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Arc Flash Analysis of Medium Voltage Level Power System using ETAP

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***Abstract*—** Electricity is the need of every day's life both at home and on industry. But sometimes it causes very dangerous incident called an arc flash hazard in industry which damages the equipment and harm the workers to a greater extent. For knowing the level of arc flash hazard and providing better protection to working personnel, analysis of it is very important. This paper presents an arc flash analysis of medium voltage level power system based on standard IEEE 1584. IEEE 30 bus network is considered for analysis purpose. Electrical Transient and Analysis Program (ETAP) Software is used for Arc Flash Hazard (AFH) analysis of medium voltage level system. Comparative analysis is carried out based on result of software and hand calculation. These results are then used to determine Personnel Protective Equipment (PPE) to protect personnel and Labels are also generated for equipment to alert operators about hazard level.

***Keywords*—** AFH analysis, PPE, FPB, AFIE, ETAP

I. INTRODUCTION

Arc fault is generated when electric current passes through air from one uncovered live conductor to another or to ground in electrical equipment. Arc Flash Hazard (AFH) exposes excessive heat, sound blast and pressure waves which can cause serious injury in electrical power systems. Temperature of arc be able to extent 20,000 K or beyond that. This is around four time of temperature of sun's surface. Electric arc sound level can reach up to 160db, which is higher than that of a jet engine sound level (140db at 30m). This level can damage the human ears. Pressure on proposed area of persons at about 2ft (0.6 m) from 25kA arc would remain around 160 lb./ft^2 (7750 N/m^2). This is enough to place a total pressure of about 480 lbs. or 2100 N on opposite of man's body.

NFPA (National Fire Protection Association) defines Arc Flash as a "dangerous condition associated with release of energy caused by electric arc". Its intensity level is measured by Arc Flash Incident Energy E (AFIE). An electrical arc occurs when insulation between two conducting objects is lost at adequate potential. Insulation failure occurs due to many reasons such as dust and impurities on surface of the insulator, corrosion of equipment, improper wok practices, improperly designed or utilized equipment, loose electrical connection.

Transformer, service entrance switchgear and generator provide high short circuit power and consequently the high energy when electrical arc occurs at instance of fault. Most of the faults occur during maintenance of switchgears or during manual operation of equipment. Arc occurs both in open air or cubical but intensity of it is higher in cubical due to high pressure developed in it. Longer arc lengths are suitable as an input for arc flash analysis of open air medium voltage system.

PPEs must be worn by working person when working around live equipment. The possibility of survival from arc flash is higher when the PPE rating is suitable with the incident energy level. The whole PPE set consist of helmet, Fire resistive clothing, face guard, safety glasses, shoes and gloves etc. which is shown in Fig.1. This is also necessary that only qualified person can enter in hazardous area [1].

For knowing the level of arc flash hazardous and providing better protection to working personnel, analysis of it is very important. This paper presents in depth study the analysis of different parameter's effect on incident energy which becomes helpful in mitigation techniques.

Section I describes introduction of an arc flash. In section II related work in Arc Flash Analysis is described. section III contains methodology follows for AFH analysis while Section IV explains modeling of the IEEE 30 bus network in ETAP. Simulated results are presented and discussed in section V with analysis of different parameters in section VI and conclusions are given in section VII.

II. ARC FLASH ANALYSIS

From many years' representative of IEEE and many researchers working in these area and many standards are developed by them for AFH analysis containing all necessary steps and equations. Occupational Safety and Health Administration (OSHA) and NFPA standards are developed specifically for people working near electrical devices. The physiology and effect of burn injury are examined [2]. Lee has analyzed that for particular range of distances pressure increases with increase of arcing current [3]. Test program has been performed to measure incident energy from 6 cycle arc on 600V, 3 phase distribution system [4]. Available ways to evaluate arc flash severity both in open air and box are discussed [5].

In this paper IEEE 30 bus network is modeled and simulated in ETAP for AFH analysis. Effect of different parameters like fault clearing time, working distance, short circuit current and gap between conductors are analyzed through simulation which can help to reduce these type of hazards.

Fig.1 Examples of PPEs for Arc Flash Protection

III. METHODOLOGY

The AFH analysis is the procedure to find out the incident energy, the high risk areas and then level of Personnel Protective Equipment (PPE) to limit the harm to personnel by electric arc.

