Proceedings of the Fourth International Conference on Computing Methodologies and Communication (ICCMC 2020)
IEEE Xplore Part Number:CFP20K25-ART; ISBN:978-1-7281-4889-2

2020 Fourth International Conference on Computing Methodologies and Communication (ICCMC) 978-1-7281-4889-2/20/$31.00 ©2020 IEEE 10.1109/ICCMC48092.2020.ICCMC-000181

A Review on ARC Flash Analysis and Calculation Methods

B.Rubini
Department of Electrical and Electronics Engineering
Vels Institute of Science, Technology and Advanced Studies
Chennai, India.
rubini.se@velsuniv.ac.in

R.Krishnakumar
Department of Electrical and Electronics Engineering
Vels Institute of Science, Technology and Advanced Studies
Chennai, India.
hodeee@velsuniv.ac.in

Abstract: ***Analysis of an Arc detection system consider the standards, responsibility, sensitivity, security of overall system protection methods. This arc flash detection system coordinate different sections like as relay section,circuit breaker section, switchgear components withstanding capability at fault level, load section, neutral grounding section. The fast Arc detection and trip times are evaluated by Present state of optical fault detection sensors are implemented for fast identification and tripping of arc functions. Optical fault detection Sensors have some disadvantages are compare to conventional and other types. This sensors not only detect the Arc lighting sometimes it will detect lightning flash or welding. Conventional types are taking more time for tripping compared to sensor types. Thecombinational study needed for each type of arc detection schemes to avoid the nuisance tripping because it will affect the overall stability of the system. Different fault levels before and after arc ignition system need to maintain reliability of the system safely and securely.***

Keywords-Arc flash mitigation, protection, safety by design, selectivity, zone selective interlocking (ZSI).

I. INTRODUCTION

Arc fault occurs due to loose connections, Mechanical faults, Pollution, Animals, Human errors. Whenfault occurs Active elements of circuit is current will reach very high order will increase twice per cycle, current flows through between L-L,L-G,L-N or within the same conduction path heavy current will affect the reliability of the system.The fault is the severe event in electrical power substation it will collapse the substation reliability also. Need to improve the system reliability to concentrate system protection level of components. During arc fault safety hazard is important to operation personal. Economically very important to consider the low industrial sectors investment level of arc protection sensors will be very high but to protect the working personnel and overall system. Arc ignition starts to produce radiation, temperature, arc blast, dust particles, toxic impact and etc. The arc strength and duration of one field or the entire substation cab be affected failure of the power distribution system. Overall substation could be damaged due to Strong release of heat energy and arc blast so substation need to completely replace.The No.of technologies introduced for mitigation of arc faults impact includes: arc time reduction, personal protective equipment, arc resistant enclosures and arc ignition pathway is less dangerous. To reduce the arcing time through fast protection system need to set the circuit breaker inputs related to calculations based on V_{L-L},V_{L-N}, Instantaneous short circuit tripping set, cable size, cable material, length of cable ,tripping set. In Arc quenching devices which will operate the bolted fault condition the arc energy release through breaker operates opening time.

II. GENERAL STEPS FOR PERFORMING ARC FLASH ANALYSIS

- Collect & enter system information required for the arc flash calculation
- Setup the system operating configuration
- Calculate 3ph bolted fault currents
- Calculate arcing fault current (IEEE only)
- Determine arc clearing time (arc duration)
- Determine the incident energy& Arc flash protection boundary calculations
- Determine hazard/risk category based on NFPA 70E requirements
- Select appropriate PPE equipment's. [6]

A. *Implementation of Optical Sensor Based ARC flash Protection*

- relay protection

- Numerical relay
- Ultra-fast arc flash protection (7-15ms)
- C.B Timing (50-80) ms relay trips (2-5) ms
- Comparison of the methods.

During arc ignition time is a critical component to decrese energy level of arc flash.NFPA 70A Explains the incident energy means conductor surface at a certain distance from the source part to release the heat energy is generated during an electrical arc event, typically expressed in Cal/cm^2 defined in IEEE 1584 as J/cm^2; 1.2cal/cm^2=5J/cm^2. Lower production down time and possibly (PPE) levels of requirements are the additional benefits included [1].

The fault is the severe event in power station fault occurs between conductors are cables we need to study the specifications, withstanding capability, thermal rating of the components, KV ratings, conductor phase, length, cable size in mm2, impedance of the conductor Phase and Neutral calculations, configurations, operating at FLA, operating conditions, constraints, optimal sizing, thermal sizing inputs and results, shock protection input like grounding resistance calculations, load type, permissible limit, cable configuration ,cable protection, cable capacity, Phase constrains operating values, optimal phase, Ground/Earth Conductors – Existing, Ground/Earth Conductors - Required - Short Circuit Current kA, Disconnect Time sec, Electric shock considering earthing type, loop current in KA, loop ohms, loop permissible Z in ohms.

