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RELAY COORDINATION FOR ENHANCED ELECTRICAL PERFORMANCE: A STUDY ON INDORAMA FERTILIZER AND CHEMICALS LIMITED

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Abstract: *The research addresses the challenge of inadequate relay coordination at the motor control center of Indorama Fertilizer and Chemicals Limited. Utilizing the Electrical Transient Analyzer program (ETAP 19.0.1), the study employs methodologies such as Load Flow Analysis, Short Circuit Analysis, and Relay Setting and Coordination with Standard Inverse Time Delay (SIT) to model and simulate the electrical network. Findings reveal that during a base case scenario, a trip sequence failure occurs when a three-phase short circuit fault arises at the terminal of the synchronous motor labeled (syn1). The backup relay (R4) activates first at 286.5 ms, followed by the primary relay (R6) at 408.1 ms, relay 2 at 630.4 ms, and relay 1 at 864.5 ms. This miscoordination results in a total blackout of the Motor Control Unit (Cmtr1) due to a single downstream fault. To enhance coordination, a new relay setting is proposed, implementing IEC standard inverse characteristics to replace the existing definite-minimum-time (DMT) scheme with a more adaptable inverse-definite-minimum-time (IDMT) scheme. The revised configuration reduces the relay operation time by over 35% compared to the original setup, providing better fault backup and significantly improving the relay's operational sequence and tripping times without major coordination issues.*

Keywords: *Fault Analysis, ETAP, Inverse Definite Minimum Time, Motor Control, Relay Coordination, Short Circuit Analysis.*

1. INTRODUCTION

Relay coordination is a critical aspect of electrical system design, ensuring that protective relays function optimally to safeguard equipment from faults and prevent significant damage. By analyzing the time-current characteristics of relays and coordinating their settings, engineers can achieve reliable and efficient protection. When it comes to efficient and reliable motor control, a well-coordinated relay system is essential. A relay coordination study on a motor control centre plays a pivotal role in ensuring the smooth and safe operation of motors in industrial settings.

This critical analysis helps identify potential issues, such as inadequate protective device settings or coordination gaps, that may lead to equipment failure or even electrical incidents. By performing a relay coordination study, engineers can evaluate the settings and coordination of protective relays within the motor control centre. This study involves analyzing various aspects, including relay time-current characteristics, protective device settings, fault current levels, and system operating conditions.

The goal is to achieve optimal coordination between the relays, minimizing equipment damage and downtime while ensuring maximum protection for personnel. Incorporating the latest industry standards and engineering practices, a relay coordination study provides valuable insights into the existing system's weaknesses and identifies areas for improvement. By fine-tuning the settings and coordination of relays, engineers can mitigate the risk of electrical faults and optimize the motor control centre's performance. Additionally, this study helps in developing effective maintenance strategies and ensuring compliance with safety regulations.

When it comes to motor control centre relay coordination studies, precision and expertise are paramount. By entrusting this task to knowledgeable professionals, industries can enhance their operational efficiency, minimize risks, and ensure the longevity of their motor control systems.

2. LITERATURE REVIEW

In the electrical power system, relay coordination is crucial to achieving appropriate fault diagnosis and fault clearing sequencing. The relays must be able to differentiate between operational currents that are normal, and overcurrent brought on by fault circumstances.

Relay coordination ensures that the relay nearest to the problem location activates first. If this relay fails, the backup relay activates in a sequential manner to give additional protection. This was shown by enhancing the relay coordination in the RSU 2 x 15MVA, 33/11KV injection substation. Idoniboyeobu, et al. (2018) simulated their network using ETAP software to establish the relay operation sequence for the current network. They successfully resolved the tripping sequence violation in their enhanced relay coordination.

Horsfall et al. (2021) said that when fault current levels rise, mainly owing to causes like increased static load, the introduction of heavy-duty electric motors, and more network interconnections, the coordination of relays becomes increasingly challenging. Their research recognizes the growing difficulties encountered by power protection systems because of increasing fault current levels. It highlights the significance of load flow studies, short circuit current analysis, and the optimal configuration of OCRs employing (SIT).

Hima et al. (2015) compare short circuit analysis and relay coordination of overcurrent relays in a radial power system of an industrial power plant using ETAP simulation and manual calculation.