Input for AFH analysis:

- Short circuit current at all the buses after short circuit analysis
- Protective device's fault clearing time from TCC

Output after AFH analysis:

- Arcing current
- Incident energy
- Flash protection boundary (FPB)
- PPE Risk category

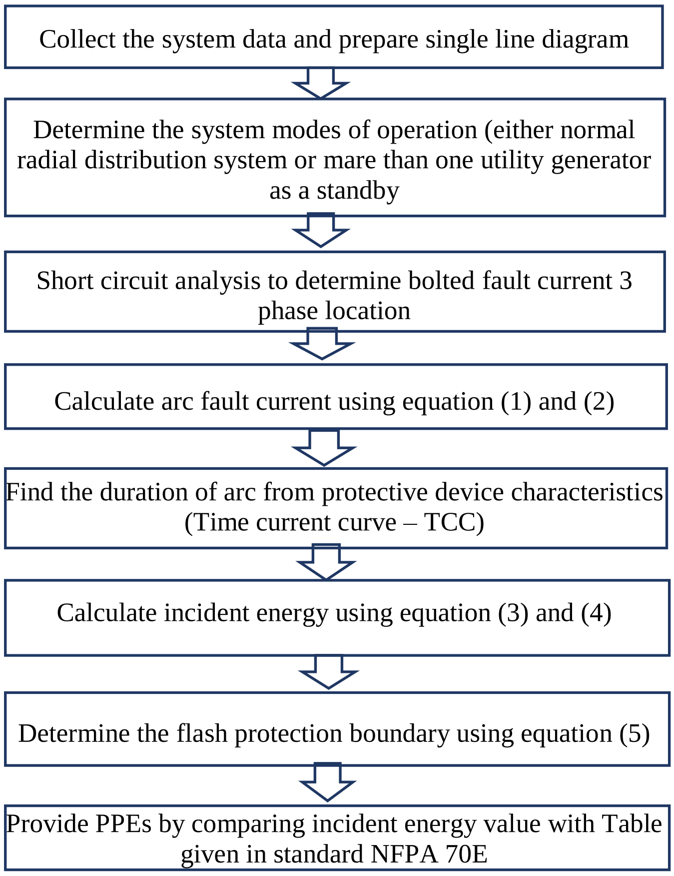

Fig.2 Flowchart for AFH analysis

IEEE 1584 is an important standard that provides necessary equations for AFH analysis. IEEE 1584 formulation is based on the empirical method and it is accurate for system having following specifications [6]:

- Voltage range:208V-15kV, three phase
- Frequency:50Hz or 60Hz
- Bolted fault current range:700A-106kA
- Gap between conductors:13mm-152mm
- Three phase faults

To find out arcing current, incident energy and flash protection boundary following equations are used [6]:

For system voltage under 1000V,

$$\log_{10} I_a = K + 0.662\log_{10} I_{bf} + 0.0966V + 0.000526G + 0.5588V(\log_{10} I_{bf}) - 0.00304G(\log_{10} I_{bf}) \quad (1)$$

where, I_a is arcing current in kA. K is -0.153 for open configuration and -0.097 for box configuration. I_{bf} is bolted fault current for three phase fault in kA. V is system voltage in kV and G is gap between conductors in mm.

For system voltage 1000V and higher,

$$\log_{10} I_a = 0.00402 + 0.983\log_{10} I_{bf} \quad (2)$$

The higher voltage case makes no distinction between open and box configuration.

$$\log_{10} E_n = K_1 + K_2 + 1.081\log_{10} I_a + 0.0011G \quad (3)$$

Where, E_n is incident energy normalized for an arc time of 0.2seconds and a working distance of 610mm. K_1 is -0.792 for open configuration -0.555 for box configuration. K_2 is 0 for ungrounded and high resistance grounded system -0.113 for grounded system.

$$E = 4.184 C_f E_n \left(\frac{t}{0.2}\right)\left(\frac{610^x}{D^x}\right) \quad (4)$$

where C_f is a calculation factor, 1 for voltage above 1kV and 1.5 for voltage at or below 1kV. t is arcing time in seconds. D is working distance in mm and x is distance exponent defined in IEEE standard 1584.

$$D_B = \left[4.184 C_f E_n \left(\frac{t}{0.2}\right)\left(\frac{610^x}{E_B}\right)\right]^{\frac{1}{x}} \quad (5)$$

Where D_B is the distance of boundary from arcing point in mm and E_B is incident energy in J/cm^2 at the boundary distance.

IV.MODIFIED IEEE 30 BUS NETWORK MODELLING AND SIMULATION

ETAP has an integrated module for AFH analysis. It works on the standard IEEE 1584 and NFPA 70E. IEEE 30 bus network is modeled and simulated in ETAP with modification of some data. The modified data of IEEE 30 bus system is given in ANNEXURE while other data are as per the standard system [7]. Fig.3 shows the single line diagram of IEEE 30 bus system.

Load flow study is performed as a first step on IEEE 30 bus system to optimize component or circuit loading and to keep system voltages within specified limits. Many types of faults occur in substation which causes discontinuous power supply from generating to consuming point [8]. For providing protection against electrical faults grounding is necessary in electrical systems [9]. Then after short circuit` study is performed to determine bolted fault current value (I_{bf}) value at each bus which is used to find out the arcing current (I_a), incident energy E and Arc Flash Boundaries.

