World Academy of Science, Engineering and Technology
International Journal of Energy and Power Engineering
Vol:16, No:9, 2022

Permanent Reduction of Arc Flash Energy to Safe Limit on Line Side of 480 Volt Switchgear Incomer Breaker

Md Abid Khan

Abstract**—**A recognized engineering challenge is related to personnel protection from fatal arc flash incident energy in the line side of the 480-volt switchgears incomer breakers during maintenance activities. The incident energy is typically high due to slow fault clearance and it can be higher than the available personnel protective equipment (PPE) ratings. A fault on the line side of the 480 Volt breaker is cleared by breakers or fuses in the upstream higher voltage system (4160 Volt or higher). The current reflection in the higher voltage upstream system for a fault in the 480-volt switchgear is low, the clearance time is slower and the inversely proportional incident energy is hence higher. The installation of overcurrent protection at 480-volt system upstream of the incomer breaker will operate fast enough and trips the upstream higher voltage breaker when a fault develops at the incomer breaker. Therefore, fault current reduction as reflected in the upstream higher voltage system is eliminated. Since the fast overcurrent protection is permanently installed, it is always functional, do not require human interventions and eliminates exposure to human errors. It is installed at the maintenance activity location and its operations can be locally monitored by craftsmen during maintenance activities.

Keywords**—**Arc flash, mitigation, maintenance switch, energy level.

I. Introduction

A common solution is adopted in the industry which is application of Energy Reduction Maintenance Switch (ERMS) in the upstream higher voltage breaker to reduce the energy level on the connection point of secondary side of the transformer (480 Volt) and line side of the 480 V breaker. Switching the ERMS "ON" prior to maintenance activities makes the protection faster for a fault in the 480-volt incomer breaker and hence lowers the incident energy. After the maintenance activities are completed, the ERMS is switched back to 'OFF' position to adjust back the protection speed. The ERMS solution requires human interventions prior and after maintenance activities and it is therefore subjected to human errors. In addition, the ERMS is installed on the upstream higher voltage system breaker which can be remote from the maintenance activity's location at the 480-volt switchgear and hence impossible to monitor at the maintenance location.

Arc Flash (AF) energy level on the connection point of secondary side (480 Volt) of transformer and line side of the downstream 480 Volt breaker is always high because of impedance of the transformer. Using of Maintenance switch, the protection coordination will be compromised and will be the cause of mis-coordination if anyone forgets to turn off the maintenance switch. The normal overcurrent relay can be installed close to the secondary side (480 Volt) of the transformer with proper coordination of existing transformer upstream relay and downstream 480 Volt incomer breaker will reduce the energy level on connection point of the secondary side (480 Volt) side of the transformer and 480 Volt line side of the downstream breaker. The new overcurrent relay will trip with proper coordination to the upstream breaker of the transformer.

A. New Relay Installation

Three CTs need to be installed between the 480 V transformer secondary and 480 Volt main circuit breaker. The relay will be wired from the CTs via CT shorting terminals and be installed on the 480 Volt switchgear. The relays will have manual local reset with flag indication. One contact of the relay needs to be wired back to 4160V upstream breaker trip circuit, so that in AF situation on connection point of secondary side (480 V) of transformer and line side (480 Volt) of the breaker, the relay will trip the upstream 4160Volt breaker. All necessary testing to be done to confirm desired relay operation.

The above relays require 120 Vac/dc external power to operate. 125Vdc can be used from the 480 V breaker control circuit. In case of fault downstream of connection point of 480 V breaker line side and secondary side (480 Volt) of the transformer, the upstream 13800Volt or 4160Volt breakers will trip before 480 V switchgear main breaker as curves for both overcurrent relays and 480 Volt main breakers are very close to each other. If the 13800Volt or 4160Volt upstream breaker will trip before the 480 Volt Switchgear main breaker in case of fault on the 480 Volt main bus then this mis-coordination will not give greater area outage. This mis-coordination is well acceptable in the industry.

B. AF Principle

This paper is based on several important standards relating to AF calculations. The calculation of AF energies has been conducted in accordance with IEEE Standard 1584 - Guide for Performing Arc-Flash Hazard Calculations. It is important to understand that equations developed in IEEE Standard 1584 are based on the AF hazard that exists when employees are working in the vicinity of live exposed electrical equipment such as

Md Abid Khan is with Saudi Aramco, Saudi Arabia (e-mail: abk453@yahoo.com).

opening a breaker door to rack the breaker in/out or removal of a back panel for inspection.