Ohore, et al. (2021) enhanced the Trans-Amadi 33KV Network by including safety relays using short-circuit current computation and a novel coordination approach. They simulated their network using version 12.6 of the ETAP program.

Amakiri et al. (2019) examined the Effurum 3 x 60 MVA 132/33KV transmission substation network in response to recent irregularities. Their investigation revealed that the primary reason for the fire, power loss, and unexpected tripping of protection devices was the mis-coordination of relay settings due to relying only on definite minimum time (DMT) and time overcurrent protection system for grading.

Mohammed & Mohammed (2020) introduced a Modified Particle Swarm Optimization (MPSO) approach that utilizes an adaptive simulated annealing inertia weight to address the issue of overcurrent relay coordination. They aimed to decrease the running time of the protective relays in their research, focusing on IEEE 15 and 30-bus networks. The research's performance metric was the operational time. The protective relays on the buses had much shorter operating times because of implementing the proposed solutions.

Mancer et al. (2015) suggested an ideal coordination method for directional overcurrent relays with series compensation by utilizing a modified version of the Particle Swarm Optimization algorithm that is based on the Time-Varying Acceleration Coefficients algorithm.

3. MATERIALS AND METHOD

3.1 Materials

The materials used for this research are:

Single Line Diagram (SLD) and Data obtained from the name plates of the various components in the field, ETAP 19.0 is used as a tool for design, simulation and relay setting.

3.2 Motor Load Specification

The specifications used for motor control center 1 and the line diagram for Indorama are presented in Table 1 and Figure 1 respectively.

Table 1: Specification for Motor Control Centre (MCC1)

S/No	Motor ID	HP	KVA	KW	Kvar	FLA
1	Syn 1	100	86.87	79.99	33.88	120.9
2	Mtr 1	75	66.2	60.47	26.93	92.1
3	Mtr 3	45	40.79	36.87	17.45	56.74
4	Mtr 5	60	53.74	48.8	22.49	74.76
5	Mtr 7	300	257	238.1	96.65	357.5

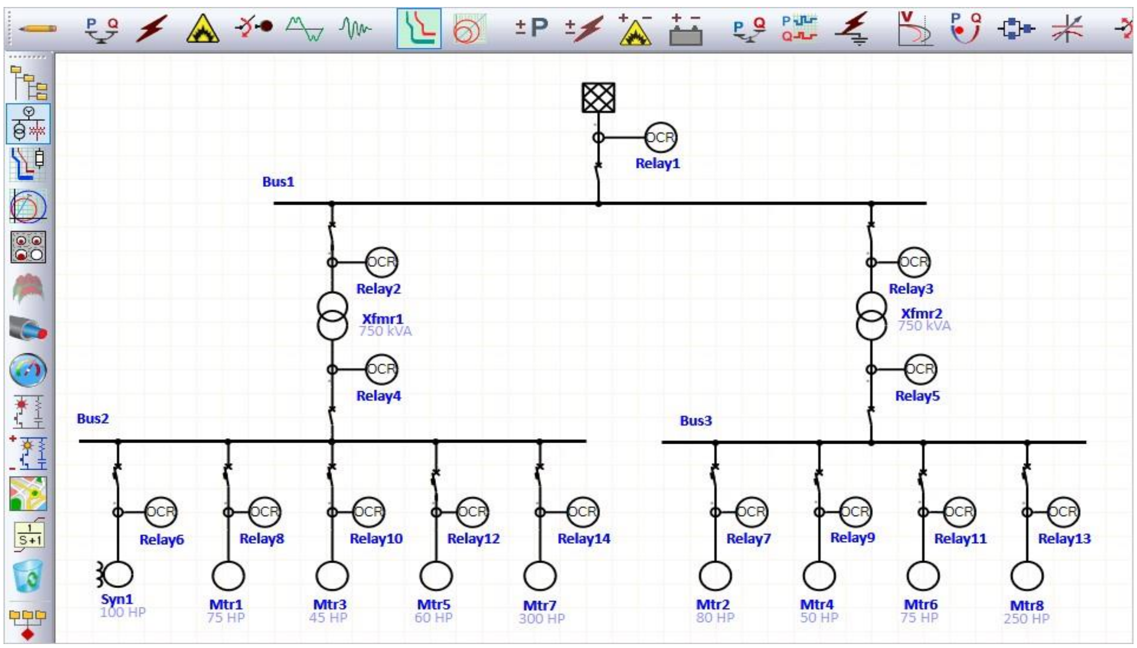

Figure 1: Single Line Diagram of Indorama Fertilizer and Chemical Limited Motor Control Centre

3.3 Methods

The research employs several techniques, including the Newton-Raphson method for Load Flow Analysis, the Per-Unit method for Short Circuit Analysis, and Relay Setting and Coordination using Standard Inverse Time Delay (SIT).

