Research Article

Analysis of Incident Energy and Arc Flash Boundaries in Industrial Electrical Systems Using ETAP

Alpiansyah Harianja

Abstract. Arc flash is a problem in electrical power systems. It happens when there are faults that make really hot explosions. These explosions can hurt people badly and damage equipment. They can also stop the system from working. The level of danger from arc flash is affected by how strong the fault current's how fast the protective devices can stop the fault. So we need to do an arc flash analysis to figure out how much energy is released and how far the arc flash can reach. This is all part of making the electrical system safer. This study is looking at arc flash in an electrical system. We used a program called ETAP. Followed the rules in the IEEE 1584 standard. We made a model of the distribution system and did some simulations to see what would happen in case of a short-circuit or arc flash. We wanted to know how much energy would be released and how far the arc flash would reach. We also wanted to know what kind of safety gear people would need to wear. We looked at the devices to see if we could make them work better and reduce the danger from arc flash. What we found out is that the amount of energy released and the distance the arc flash reaches are different at each point in the system. It depends on how strong the fault current's how fast the protective devices can stop the fault. If the protective devices work fast they can reduce the amount of energy released during an arc flash. This makes it safer for people. We were able to make the system safer by changing the settings, on the devices. This made the energy released during an arc flash lower. Made it safer for people to work with the electrical system. We hope this study will help make electrical systems safer and more reliable.

Keywords: Arc Flash, ETAP, Electrical Safety, IEEE 1584 Protection System, Incident Energi

Author(s):

Alpiansyah Harianja
Department of Electrical Engineering, Universitas Presiden
E-mail: alpiansyah.harianja@student.president.ac.id

Corresponding Author: Alpiansyah Harianja (alpiansyah.harianja@student.president.ac.id)

How to Cite This Article: Harianja, A. (2026). Analysis of Incident Energy and Arc Flash Boundaries in Industrial Electrical Systems Using ETAP. Journal of IoT and Cybersecurity Systems, 1(1), 52–65. https://doi.org/10.58291/jicss.v1i1.8

Received : 6 June, 2026; Revision: 29 June, 2026; Accepted: 8 July, 2026; Publication: 9 July, 2026.

1. Introduction

An electrical protection system in a power system has to work the way it is supposed to according to what it is meant to do and the protection requirements against all kinds of electrical faults. If the protection does not work well together it can cause problems like equipment getting damaged, power distribution stopping, production downtime and safety hazards for workers. So the coordination and setting of devices have to be carefully planned to make the electrical system more reliable and safe. One of the electrical hazards that has to be thought about when doing protection studies is the arc flash phenomenon. The arc flash is like an electrical explosion that happens when there is a short circuit or insulation failure and it makes extremely high temperatures and pressure. The energy that is made during an arc flash event can cause bad injuries, burns, equipment failure and fire hazards. How bad the arc flash hazard is depends on a things, including how much fault current there is, how long it takes for the protective device to turn off the power and how the system is set up. So it is necessary to do an arc flash analysis to figure out the incident energy and the arc flash boundary in an electrical system. To calculate the arc flash we need to do a short-circuit analysis and protection coordination studies. The incident energy value comes from the arcing fault current, which is calculated based on short-circuit analysis and the operating time of protective devices. In this study we used ETAP based on the IEEE 1584 standard to do the analysis and simulation. We used the software to make a model of the distribution system do fault analysis and check the arc flash hazard level at each point in the system. The goal of this research is to look at the incident energy and arc flash boundary in an electrical system and to see how well the protection device settings work to reduce arc flash hazards. We hope that the results of this study will make electrical safety better help us follow the NFPA 70E standards and minimize the risk of injuries, equipment damage and fire incidents in facilities. We are talking about arc flash and electrical protection systems. How they can help keep people safe. The arc flash research is important for electrical systems and, for the people who work with them.(Bottaro et al., 2025; Budiyanto et al., 2024; Nhat & Ngoc, 2025).

Figure 1 shows a typical warning label for electrical arc flash hazards that is usually placed on electrical devices. This label contains crucial safety details, such as the energy level of an incident, the boundary for arc flashes, the standard voltage of the system, and the necessary gear for personal protection. These labels help maintenance workers recognize possible dangers before working with live equipment and aid in following IEEE 1584 and NFPA 70E safety regulations.

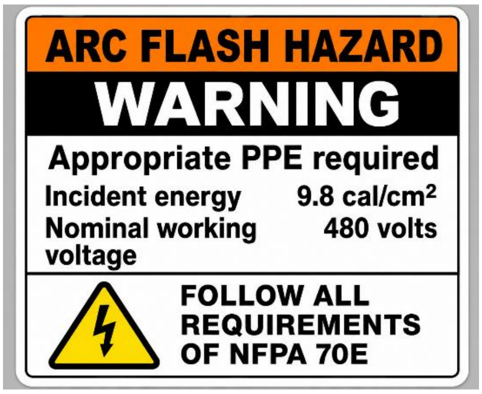


Figure 1. Electrical arc hazard labelling (Source: wikipedia)

2. Methods

2.1. Literature Review and Research Gaps

Previous research has thoroughly examined arc flash hazards through the IEEE 1584 standard and simulation tools like ETAP, which are utilized to estimate incident energy and arc flash boundaries within industrial electrical systems. These investigations have revealed that the magnitude of fault current and the operating time of protective devices are the key factors that affect the severity of arc flash incidents. However, the majority of current studies predominantly concentrate on calculating incident energy and assessing hazards, with insufficient attention given to analyzing the sensitivity of various operating parameters and the effectiveness of protection coordination in mitigating arc flash risks. Moreover, there is a scarcity of comparative studies that explore the impact of fault current, protective device clearing time, and working distance on incident energy across different operating conditions. Consequently, this study aims to fill these gaps by conducting a thorough arc flash analysis using ETAP, which includes short-circuit analysis, incident energy assessment, arc flash boundary evaluation, and sensitivity analysis to ascertain the relative impact of essential system parameters. The results are anticipated to yield practical recommendations for enhancing protection coordination and bolstering electrical safety in industrial power distribution systems.(Cabello et al., 2023; Cramm et al., 2025; Fidya Eka Prahesti et al., 2023).

