**Proceedings of 15th IOE Graduate Conference**
*Peer Reviewed*
**Year: 2024 Month: May Volume: 15**
**ISSN: 2350-8914 (Online), 2350-8906 (Print)**

# Analysis of Arc Flash and Mitigation Techniques in Substation Protection of Attariya Substation Nepal

In Bahadur Rai [a], Akhileshwar Mishra [b], Jeetendra Chaudhary [c]

[a, b, c] *Department of Electrical Engineering, Pulchowk Campus, IOE, Tribhuvan University, Nepal*
[a] 078mspse008.in@pcampus.edu.np, [b] akhileshwar@ioe.edu.np, [c] jeetendra@ioe.edu.np

**Abstract**
Arc flash is a type of electrical explosion that can occur when there is a sudden and high current flow either between a conductor and ground or between two conductors. Arcing flash produces intense heat and light, and can release large amounts of energy. Arc flash analysis is required to quantify the associated risk and minimize the possible consequences with optimal protective measures. The electrical power system in Nepal is in growing phase. There are number of substations being upgraded, new substation being constructed. However, the consideration of arc flash analysis in substation protection system are not found to the level it required. The arc flash analysis is one of the important consideration for protection and control design of substation. The principal objective of this study is to quantify potential risks associated with arc flash events in the Attariya Substation and devise effective mitigation techniques. The Attariya substation is located in Far western province, Kailali District, Nepal. There were unofficial record of number of incidents related to arc flash in Attariya substation such as fire in low voltage (LV) switchgear and arcing due to underground (UG) cable termination explosion. The transformers in Attariya substation has been upgraded with higher capacity, which might have resulted in higher fault level in the substation. Thus, this study presents result of comprehensive analysis of arc flash and mitigation technique in Attariya substation. The substation's electrical power system model is created and assessed through the utilization of ETAP 19.01 software, known as the Electrical Transients Analyzer Program. There are two 16.6 MVA 33/11 kV transformers each of them connected to respective incomer and a normally open 11 kV bus tie circuit breaker. While analyzing the substation with existing protection devices (PD) and circuit breaker (CB) setting the fault clearing time and incident energy are observed to be at higher level than the proposed alternative setting of protective devices and circuit breakers. With alternative setting of protective devices the possible risk from arc flash incidents have been minimized significantly and minimize possible risk of equipment damage and injury to operating personnel.

**Keywords**
Time-current curve (TCC), Arc flash, Fault Clearing Time (FCT), Arc Flash Boundary (AFB), Incident Energy

## 1. Introduction

The analysis of arc flash hazards and implementation of effective mitigation techniques are of utmost importance in ensuring the safe operation of electrical system and preventing possible consequences. Understanding the hazards associated with arc flashes and implementing appropriate protection measures are critical for safeguarding personnel and infrastructure. Arc flash is an electrical explosion that can occur when there is a sudden and high-current flow either between a conductor and ground or between two conductors. Arc flashes produces intense heat and light, and can release large amounts of energy. It can also create a shock wave that can travel through the air and cause damage to equipment and structures. An Arc Flash Hazard is defined as a potential source of harm or damage linked to the discharge of energy resulting from an electric arc. The significant decrease in injuries, damages, and their respective costs underscores the importance of conducting thorough arc flash analysis. However, in Nepal the classification of electrical incidents have not started yet but with the increase in power system the classification and standard record is required to identify the specific cause and take possible action. Number of fire incident have been noticed in industries and commercial building due to electric faults and the failure to promptly clear in a safe manner. Comprehensive analysis of arc flash hazard is required in electrical power system with the increase in its complexity as well as with increase in capacity, without proper analysis the coordination of protective devices could not be identified and the fault may not be cleared in safe timing which cause the arc flash with possible consequences. In this paper, result of arc flash analysis of Attariya Substation Nepal is presented to show the level of arc flash hazard present in the substation and to minimize the arc flash hazard with proper method of mitigation with minimum cost. This study demonstrates the extent to which incident energy levels can be minimized through alternative settings of the protective and fault-clearing devices at the Attariya substation, as examined in the case study. With the obtained results possible risk of arc flash can be quantified and recommend the suitable action of minimizing the possible risk, thus saving the cost of injury and damage to the electrical equipment and infrastructures.