The testing and subsequent development of the IEEE Standard 1584 AF equations was completed with exposed equipment. However, it is interesting to note that NFPA 70E – Standard for Electrical Safety in the Workplace considers activities such as reading door meters (closed door) as non-obtrusive and rates this activity with a hazard risk category 0. This is with the understanding that the risk would be low, even though there is no guarantee that non-arc resistant switchgear would contain an arc blast.

Given that the risk is much higher when live equipment is exposed, it is always preferred option to work on de-energized equipment. Alternately, other methods of reducing possible exposure to AF hazard can be examined. For example, using remote open/close and automatic breaker racking would reduce an employee's exposure. As stated in IEEE Standard 1584, PPE should be the last line of defense for an AF hazard [1].

NFPA 70E states "Live parts to which an employee might be exposed shall be put into an electrically safe work condition before an employee works on or near them, unless the employer can demonstrate that de-energizing introduces additional or increased hazards or is infeasible due to equipment design or operational limitations" [2]. ANSI/IEEE Standard 141 states "Protection in an electric system is a form of insurance. It pays nothing as long as there is no fault or other emergency, but when a fault occurs it can be credited with reducing the extent and duration of the interruption, the hazards of property damage, and personnel injury" [3].

ETAP software is utilized for coordination and AF analysis for this paper. The software calculates the bolted three phase fault current and then estimates the arc current using the IEEE Standard 1584 equations. In accordance with IEEE Standard 1584, the software determines the tripping time and incident energy at 100% of the estimated arc current and then repeats the calculations at 85% of the estimated arc current. The software compares the results and then reports the highest incident energy of the two calculations.

Within a modeling process it is necessary to make assumptions, particularly when an electrical power system has been in place for many years. System data may not be available, which could prevent the AF study from progressing, but the use of reasonable, justifiable assumptions will allow completion of the study. IEEE Standard 399 states "The operation of protective devices can be estimated by graphic representation of the time-current characteristics curves (TCCs) of these devices. By plotting these characteristics on a common graph, the relationship of the characteristics among the devices is immediately apparent" [4].

Per the ETAP study software, trip times are determined by comparing the arc current to the protective device tripping curve. For breakers, contact opening time is added to the protective device trip time which the ETAP software has assumed to be 0 cycles for low voltage (< 1 kV) molded case breakers with integral trip units, 5 cycles for low voltage power circuit breakers, and 5 cycles for medium voltage (1 to 35 kV). Both the short-circuit current and *X/R* ratio are important in medium-voltage circuit breaker application [5].

It is important to note the distinction between an AF hazard, which pertains to heat energy only and is the focus of this paper, and an arc blast hazard, which pertains to a pressure wave and is not the primary focus of this paper. The AF rating of PPE is concerned with protection from heat energy.

II. Experimental Verification and Result Analysis

In this paper, part of 400MVA coal fired power plant power system (4160Volt/480 Volt transformer with 4160Volt and 480 Volt busses) has been presented.