3.3.1 Load Flow Analysis (Newton- Raphson Method)

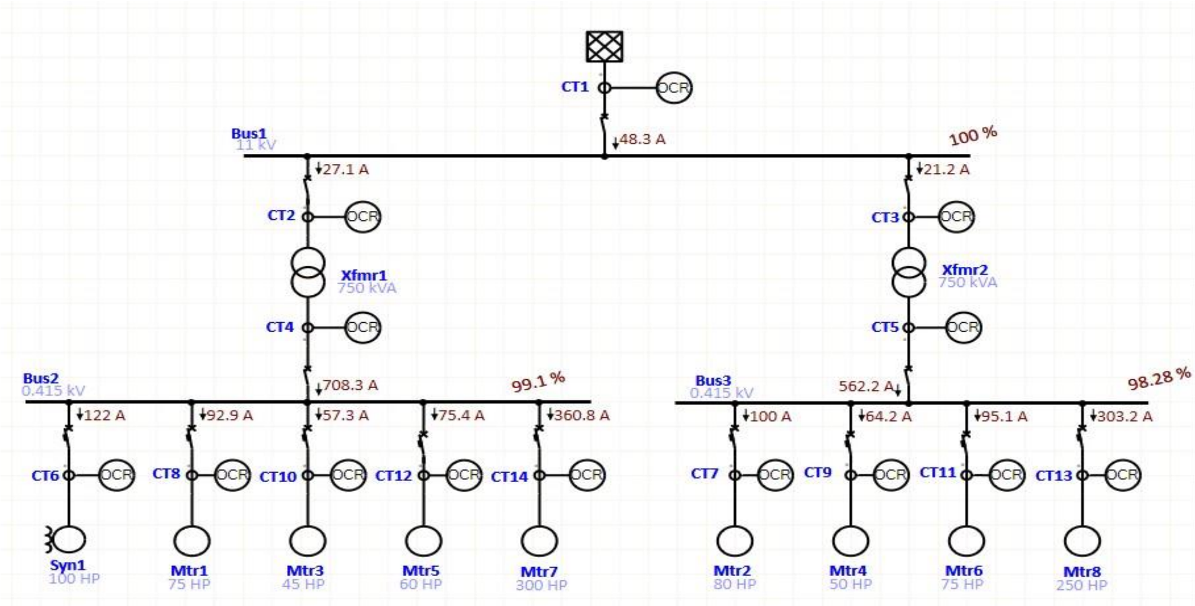

Figure 2: Etap Simulation of Load Flow Analysis on the Network

3.3.2 Short Circuit Analysis (Per-Unit Method)

Short circuit analysis is used to calculate the short circuit current and determine the circuit breaker's breaking and making capacity. Conducting a comprehensive short circuit analysis can help identify and resolve potential issues with the Motor Control Center (MCC) system, ensuring reliable and secure operation. All components on the network, including the supply grid, transformer, lines, and motors, are characterized by an impedance (Z). The per-unit method is used to determine the short circuit impedance values of the grid network and upstream transformers from the fault point.

Per–Unit Short Circuit Based Model:

Per Unit Quantity (voltage, current etc.) = $\frac{Actual\ Quantity}{Base\ Quantity}$ (1)

Base Current (Amperes) = $\frac{Base\ KVA}{\sqrt{3}(base\ kv)}$ $\frac{Base\ MVA}{\sqrt{3}\ (base\ kv)}$ or (2)

Base Impedance (Ohm) = $\frac{(Base\ KV)^2}{Base\ MVA}$ or $\frac{(Base\ V)^2}{Base\ KVA}$ (3)

Zp.u = $\frac{Actual\ impedance\ in\ ohms\ ,(base\ MVA)}{(base\ KV)_2}$ (4)