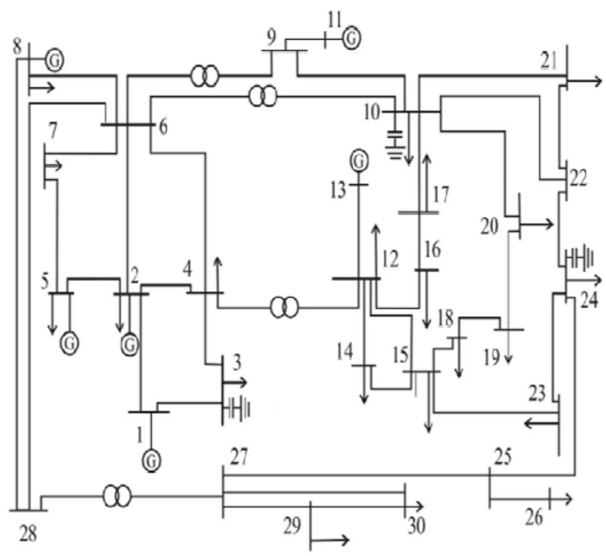

Fig.3 Single line diagram of IEEE 30 bus Power System

Then after protective devices settings and coordination is done for proper sequence tripping of PDs near the faulted bus and keep unprotected areas less affected by faulty condition. Protective device coordination is important part of arc flash analysis to find out fault clearing time of each PDs which is further used to find out incident energy E and Arc Flash Boundaries (AFB) in AFH analysis.

V. RESULTS AND DISCUSSION

Considering bus 26 of the IEEE 30 bus system, AFH analysis is carried out with short circuit analysis and relay coordination. As shown in Fig.4, when fault occur at the bus 26, CB49 trip first and then CB1 and CB5 whereas proper coordination is when CB5 trip first and then CB51 and then CB49.

ETAP has provision in star mode toolbar for fault insertion at any bus and to see the sequence of protective device tripping. Improper relay coordination is also shown in Fig. 4 and Fig.5. For proper relay coordination we can change either CB model or relay settings. Required relay coordination and Time Current Curve(TCC) graphs for it are shown in Fig.6 and Fig.7.Similarly, coordination of all protective devices is done. After proper coordination, Arc flash analysis is performed which will give required PPE ad labels.