## 2. Literature Review

In [1], the authors discuss the types and volume of arc flash injuries documented by OSHA inspectors in the United States from April 1984 to June 2007. The authors consider various injury types and occurrences categorized by voltage class (ranging from 120 V to 240 kV), the frequency of events across different equipment classes and typical tools used, as well as the detailed descriptions of numerous incidents. In [2], IEEE Std. 1584 provides a standardized procedure for carrying out arc flash analysis. Its range of application includes fault current from 500A to 106kA and three phase voltages between 208 V and 15 kV. For the voltage above 15 kV Lee method of formulae can be applied [3]. In [4], the authors discuss the necessity of high voltage arc flash examination. The authors contrasts the many arc flash analysis methods that are available and examines the consistency of the findings. In [5], the authors presents a case study of SSN substation situated in North Florida. The authors have modeled electrical power system of SSN substation utilizing ETAP 14.01. Then, the authors have evaluated with reference to standard method and guidelines. Various substation configurations were taken into consideration when performing study. For the analysis, the IEEE Std. 1584 guidelines were employed. In [6], the standard has provided guidelines and standards for workplace electrical safety, emphasizing the dangers associated with electrical systems and arc flash incidents. Primary goals of NFPA 70E-2018 are to safeguard employees from electrical hazards and lower the possibility of accidents and fatalities. In [3], the authors have conducted an analysis of arc flash on the IEEE 8 bus test system using the DIgSILENT software. The determination of incident energy (IE) involved applying the methodology outlined in the IEEE Std. 1584 and NFPA 70E-2018. In [7], the IEEE Std. 242-2001, commonly referred to as the IEEE Buff Book, offers standardized guidelines for conducting protection coordination studies in power systems. This guide delineates key principles for ensuring the protection and efficient coordination of industrial and commercial power systems, aimed at safeguarding them against potential anomalies expected during operation. In [8], the authors provides IEEE four node test feeder, with a simple test feeder to examine our method of arc analysis. The authors explain all the necessary data and parameters required to model the test system using selected tool.

## 3. Methodology

IEEE Std. 1584 [2] is the main reference of arc flash analysis of this study and [7] IEEE Std. 242-2001 is the reference for protection coordination study. This study initiated with the collection of all the necessary data from Attariya substation Nepal and proceeding system modeling in ETAP 19.01. Performed sequential checks of load flow, short circuit fault level, protection coordination and finally arc flash analysis is performed for existing system. Then effective method of reducing incident energy and possible risk of arc flash has been identified and presented in this study.

### 3.1 Equations for Arc Flash Calculations

The criteria under which the IEEE Std. 1584 calculation method remains applicable are as follows [2]:

1. Range of Voltage: 208 V-15 kV
2. System frequency: Sixty or Fifty Hertz
3. Current in bolted fault condition
   (a) For voltage-208V to 600V: 500A to 106kA
   (b) For voltage-601V to 15kV: 200A to 65kA
4. Gaps between conductors:
   (a) For voltage-208V to 600V: 6.35mm to 76.2mm
   (b) For voltage- 601V to 15kV: 19.05mm to 254mm
5. Working distances of 305 millimeters or more
6. Electrode configuration: VCB,VCBB,HCB,VOA and HOA

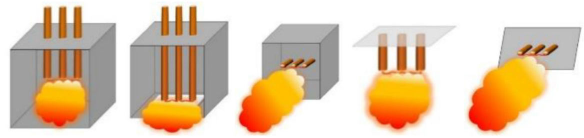


**Figure 1:** Electrode configuration [4]

Figure 1 represents electrode configurations as per IEEE Std. 1584, where VCB stands for vertical electrodes contained within enclosures, VCBB signifies vertical electrodes terminated within an insulating barrier inside an enclosure, HCB refers to horizontal electrodes housed within enclosures, VOA indicates vertical electrodes located in open air, and HOA denotes horizontal electrodes situated in open air. Incident Energy (E), Arcing fault current (Ia), and Arc Flash Boundary (AFB) are calculated with the following equations [2, 5]:

$$\log I_a = k + 0.662 \log I_{bf} + 0.000526G + 0.0966V - 0.00304G \log I_{bf} + 0.5588V \log I_{bf} \quad (1)$$

$$\log E_n = k_1 + k_2 + 0.0011G + 1.081 \log I_a \quad (2)$$

$$E = C_f \cdot E_n \left(\frac{610^x}{D^x}\right) \cdot \left(\frac{t}{0.2}\right) \quad (3)$$

$$\mathrm{D_B} = \left[C_f \cdot E_n \left(\frac{610^x}{E_\mathrm{B}}\right) \cdot \left(\frac{t}{0.2}\right)\right]^{1/x} \quad (4)$$

Where, $I_a$ and $I_{bf}$ are arcing and bolted fault currents in kA respectively. $k$ and $k1$ equal $-0.097$ and $-0.555$ for box configuration, and $-0.153$ and 0.792 for open configurations respectively. $V$ is the system voltage in kV. $G$ denotes gap between conductors in millimeters. $k2$ is 0 and $-0.113$ for ungrounded (high-resistance grounded) and grounded system respectively. $E_n$ signifies normalized incident energy in $\mathrm{cal/cm^2}$. For voltages exceeding 1 kV, $C_f$ is set to 1, while for voltages below 1 kV, it is adjusted to 1.5. The parameter $D$ and $t$ represents working distance in millimeters and arcing time respectively. Distance exponent, denoted by $x$, is determined according to IEEE Std. 1584. $E_B$ represents incident-energy $\mathrm{cal/cm^2}$ at boundary distance $D_B$ measured in mm.

