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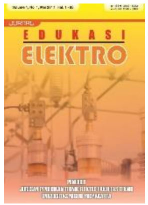

Protection Coordination Analysis Study Considering the Arc Flash in the Electrical System of PLTU Paiton Unit III Using IEEE Standard 1584-2002

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Abstract— Arch flash is a disorder that often occurs in the electrical system of an industry or factory. In this research focusing on the analysis of the protection system by considering arc flash, it will be discussed in detail at the existing factory in East Java, namely PLTU Paiton unit 3 which is developing a unit with a capacity of 1x815 MW. The electrical system at PLTU Paiton unit 3 discusses only high and medium voltage systems. In order to support the continuity of the plant, to connect the Java-Bali electricity system, it is necessary to have a good protection coordination system to avoid black out due to one of the impacts caused by the arc of fire. After coordination of protection in the Paiton PLTU unit 3 system, arc analysis will be simulated with IEEE 1584-2002 standard calculations to find the magnitude of energy incidents and determine the safety limits of workers and personal protective equipment according to NFPA 70E standards. The results of the study after resetting the protection coordination of PLTU Paiton unit 3 using differential relay on the SWGR-3A bus incident value of arc energy and Flash Protection Boundary (FPB) value decreased which originally reached a level outside level 4 (>40cal / cm2) to level 3 (8.1-25cal / cm2), on the SWGR-3B bus the incidence energy value was at level 3 (8.1-25cal / / cm2) dropped to level 2 (4.1-8cal / cm2), for coal hand sys bus SWGR A the energy incident value from level 3 (8.1-25cal//cm2) drops to level 0 (0 - 1.2cal/cm2), while for the coal hand sys SWGR B bus the energy incident value when existing conditions reach level 3 (8.1-25cal//cm2) drops to level 0 (0-1.2cal/cm2). After obtaining the energy level of the bus, then personal protective equipment can be determined.

Keywords: protection, coordination, arc flash, arc fire, incident energy, NFPA 70E

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1 Introduction

PLTU Paiton Unit 3 is one of the projects to accelerate the construction of phase 2 power plants with a capacity of 1x815 MW net fueled by coal. To make the Java-Bali electricity system single and integrated, the plant is connected to a 500 kV transmission line. With a large capacity, the plant is very influential on the system electricity and load demand in the Java-Bali area, so very high reliability and continuity are needed. However, disruptions to the electric power system may occur even in a good electric power system [1].

In the event of a disruption, several consequences will arise and all of them will cause losses to the plant. One factor that is also calculated in determining the protection system settings in a plant is the danger of arc flash or arc fire which is often forgotten by field installers [2].

Arc flash is a spark phenomenon because of a short circuit current in the electric power system [3]. This arc flash will appear at the location of the short circuit. This arc is very dangerous if it is not considered in the electric power protection system, due to the result of the arc can damage equipment can even endanger the safety and lives of workers [4]. So that by calculating arcing current and incident energy, it will be known the level of arc-flash hazard energy that may occur in the system, so that the selection of safety equipment can be calculated to reduce the danger level of arc-flash energy [5].

2 Basic Theory

2.1. Interference with the Electric Power System

Such disturbances are abnormalities in the electric power system that cause an unbalanced current flow in a three-phase system [6]. Based on the origin, interference is divided into two, namely interference from within the system and interference from outside the system, while based on the nature of interference is divided into two, namely temporary interference (temporary) and permanent interference (stationary) [7].

2.2. Electric Power Safety System

The basis of safety equipment is the safety relay, circuit breaker, and fuse [8]. While the security system consists of A collection of protection equipment coordinated with each other to operate selectively. Overcurrent relay is used to secure overload and short circuit faults. The overcurrent relay will work When there is current flowing in the circuit exceeding the allowable setting limit [9]. The use of overcurrent relay in industrial electrical systems must be adjusted based on the coordination of the relay that has been set correctly. So that when a system occurs a disturbance this relay can work quickly [10]. Overcurrent relay settings should not work at times of maximum load. According to IEEE 242 standard on overcurrent relay protection coordination, analog relay generally works with a time of 0.3-0.4 seconds [11]. As for the microprocessor-based digital relay, it will work at 0.2-03 seconds. The purpose of the standard relay working time is to ensure the backup zone will work if the primary zone fails to work and to avoid simultaneous trips [12].