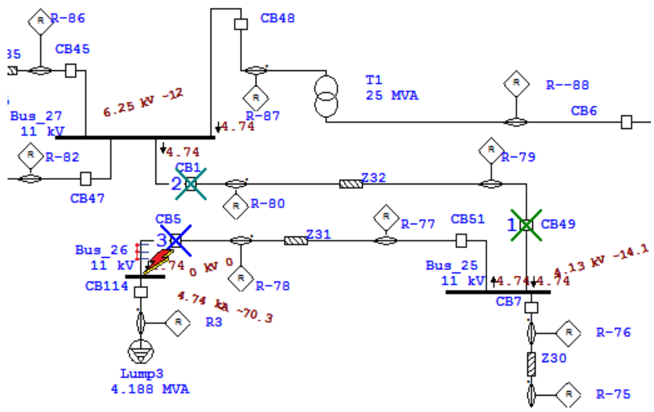

Fig.4 Improper relay coordination at bus 26

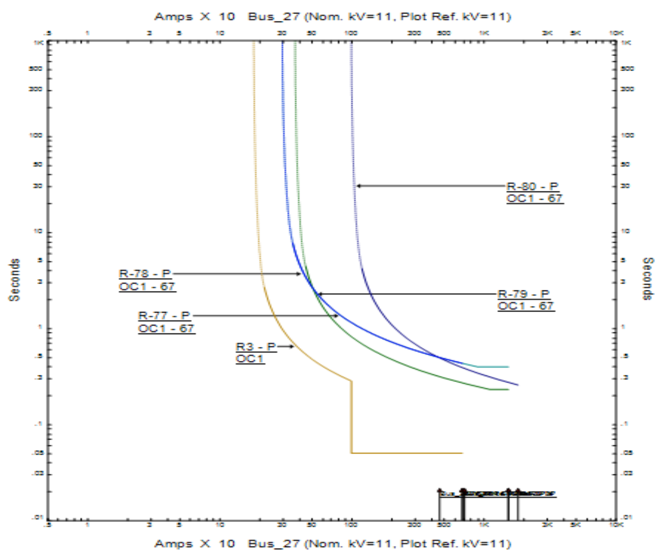

Fig.5 TCC Graph for CB 1, 5, 49 and 51

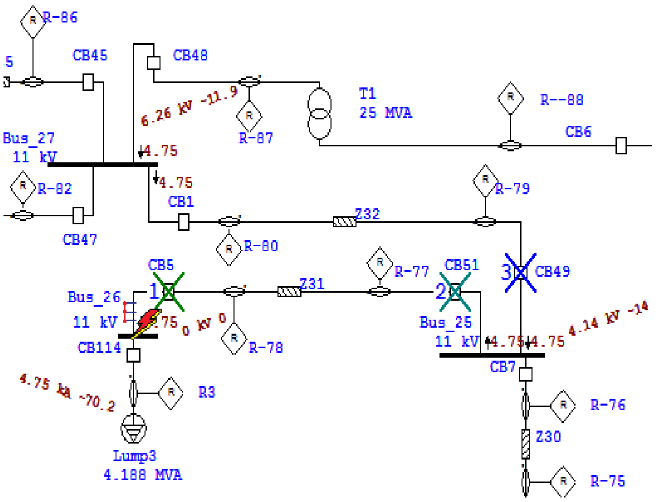

Fig.6 Required relay coordination at bus 26

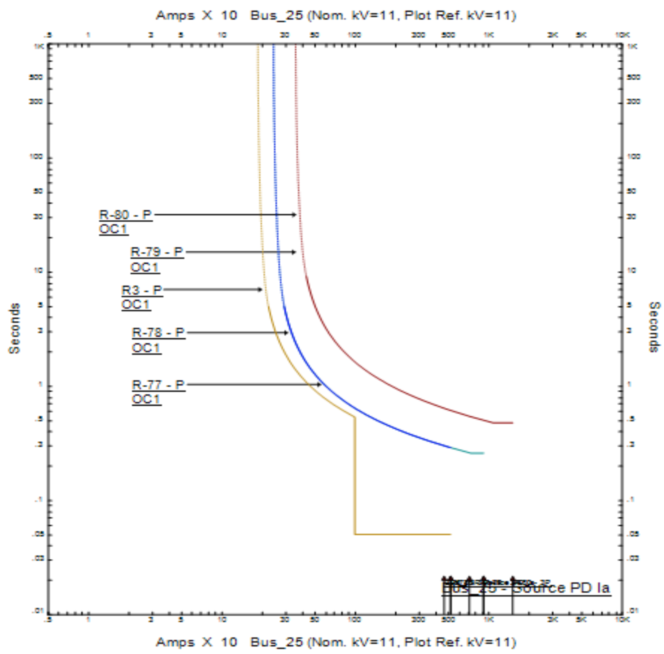

Fig.7 TCC graph with required relay coordination at bus 26

The Bus Arc Flash page in ETAP contains quick incident energy calculator, which is powerful analysis tool that allow us to perform a quick Arc Flash analysis at the bus level when we know some input data necessary to calculate the incident energy. Following input data is necessary to perform AFH analysis:

- The short circuit current (kA) at all the buses after short circuit study.
- The Fault Clearing Time (FCT) in sec from TCC graph with proper sequence coordination.
- The gap between conductors (mm).
- The working distance (mm).
- Equipment type (switchgear, MCC or open air).

AFH analysis results from the global calculation for bus 26 is shown in Fig.8 and TCC graph with all energy categories and calculated energy is shown in Fig.9.