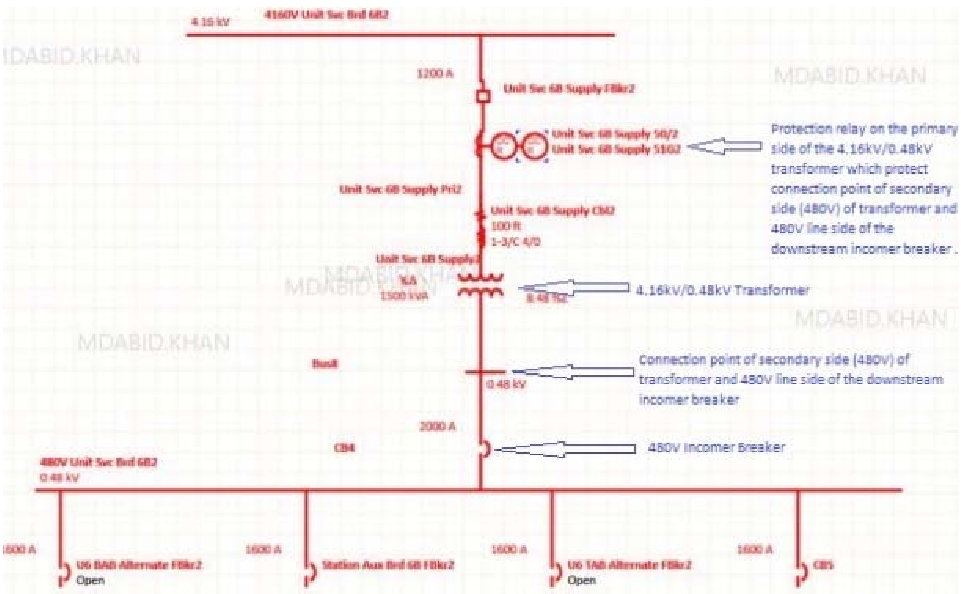

Fig. 1 The electrical system where 480 Volt incomer breaker does not protect connection point (Bus 8) of secondary side (480 Volt) of transformer and 480 Volt line side breaker

The bus 8 is protected by 1500 kVA transformer primary protection which has slow fault clearing time on Bus 8 and that's why AF energy is very high at Bus 8. The maintenance switch can be installed on the transformer primary protection relay which basically enables instantaneous setting without delay to reduce the AF energy level on the connection point of secondary side of the transformer and line side of the 480 V incomer breaker but there will be no coordination on 480 Volt Bus. It is worth to mention that turning on instantaneous setting by maintenance switch will not allow transformer to energize because transformer inrush current will trip the upstream breaker by transformer primary side relay.

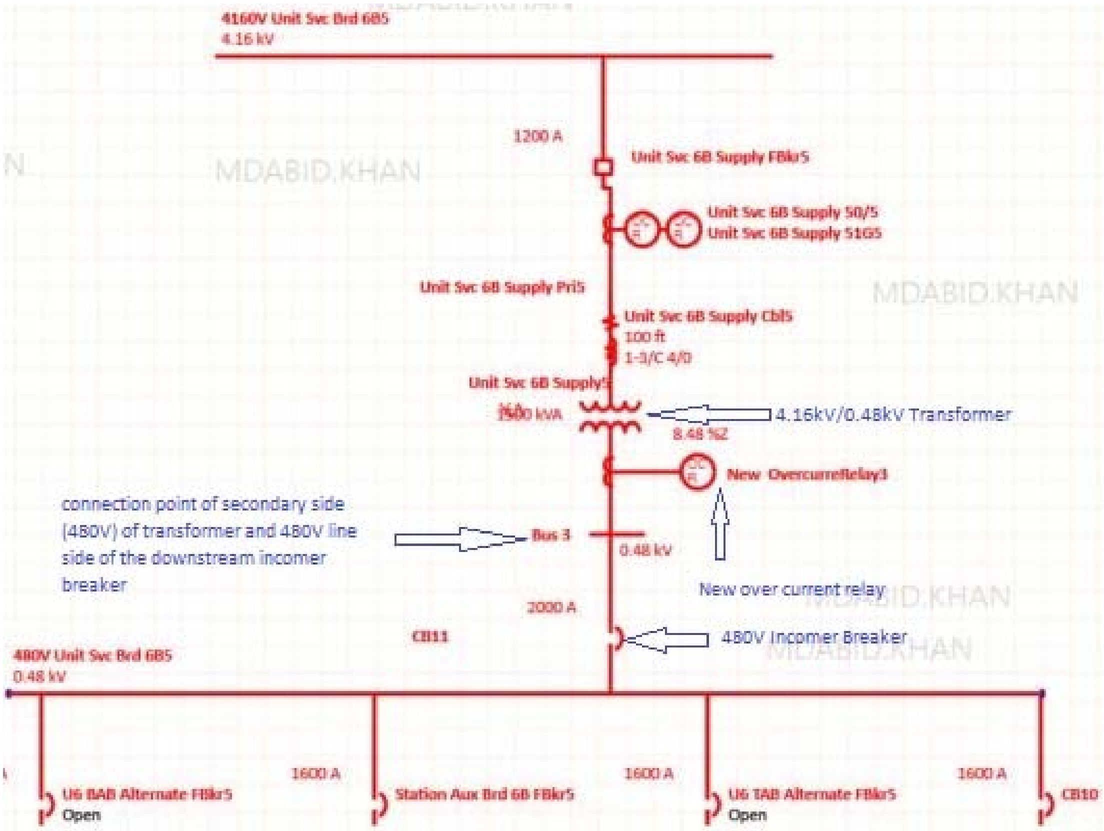

Fig. 2 Installation location of the new over current relays with CTs (Current Transformers) which are close to the secondary side (480 V) of the transformer

The additional protection relay which will be installed close to the secondary side (480 Volt) will reduce the AF energy level on the connection point (Bus 8) of secondary side (480 Volt) of transformer and 480 V line side of the downstream incomer breaker.