It is obvious that IEEE Std. 1584 guidelines, provides the calculation only up to 15 kV. In cases where the voltage surpasses 15 kV or the gap extends beyond the model's specified range, the Lee method might be implemented to determine the incident energy, employing the following equation:

$$E = 2.142 \times 10^6 \times \left(\frac{t}{D^2}\right) \times I_{bf} \quad (5)$$

$$D_B = \left[2.142 \times 10^6 \times V \times \left(\frac{t}{E_B}\right) \times I_{bf}\right]^{1/2} \quad (6)$$

Where, $I_{bf}$, $E$, $V$, $t$, $D$, $D_B$ and $E_B$ represents incident energy in cal/cm$^2$, kV voltage, arcing time-seconds, distance from possible arcing point, boundary distance measured in millimeters and incident energy at boundary in cal/cm$^2$ respectively.

### 3.2 Data Collection and System Modeling

The site visit to Attariya substation has been completed and all the necessary data have been collected. The gathered information encompasses equipment specifications, including voltage rating, MVA rating, impedance, system fault level, X/R ratio, and protection settings of the substation. The panel's electrode configuration was validated and documented following the guidelines specified in IEEE Std. 1584 [2].The substation electrical system has been modeled in ETAP 19.01 with reference to the collected data and information. The modeling of system includes 33kV Bus-bar system and all the 11kV distribution switchgears. Figure 2 shows the single line diagram of Attariya Substation. It contains two 16.6 MVA, 33/11 kV power transformer, One 0.250 MVA, 33/0.400 kV station service transformer, five 3.3 MVA feeders and one 1.5 MVA feeders. There are two incomers in 11 kV switchgear with a bus tie circuit breaker in normally open configuration. The main 33 kV incomer has been protected by OCR, two power transformer have been protected by differential relays separately, 11 kV incomers are protected by multifunction relay with OCR and EF enabled, six outgoing feeders are also protected by multifunction relay with over current relay (OCR) and Earth Fault (EF) enabled. The Station service transformer high voltage (HV) side protected by fuse element and LV side protected by molded case circuit breaker (MCCB). Original setting of protective device and circuit breaker have been recorded and implemented in the substation model prepared for the analysis.

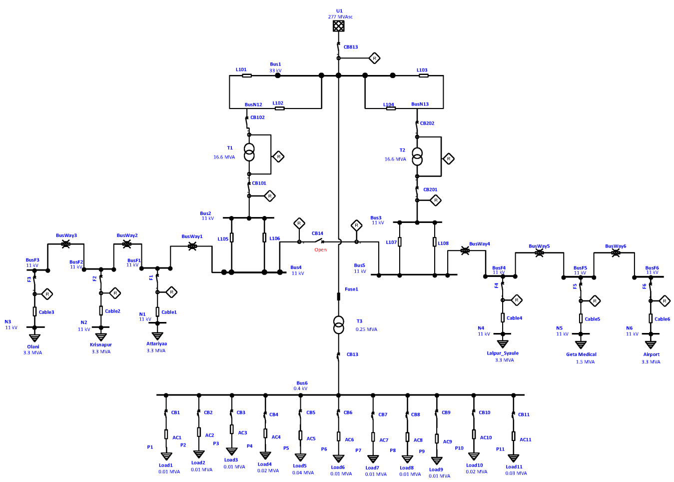

**Figure 2:** Single line diagram of case study Attariya substation

There are 11 outgoing circuits from station service distribution panel, each circuit protected with 4 pole miniature circuit breaker (MCB). The loading of the outgoing feeders are considered with respect to the average loading of the feeders, normally feeders loading found to be 50 percent of the total MVA rating. The OCR of five feeders have been set to trip at 195 A, one 1.5 MVA feeder OCR has been set to trip at 60 A. All the outgoing feeder circuit breakers are rated 1250 A, with breaking Capacity 25 kA and making capacity of 63 kA. While two incomers CB rated 2000 A, with braking capacity of 25 kA, and making capacity of 63 kA. The Bus bars and Bus ways are rated 2500A, with 25kA Peak and electrode configuration in panel are HCB with reference to Std.1584 Guideline [2]. General Spacing line-line are 152 mm wile line-ground spacing noted 52mm. The UG cables connected from the indoor switchgear panel to the outdoor distribution pole termination in open air horizontal that means HOA configuration. Power transformer breaker are rated 2000A, with breaking capacity 25kA and making capacity 65 kA. The Bus 1 is considered as swing bus which will be connected to 132 kV bus bar through grid transformer. The six 630 mm2 UG cable connects 33 kV Bus bar to transformer 1, that means two 630 mm2 cable in each phase and similar applies to transformer 2. The 11kV output from 16.6 MVA transformer has been connected to indoor switchgear Incomer 1 by six 400 mm2 UG cable, that means two cable in each phase, and similar applies connection between transformers to incomer 2. The 11kV switchgear to outdoor distribution pole has been connected by 300 mm2 UG cable. For one 1.5 MVA feeder 95 mm2 cables have been installed.