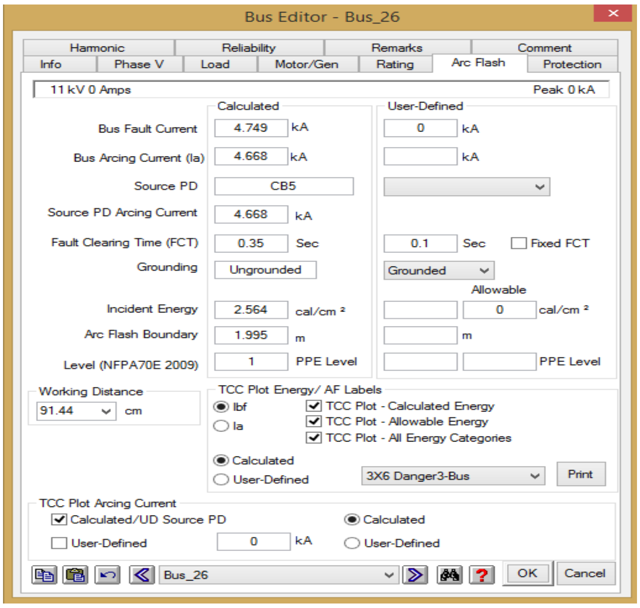

Fig.8 Bus editor view for arc flash

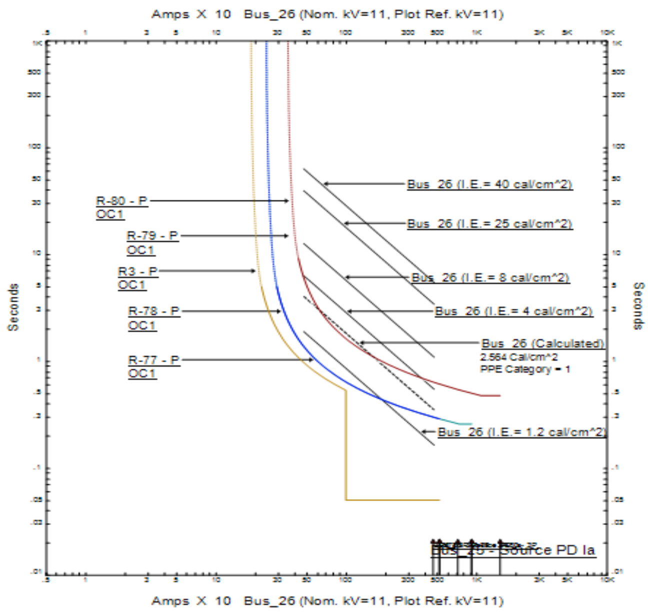

Fig.9 TCC for bus 26 with energy level

Switchgear configuration is used as an equipment type. From Fig.9, it can be seen that, different energy categories are displayed on graph and calculated incident energy is 2.564 cal/cm^2 with category 1 or B.

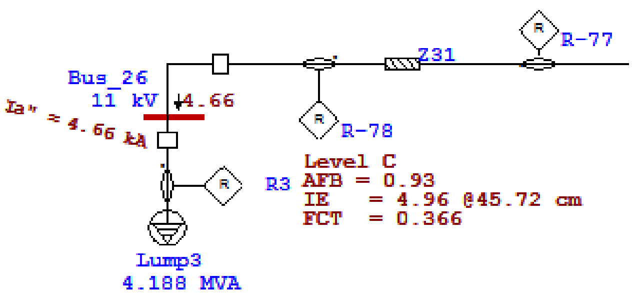

Fig.10 Incident energy value at bus 26 without proper relay coordination

Without proper relay coordination incident energy value is 4.96 Cal/cm^2 at fault clearing time 0.366sec and category is also higher category C which is shown in Fig.10 but with the proper relay settings and coordination, FCT is decreased to 0.35 sec with incident energy value 2.56 cal/cm^2 and category B shown in Fig.11. hence proper coordination is the important part of AFH analysis.

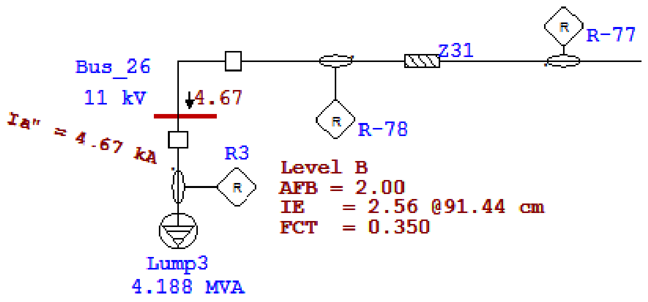

Fig.11 Reduced incident energy at bus 26 with proper relay coordination

Once short circuit analysis and protective device coordination has been done, IEC Arc-Flash tool is used in ETAP to obtain bolted fault current (I_{bf}), arcing current (I_a), incident energy (E) and arc flash boundary (AFB). These results are also verified by hand calculation. The comparative results are shown in Table 1.

Using print option, required label can be generated which will give all necessary information to person working near energized equipment. The label for bus 26 is shown in Fig.12.

In the label all necessary information like arc flash boundary, incident energy, working distance, category and different shock protection boundaries are indicated which help workers to take safety actions and protect themselves with appropriate Personnel protective equipment (PPE).

There are different types of label generation options available in ETAP, from which one can generate proper label which also indicate required PPEs along with incident energy, arc flash boundary and different shock protection boundary. So it can help operator quickly.

Table 1. Arc Flash Analysis Results

BUS ID	RESULTS OBTAINED USING ETAP				HAND CALCULATION RESULTS	
	I_{bf} (kA)	I_a (kA)	E (cal/cm^2)	AFB (m)	E (cal/cm^2)	AFB (m)
1	37.7	35.7	47.22	39.83	47.23	40.00
2	44.6	42.2	54.13	45.84	54.15	46.03
3	30.5	29.0	24.74	20.49	24.76	20.59
4	35.1	33.3	53.95	45.67	53.94	45.85
5	31.2	29.7	39.08	32.79	39.04	32.89
6	36.4	34.5	61.81	52.53	61.86	52.78
7	28.4	27.0	24.85	20.59	24.87	20.69
8	29.5	28.1	48.14	40.63	48.11	40.76
9	21.7	20.7	39.02	32.74	39.07	32.91
10	20.1	19.3	34.44	28.79	34.45	28.93
11	16.6	16.0	30.63	25.30	30.27	25.33
12	16.7	16.1	26.44	21.95	26.49	22.07
13	15.4	14.8	28.02	23.29	27.98	23.35
14	11.4	11.1	10.58	8.563	10.62	8.632
15	12.7	12.3	12.68	10.33	12.74	10.41
16	10.4	10.1	7.884	6.329	7.88	6.350
17	7.66	7.47	3.755	2.953	3.78	2.985
18	8.37	8.15	4.127	3.253	4.146	3.282
19	9.91	9.62	5.305	4.212	5.305	4.228
20	11.3	11	10.88	8.816	10.93	8.892
21	16.8	16.2	19.85	16.35	19.86	16.42
22	16.5	15.9	20.72	17.09	20.70	17.14
23	8.59	8.36	4.243	3.348	4.25	3.368
24	5.04	4.94	2.778	2.167	2.76	2.160
25	7.40	7.22	6.843	5.471	6.84	5.488
26	4.75	4.67	2.564	1.995	2.55	1.990
27	10.4	10.1	12.76	10.38	12.81	10.46
28	25.8	24.7	18.01	14.79	17.96	14.81
29	6.58	6.43	6.769	5.410	6.79	5.451
30	6.13	6.00	6.145	4.898	6.10	4.884

