relay-7	30.516	340		Phase - OC1 - 51
365	CB-7		25.0		Tripped by Relay-7 Phase - OC1 - 51
700	Relay-4	30.516	700		Phase - OC1 - 51
725	CB-4		25.0		Tripped by Relay-4 Phase - OC1 - 51
971	Relay-2	1.18	971		Phase - OC1 - 51
1051	CB-2		80.0		Tripped by Relay-2 Phase - OC1 - 51
2232	Relay-1	1.18	2232		Phase - OC1 - 51
2312	CB-1		80.0		Tripped by Relay-1 Phase - OC1 - 51

Fig 11 Sequence of Operation with fault on CH01 (611.2KW)

Fault insertion on Chiller CH05

Similarly for fault insertion on CH05 the relay sequence of operation shown in Fig3.4(b) are proper. A closer look at the sequence of operation between them shown in Fig4.2 shows that Relay-13 which is connected directly to CH05 trips at 340msec. The trip time interval between relay-13 and relay-5 is 372msec. Same goes for relay-3 and relay-1 the trip time interval between them is as low as 1,261msec.

Sequence-of-Operation Events - Output Report: RC1

3-Phase (Symmetrical) fault on bus: Bus11

Data Rev.: Base Config: Normal Date: 10-10-2024

Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
340	Relay-13	30.516	340		Phase - OC1 - 51
365	CB-13		25.0		Tripped by Relay-13 Phase - OC1 - 51
712	Relay-5	30.516	712		Phase - OC1 - 51
737	CB-5		25.0		Tripped by Relay-5 Phase - OC1 - 51
971	Relay-3	1.18	971		Phase - OC1 - 51
1051	CB-3		80.0		Tripped by Relay-3 Phase - OC1 - 51
2232	Relay-1	1.18	2232		Phase - OC1 - 51
2312	CB-1		80.0		Tripped by Relay-1 Phase - OC1 - 51

Fig12: Sequence of Operation with fault on CH05

Table 4:All Relay data and settings

Designated Bus	Relay ID	Manufacturer & Model	PT / CT Ratio	Device Function	Trip Element	Curve	OCR (51, 51V), OLR (49, Acc.)		
							Pickup	Prim. Amps	Time Delay
LV-BUS-1	Relay-8	Siemens 7SJ64	1000:1	Overcurrent	Phase	IEC - Normal Inverse	0.970	970.000	0.150
LV-BUS-1	Relay-9	Siemens 7SJ64	1000:1	Overcurrent	Phase	IEC - Normal Inverse	0.970	970.000	0.150
LV-BUS-2	Relay-12	Siemens 7SJ64	1000:1	Overcurrent	Phase	IEC - Normal Inverse	0.970	970.000	0.150
LV-BUS-2	Relay-13	Siemens 7SJ64	1000:1	Overcurrent	Phase	IEC - Normal Inverse	0.970	970.000	0.150
LV-BUS-2	Relay-14	Siemens 7SJ64	1000:1	Overcurrent	Phase	IEC - Normal Inverse	0.970	970.000	0.150
MV-BUS	Relay-1	Siemens 7SJ64	300:1	Overcurrent	Phase	IEC - Normal Inverse	0.840	252.000	0.500
MV-BUS	Relay-2	Siemens 7SJ64	300:1	Overcurrent	Phase	IEC - Normal Inverse	0.370	111.000	0.300
LV-BUS-1	Relay-4	Siemens 7SJ64	3200:1	Overcurrent	Phase	IEC - Normal Inverse	0.870	2784.000	0.300
MV-BUS	Relay-3	Siemens 7SJ64	300:1	Overcurrent	Phase	IEC - Normal Inverse	0.370	111.000	0.300
LV-BUS-2	Relay-5	Siemens 7SJ64	3200:1	Overcurrent	Phase	IEC - Normal Inverse	0.870	2784.000	0.300
LV-BUS-1	Relay-7	Siemens 7SJ64	1000:1	Overcurrent	Phase	IEC - Normal Inverse	0.970	970.000	0.150

IV. CONCLUSION AND RECOMMENDATION

Conclusion

In the event of fault occurrence in the Chiller Load Network, irrespective of the fault location protection of the network has been assured through fault analysis and protection coordination study.

This network has been protected through the selection of appropriate CT size, calculation of pickup and TMS values. They are various relay curve but the IEC Normal Inverse curve was used in this project.

It is also important to note that in some cases, the use of calculated pickup and TMS values may not guarantee a perfect relay coordination hence, the reliance on TCC Curve fitting. Even in cases where the relays are already operating sequentially TCC curve fitting can improve the effectiveness of the relays by reducing the trip time intervals between relays ensuring not just sequential but timely interruption of fault current.

In TCC curve fitting relay coordination can be achieved by changing only the TMS Values while the pickup values remain unchanged. This is to ensure the pickup is not too small resulting in tripping of the Chillers when they are operating at full load and not too large resulting in inability to trip during faults that are below the selected pickup.5.2 Recommendations

***Recommendatio*n**

1. The rules for TCC Curve fitting might not be very clear hence, professional and highly skilled personnel are required to perform this task.
2. During Load analysis, fault analysis and protection studies consideration should be given to spares for future expansion

References

[1] Anupreyaa K; Karthiga T. S, "Relay Coordination for Distributed System," in 2016 Second International on Science Technology Engineering and Management (ICONSTEM), Chennai, India, 2016.

[2] Dikio I. C, Braide S. L; Igbogidi O. N, "Improved Relay Coordination in Port Harcourt Distribution Network. case study of RSU 2*15MVA, 33/11KV Injection Substation," American Journal of Engineering Research (AJER), vol. 7, no. 7, pp. 43-56, 2018.

[3] Dan Horsfall, Naanee Barinyima, "Intelligent Relay Coordination on Motor Control Center. Case study of Indorama Petrochemical company," European Journal of Science, Innovation and Technology, vol. 3, no. 6, pp. 305-312, 2023.

[4] HVAC Investigators, "The basics of chillers: How they work, where they're used, and common problems," n.d.

[5] Satyadeo V, "Motor Control Center Purpose, Classification and Advantage," 2022.

[6] Sowmiya T; Sujatha B, "Overcurrent Relay Coordination in Radial Distribution System.," International Journal of Advanced Research in Science, Communication and Technology (IJARSCT), vol. 12, no. 1, pp. 298-303, 2021.

[7] Atin C., "Importance of Motor Protection in modern industries," Schneider Electric, 2019.

[8] Hairi M, H; Muhammad N, K; Ahmad S, M; Mohamed M, F; Sharizal A. S, "Modelling an Overcurrent Relay Protection and Coordination in a Power System Network using PSCAD Software," International Journal of Electrical Engineering and Applied Science (IJEEAS), vol. 4, no. 1, pp. 35-38, 2021.

[9] Hairi P. A; Vaibhav M.S; Anuradha D, "Relay Coordination using ETAP," International Journal of Science and Engineering Research, vol. 6, no. 5, pp. 1583-1588, 2015.