For setting the overcurrent relay by setting the low set (inverse) with reference to the British BS standard 142-1983 the pickup limit is between 1.05 – 1.3 I nominal [13]. In addition to determining I, the pickup also determines the curvature of the Time Dial curve as an example using the brand AREVA – micom p139 as follows:

$$.t = k \times \frac{a}{(\frac{I}{Ireff})^{b} - 1} \quad (1)$$

Explanation:

t: is time delay
k: is the curvature of the curve or time dial (TMS)
I: is the value of the contribution current in amperes
Ireff: is the value of the pickup current in amperes
A and B: are Inverse Coefficients

Meanwhile, setting the high set (instantaneous) is related to the minimum Isc. The minimum Isc is a 2-phase short circuit current (line to line) with minimum generation at steady state multiplied by 0.866 or with the following limits:

$$1,6 \times I_{FLA} \leq I_{set} \leq 0,8 \times I_{sc\ minimum} \quad (2)$$

2.3. Arc flash

The definition of arc fire is the relayase of heat energy that is so high that it causes arc faults or bolted Fault. The arc produces an impact in the form of radiation heat that can produce the surrounding air temperature to 35000° F, blinding light that can interfere with vision to even damage a person's eyes, and enormous pressure [14], [15].

Some of the variables that affect it include the maximum bolted fault current, the time of protection equipment to eliminate interference, the distance between conductors, the system voltage, and the distance of arc points to workers [15].

2.1.1 Arc Calculation

To be able to perform arc flash calculations using the IEEE 1584-2002 standard first thing All you must do is find the bolted fault current value obtained from a 3-phase short circuit [16]. After that, the calculation of arcing current is carried out with the following formula for the calculation of arc current at voltage levels below 1000V can use the following equation:

$$\lg I_a = K + 0{,}662 \lg I_{bf} + 0{,}0966\, V + 0{,}000526\, G + 0{,}5588\, V (\lg I_{bf}) - 0{,}00304\, G (\lg I_{bf}) \quad (4)$$

As for the calculation of arc current with a voltage level of ≥ 1000V can use the equation below:

$$\lg Ia = 0{,}00402 + 0{,}983 \lg I_{bf} \quad (5)$$

Explanation:

Lg : log10
Ia : arcing current (kA)
K : constant for open configuration is -0.153 and constant for box configuration is - 0.097
lg Ibf : bolted fault current at three-phase fault (symmetrical RMS) (kA)
V : system voltage (kV)
G : gap distance between conductors (mm)

After the value of En is obtained, to calculate the magnitude of the incidence energy E the following equation is used:

$$E = 4{,}184 \times C_f \times E_n \times \left(\frac{t}{0{,}2}\right) \times \left(\frac{610}{D^x}\right) \quad (6)$$

Explanation:

E : incident energy (J/cm2)
Cf : multiplier factor 1.0 for voltages above 1kV, and 1.5 for voltages below 1kV
En : incident energy normalized
t : arcing time (seconds) that can be seen in the Table
D : working distance (mm)
X : exponent distance

2.1.2 Flash Protection Boundary

Flash Protection Boundary is when an arc hazard occurs, a worker who is within this boundary can still be affected by second-degree burns if he does not use personal protective equipment when the energy incident rate is 5 J/cm2 (1.2 cal/cm2) [17].

Flash protection boundary can be calculated using the following equation [2]:

$$D_B = \left[4{,}184 \times Cf \times En \times \left(\frac{t}{0{,}2}\right)\left(\frac{610^x}{Eb}\right)\right]^{1/x} \quad (7)$$

D_B : limit distance from arc point (mm)

C_f : calculation factor (1.0 for voltages above 1 kV, 1.5 for voltages below or equal to 1 kV)
En : normal incident energy
EB : incident energy in J/cm2 at distance limit t = time (seconds)
x : exponent distance
Ibf : bolted fault current (kA)

EB can be set to 5.0 J/cm2 for bare skin (no hood) or rating from PPE submitted (5.0 J/cm2 = 1.2 cal/cm2).

2.2 Category of Arc Energy with Personal Safety Equipment According to NFPA 70E-2009 Standard

Personal protection equipment is categorized based on the magnitude of the energy incident in the arc flash according to NFPA Standard 70E – 2009 by considering the impact caused by burns [18].