## 4. Comprehensive System Analysis

Comprehensive analysis of Attariya substation includes the following power system analysis: (a) Load-Flow (b) Short-Circuit (c) Protection-Coordination and (d) Arc Flash Analysis

**Table 1:** Load Flow Result

| Bus ID | Voltage kV | Voltage % | Current | %PF |
|---|---|---|---|---|
| Bus1 | 33.00 | 100.00 | 163.9 | 88.5 |
| Bus2 | 11.00 | 100.746 | 261.6 | 90 |
| Bus3 | 11.00 | 101.033 | 214.4 | 89.2 |
| Bus4 | 11.00 | 100.739 | 261.6 | 90 |
| Bus5 | 11.00 | 101.026 | 214.5 | 89.2 |
| Bus6 | 0.400 | 98.703 | 110.1 | 91.4 |
| BusF1 | 11.00 | 100.739 | 261.6 | 90.0 |
| BusF2 | 11.00 | 100.739 | 174.4 | 90.0 |
| BusF3 | 11.00 | 100.739 | 87.2 | 90.0 |
| BusF4 | 11.00 | 101.026 | 214.5 | 89.2 |
| BusF5 | 11.00 | 101.026 | 127.1 | 88.6 |
| BusF6 | 11.00 | 100.026 | 87.5 | 90.0 |
| N1 | 11.00 | 100.731 | 87.2 | 90.0 |
| N2 | 11.00 | 100.731 | 87.2 | 90.0 |
| N3 | 11.00 | 101.729 | 87.2 | 90.0 |
| N4 | 11.00 | 101.015 | 87.2 | 90.0 |
| N5 | 11.00 | 101.018 | 39.8 | 85.0 |
| N6 | 11.00 | 101.018 | 87.5 | 90.0 |

Table 1 presents the load flow result of Attariya substation considering normal operation configuration, where Bus tie breaker CB13 have been in normally open condition. The loading of all the buses are normal, there are not any constraints violations. The voltage kV represents nominal voltage and current presented in Ampere. Table 2 presents short circuit study result of Attariya substation for the fault at the given Bus ID location. Table 3 presents the result of arc flash analysis (AFA) obtained for Attariya substation existing condition. The simulation diagram is presented in Figure 3. Incident energy of 33 kV bus1 is extremely high. Which may cause second degree burn up to around 9 meter from the bus bar. The fault clearing time are different for different buses range from 0.035 Sec to 1.8 Sec. The result is obtained for the existing setting of protective devices and circuit breakers. The incident energy of other buses could be observed as mentioned in Table 3 and the effective mitigation measure shall be identified to reduce the incident energy as well as FCT related to the fault at respective bus.