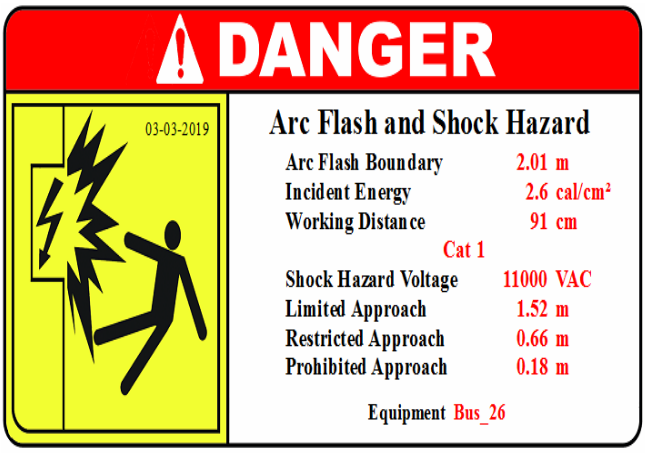

Fig.12 Label for Bus 26

Similarly labels for different buses and categories are generated which is shown in Fig.13. This label also indicates required PPEs to person working near energized equipment.

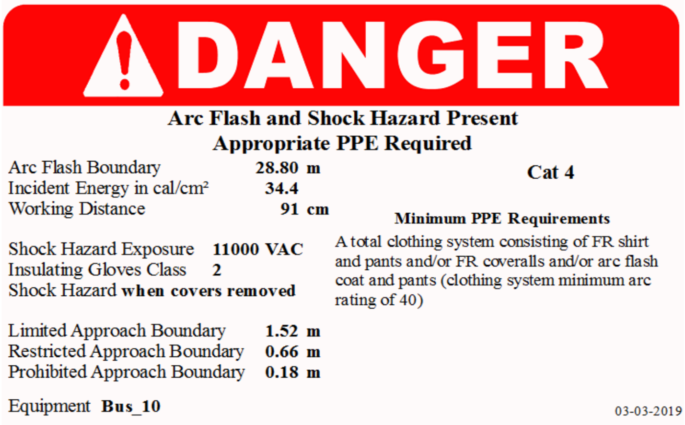

Fig. 13 Label for Bus 10 with category 4

VI. ANLAYSIS OF DIFFERENT PARAMETERS

There are different parameters on which incident energy depends:

A. Short circuit current
B. Gap between conductors
C. Working distance
D. Fault clearing time

Effects of these parameters on incident energy are discussed with simulated results and graphs. Here four buses are taken for analysis purpose.

A. Incident energy Vs short circuit current

At each bus short circuit current value is different. This value is changed by different ratio and then results are simulated. The incident energy is changed by adjustment in short circuit current at different buses which is shown in Fig.14. All other parameters other than short circuit current are unchanged.

When short circuit current increases, arcing current increases which can increase the incident energy. While decrease of short circuit current decreases the arcing current and then the incident energy.

From these analyses we can take necessary action to reduce short circuit current with current limiting fuses and circuit breakers to reduce incident energy.

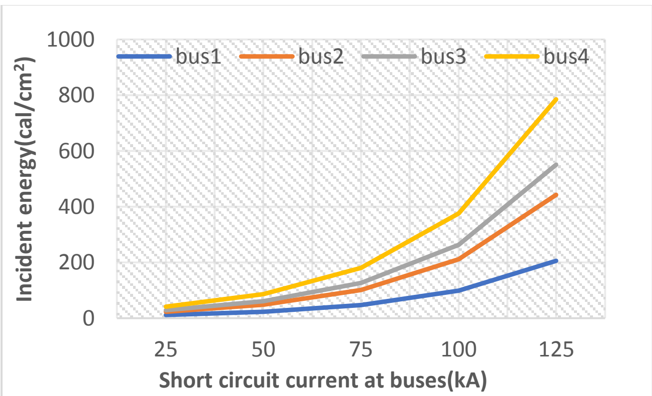

Fig.14 Simulated incident energy vs. short circuit current

B. Incident energy vs. gap between conductors

The gap between conductors for all the buses is 153mm, which is to be changed by different ratio and results are simulated. Other parameters are unchanged.