Here is a table of personal protection equipment:

Table 1. Personal Protective Equipment Category [19]

Category	Personal Protective Equipment	Clothes used
0	• Eye Protection • Ear Protection • Long sleeved shirt •Long pants	
1	• Fire Retardant Clothing • Eye Protection • Ear Protection •Long pants	
2	• Face and Head Shield • Fire Retardant Clothing • Eye Protection • Ear Protection •Long pants	
3	• Flash Suit Hood • Face and Head Shield • Fire Retardant Clothing • Eye Protection • Ear Protection •Long pants	
4	• Up to 40 cal/cm2 Flash Suit Hood • Face and Head Shield • Fire Retardant Clothing • Eye Protection • Ear Protection •Long pants	

3 Electrical System of PLTU Paiton Unit 3

PLTU Paiton unit 3 has one plant to meet the electricity needs of its electricity system (utility) and to supply power to PLN or the 500 kV grid. With the main generating capacity using a voltage level of 27 KV, a transformer is needed to lower the voltage level of 13.8 KV and 6.9 KV. The generation and transformer capacity of PLTU Paiton Unit 3 at medium voltage. At PLTU Paiton Unit 3, the load is dominated by motors, both large and small capacity motors. The company's electrical system can be seen in Fig.1

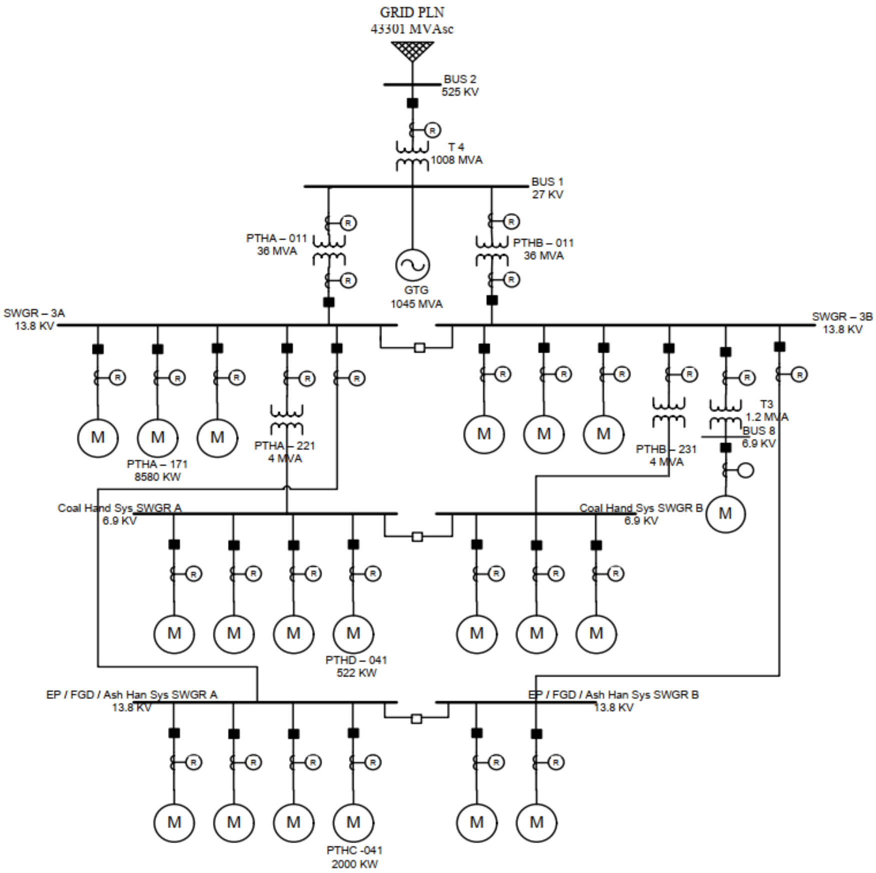

Fig. 1. Electrical system of PLTU Paiton unit 3

4 Simulation and analysis result

4.1. Phase Fault Relay Protection Coordination

In this study, evaluation was used in typical 2A as an example for coordination of phase fault overcurrent relay protection. The following is the coordination of phase fault overcurrent relay protection in the initial existing conditions:

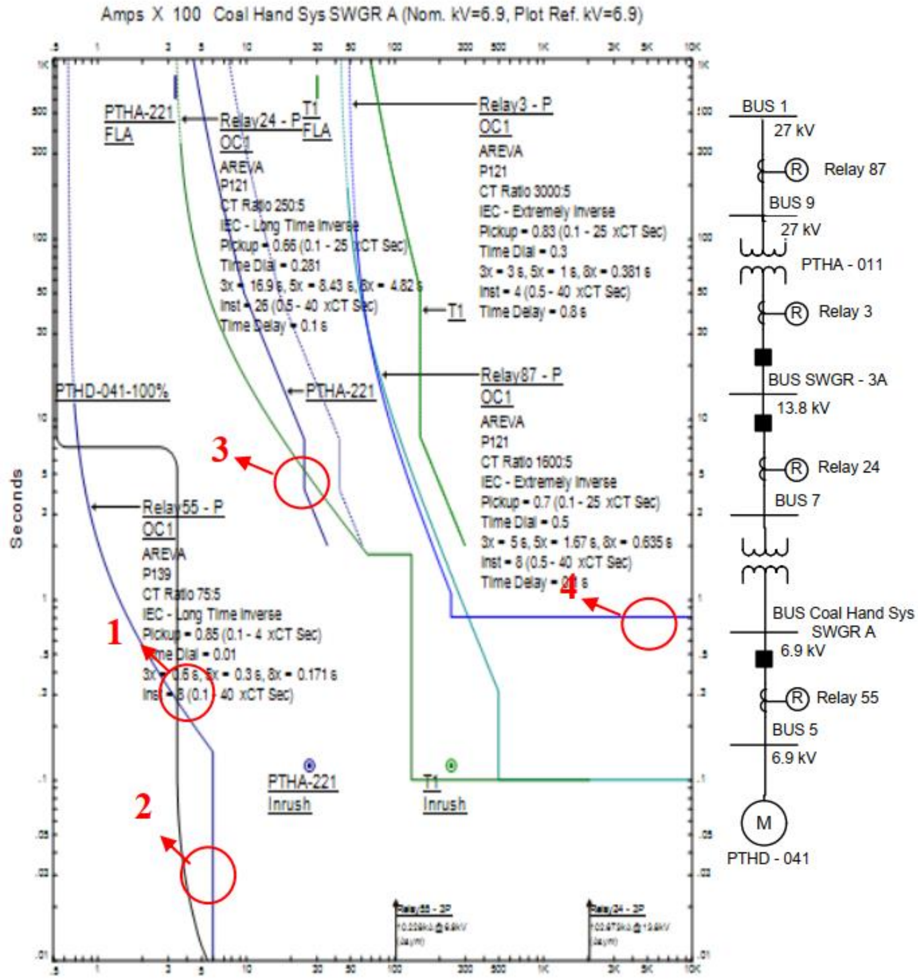

Fig. 2. Plot the safety curve of typical existing conditions 2A

From the results of the plot of the existing safety curve typical 2A, it can be seen that there are still some improper coordination, namely: in circle number 1, the inverse curve of relay 55 still touches the motor starting curve, thus interfering with the temporary motor starting, then in circle number 2, the instantaneous relay 55 curve has no delay, this is not in accordance with IEEE 242 standards, then in circle number 3, the inverse curve of relay 24 touches the damage curve of the PTHA-221 transformer, and in circle number 4, Time delay between relay is not up to standard, which is not in the range of 0.2 – 0.4 seconds.

4.2. Coordination of Overcurrent Protection relay to the Ground Fault Relay

Coordination of the relay of overcurrent disturbances to the ground also needs to be done to overcome when experiencing a short circuit to the ground. In setting the fault relay to the ground, this is related to the value of NGR (Neutral Grounding Resistor) on an equipment, usually found in transformers and generators. In its coordination, it differs at each voltage level and takes into account the form of its grounding. When the grading meets the delta (Δ), the grading resets by 0.1 seconds.

For example, the existing conditions of coordination of overcurrent relay protection of typical ground fault can be seen in Fig. 3.