2.2. Objective

Objective of this research are:

1. We need to use ETAP simulation to look at the incident energy in a situation.
2. The arc lash boundary has characteristics and we want to see how it behaves when things are working in different ways.
3. We have to check how the fault current and the time it takes to clear the fault and the distance we are working from affect the results of the ETAP simulation.
4. To make sure the results, from the ETAP simulation are correct we will compare them to what's written in recent journals and the standards set by IEEE 1584 for arc lash safety.

2.3. Data and Methods

2.3.1. System Description

We used the ETAP software to make a diagram of the system. The ETAP software helped us see what would happen if there was a circuit or an arc flash at different parts of the system, like the buses and the feeder locations. We did this for buses and feeder locations to get a good idea of how the system would work in different situations. (Hardi et al., 2021; Yadav et al., 2024)

Then, the system descriptions are:

1. Utility source
2. Main Bus
3. Distribution feeders
4. Protective circuit breakers and
5. Fuse
6. Industrial loads

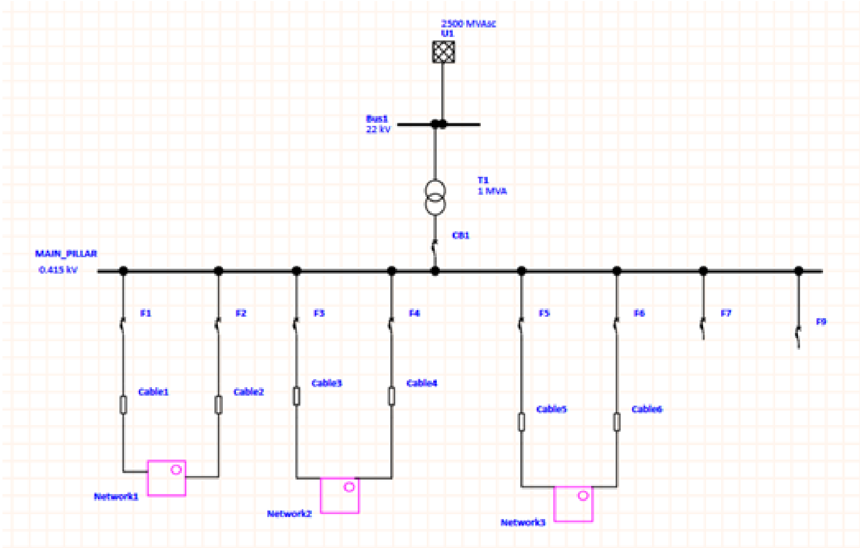


Figure 2. Single line diagram distribution network (Source: self-documentation)

Figure 2 shows the single-line diagram from ETAP that is utilized in this research. The model illustrates the entire electric distribution system used in industry, comprising the utility supply, transformer, primary distribution bus, outgoing feeders, circuit breakers, and the loads connected to it. This setup serves as the foundation for performing short-circuit calculations and simulations of arc flashes in different operating scenarios.(Budiyanto et al., 2024; Budiyanto & Silalahi, 2023; Mohd Azmi et al., 2022).

2.3.2. Data Description

The information we used for this project came from simulations we did with ETAP of a low-voltage system that is used in industry. The information we collected includes how strong the fault current is, how much energy is released when something goes wrong how long it takes for the breaker to turn off how away the arc flash can reach and how far away people are working. We tried different scenarios by changing how long it takes for the protective devices to kick in and how strong the fault current is.(Lu et al., 2025) We took the details from the simulations. Put them into a CSV file and then used Python to look at the numbers and see how different things affect the results.(Kulor et al., 2024; Nhat & Ngoc, 2025).

Table 1. System parameters

Parameter	Value
System Voltage	480 V
Grid Rating	22 kVA
Frequency	50 Hz
Fault Current Range	5 – 25 kA
Clearing Time Range	0.05 – 0.30 s
Working Distance	300 – 600 mm

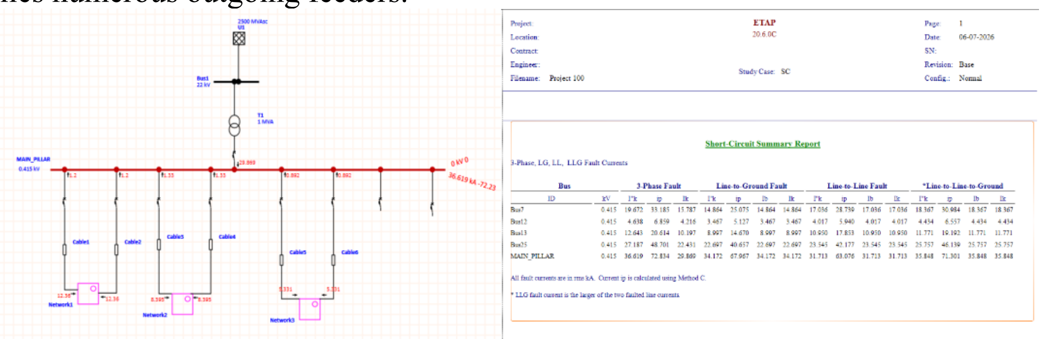
Table 1 provides an overview of the electrical specifications applied in the ETAP simulation. These specifications consist of device ratings, short circuit current levels, operating times for protective devices, safety distances, and voltage of the system. The chosen specifications follow the IEEE 1584 guidelines and act as the main input factors for determining incident energy and arc flash limits.(Li et al., 2025; Liang et al., 2025; Virtudez et al., 2026).