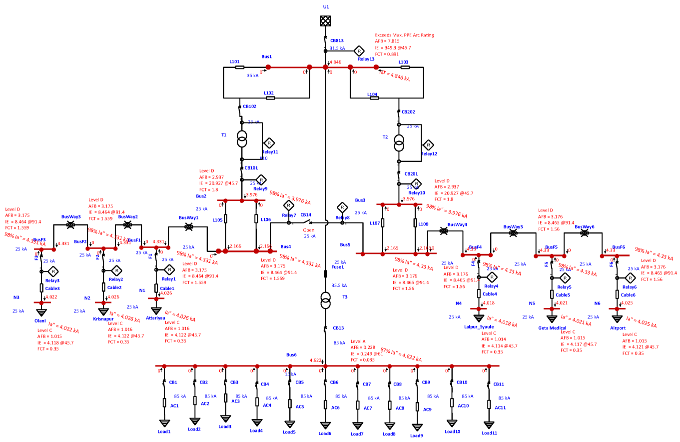

**Figure 3:** AFA simulation diagram for existing condition

**Table 2:** Short Circuit Result

| Bus ID | Voltage kV | Symm. kA rms | Asymm. kA rms |
|---|---|---|---|
| Bus1 | 33.00 | 4.846 | 7.375 |
| Bus2 | 11.00 | 4.777 | 7.269 |
| Bus3 | 11.00 | 4.777 | 7.269 |
| Bus4 | 11.00 | 4.771 | 7.250 |
| Bus5 | 11.00 | 4.770 | 7.247 |
| Bus6 | 0.400 | 7.881 | 8.011 |
| BusF1 | 11.00 | 4.771 | 7.250 |
| BusF2 | 11.00 | 4.771 | 7.249 |
| BusF3 | 11.00 | 4.771 | 7.249 |
| BusF4 | 11.00 | 4.770 | 7.247 |
| BusF5 | 11.00 | 4.770 | 7.247 |
| BusF6 | 11.00 | 4.770 | 7.247 |
| N1 | 11.00 | 4.751 | 7.817 |
| N2 | 11.00 | 4.751 | 7.816 |
| N3 | 11.00 | 4.747 | 7.174 |
| N4 | 11.00 | 4.742 | 7.519 |
| N5 | 11.00 | 4.745 | 7.101 |
| N6 | 11.00 | 4.750 | 7.184 |

**Table 3:** Existing Condition Arc Flash Analysis Result

| Bus ID | Voltage (kV) | $I_{bf}$ (kA) | $I_a$ (kA) | IE cal/cm$^2$ | FCT (sec) | AFB ( m ) |
|---|---|---|---|---|---|---|
| Bus1 | 33.00 | 4.846 | 4.846 | 349.3 | 0.891 | 7.815 |
| Bus2 | 11.00 | 4.777 | 3.976 | 20.93 | 1.8 | 2.937 |
| Bus3 | 11.00 | 4.777 | 4.331 | 20.93 | 1.8 | 2.937 |
| Bus4 | 11.00 | 4.771 | 4.330 | 8.46 | 1.559 | 3.175 |
| Bus5 | 11.00 | 4.770 | 4.622 | 8.47 | 1.56 | 3.176 |
| Bus6 | 0.400 | 7.881 | 5.298 | 0.249 | 0.035 | 0.228 |
| BusF1 | 11.00 | 4.771 | 4.331 | 8.46 | 1.559 | 3.175 |
| BusF2 | 11.00 | 4.771 | 4.331 | 8.46 | 1.559 | 3.175 |
| BusF3 | 11.00 | 4.771 | 4.331 | 8.46 | 1.559 | 3.175 |
| BusF4 | 11.00 | 4.770 | 4.330 | 8.47 | 1.56 | 3.176 |
| BusF5 | 11.00 | 4.770 | 4.330 | 8.47 | 1.56 | 3.176 |
| BusF6 | 11.00 | 4.770 | 4.330 | 8.47 | 1.56 | 3.176 |
| N1 | 11.00 | 4.751 | 4.026 | 4.12 | 0.35 | 1.016 |
| N2 | 11.00 | 4.751 | 4.026 | 4.12 | 0.35 | 1.016 |
| N3 | 11.00 | 4.747 | 4.022 | 4.12 | 0.35 | 1.015 |
| N4 | 11.00 | 4.742 | 4.018 | 4.11 | 0.35 | 1.014 |
| N5 | 11.00 | 4.745 | 4.021 | 4.12 | 0.35 | 1.015 |
| N6 | 11.00 | 4.750 | 4.026 | 4.12 | 0.35 | 1.015 |

## 5. Analysis of Mitigation and Recommendation

From the analysis of the existing conditions, fault clearing times are found within the range of seconds. This has resulted in high incident energy levels at various buses, ranging from risk category 1 to beyond risk category 5. The arc flash is new to the substation personnel at Attariya substation, where there was a lack of protective gear for arc flash incidents, and no warning or caution labels about possible arc flash incidents were present. The awareness of arc flash hazards is found to be below the required level. In addition to these existing conditions for mitigating arc flash hazards in the substation, there are several possible methods to reduce fault clearing times and minimize incident energy levels. One method is to replace circuit breakers and protective devices, but this approach incurs a significant cost for the utility. On the other hand, the settings of protective devices could be adjusted alternatively with proper coordination to achieve a lower fault clearing time than the existing one. This second method reduces incident energy with almost no expenses and is considered economical. The analysis of the Attariya substation has been conducted with alternative settings of protective devices, as shown in Table 4. With the new settings of devices, the coordination has been studied and found to be accurate according to IEEE Std 242-2001. The TCC curves can be observed in Figure 4, Figure 5, and Figure 6. Additionally, calculated fault clearing time falls within the range specified by IEEE Std. 242-2001. A significant improvement in fault clearing time and a reduction in incident energy levels have been observed, as shown in Table IV. This adjustment of settings for protective devices will significantly reduce the risk of arc flash hazards and minimize possible consequences. Table 4 represents the recommended alternative settings for protective devices for Attariya Substation Nepal to reduce both fault clearing time and incident energy. It is also essential to maintain regular monitoring and assessments to uphold the sustained effectiveness of the implemented measures.