Fig. 3 is the screen shots from ETAP software which present AF level and category on the connection point of secondary side (480 Volt) of transformer and line side of the downstream 480 Volt breaker the before or after of installation of additional over current relay with CTs close to the secondary side (480 Volt) of the transformer.

It is very common that AF level is dangerous on bus at the line side 480 Volt incomer breaker without installation of new additional over current relay on the secondary side (480 Volt) of the transformer or installation of maintenance switch on primary side of the transformer.

By installation of the additional new relay on the close to the secondary side of the 1500 kVA transformer will reduce the energy level to 19.439 cal/cm^2 on the bus 480 V Stn Svc Brd 6B Main.

Power System coordination by fault insertion (PD sequence of operation) from the ETAP software is utilized to present how system coordination works with installation with the installation of normal over current relay with an instantaneous element with time dial and CTs close to the secondary side (480 Volt) of the transformer.

The coordination of 1500 kVA transformer upstream relay and 480 Volt incomer breaker is well coordinated while additional relay close to the secondary side of the 1500 kVA transformer is installed.

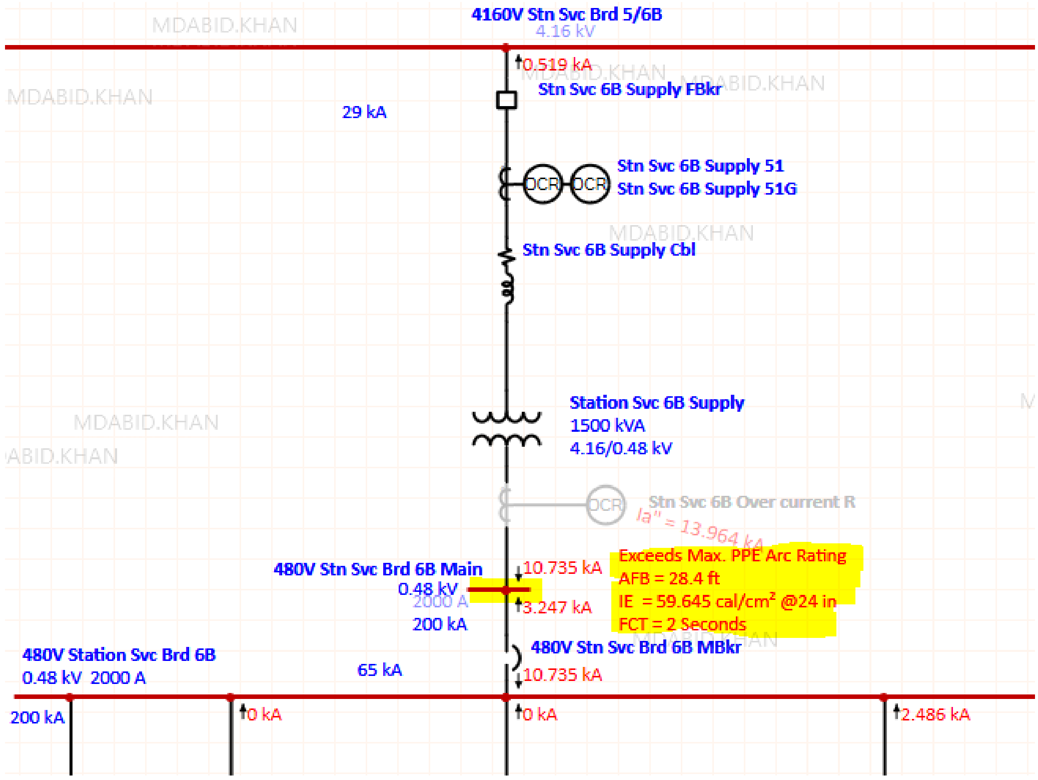

Fig. 3 AF level and category on Bus 480 V Stn Svc Brd 6B Main bus without installation of additional relay close to the secondary side of the 1500 kVA transformer