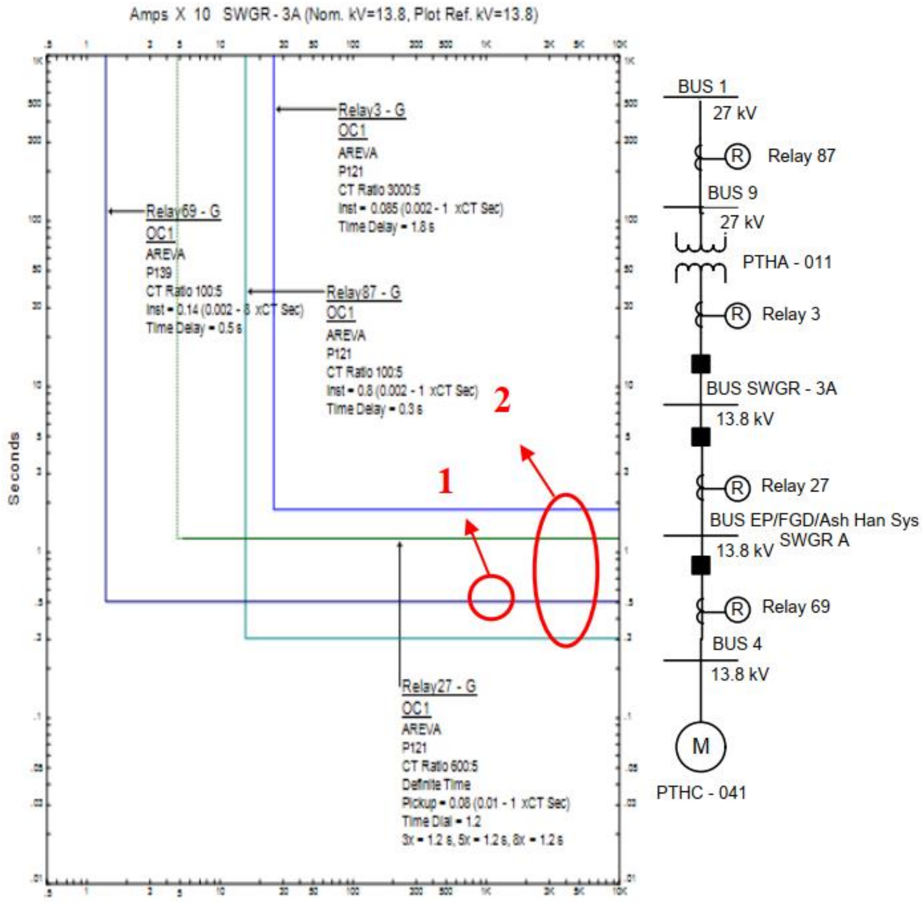

Fig. 3. Plot of typical existing condition ground fault safety curve 2

From the results of the plot of the existing safety curve typical 2, it can be seen that there is still some wrong coordination, namely: in circle number 1, the ground relay curve 55 looks to work when 5 seconds, while supposedly to secure the motor, just 0.1 seconds to make a trip when a ground fault occurs And in circle number 2, the ground curves of relay 24, relay 3, and relay 87 do not work according to the correct gradings time. It is not compliant with the IEEE 242 standard. From the results of the coordination above, the arc flash value is obtained as follows:

Table 2. Arc Energy Simulation Data Typical Existing Conditons 2

ID Bus	I Bolt (kA)	FCT (cyc)	I Arc (kA)	Inc. Level (cal/ cm2)	Level Energy
SWGR – 3A	52,7	42,5	49,72	84,48	>Max
Coal Hand Sys SWGR A	6,82	108,72	6,671	18,61	3

After resetting, it can be seen that relay 55 does not interfere with the motor starting and relay 24 does not touch the transformer damage curve, and relay 3 grading time is in accordance with IEEE 242 standards for phase fault coordination, while for resetting ground fault gradings time is in the range between 0.2 – 0.4 seconds.