3. Result and Discussion

3.1. Short-Circuit Analysis

The ETAP short-circuit simulation shows that the available fault current at the bus is about 9.78 kA. This fault current is different because of the feeder impedance and the characteristics of the transformer. The ETAP short-circuit simulation is really helpful to see what the fault current at the bus will be. The fault current, from the ETAP short circuit simulation can be big or small depending on the feeder impedance and the transformer characteristics.electrical protection system. These findings confirm the efficacy of the proposed ETAP-based approach for assessing and mitigating arc flash hazards in industrial power systems.

Figure 3 shows the short-circuit analysis utilizing ETAP at the main utility bus. The utility source, transformer, and main bus that make up the main power supply for the industrial electrical distribution system are shown in Figure 3(a) as a single-line design. The beginning of the electrical power flow before it is transmitted to feeders downstream is represented by this part. The findings of the ETAP short-circuit analysis at the main utility bus are displayed in Figure 3(b). In order to provide the electrical parameters needed for protection studies, the simulation computes the fault conditions at this site. These findings are utilized as the first point of reference for figuring out the available fault level, and they are then fed into the IEEE 1584-based arc flash analysis. Figure 4 shows the short-circuit analysis of the incoming utility supply and the primary distribution bus in the ETAP model. Figure 4(a) shows the connection between the utility source, transformer, incoming circuit breaker, and the main distribution bus, which acts as the principal point for receiving electrical power before it is dispersed across the industrial network. The findings of the ETAP short-circuit investigation at the main distribution bus are displayed in Figure 4(b). This location's fault characteristics, including the electrical parameters needed for protection studies, are provided by the simulation. The fault current distribution, protective device operation, and the ensuing arc flash analysis based on IEEE 1584 are all directly impacted by the short-circuit performance of the main distribution bus because it supplies numerous outgoing feeders.



Project:
Location:
Contract:
Engineer:
Filename: Project 100

ETAP
20.6.0C

Study Case: SC

Page: 1
Date: 06-07-2026
SN:
Revision: Base
Config.: Normal

Short-Circuit Summary Report

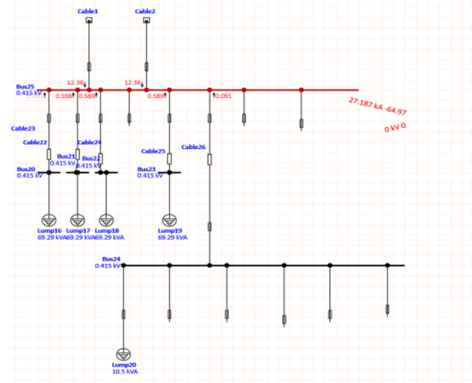
3-Phase, LG, LL, LLG Fault Currents

Bus		3-Phase Fault			Line-to-Ground Fault				Line-to-Line Fault				*Line-to-Line-to-Ground			
ID	kV	I"k	ip	Ik	I"k	ip	Ib	Ik	I"k	ip	Ib	Ik	I"k	ip	Ib	Ik
Bus7	0.415	19.672	33.185	15.787	14.864	25.075	14.864	14.864	17.036	28.739	17.036	17.036	18.367	30.984	18.367	18.367
Bus12	0.415	4.638	6.859	4.216	3.467	5.127	3.467	3.467	4.017	5.940	4.017	4.017	4.434	6.557	4.434	4.434
Bus13	0.415	12.643	20.614	10.197	8.997	14.670	8.997	8.997	10.950	17.853	10.950	10.950	11.771	19.192	11.771	11.771
Bus25	0.415	27.187	48.701	22.431	22.697	40.657	22.697	22.697	23.545	42.177	23.545	23.545	25.757	46.139	25.757	25.757
MAIN_PILLAR	0.415	36.619	72.834	29.869	34.172	67.967	34.172	34.172	31.713	63.076	31.713	31.713	35.848	71.301	35.848	35.848

All fault currents are in rms kA. Current ip is calculated using Method C.

* LLG fault current is the larger of the two faulted line currents.

Figure 3. Short-circuit simulation of the main utility bus: (a) Single-line network configuration (b) ETAP short-circuit calculation results.
Source: self-documentation.