In resolving Zpu for power grid/source

Zpu = $\frac{Zohm,}{zbase}$, but Zbase = $\frac{V^2 base}{Sbase}$ (5)

Fault MVA = $\frac{Base\ MVA}{X_{eq}\ (pu)}$ (6)

Xef (pu) = $Fault Base\ MVA MVA$ (7)

Rpu = $X_{eq}(X/R\ pu))$ (8)

$Z\,pu = \sqrt{R^2 + X^2}$ (9)

From the equation:

Zohm = Zpu x Zbase

For Zpu for transformer

$Z_{pu}{}^{n} = Z\cdot pu\ (V^{V}{}_{B}{}^{B}{}_{n}{}^{o})^2 (S_{S}{}^{B}{}_{B}{}^{n}{}_{o})$ (10)

$x\ Z\,pu\ x\ ()$

$$Xpu = \frac{R}{\sqrt{1+\left(\frac{X}{R}\right)^2}}$$ (11)

Zpu total = Zpu (Source) + Zpu (Transformer)

$$\text{Fault current} = \frac{Fault\ MVA}{\sqrt{3}\ X\ V\ l-l}$$ (12)

Where V-L-L = line to line voltage

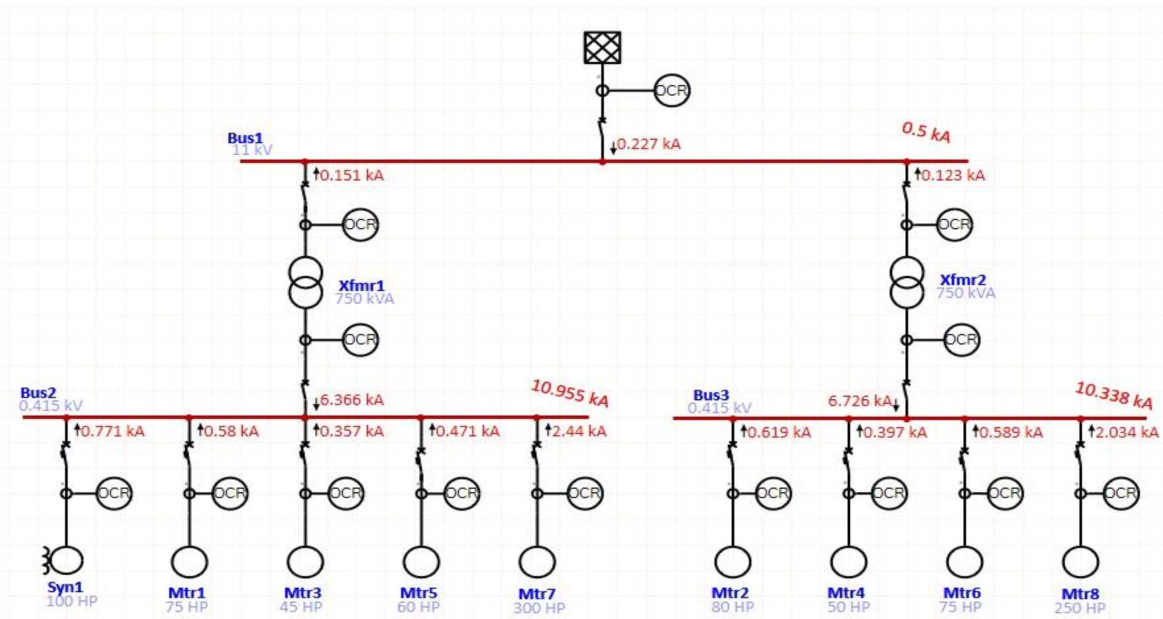

Figure 3: Etap Simulation of Short Circuit Analysis (SCA) on the Network

Calculation Of 3-Phase Short Circuit Current of The Network Using Hand Calculation:

The fault current flows from the Grid (Source) through (XFMR1) 750KVA and (XFMR2) 750KVA Connected in parallel. MVA_{SC} (Grid) = 323.893MVA

o.