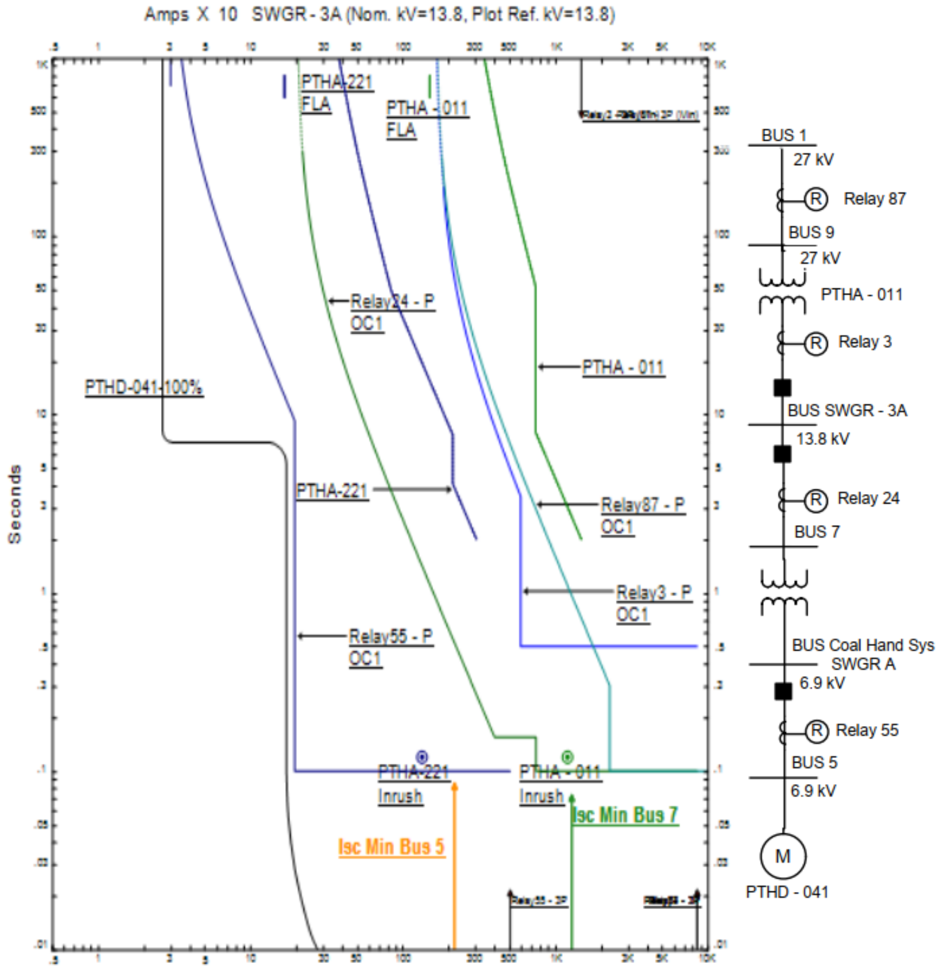

Fig. 4. Safety curve plot of typical resetting conditions 2a

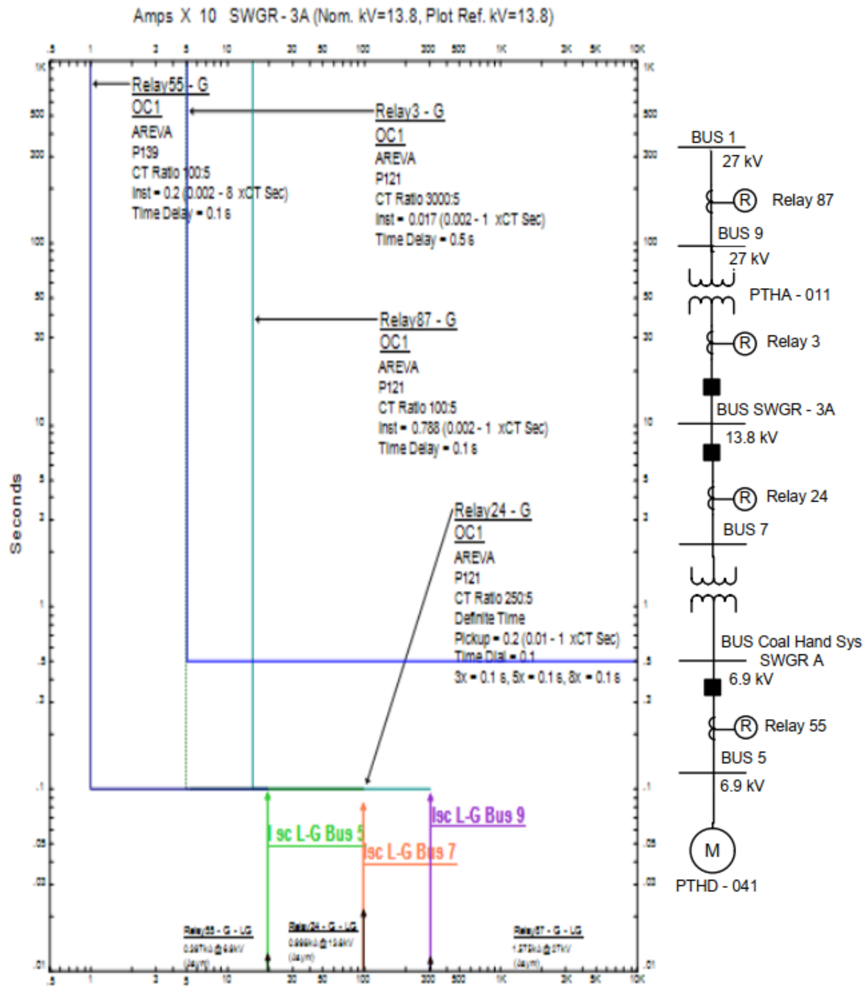

Fig. 5. Plot of ground fault safety curve typical resetting condition 2

So, after resetting the coordination on typical 2 representing SWGR-3A buses and Coal Hand Sys SWGR A buses, we will see the magnitude of the arc energy incident on both buses. The results of arc simulation can be seen in Table 4 and compared with manual calculations according to IEEE 1584-2002 standards.

Table 3. Comparison data of arc energy simulation results of existing resetting conditions

ID Bus	*Existing*		*Resetting*	
	Inc. Level (cal/cm^2)	**Category**	**Inc. Level (cal/cm^2)**	**Category**
SWGR-3A	84,481	>Max	56,54	>Max
Coal Hand Sys SWGR A	20,335	3	3,609	1

From Table 3 it can be seen that the results of energy incidents after resetting still exceed the maximum or more than 40 cal/cm2, so there is no personal protective equipment that is able to withstand such a large amount of energy according to NFPA 70E-2009 standards, therefore it is recommended to add a differential relay on buses that exceed the maximum level.

4.3. Arc Energy Measurement Using IEEE 1584-2002 Standard Resetting Conditions

Here is an example of incident energy calculation and flash protection boundary based on IEEE 1584-2002:

Bus SWGR – 3A
Calculate arcing current (Ia) :
$\log(I_a) = 0.00402 + 0.983 \log(I_B)$
$\log(I_a) = 0.00402 + 0.983 \log(52.706) \log(I_a) = 1{,}697$ $I_a = 49{,}77$kA

calcukate normalized energy (En) :
$En = 10^{K1+K2+1.081\log(Ia)+0.0011G}$
$En = 10^{-0{,}555+(-0.113)+1.081\times1.697+0.0011\times275}$
$En = 29.413\ J/cm^2$

After calculating the normalized energy, then finding the energy incident value, it is found that the energy incident value is 56.8 cal/cm2. The value is used to find the distance limit value of the arc which is 48.145m. From the results of manual calculations of arc energy incidents according to IEEE 1584-2002 standards, the results are 56.8 cal / cm2 while if using simulations, the results are obtained 56.54 cal/cm2 the difference obtained is very small, but the level of energy produced causes the safe distance of workers is also still very far