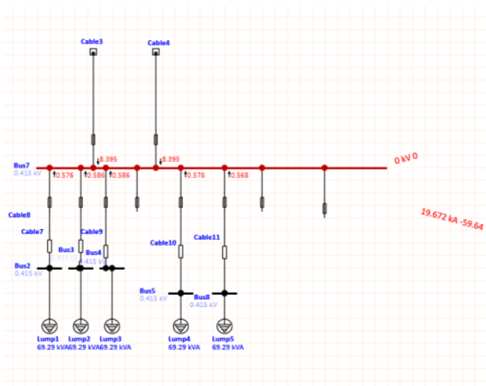


Short-Circuit Summary Report

3-Phase Fault Currents

Bus		Device		Device Capacity (kA)				Short-Circuit Current (kA)					
				Making									
ID	kV	ID	Type	Peak	Ib sym	Ib asym	Idc	I"k	ip	Ib sym	Ib asym	Idc	Ik
Bus7	0.415	Bus7	Bus					19.672	33.185				15.787
	0.415	Fuse17	Fuse		100.000	124.686		19.672	33.185	18.720	19.269	4.563	
	0.415	Fuse1	Fuse		100.000	124.686		19.672	33.185	18.720	19.269	4.563	
	0.415	Fuse14	Fuse		100.000	124.686		19.672	33.185	18.720	19.269	4.563	
Bus12	0.415	Bus12	Bus					4.638	6.859				4.216
	0.415	Fuse23	Fuse		100.000	124.686		4.638	6.859	4.543	4.545	0.153	
	0.415	Fuse13	Fuse		50.000	66.539		4.638	6.859	4.543	4.545	0.153	
	0.415	Fuse18	Fuse		50.000	66.539		4.638	6.859	4.543	4.545	0.153	
	0.415	Fuse19	Fuse		50.000	66.539		4.638	6.859	4.543	4.545	0.153	
	0.415	Fuse20	Fuse		50.000	66.539		4.638	6.859	4.543	4.545	0.153	
	0.415	Fuse21	Fuse		50.000	66.539		4.638	6.859	4.543	4.545	0.153	
Bus13	0.415	Bus13	Bus					12.643	20.614				10.197
	0.415	Fuse27	Fuse		100.000	124.686		12.643	20.614	12.079	12.289	2.261	
	0.415	Fuse7	Fuse		100.000	124.686		12.643	20.614	12.079	12.289	2.261	
	0.415	Fuse24	Fuse		100.000	124.686		12.643	20.614	12.079	12.289	2.261	
Bus25	0.415	Bus25	Bus					27.187	48.701				22.431
	0.415	Fuse52	Fuse		100.000	124.686		27.187	48.701	26.031	27.593	9.152	
	0.415	Fuse53	Fuse		100.000	124.686		27.187	48.701	26.031	27.593	9.152	
	0.415	Fuse66	Fuse		100.000	124.686		27.187	48.701	26.031	27.593	9.152	
MAIN_PILLAR	0.415	MAIN_PILLAR	Bus					36.619	72.834				29.869

Figure 4. Short-circuit analysis of the incoming utility supply and main distribution bus: (a) Incoming utility supply configuration (b) ETAP short-circuit analysis results at the main distribution bus.
Source: self-documentation.



Project:
Location:
Contract:
Engineer:
Filename: Project 100

ETAP
20.6.0C

Study Case: SC

Page: 1
Date: 06-07-2026
SN:
Revision: Base
Config.: Normal

Short-Circuit Summary Report

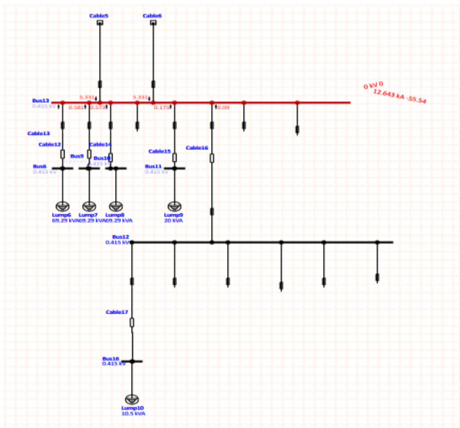
3-Phase, LG, LL, LLG Fault Currents

Bus		3-Phase Fault			Line-to-Ground Fault				Line-to-Line Fault				*Line-to-Line-to-Ground			
ID	kV	I"k	ip	Ik	I"k	ip	Ib	Ik	I"k	ip	Ib	Ik	I"k	ip	Ib	Ik
Bus7	0.415	19.672	33.185	15.787	14.864	25.075	14.864	14.864	17.036	28.739	17.036	17.036	18.367	30.984	18.367	18.367
Bus12	0.415	4.638	6.859	4.216	3.467	5.127	3.467	3.467	4.017	5.940	4.017	4.017	4.434	6.557	4.434	4.434
Bus13	0.415	12.643	20.614	10.197	8.997	14.670	8.997	8.997	10.950	17.853	10.950	10.950	11.771	19.192	11.771	11.771
Bus25	0.415	27.187	48.701	22.431	22.697	40.657	22.697	22.697	23.545	42.177	23.545	23.545	25.757	46.139	25.757	25.757
MAIN_PILLAR	0.415	36.619	72.834	29.869	34.172	67.967	34.172	34.172	31.713	63.076	31.713	31.713	35.848	71.301	35.848	35.848

All fault currents are in rms kA. Current ip is calculated using Method C.

* LLG fault current is the larger of the two faulted line currents.

Figure 5. Short-circuit analysis of the distribution feeders and protective devices: (a) Distribution feeder configuration (b) ETAP short-circuit analysis results of the feeder circuits.
Source: self-documentation.



Project:
Location:
Contract:
Engineer:
Filename: Project 100

ETAP
20.6.0C

Study Case: SC

Page: 1
Date: 06-07-2026
SN:
Revision: Base
Config.: Normal

Short-Circuit Summary Report

3-Phase, LG, LL, LLG Fault Currents

Bus		3-Phase Fault			Line-to-Ground Fault				Line-to-Line Fault				*Line-to-Line-to-Ground			
ID	kV	I"k	ip	Ik	I"k	ip	Ib	Ik	I"k	ip	Ib	Ik	I"k	ip	Ib	Ik
Bus7	0.415	19.672	33.185	15.787	14.864	25.075	14.864	14.864	17.036	28.739	17.036	17.036	18.367	30.984	18.367	18.367
Bus13	0.415	12.643	20.614	10.197	8.997	14.670	8.997	8.997	10.950	17.853	10.950	10.950	11.771	19.192	11.771	11.771
Bus25	0.415	27.187	48.701	22.431	22.697	40.657	22.697	22.697	23.545	42.177	23.545	23.545	25.757	46.139	25.757	25.757
MAIN_PILLAR	0.415	36.619	72.834	29.869	34.172	67.967	34.172	34.172	31.713	63.076	31.713	31.713	35.848	71.301	35.848	35.848