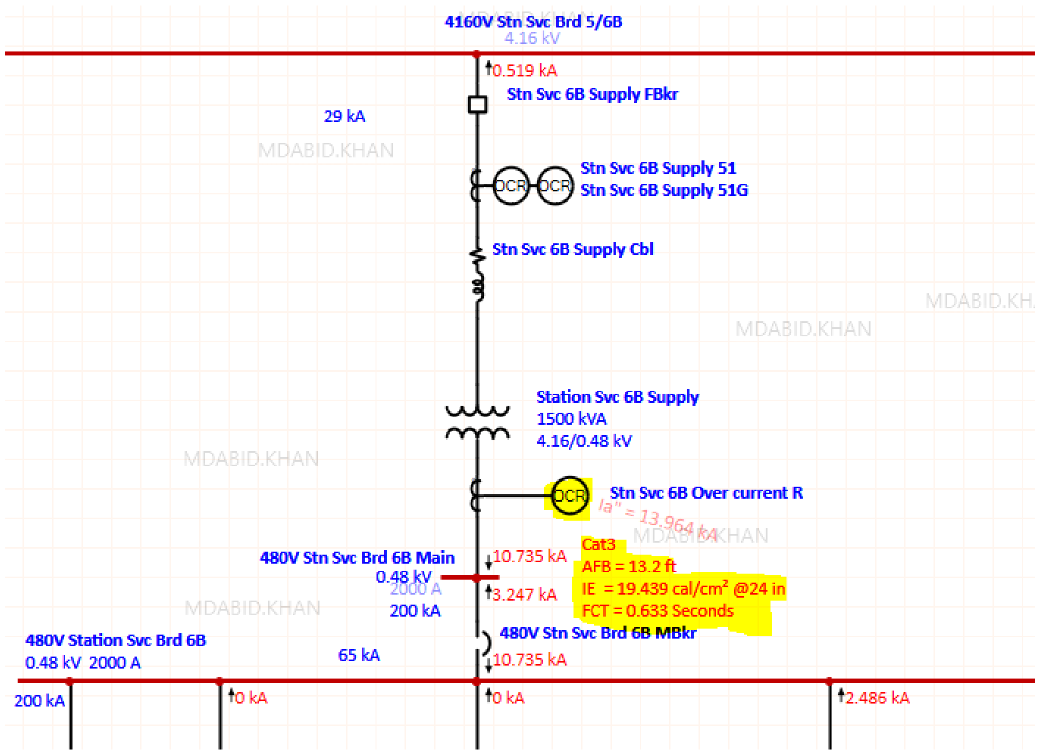

Fig. 4 480 V Stn Svc Brd 6B Main bus on the line side of the 480 V Stn Svc Brd MBkr has 19.439 cal/cm2 which is AF Category 3