**Table 4:** Alternative Protective Device Setting

| Relay ID | CT Ratio | PSM | TDS |
|---|---|---|---|
| Relay1 | 300:1 | 0.65 | 0.10 |
| Relay2 | 300:1 | 0.65 | 0.10 |
| Relay4 | 300:1 | 0.65 | 0.10 |
| Relay5 | 300:1 | 0.20 | 0.10 |
| Relay6 | 300:1 | 0.65 | 0.10 |
| Relay7 | 900:1 | 0.69 | 0.20 |
| Relay8 | 900:1 | 0.69 | 0.22 |
| Relay9 | 900:1 | 0.69 | 0.25 |
| Relay10 | 900:1 | 0.69 | 0.25 |
| Relay13 | 900:1 | 0.50 | 0.30 |

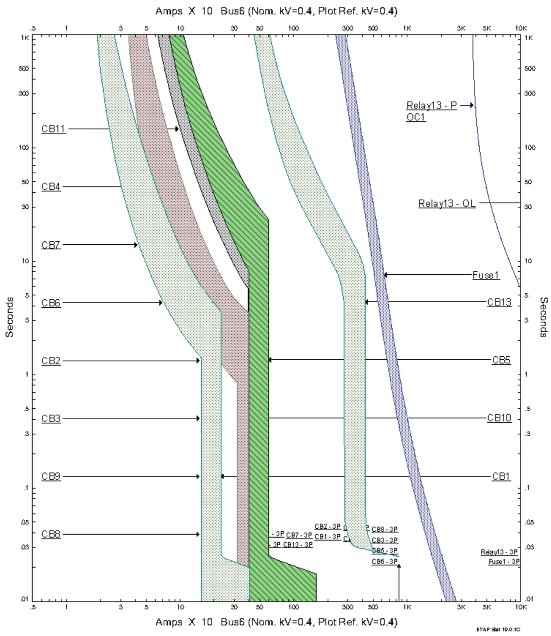


**Figure 4:** TCC of LVCB, HV Fuse and Relay 13 with alternative setting

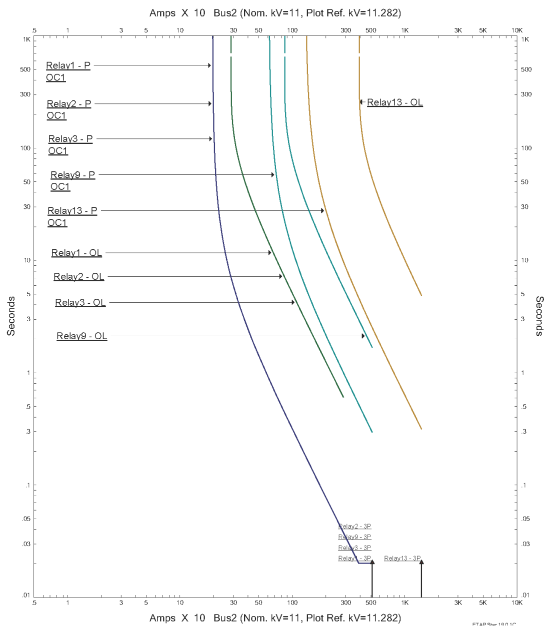


**Figure 5:** TCC of Relay1, 2, 3, 9 and 13 with alternative setting

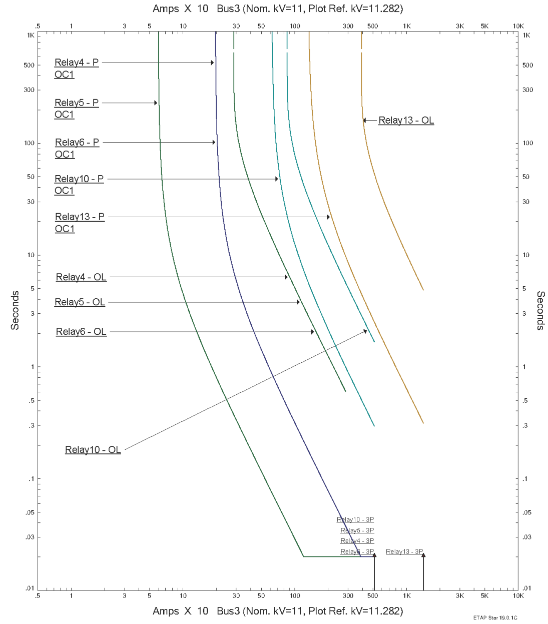


**Figure 6:** TCC of Relay 4, 5, 6, 10 and 13 with alternative setting

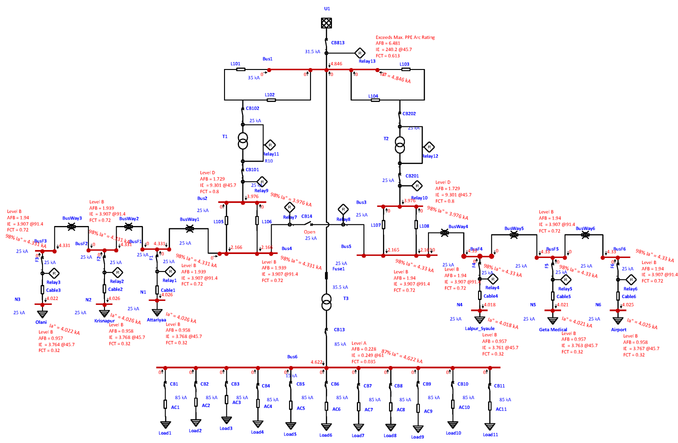

**Figure 7:** AFA simulation diagram of with Alternative Protective Device Setting

The TCC curves for various protective devices installed in the Attariya substation are depicted in Figure 4, Figure 5, and Figure 6. From the TCC curve analysis, it is evident that there are no intersections between the curves. This implies that only one device will be actuated at a time, ensuring proper coordination. The protection coordination study was conducted using ETAP 19.01, applying faults at various locations within the system model. The sequence of operation for protective devices and fault clearing devices was observed and found to be well-coordinated according to IEEE Std 242-2001. Table 4 presents the results of the arc flash analysis for the Attariya substation