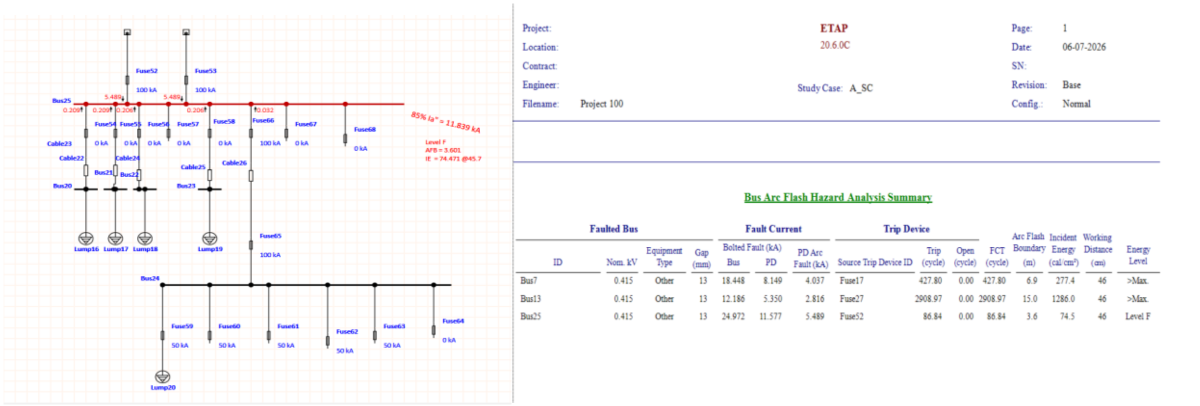
All fault currents are in rms kA. Current ip is calculated using Method C.

* LLG fault current is the larger of the two faulted line currents.

Figure 6. Short-circuit analysis of the industrial load distribution network: (a) Industrial load distribution configuration (b) ETAP short-circuit analysis results at the load bus.
Source: self-documentation.

The short-circuit analysis of the outgoing distribution feeders and the safety devices attached to them is shown in Figure 5. In Figure 5(a) The primary industrial electrical circuit distribution circuit breakers are shown in the electrical power. The ETAP short-circuit analysis results for the feeder circuits are shown in Figure 5(b). The simulation assesses each feeder's electrical reaction in the event of a problem and confirms that the protective devices are effective in isolating network segments that are experiencing faults. The electrical electrical electrical electrical electrical electrical electrical electrical electrical electrical electrical electrical electrical coordination cooperation coordination.

Figure 6 shows a short-circuit assessment of an industrial load distribution network. In Figure 6(a), you can see how the distribution lines are connected to the industrial loads that are part of the ETAP model. Each load receives its power from a separate line protected by a dedicated circuit breaker, which represents the downstream portion of the electrical distribution setup. Figure 6(b) shows the results of an ETAP short-circuit analysis on the load bus during a fault. This simulation examines how the fault affects the lower bus and provides the electrical data needed to coordinate protection and assess arc flash risk. These findings help identify areas of greater electrical hazard and assist in assessing how well the protection system is performing, in accordance with IEEE 1584.

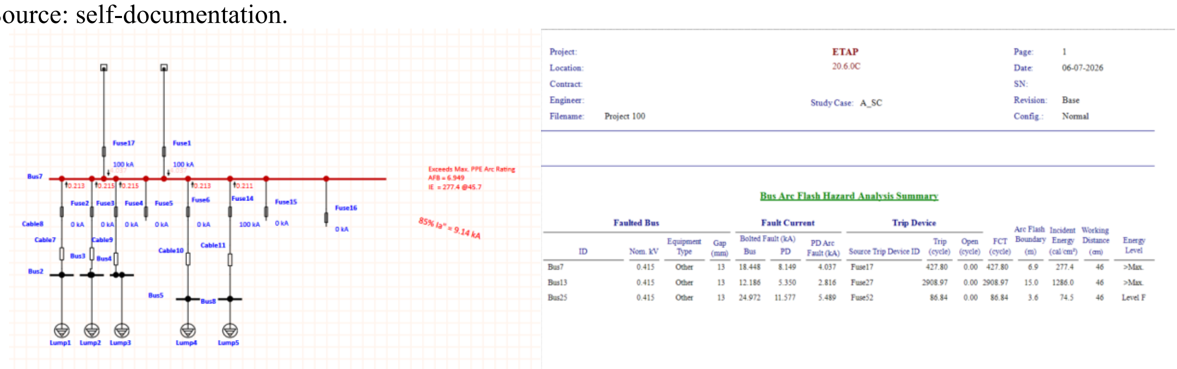


Project: | ETAP 20.6.0C | Page: 1
Location: | | Date: 06-07-2026
Contract: | | SN:
Engineer: | Study Case: A_SC | Revision: Base
Filename: Project 100 | | Config.: Normal

Bus Arc Flash Hazard Analysis Summary

Faulted Bus				Fault Current			Trip Device							
ID	Nom. kV	Equipment Type	Gap (mm)	Bolted Fault (kA) Bus	Bolted Fault (kA) PD	PD Arc Fault (kA)	Source Trip Device ID	Trip (cycle)	Open (cycle)	FCT (cycle)	Arc Flash Boundary (m)	Incident Energy (cal/cm²)	Working Distance (cm)	Energy Level
Bus7	0.415	Other	13	18.448	8.149	4.037	Fuse17	427.80	0.00	427.80	6.9	277.4	46	>Max.
Bus13	0.415	Other	13	12.186	5.350	2.816	Fuse27	2908.97	0.00	2908.97	15.0	1286.0	46	>Max.
Bus25	0.415	Other	13	24.972	11.577	5.489	Fuse52	86.84	0.00	86.84	3.6	74.5	46	Level F

Figure 7. Arc flash analysis results at distribution bus A: (a) ETAP arc flash hazard label and (b) Detailed arc flash analysis results for distribution bus A.
Source: self-documentation.