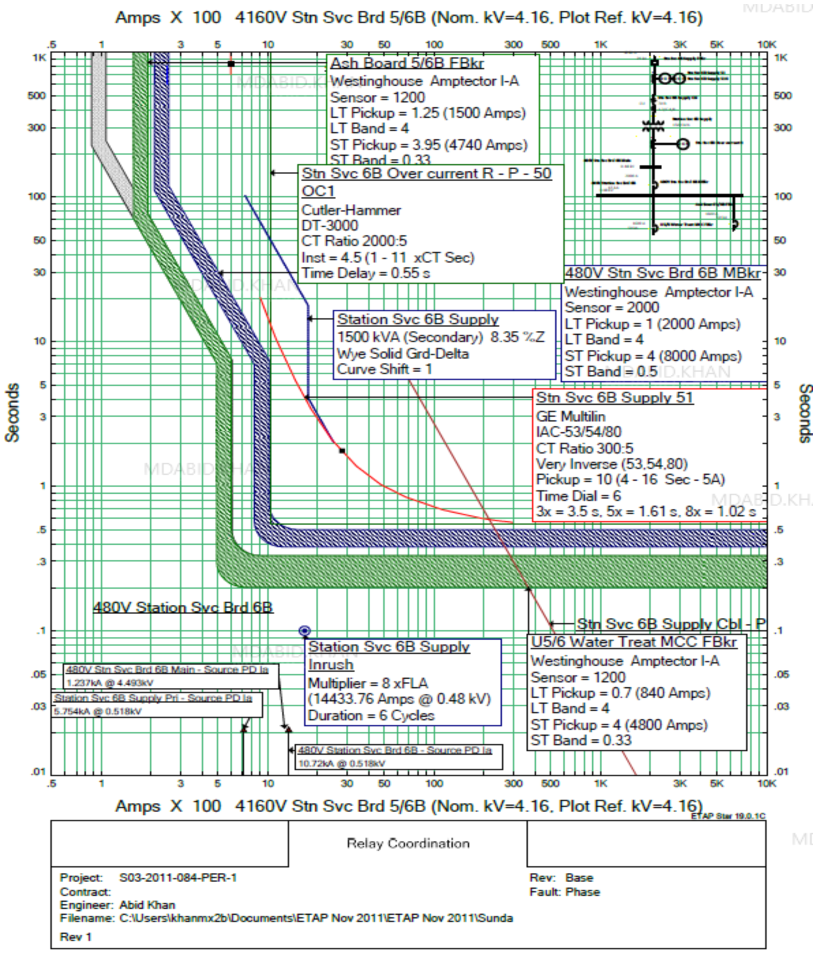

Fig. 5 Time Current Curve for well coordination of the new additional overcurrent relay (Stn Svc 6B over current R) with 1500KVA transformer's upstream relay and 480 Volt breaker (480 Volt Stn Svc Brd 6B MBkr)

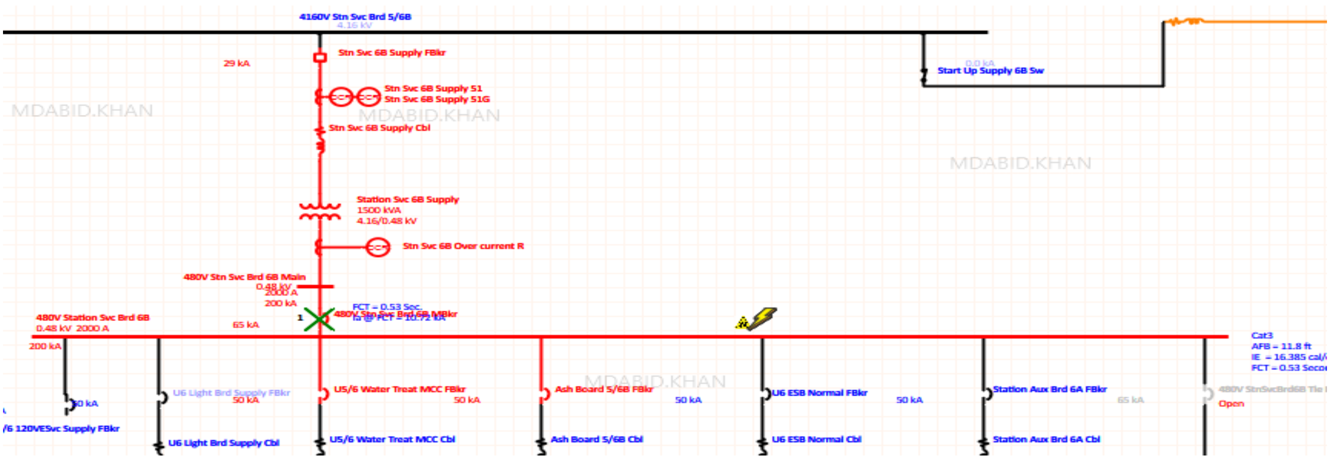

Fig. 6 Coordination from ETAP software for 480 Volt incomer breaker and 1500kVA transformer upstream relay