with alternative settings for protective devices, as mentioned in Table 4. It is observed that the incident energy level at 11kV buses has significantly reduced, mitigating the risk of injury and burns in accordance with NFPA 70E due to alternative protective device settings. The simulation diagram is shown in Figure 7. The calculated fault clearing time falls within the range specified by IEEE Std. 242-2001.

**Table 5:** Arc Flash Analysis Result With Alternative PD Setting

| Bus ID | Voltage (kV) | $I_{bf}$ (kA) | $I_a$ kA | IE cal/cm$^2$ | FCT (sec) | AFB ( m ) |
|---|---|---|---|---|---|---|
| Bus1 | 33.00 | 4.846 | 4.846 | 240.24 | 0.613 | 6.481 |
| Bus2 | 11.00 | 4.777 | 3.976 | 9.3 | 0.8 | 1.729 |
| Bus3 | 11.00 | 4.777 | 3.976 | 9.3 | 0.8 | 1.729 |
| Bus4 | 11.00 | 4.771 | 4.331 | 3.91 | 0.72 | 1.939 |
| Bus5 | 11.00 | 4.770 | 4.330 | 3.91 | 0.72 | 1.94 |
| Bus6 | 0.400 | 7.881 | 5.298 | 0.249 | 0.035 | 0.228 |
| BusF1 | 11.00 | 4.771 | 4.331 | 3.91 | 0.72 | 1.939 |
| BusF2 | 11.00 | 4.771 | 4.331 | 3.91 | 0.72 | 1.939 |
| BusF3 | 11.00 | 4.771 | 4.331 | 3.91 | 0.72 | 1.94 |
| BusF4 | 11.00 | 4.770 | 4.330 | 3.91 | 0.72 | 1.94 |
| BusF5 | 11.00 | 4.770 | 4.330 | 3.91 | 0.72 | 1.94 |
| BusF6 | 11.00 | 4.770 | 4.330 | 3.91 | 0.72 | 1.94 |
| N1 | 11.00 | 4.751 | 4.026 | 3.77 | 0.32 | 0.958 |
| N2 | 11.00 | 4.751 | 4.026 | 3.77 | 0.32 | 0.958 |
| N3 | 11.00 | 4.747 | 4.022 | 3.76 | 0.32 | 0.957 |
| N4 | 11.00 | 4.743 | 4.018 | 3.76 | 0.32 | 0.957 |
| N5 | 11.00 | 4.746 | 4.021 | 3.76 | 0.32 | 0.957 |
| N6 | 11.00 | 4.750 | 4.025 | 3.77 | 0.32 | 0.958 |