Project: | ETAP 20.6.0C | Page: 1
Location: | | Date: 06-07-2026
Contract: | | SN:
Engineer: | Study Case: A_SC | Revision: Base
Filename: Project 100 | | Config.: Normal

Bus Arc Flash Hazard Analysis Summary

Faulted Bus				Fault Current			Trip Device							
ID	Nom. kV	Equipment Type	Gap (mm)	Bolted Fault (kA) Bus	Bolted Fault (kA) PD	PD Arc Fault (kA)	Source Trip Device ID	Trip (cycle)	Open (cycle)	FCT (cycle)	Arc Flash Boundary (m)	Incident Energy (cal/cm²)	Working Distance (cm)	Energy Level
Bus7	0.415	Other	13	18.448	8.149	4.037	Fuse17	427.80	0.00	427.80	6.9	277.4	46	>Max.
Bus13	0.415	Other	13	12.186	5.350	2.816	Fuse27	2908.97	0.00	2908.97	15.0	1286.0	46	>Max.
Bus25	0.415	Other	13	24.972	11.577	5.489	Fuse52	86.84	0.00	86.84	3.6	74.5	46	Level F

Figure 8. Arc flash analysis results at distribution bus B: (a) ETAP arc flash hazard label and (b) Detailed arc flash analysis results for distribution bus B.
Source: self-documentation.

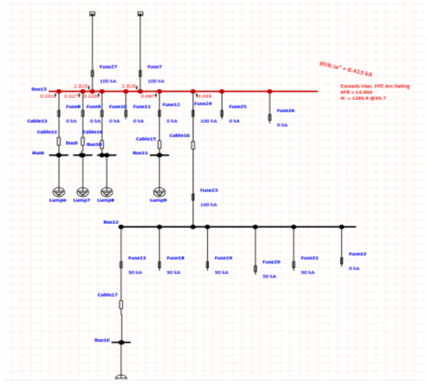
3.2. Incident Energy Analysis

The incident energy calculation shows that when you have a fault current and a longer time for the breaker to clear this increases the level of danger, from an arc flash. The arc flash hazard level is higher when the fault current is higher and the breaker takes longer to clear. This means the arc flash hazard level is really affected by the fault the breaker clearing time. The arc flash hazard level increases when the fault current is higher and the breaker clearing time is longer.

Figure 7 shows the results of the ETAP arc flash hazard study for Distribution Bus A. In Figure 7(a), you can see the arc flash hazard labels created by ETAP. These labels highlight the incident energy, arc flash limits, and the personal protective equipment (PPE) required for safety. The warning message “Exceeds Maximum” means that the calculated incident energy is higher than Figure 7(b) provides a more detailed view of the arc flash analysis results for Distribution Bus A. The simulation shows that the incident energy is 74.5 cal/cm², the arc current is 11,839 kA, and the arc flash boundary is approximately 85 inches (2.16 m). These measurements indicate a significant arc flash risk, meaning that persons working within the arc flash boundary need to follow proper safety protocols. The high incident energy highlights the need for effective protection coordination and reducing the time required for protective devices to clear, to limit thermal energy exposure as stated by IEEE 1584.

Figure 8 shows the results of the ETAP arc flash analysis for Distribution Bus B. In Figure 8(a), you can see the arc flash hazard label generated by ETAP. This label includes information about the calculated incident energy, arc flash limits, and required personal protective equipment (PPE). As in Figure 7, the "Exceeds Maximum" warning indicates that the available PPE level is insufficient for the calculated energy level. Figure 8(b) presents the detailed results of the ETAP calculation. The simulation shows an incident energy of 27.74 cal/cm², an arc current of 9.14 kA, and an arc flash boundary of approximately 85 inches (2.16 m). While the incident energy is lower than that found for Distribution Bus A, it is still significantly higher than standard arc-rated PPE can handle. These findings mean that workers are still at serious risk of heat hazards within the arc flash boundary, emphasizing the importance of better protection management and faster fault clearance processes to reduce the risk of arc flash incidents.

Figure 9 shows the results of the ETAP arc flash analysis for the most important distribution bus in the electrical system. The simulation finds an incident energy of 129. 5 cal/cm², an arcing current of 6. 413 kA, and an arc flash boundary of about 395 inches (10. 03 m). The ETAP hazard label shows the warning level “Exceeds Max,” meaning that the calculated incident energy is greater than what standard arc-rated PPE can protect against. Although the calculated arc current is lower than that seen in Figures 7 and 8, the incident energy is significantly higher. This finding indicates that the time required for the protective device to respond has a greater influence on the incident energy than the arc current itself. Consequently, the extended arc flash boundary of 10.03 m represents the highest exposure risk to personnel among the buses studied. Therefore, it is critical to optimize the protection settings and shorten the time required for fault clearing to lower the incident energy and improve compliance with the safety standards outlined in IEEE 1584 and NFPA 70E.



Project: | ETAP 20.6.0C | Page: 1
Location: | | Date: 06-07-2026
Contract: | | SN:
Engineer: | Study Case: A_SC | Revision: Base
Filename: Project 100 | | Config.: Normal

Bus Arc Flash Hazard Analysis Summary

Faulted Bus				Fault Current			Trip Device							
ID	Nom. kV	Equipment Type	Gap (mm)	Bolted Fault (kA) Bus	Bolted Fault (kA) PD	PD Arc Fault (kA)	Source Trip Device ID	Trip (cycle)	Open (cycle)	FCT (cycle)	Arc Flash Boundary (m)	Incident Energy (cal/cm²)	Working Distance (cm)	Energy Level
Bus7	0.415	Other	13	18.448	8.149	4.037	Fuse17	427.80	0.00	427.80	6.9	277.4	46	>Max.
Bus13	0.415	Other	13	12.186	5.350	2.816	Fuse27	2908.97	0.00	2908.97	15.0	1286.0	46	>Max.
Bus25	0.415	Other	13	24.972	11.577	5.489	Fuse52	86.84	0.00	86.84	3.6	74.5	46	Level F

Figure 9. Arc flash analysis results at the most critical distribution bus.
Source: self-documentation.