MVA_{SC} (XFMR1) $\frac{75\ X100}{10}$ $=MVA_{SC}(XFMR2) = = 7.5MVA$

$MVA_{SC\ (Res)}$ of XFMR1 and XFMR2 = 7.5 + 7.5 = 15MVA

$$MVA_{SC}\ total = \frac{1}{\frac{1}{323.893}+\frac{1}{15}} = 14.336$$

$$\text{Fault Current at The Point of Fault} = \frac{14.336}{\sqrt{3}*0.415} = 19.944kA \approx 20kA.$$

3.3.3 Protective Apparatus Modelling

Current Transformer Setting

Current setting of a relay is set at 20% of the operating current (FLA) which is giving by

CT setting = $0.2 * FLA$ (13)

CT Sizing calculation for CT1

Full Load Current of Associated Device (GRID) = 48.3A

N/B: CT Primary Current rating should be 20% more than the full load current of the associated device.

$\frac{48.3A}{1} \frac{20}{100}$ X = 9.66A

$9.66A + 48.3A = 57.96A$ CT ratio =100:1 or 100:5.

Same procedure was carried out for other current transformers in the network to ascertain their suitable ratings.

Relay Pickup Current (Ipu)

$$I_{pu} = \frac{\text{Relay Current setting}}{\text{CT ratio}} \quad (14)$$

Fault in Relay Primary Coil

$$\text{Fault in Relay coil} = \frac{\text{Short Circit Fault Current (kA)}}{\text{CT ratio}} \quad (15)$$

Plug Setting Multiplier (PSM)

$$PSM = \frac{\text{Fault in Relay Coil}}{\text{Pickup Current}} \quad (16)$$

Relay Time Dial Multiplier Curve Type: Standard Inverse

$$\text{Time of operation} = \text{Time multiplier settings x} \left(\frac{K}{(PSM)^{\alpha} - 1}\right) \quad (17)$$

Where k = 0.14, α = 0.02.

Designed Calculation for Improved Coordination for Motor Control Centre1

For Relay 6

Full Load Current of Synchronous Motor (Syn1) =120.86A

CT 6 Primary Current =120% of Motor Full Load Current = 1.2x120.86 = 145.032A

CT ratio = $\frac{150}{5}$ Fault Current = 0.771kA

$$\text{Current in Relay Coil} = \frac{\text{Fault Current}}{\text{CT ratio}}$$

$$= \frac{771\ A}{150} x5 = 25.7A$$

$$\text{Relay Pickup Current } (I_{pu}) = \frac{1.2\text{xFull Load Current}}{\text{CT ratio}}$$

$$I_{Pu} = \frac{1.2x120.86}{150} x5 = 5$$

$$\text{Plug Setting Multiplier (PSM)} = \frac{\text{Current in Relay Coil}}{\text{Pickup Current}}$$

$$PSM = \frac{25.7\ A}{5\ A} = 5.32A$$

$$\text{Time of Operation (Top)} = \left[\frac{A}{PSM^{0.02} - 1}\right] X\ TMS$$

$$Top = \frac{0.14}{[5.32]^{0.02} - 1} X\ 0.05 = 0.206$$

For Relay 4

Time of operation of Relay 4 = 100 + 206 = 306ms

Full Load Secondary Current of Transformer 1 =1043.40 A

CT 4 Primary Current =120% of Transformer 1 Full Load Secondary Current

= 1.2x1043.40 = 1252.08 A

CT ratio = $\frac{1300}{5}$ Fault Current = 21.495kA

Current in Relay Coil = $\frac{\text{Fault Current}}{\text{CT ratio}}$

= $\frac{21495 \text{ A}}{1300}$ x5 = 82.6730 A

Relay Pickup Current (I_{pu}) = $\frac{\text{1.2xFull Load Current}}{\text{CT ratio}}$

$I_{Pu} = \frac{1.2x1043.40}{1300}$ x5 = 4.81569A

Plug Setting Multiplier (PSM) = $\frac{\text{Current in Relay Coil}}{\text{Pickup Current}}$