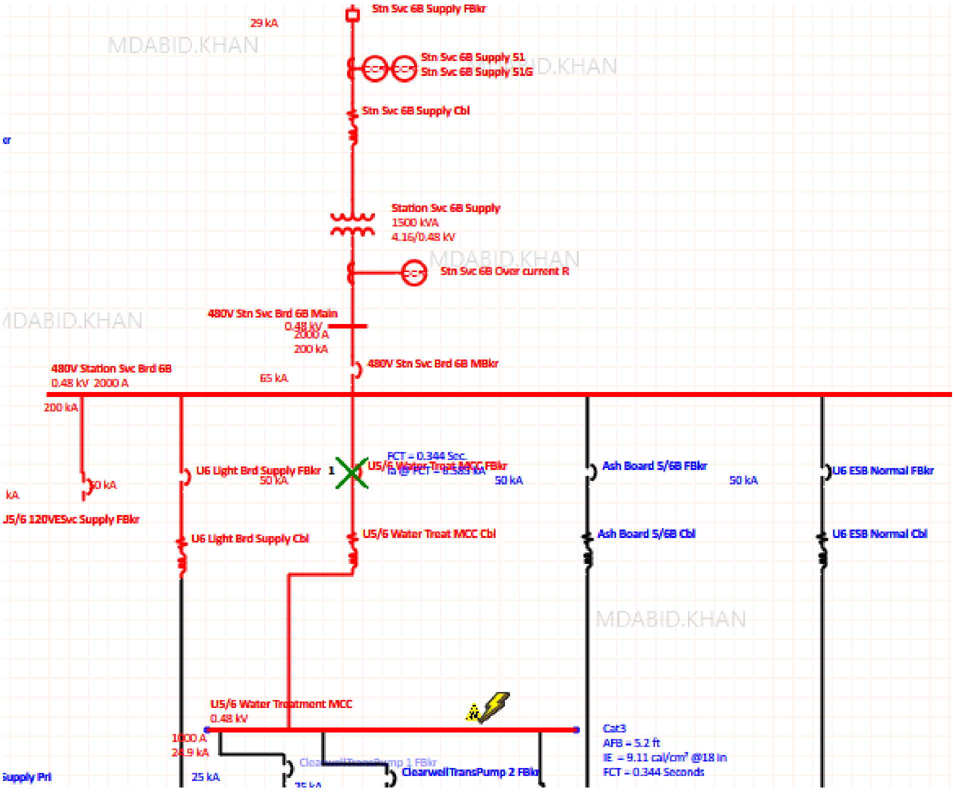

Fig. 7 Coordination of 480 Volt feeder breaker and incomer breaker while additional relay is installed on the secondary side (480 Volt) of the 1500 kVA transformer

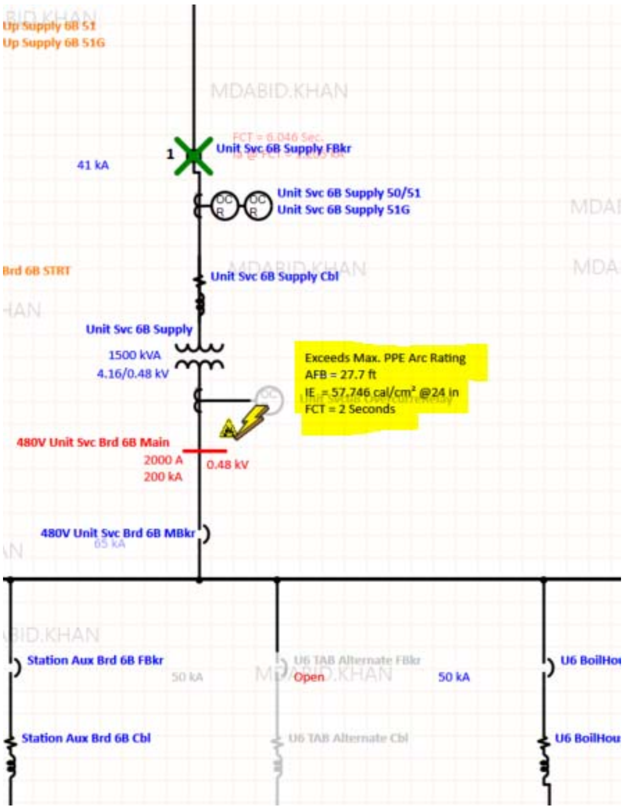

Fig. 8 Coordination of 480 Volt incomer breaker and transformer upstream relay without additional relay on the secondary side of the 1500 kVA transformer

480 Volt feeder breaker will trip first if any short circuit incident occurs on feeder bus with the installation of the additional over current relay close to the secondary side of 1500 kVA transformer.