3.3. Discussion

Table 2 show the results align with earlier research conducted in accordance with the IEEE 1584 standard, affirming that the coordination of protection and the clearing time of protective devices are essential in reducing arc flash risks. This study enhances the current knowledge base by delivering a thorough ETAP-based evaluation that encompasses short-circuit analysis, incident energy assessment, arc flash boundary identification, and sensitivity analysis within an industrial electrical distribution framework. The insights gained provide actionable recommendations for optimizing protection configurations, enhancing personnel safety, and bolstering the reliability of industrial power systems. However, the study's limitations stem from its dependence on simulation data and established operating conditions, which may not entirely capture the intricacies of actual industrial settings. Therefore, the findings should be viewed in light of the assumptions inherent in the simulation model, and it is advisable to conduct further validation through field measurements and a variety of industrial case studies to enhance the applicability of the results.

Table 2. Summary arc flash analysis

Analysis Result	Interpretation
Figure 3 describe the incoming utility source supplies the industrial distribution system through the main circuit breaker. The bus voltage remains close to the nominal value (approximately 22 kV), indicating that the power source is operating under normal conditions.	A stable source voltage provides a reliable basis for short-circuit and arc flash simulations. Variations in the source characteristics directly influence the available fault current throughout the network.(Alhamrouni et al., 2024).
Figure 4 describe the main bus distributes electrical power to multiple outgoing feeders through individual protective devices. The feeder configuration creates different electrical paths with varying impedance values.	The feeder impedance affects the magnitude of prospective fault current at downstream buses. Buses located farther from the source generally experience lower fault current because of increased system impedance.(Alhamrouni et al., 2024)

Analysis Result	Interpretation
Figure 5 describe protective circuit breakers are installed at each feeder to isolate faulted sections of the electrical system. Their operating characteristics determine the fault clearing time during abnormal conditions.	Faster breaker operation reduces the duration of the electrical arc, leading to lower incident energy and a smaller arc flash boundary. Therefore, protection coordination is one of the most significant factors influencing arc flash severity.(Alhamrouni et al., 2024)
Figure 6 describe the complete ETAP single-line model integrates the utility source, buses, cables, protective devices, and industrial loads into a unified electrical network for simulation.	The integrated model enables accurate short-circuit calculations, incident energy estimation, and arc flash boundary determination in accordance with IEEE 1584. It provides the foundation for evaluating electrical safety and optimizing protection settings.(Alhamrouni et al., 2024)
Figure 7 describe the ETAP arc flash analysis at one of the distribution buses. The simulation produced an incident energy of 74.5 cal/cm², an arcing current of 11.839 kA, and an arc flash boundary of approximately 85 inches (2.16 m). The warning status indicates "Exceeds Max", showing that the incident energy exceeds the protection capability of standard arc-rated PPE.	High arc flash hazard. Personnel working within 2.16 m of the equipment are exposed to severe thermal energy capable of causing serious burn injuries. Optimization of protection coordination and reduction of breaker clearing time are recommended to lower the incident energy.(Alhamrouni et al., 2024)
Figure 8 describes the ETAP arc flash analysis for another distribution bus with an incident energy of 27.74 cal/cm², an arcing current of 9.14 kA, and an arc flash boundary of approximately 85 inches (2.16 m). Although the incident energy is lower than that in Figure 7, the simulation still reports "Exceeds Max", indicating that the available PPE is insufficient for safe energized work.	Very high arc flash hazard. Despite the lower arcing current, the incident energy remains above the acceptable PPE rating, emphasizing that protective device operating time significantly influences arc flash severity. Improved protection coordination is necessary to reduce personnel exposure.(Alhamrouni et al., 2024)
Figure 9 describes the ETAP arc flash analysis at the most critical distribution bus. The simulation recorded an incident energy of 129.5 cal/cm², an arcing current of 6.413 kA, and an arc flash boundary of approximately 395 inches (10.03 m). The "Exceeds Max" warning confirms an extremely hazardous operating condition that exceeds conventional PPE protection limits.	Extremely critical arc flash hazard. Although the arcing current is lower than in Figures 7 and 8, the significantly longer protective device clearing time results in the highest incident energy and the largest arc flash boundary. Immediate optimization of protection settings is essential to reduce thermal exposure and improve compliance with IEEE 1584 and NFPA 70E safety requirements.(Alhamrouni et al., 2024)

Source: self-documentation.

6. Conclusions and Future Directions

This research illustrates that the ETAP-based arc flash analysis serves as an effective method for assessing incident energy and arc flash boundaries within industrial electrical distribution systems, in line with the IEEE 1584 standard. The results indicate that the clearing time of protective devices is the primary factor affecting arc flash severity, while the magnitude of fault current and the working distance also play significant roles in determining hazard levels. The suggested methodology offers practical assistance in optimizing protection coordination, enhancing personnel safety, and improving the operational reliability of industrial power systems. Future studies should include field measurement data, explore dynamic operating conditions, and assess the effects of renewable energy integration and advanced protection technologies to further enhance the precision and relevance of arc flash hazard assessments.

Acknowledgements: The author would like to express deepest thanks to Professors and Head of the Electrical Engineering, for their suggestion throughout the study. The author would thanks to the supervisor Ir. Lukman Medriavin Silalahi, A.Md., ST., MT., IPM., ASEAN-Eng., APEC-Eng, for giving this opportunity and his invaluable comments and guidance during this study. And finally, the author wishes to thank to all persons who helped with necessary assistance for this study.