**Table 6:** AFA Comparison Existing Vs Alternative

| Bus ID | IE Exist. cal/cm$^2$ | IE Alt. cal/cm$^2$ | FCT Exist. Sec | FCT Alt. Sec | IE Red. cal/cm$^2$ | FCT Red. Sec |
|---|---|---|---|---|---|---|
| Bus1 | 349.3 | 240.24 | 0.891 | 0.613 | 109.06 | 0.278 |
| Bus2 | 20.93 | 9.3 | 1.8 | 0.8 | 11.63 | 1.000 |
| Bus3 | 20.93 | 9.3 | 1.8 | 0.8 | 11.63 | 1.000 |
| Bus4 | 8.46 | 3.91 | 1.559 | 0.72 | 4.55 | 0.839 |
| Bus5 | 8.47 | 3.91 | 1.56 | 0.72 | 4.56 | 0.840 |
| Bus6 | 0.249 | 0.249 | 0.035 | 0.035 | 0.00 0 | 0.000 |
| BusF1 | 8.46 | 3.91 | 1.559 | 0.72 | 4.55 | 0.839 |
| BusF2 | 8.46 | 3.91 | 1.559 | 0.72 | 4.55 | 0.839 |
| BusF3 | 8.46 | 3.91 | 1.559 | 0.72 | 4.55 | 0.839 |
| BusF4 | 8.47 | 3.91 | 1.56 | 0.72 | 4.56 | 0.840 |
| BusF5 | 8.47 | 3.91 | 1.56 | 0.72 | 4.56 | 0.840 |
| BusF6 | 8.47 | 3.91 | 1.56 | 0.72 | 4.56 | 0.840 |
| N1 | 4.12 | 3.77 | 0.35 | 0.32 | 0.35 | 0.030 |
| N2 | 4.12 | 3.77 | 0.35 | 0.32 | 0.35 | 0.030 |
| N3 | 4.12 | 3.76 | 0.35 | 0.32 | 0.36 | 0.030 |
| N4 | 4.11 | 3.76 | 0.35 | 0.32 | 0.35 | 0.030 |
| N5 | 4.12 | 3.76 | 0.35 | 0.32 | 0.36 | 0.030 |
| N6 | 4.12 | 3.77 | 0.35 | 0.32 | 0.35 | 0.030 |

A comparison between existing (Exist.) and alternative (Alt.) protective device settings at the Attariya substation is presented in Table 6. Results show a noteworthy reduction (Red.) in incident energy (IE) and improved fault clearing times at bus locations, leading to a significantly reduced arc flash boundary. The alternative settings are considered viable, effectively reducing arc flash hazards and minimizing potential damage and injuries. Fault clearing times for all buses has been improved. It is recommend to include warning labels at key locations with information on required PPE, arc flash boundary, and incident energy levels, contributing to cost-effective prevention of arc flash incidents.

## 6. Conclusion

This paper presents a comprehensive arc flash analysis of the Attariya substation, a vital source of electricity for Kailali district, Nepal. The study focuses on the real-world scenario of Attariya substation, chosen based on past incidents and upgrades. The analysis reveals that existing protective settings, while within IEEE Std. 242-2001 limits, pose heightened risks, potentially requiring costly measures. However, alternative coordinated settings significantly reduce fault clearing time, arc flash risk, and incident energy, emphasizing the importance of arc flash analysis for substation protection. The study underscores the need for safety measures, connecting with broader power system studies. As Nepal's power system expands, implementing arc flash analysis becomes crucial for safety, operational efficiency and robust substation electrical infrastructure, aligning with global practices.

## Acknowledgments

The authors would like to extend their sincere appreciation to the Nepal Electricity Authority Attariya Grid Branch for generously providing access and necessary information, allowing for the successful execution of the analysis. Furthermore, the authors express their gratitude to all the dedicated supporting personnel whose contributions were instrumental in the completion of this study.

## References

[1] C.M. Wellman. OSHA arc-flash injury data analysis. In *IEEE IAS Electrical Safety Workshop*, pages 1–5. IEEE IAS Electrical Safety Workshop, 2012.

[2] IEEE. IEEE guide for performing arc - flash hazard calculations 1584-2018. *IEEE Industry Application Society*, 2018.

[3] A. Bukar M.A. Gana and Smaila Y.A. Arc flash study of IEEE 8 bus test system using digital simulation and electrical network analysis platform. *Arid Zone Journal of Engineering, Technology and Environment*, 19:1–12, 2023.

[4] G. Praise and P.A. Scarpino. A basic assessment of arc flash in low voltage ac. *IEEE Transactions on Industry Applications*, 57:4513–4519, 2021.

[5] A. Asrari, B. Ramos, S. Lavoie, and M. Churilla. Arc flash analysis of silver springs north switchyard — a case study in North Florida. In *North American Power Symposium (NAPS)*, pages 1–6, 2017.

[6] National Fire Protection Association. Standard for electrical safety in workplace NFPA70E 2018. *IEEE Transactions on Industry Applications*, 51:2709–2716, 2018.

[7] IEEE. IEEE std 242-2001 - IEEE recommended practice for protection and coordination of industrial and commercial power systems (ieee buff book). *IEEE Industry Application Society*, 2001.

[8] IEEE PES Test Feeder Working Group. 4-bus test feeder, July 2017. Accessed on March 3, 2024.