With increase in gap between conductor incident energy increases while with decrease of gap incident energy also decreases which is shown in Fig.15. Here graph of bus 2 and bus 4 are overlapped due to their approximate same incident energies.

Adjustment of gap between conductors for reduction in incident energy is a difficult task, so other methods are used for incident energy reduction.

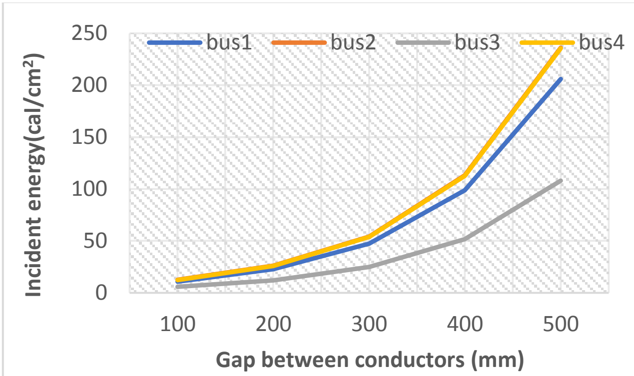

Fig.15 Simulated incident energy vs gap between conductors

C. Incident energy vs working distance

The working distance from energized equipment for all the buses is 914.4mm. This distance is varied in different ratios and different results are simulated.

We can analyze that with increase in working distance, incident energy decreases while with decrease in working distance incident energy increases is shown in Fig.16. So there is inverse relation between working distance and incident energy. Remotely operated devices and remote racking system is used to increase the working distance and reduce the incident energy.

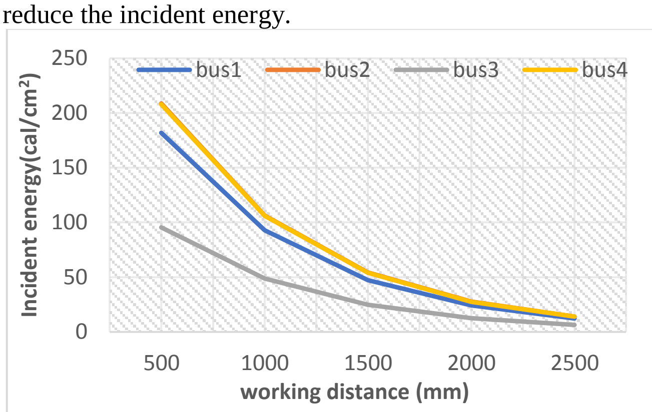

Fig.16 Simulated incident energy vs working distance

D. Incident energy vs fault clearing time

The Fault clearing time at all the buses is determined from TCC after running protective device coordination. This time is varied in different ratios and results are simulated. The corresponding graph for four buses is shown in Fig.17.

With increase in fault clearing time incident energy increases while with decrease in fault clearing time incident energy decreases. Hence Fault clearing time reduction is important action to reduce incident energy. FCT is reduced by proper relay settings and coordination or by replacing existing protective devices with new one.

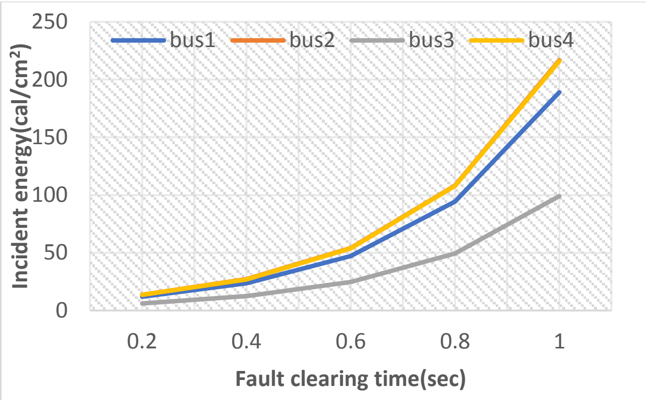

Fig.17 Simulated incident energy vs fault clearing time

Hence analysis of different parameters suggests different ideas about incident energy reduction. It also suggests different mitigation techniques. Many researchers are working towards these areas for reducing incident energy and mitigating this type of dangerous hazardous whether then use of different PPEs.

Various methods are available to reduce incident energy but best and suitable method is to reduce the fault clearing time by proper relay coordination and relay settings. With the advancement of technologies, we can mitigate arc flash hazard either by changing switchgear design or by changing protective device schemes.

In Fig.18 different parameter's effect are compared. It shows that incident energy increases continuously with short circuit current and fault clearing time. Gap between conductors not much affects the incident energy while incident energy decreases drastically with working distance.