Conflicts of Interest: The authors declare no conflict of interest.

AI Declaration

During the preparation of this manuscript, the authors used AI-assisted technologies to improve language quality and readability. All intellectual content, analysis, and conclusions remain the sole responsibility of the authors.

References

Alhamrouni, I., Abdul Kahar, N. H., Salem, M., Swadi, M., Zahroui, Y., Kadhim, D. J., Mohamed, F. A., & Alhuyi Nazari, M. (2024). A Comprehensive Review on the Role of Artificial Intelligence in Power System Stability, Control, and Protection: Insights and Future Directions. In *Applied Sciences (Switzerland)* (Vol. 14, Number 14). Multidisciplinary Digital Publishing Institute (MDPI). https://doi.org/10.3390/app14146214

Bottaro, M., Eduardo Caires, L., Futoshi Obase, P., Ohara de Carvalho, T., & Tatizawa, H. (2025). A Comprehensive Analysis of the Influence of Thermal Insulating Materials on Arc Rating Tests. *IEEE Transactions on Instrumentation and Measurement*, *74*, 1–9. https://doi.org/10.1109/TIM.2025.3529562

Budiyanto, S., & Silalahi, L. M. (2023). Internet of Things for 4.0 Industry Revolution. *Journal of Innovation and Community Engagement*, *4*(3 SE-Articles), 164–173. https://doi.org/10.28932/ice.v4i3.7316

Budiyanto, S., Tomohardjo, I., Iman, F. N., & Silalahi, L. M. (2024). Application of Electrical Technology Using Website as a Digital Communication Science Media Based on

Information and Communication Technology at Amari Teaching and Learning Centre. *Journal of Innovation and Community Engagement*, *5*(4 SE-Articles), 253–261. https://doi.org/10.28932/ice.v5i4.10020

Cabello, J. R., Bullejos, D., & Rodriguez-Prieto, A. (2023). Analysis of Incident Energy and Arc Flash Boundary Behavior in Electric Power Distribution Systems. *IEEE Access*, *11*, 54165–54174. https://doi.org/10.1109/ACCESS.2023.3280050

Cramm, H., Cox, M., Norris, D., Reid, N., Tam-Seto, L., Dekel, R., Fear, N. T., Delaney, L., Richmond, R., & Mahar, A. (2025). Lifestyle Dimensions of Public Safety Personnel Families: There's No Life Like It. *Journal of Occupational Rehabilitation*, *35*(2), 268–277. https://doi.org/10.1007/s10926-024-10213-y

Fidya Eka Prahesti, Elsanda Merita Indrawati, Rezi Delfianti, & Vania Aprilia Ukhti. (2023). Protection Coordination Analysis Study Considering the Arc Flash in the Electrical System of PLTU Paiton Unit III Using IEEE Standard 1584-2002. *Jurnal Edukasi Elektro* , *7*(2), 121–132.

Hardi, S., Andira, R., Nisja, I., Octrialdi, B., & Pinem, M. (2021). Economic Design of Substation Grounding Grid using ETAP Software: A Case Study of 2 x 500 MVA Galang Substation. *Journal of Physics: Conference Series*. https://doi.org/10.1088/1742-6596/1811/1/012055

Kulor, F., Apprey, M. W., Agbevanu, K. T., Gasper, G. K., & Akorta, J. A. (2024). Invisible threats: An investigation of electrical hazards and safety practices among residential electricity consumers. *Heliyon*, *10*(14), e34470. https://doi.org/10.1016/j.heliyon.2024.e34470

Li, G., Guo, J., Kang, Y., Huang, Q., Zhao, J., & Liu, C. (2025). Classification and Prevention of Electrical Fires: A Comprehensive Review. *Fire*, *8*(4), 154. https://doi.org/10.3390/fire8040154

Liang, J., Qiu, Y. (Lucy), Wang, B., Shen, X., & Liu, S. (2025). Impacts of heatwaves on electricity reliability: Evidence from power outage data in China. *IScience*, *28*(2), 111855. https://doi.org/10.1016/j.isci.2025.111855

Lu, M., Mu, W., Qin, M., Koehler, A., Fang, J., & Goetz, S. M. (2025). Differential Detection of Feeder and Mesh Impedances Through a Series–Parallel Direct-Injection Soft Open Point. *IEEE Transactions on Power Electronics*, *40*(1), 1964–1973. https://doi.org/10.1109/TPEL.2024.3456071

Mohd Azmi, K. H., Mohamed Radzi, N. A., Azhar, N. A., Samidi, F. S., Thaqifah Zulkifli, I., & Zainal, A. M. (2022). Active Electric Distribution Network: Applications, Challenges, and Opportunities. In *IEEE Access* (Vol. 10, pp. 134655–134689). Institute of Electrical and Electronics Engineers Inc. https://doi.org/10.1109/ACCESS.2022.3229328

Nhat, N. N., & Ngoc, T. N. (2025). Arc flash analysis using ETAP platform. *Journal of Physics: Conference Series*, *2949*(1). https://doi.org/10.1088/1742-6596/2949/1/012019

Virtudez, T. G., Gulben, W., Gulben, E. J., & Cultura, A. B. (2026). Design and evaluation of protection system of 50mva, 138/69/13.8kv power transformer of Bislig Substation of

the National Grid Corporation of the Philippines. *International Journal of Multidisciplinary Education and Research*. Retrieved www.multieducationjournal.com
Yadav, A. K., Kumar, A., & Sinha, S. (2024). A review of concentrated solar power status and challenges in India. *Solar Compass*, *12*, 100079. https://doi.org/https://doi.org/10.1016/j.solcom.2024.100079