PSM = $\frac{82.6730 \text{ A}}{5 \text{ A}}$ = 17.1674

Time of Operation (Top) = $\frac{0.14}{[PSM]^{0.02}-1}$ X TMS

$0.306 = \frac{0.14}{[17.1674]^{0.02}-1} X\ TMS = 2.39284 * TMS$

TMS= $\frac{0.306}{2.39284} = 0.1$

For Relay 2

Time of operation of Relay 2 = 100 + 306 =406ms

Full Load Primary Current of Transformer 1 =39.36 A

CT 2 Primary Current =120% of Transformer 1 Full Load Secondary Current

= 1.2x39.36 = 47.23 A

CT ratio = $\frac{50}{5}$ Fault Current = 0.151kA

Current in Relay Coil = $\frac{\text{Fault Current}}{\text{CT ratio}}$

= $\frac{151 \text{ A}}{50}$ x5 = 15.1 A

Relay Pickup Current (I_{pu}) = $\frac{\text{1.2xFull Load Current}}{\text{CT ratio}}$

$I_{Pu} = \frac{1.2x39.36}{50}$ x5 = 4.72 A

Plug Setting Multiplier (PSM) = $\frac{\text{Current in Relay Coil}}{\text{Pickup Current}}$

PSM = $\frac{15.1 \text{ A}}{4.72 \text{ A}}$ = 3.2

Time of Operation $(Top) = \frac{}{[PSM]^{0.02}-1}$ X TMS

$0.406 = \frac{0.14}{[3.2]^{0.02}-1} X\ TMS = 5.948 * \text{TMS}$

TMS= $\frac{0.406}{5.948} = 0.068 \approx 0.1$

For Relay 1

Full Load Primary Current of Generator 1 =82.01 A

CT 1 Primary Current =120% of Generator 1 Full Load Secondary Current

= 1.2x82.01 = 98.4 A

CT ratio = $\frac{100}{5}$

Fault Current = 0.227kA

Fault Current

Current in Relay Coil = ________

CT ratio = 227 A x5 = 11.4 A

100 1.2xFull Load Current

Relay Pickup Current (I_{pu}) =

CT ratio 1.

$I_{Pu} = \frac{2x82.01}{100}$ x5 = 4.92A

Current in Relay Coil

Plug Setting Multiplier (PSM) = ______________

Pickup Current 11.4 A

PSM = ____ =2.32

4.92 A

A

Time of Operation $(Top) = \frac{}{[PSM]^{0.02}-1}$ X TMS

$0.506 = \frac{0.14}{[2.32]^{0.02}-1} X\ TMS = 8.248 * \text{TMS}$

TMS= $\frac{0.506}{8.248} = 0.061 \approx 0.1$

4. RESULTS AND DISCUSSION

Figure 4 illustrates the coordination of the relays tasked with protection during a three-phase shortcircuit fault at the terminal of the synchronous motor labeled Syn1 in Motor Control Center 1. The backup relay R4, located upstream from the fault, activated first at 286.5 ms, followed by the primary relay R6, which tripped at 408.1 ms downstream from the fault. This sequence results in a total blackout of the entire Motor Control Unit (Cmtr1) due to a single downstream fault in a motor unit, highlighting issues with relay coordination.