4.4. Arc energy after differential relay addition

FCT (Fault Clearing Time) is the time when the CB is completely open when a disturbance occurs, whether the CB breaks the fault greatly affects the magnitude of the arc energy incident. In this case, the differential relay has a very fast time of between 1-3 cycles. Table 5 is a comparison before using differential relay and after using differential relay. After the addition of a simulated differential relay, a smaller arc energy is obtained, this is because the disconnection time to interference is shorter.

Table 4. Comparison data of arc energy simulation results before and after differential relay addition

ID Bus	Before using differential relay			After using differential relay		
	Inc. Level (cal/cm^2)	FCT (sec.)	Category	Inc. Level (cal/cm^2)	FCT (sec.)	Category
SWGR-31	56,54	0,37	>Max	8,928	0,09	3
SWGR-3B	3,609	0,386	1	0,842	0,09	0

5 Conclusion

Based on the results of the study of protection coordination and arc energy at PLTU Paiton Unit 3, it was found that the coordination of relay protection of overcurrent phase faults and ground fault disturbances has not been well coordinated, causing the relay time to work for a long time. After the reset, the protection coordination is still in the category of more than the maximum or more than 40 cal/cm2. After the differential relay addition study, the incident value of arc energy decreased, because the differential relay was able to secure with a very fast time so that the disconnection time became short. The short disconnection time has an impact on energy incidents that are also reduced, so that PPE (Personal Protective Equipment) used in the area can be determined according to NFPA 70E-2009 standards.

Therefore, it is necessary to study the correct coordination of protection to avoid the occurrence of unwanted electrical disturbances. The addition of differential relay to this study is highly recommended to reduce the risk of large energy incidents.

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