The upstream relay of the 1500 kVA transformer usually trips 4160 Volt breaker if any short circuit incident occurs on the connection point of secondary side (480 Volt) of transformer and line side of the downstream 480 Volt incomer breaker. The fault clearing time is more than 2 seconds but we limit maximum fault clearing time 2 seconds which is supported by IEEE1584 [1]. The fault clearing time is very slow which increase the AF energy level very high.

With the proper coordination, the new additional over current relay (Stn Svc 6B Over current R) will trip 1500 kVA transformer upstream breaker if any short circuit incident occurs on the connection point of secondary side (480 Volt) of transformer and line side of the downstream 480 Volt breaker. The fault clearing is 0.633 seconds that helps to reduce the AF energy level.

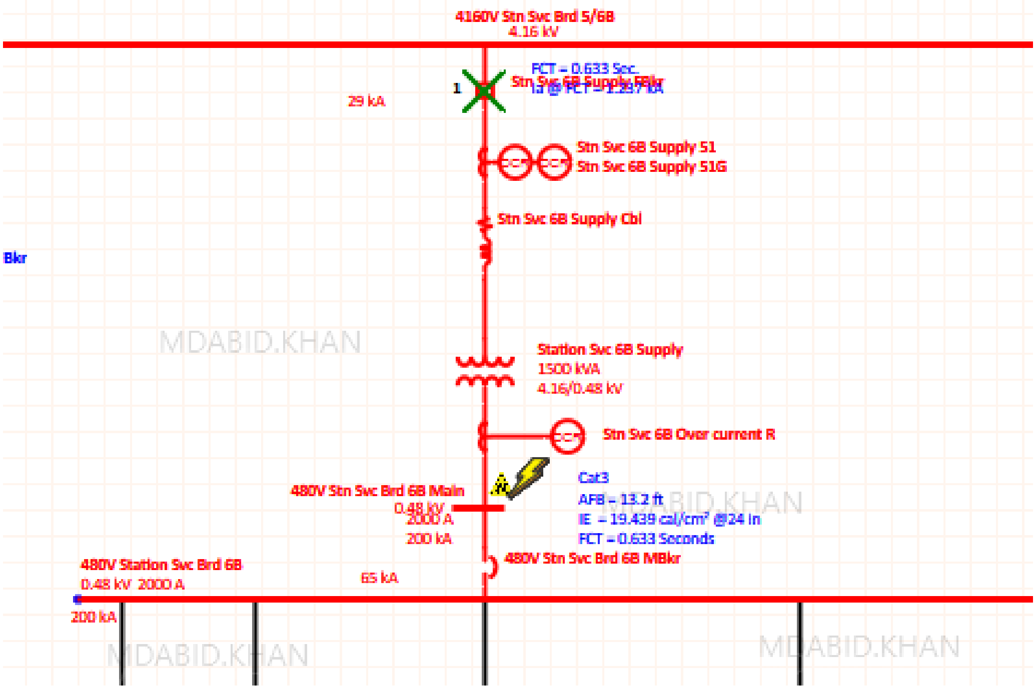

Fig. 9 Coordination of 480 Volt incomer breaker and transformer upstream relay with additional relay on the secondary side of the 1500 kVA transformer

III. Conclusion

Installation of additional relay will automatically control the AF energy level to the lowest level on connection point of the secondary side (480 Volt) side of the transformer and 480 Volt line side of main switchgear breaker. Installation of maintenance switch on the primary side (4160 Volt or 13800 Volt) of the transformer can be replaced by this design to reduce AF energy level on connection point of the secondary side (480 Volt) side of the transformer and 480 V line side of the downstream breaker and it has greater safety impact for employees and equipment than maintenance switch.

References

[1] Daleep Mohla, Jim Phillips, "IEEE Standard 1584" (IEEE guide for performing Arc Flash hazard Calculations), 2021, pp. 20-22, 40 and 34-43.

[2] NFPA-70E (National Fire Protection Association), 2018, pp. 15, 24-29 and 32-37.

[3] Wallace S. Read, Donald C. Loughry, "ANSI/IEEE Std 141" (IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems), 1993, pp. 186.

[4] Donald C. Loughry, Richard J. Holleman, "IEEE Std. 399" (IEEE Recommended Practice for Industrial and Commercial Power System Analysis), 1998, pp.429.

[5] Donald N. Heirman, James T. Cario, "ANSI/IEEE Std 242" (IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial), 2001, pp.26.