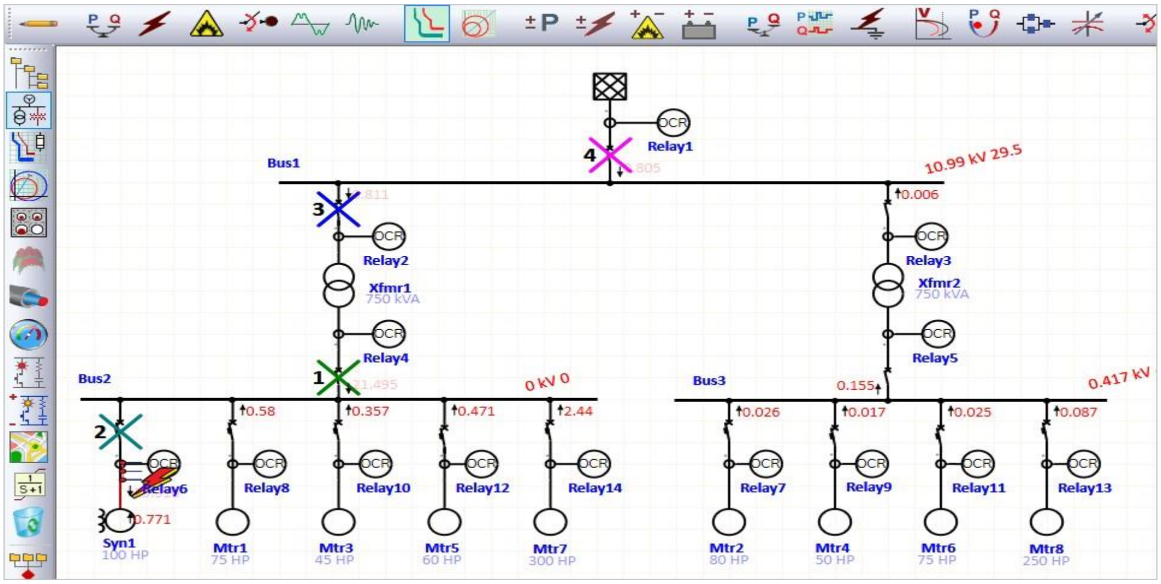

Figure 4: Base Case Simulation of Indorama Fertilizer and Chemical Limited Motor Control Centre

Figure 5 shows the improved relay coordination for Indorama motor control centre1 due to threephase short-circuit fault that occurred at the terminal end of a synchronous motor tagged Syn1. The result shows that the new settings provide a backup over fault in the system that is streamlined and does not result in gross miss-coordination. It is noted that after the relay setting has been changed, the operating sequence and time of the relay improved significantly. The primary relay R6 downstream from the point of fault tripped at 181.4ms followed by the backup relay R4 upstream from the point of fault at 294.8ms delayed by at least 150ms. If for any reason relay 4 fails to operate, then relay 2 will swing into action at 344.0ms and finally relay 1 at 569ms as shown in Figure 4 while figures 5 and 6 show the alert view and plot of improved sequence of operation for MCC1 respectively. This results further validates the findings of Horsfall et al (2021) that standard inverse time delay method gives better accommodation for the operation of the circuit breakers as compared to other inverse time delay characteristics such as Very Inverse (VIT), Extremely Inverse (EIT) etc.

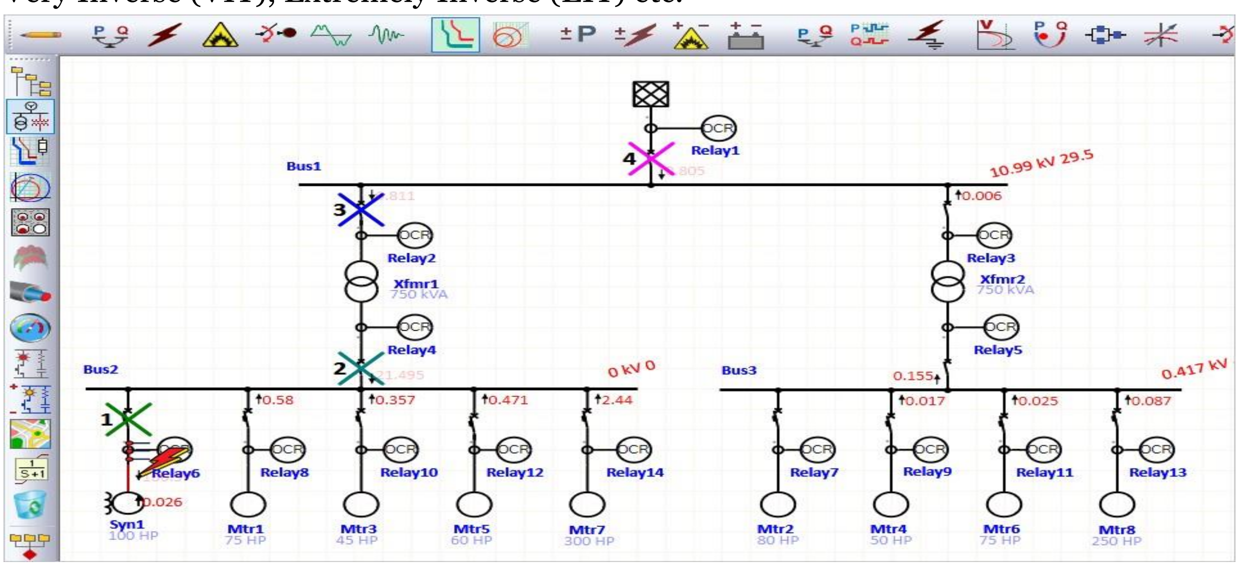

Figure 5: Improved Relay Coordination for Indorama Fertilizer and Chemicals Limited Motor Control Centre

Comparison of Protective Device Sequence of Operation

Table 5 shows the compared sequence of operation of the protective relays for both existing and improved case. It is noted that after the relay setting has been changed, the operating sequence and time of the relay improved significantly. The primary relay R6 downstream from the point of fault tripped at 181.4ms as compared to 408.1ms in the base case.