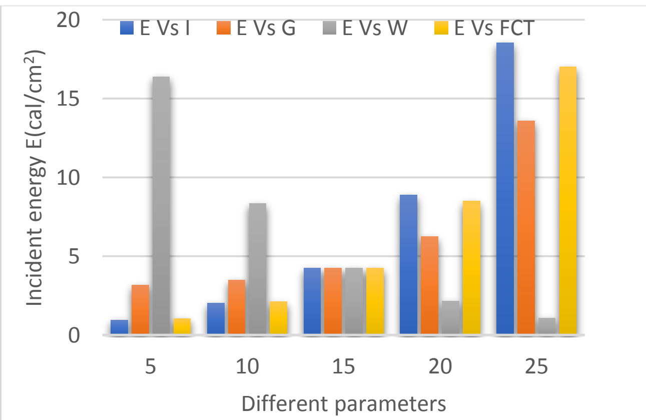

Fig.18 Comparison of different parameter's effects on incident energy

Effect on PPE category with change in incident energy is analyzed in Fig.19. PPE category increases with increase of incident energy. Hence PPE with higher rating in cal/cm^2 is to be used for protection against such a higher incident energy level. Better solution is to reduce the incident energy level by reduction of different parameters rather than to use PPEs with higher rating.

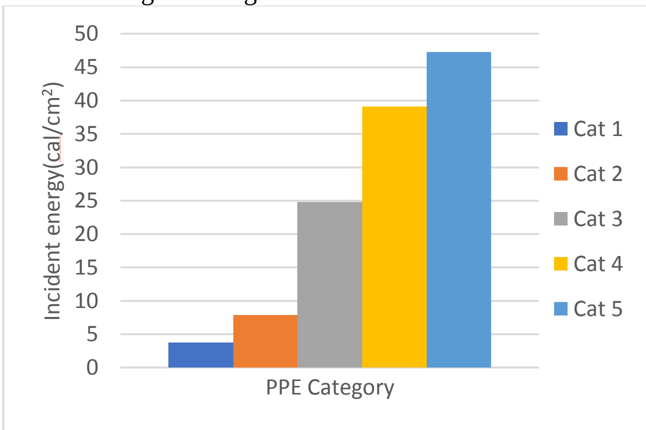

Fig.19 Incident energy Vs PPE category

VII. CONCLUSION

IEEE 30 bus network is modelled and simulated in ETAP to determine the level of hazard and then to provide better protections to working personnel and equipment after running AFH analysis. Different parameter's effect on incident energy is analyzed through this simulated IEEE 30 bus system. The analysis shows that incident energy increases with increase of short circuit current, fault clearing time and gap between conductors while incident energy decreases with increase of working distance.

Among all these four parameters, fault clearing time and working distance very much affect incident energy. So more attention has to be given to develop and analyse the various techniques which can reduce the fault clearing time and increase the working distance.

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REFERENCES

[1]. Standard for Electrical Safety in the Workplace, NFPA70E-2015, Quincy, MA, USA: NFPA.
[2]. T. Gammon, W. Lee, Z. Zhang and B. C. Johnson, "“*Arc Flash” Hazards, Incident Energy, PPE Ratings and Thermal Burn Energy-A Deeper Look*", in IEEE Transactions on Industry Applications, vol.51, no.5, pp. 4275-4283, 2015.
[3]. R. H. LEE, "*Pressure Developed by Arcs", in IEEE Transactions on Industry Applications*, vol. IA-23, no. 4, pp. 1-4, 1987.
[4]. R. L. Doughty, T. E. Neal, and H. L. Floyd, "*Predicting Incident Energy to Better Manage the Electric Arc Hazard on 600-V Power Distribution Systems*", in IEEE Transactions on Industry Applications, vol.36, no. 1, pp.1-13, 2000.
[5]. T. A. Short, "*Arc-Flash Analysis Approaches for Medium-Voltage*

Distribution", in IEEE Transactions on Industry Applications, vol.47, no.4, pp.1-8, 2011.
[6]. "Guide for performing arc-flash hazard calculations.", IEEE 1584-2002.
[7]. T.K. Nagsarkar and M.S. Sukhija, "Power System Analysis", Oxford higher education publisher, India, pp.650-652, 2011.
[8]. A. Yadav, V. K. Harit, "Fault identification in sub-station by using neuro-fuzzy technique", International Journal of Scientific Research in Computer Science and Engineering, Vol.4, Issue.6, pp.1-7, 2016.
[9]. S. V.V.S.K. Reddy, K. Satyanarayana, "Sensing of ground fault in bipolar LVDC grid", International Journal of Scientific Research in Network Security and Communication, Vol.6, Issue.6, 2018.
[10]. A. Khan, M. M. Aman, "Investigation of effect of critical incident energy parameters using ETAP to reduce arc flash hazards", In the proceeding of the 2018 First International Conference on Power, Energy and Smart Grid(ICPESG), Mirpur Azad Kashmir, pp.1-6, 2018.

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ANNEXURE

BUS NO.	GENERATOR NO.	KV	MW_GEN
1	1	15	50
2	2	15	80
5	3	15	50
8	4	15	20
11	5	11	20
13	6	11	20