Table 2: Compared Relay Coordination Scheme for Motor Control Centre 1

Fault Type	Primary Protection	Base Case Sequence	Time (ms)	Improved Case Sequence	Time (ms)
		Relay4	**286.5**	**Relay6**	**181.4**
3-ph	**Relay6**	**Relay6**	**408.1**	**Relay4**	**294.8**
		Relay2	**630.4**	**Relay2**	**344**
		Relay1	**864.5**	**Relay1**	**569**

Furthermore, a 35% reduction in the relay operation time was observed as the backup relay R4 upstream from the point of fault tripped at 294.8ms as compared to 286.5ms in the base case then relay 2 tripped at 344.0ms as compared to 630.4ms in the base case and finally Relay 1 at 569ms as compared to 864.5ms in the base case respectively. Figure 6 below shows the comparison plot of relay coordination for both base case and improved case in Indorama MCC1.

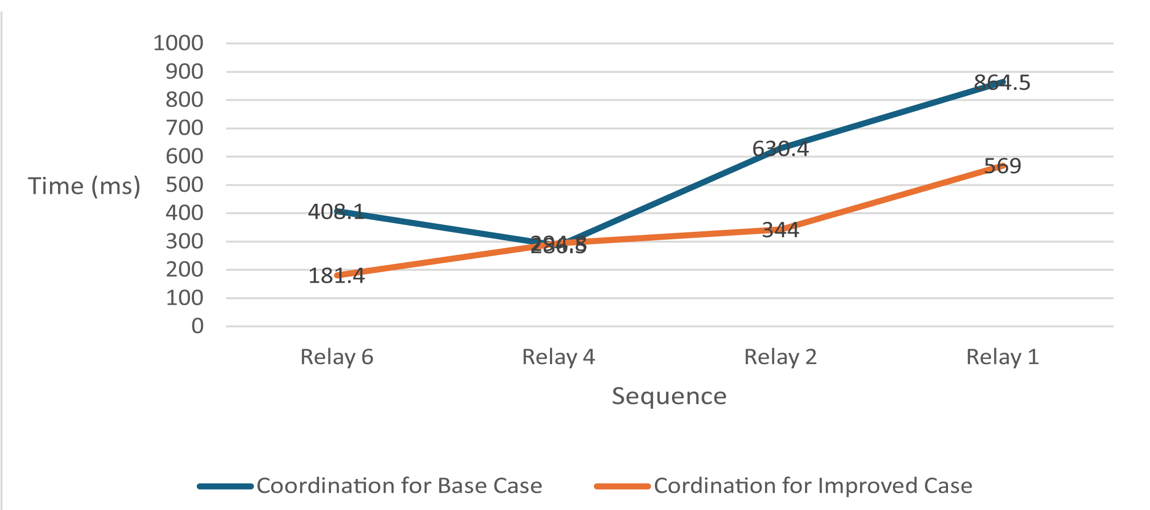

Figure 6: Comparison of Sequence of Operation for Relay Coordination in MCC1

5. CONCLUSION

This study analyzed relay coordination to address the issues faced at the motor control center of Indorama Fertilizer and Chemicals Limited. The existing network comprises two motor control centers, MCC1 and MCC2, connected to bus 2 and bus 3, respectively. Each bus serves as a common connection point for powering individual motors and associated protective devices, including contactors, overload relays, overcurrent relays, and circuit breakers, which are essential for fault and overload protection. A new relay setting was developed, focusing on appropriate plug settings and time multiplier adjustments for the various relays, utilizing IEC Standard Inverse Time Delay to enhance the coordination scheme in Motor Control Unit (Cmtr 1). This approach ensures that coordination begins downstream from the fault point and extends to the upstream supply station. The original definite-minimum-time (DMT) scheme was replaced with a more adaptable inverse-definite-minimum-time (IDMT) scheme. The results indicate that the new settings effectively provide backup for faults within the system.

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