Table I –Represents the literature survey of arc flash mitigation different methods and optical sensors

S.NO	TYPE	ADVANTAGES	DISCUSSION
1.	Time existing over current relays	Present hardware, Present technology	Cost of coordination study, trip time is high (0.5 to 2 sec), Improved by margins.
2.	Bus differential protection for high impedance	Fast, secure, easy to set <1.5 cycles	Requires surplus relay, CTs, wiring connection. 0.107 sec opening time, Testing is difficult.
3.	Bus differential protection for low impedance.	Fast, secure, easy to set <1.5 cycles	Requires surplus relay, CTs, wiring connection.0.107 sec opening time, testing is difficult.
4.	Bus bar protection	Over current relay between main and feeder implementation of existing methods.3 to 5 cycles, secure, communications channels using fiber and transceivers.	Bus bar setting time for CT was more difficult and delayed tripping for fault in feeder breaker. CT tripping time is 0.17 sec. Energy 6.4 Cal/cm^2,boundary level 5.1meter.
5.	During maintenance Instantaneous over current protection	In existing method overcurrent relay fixed with main and feeder. Fast response. <1.5cycles, Cost control for control switch,wiring installation.	Changes in procedure during maintenance. Tripping time is 0.12sec,Energy 4.5 Cal/cm^2, boundary level 3.5 meter.
6.	Fast bus tripping condition +arc flash detection	Fastest detection, cost low, self- testing, secure with 2 individual detections.	Tripping time is less=0.17sec to0.0858sec.Energy less from 6.4 to 3.2 Cal/cm^2. Boundary levels less from 5.1 to 2.5 meter.
7.	Instantaneous tripping condition + arc flash detection	Fastest detection, cost low, self- testing, secure with 2 individual detections.	Tripping time is less=0.12sec to0.0858sec.Energy less from4.5 to 3.2 Cal/cm^2. Boundary level less from 3.5 to 2.5 meter.
8.	From arc flash testing to verify the breaker trip curves (generic, trip curve methods)	Tripping time is fast, incident energy level is low. To verify breaker trip curve when evaluating protective devices.	During maintenance setting for 3cycles can be turned down to the breaker used.HRC=2.
9.	Bus differential protection with zone selective interlocking	Fast tripping of C.B, Bus differential protection (87B) very long time. Space and cost low (LV Switchgear not applicable). Eliminating extra C.Ts.	Total fault clearing time:(83ms-100ms)-old;new-125ms Breaker clearing time:2-3 cycles. Automatic. Incident energy lowered at (M.V)-100-30 Cal/cm2.

			ZSI:3-10 cycles
10.	Energy reducing maintenance switch(EMRS)-lower trip unit pick-up levels	To decrease the arc flash incident energy level in Low Voltage MCC	Incident energy:118 Cal/cm2 to 6 Cal/cm2
11.	Partial discharging sensing(high frequency discharges in insulation systems MV & HV)	Fast Fault predictions Permanently installed (coupling capacitors, RFCT, RTD couplers)-connected an external PD relay and online continuous monitoring system.	Generator, motor, transformers protection implemented by switch gear technology for partial discharge event.
12.	Optical detection relays	Relay tripping is very fast compare to other conventional and any over current protection. Advanced level point sensors and loop sensors are connected to CTs.	After arc flash incident no guarantee for optical sensors. This connected integral part of switch gear assembly.so not tested and not recommended.

Review of the standards impacting arc-flash calculations. Arc flash energy if proportional to V*I*t. Arc calculations depends on the frequencyas well as time. Failure of frequency calculated by using equation (1) refers to the no.of failures may happen during a time period.

$$F = \frac{Amount\ of\ failures}{studied\ period\ (*circuit\ length\left(for\ transmission\ \frac{lines}{cables}\right)} \quad (1)$$

Relationship between the mean time frequencies, mean time to failure is calculated using (2)

$$F = \frac{1}{Mean\,time\ to\ failure + Mean\ time\ to\ repair} \quad (2)$$

Arc flash produces the Dangerous levels of radiation, temperature and ultraviolet (UV), Pressure waves, sound waves, smoke[2].

III. ARC FLASH CALCULATIONS

- NFPA 70E-2004 is basis for PPE
- Includes calculation for informational purposes
- IEEE 1584.

In advanced level of optical sensors was the fast tripping timeworks with the arc fault protection system. The Optical sensors evaluates the light or luminescence and senses from arc fault as well as the beginningrateof luminescence value changes in on time or changes with sharpness [3]. During arc fault condition, arc will produce heavily in surface of the conductor optical sensors are identified that light rays and findingon the sensors with high demands of an arc fault places tripping reliability and resistance to false tripping. The conditions of the use of the systemapplied for Low voltage switchgear panel under consideration of

- Arc has low light intensity(1KA,spacing 10 mm, copper electrodes)
- Arc has high light intensity(25KA,spacng 100 mm, aluminium electrodes)
- Irrelevant light(switching arcs, lighting, sunlight, light reflections)
- System installation covered by Sensors
- Hazard /Risk category (HRC)is now called PPE category
- HRC has been eliminated
- Hazard analysis is now risk assessment
- Other changes were made as well-always review latest standards

  Relay selective Methods
- Fast bus trip schemes
- Bus differential relay
- Maintenance mode scheme
- Arc-flash Detection(AFD with overcurrent)

Arc fault calculation based on utility fault current, point to point method, steps to be followed by software tools. Available fault current ampere rating from local utility, type of conductor selection, length of conductor, no.of conductors per phase, select phase and neutral conductor sizes these data's are needed to calculate the fault current.

$$I = \frac{KVA*1000}{E} = trans.FLA \quad (3)$$

$$Isca = \frac{trans.FLA*100*PF}{transformer\ Z} \quad (4)$$

From this equation (4) I_{sca} explains the ampere short-circuit current RMS symmetrical.Point to point method need to consider for 'f' factor which includes 2*L*I; N*C*$E_{L\text{-}N}$; Multiplier; length of conductor, this calculations used for fault current at service equipment, service equipment to panel board, single phase feeder, single phase branch. The arc length varies in different cases, fault current is not constant at fault level, equation(4) is derived from the magnitude of arcing current [9].To develop (APS) arc protection system is essential tool for designing switchgear and switchgear componentsdeveloped by a fast earthing switch. Design method of optical sensors considered initial parameter of luminance of light source, and sensors are point, loop sensors, relays, and arc eliminators. This type of sensors fixed by separate places like point sensors placed in compartment of the switchgear, loop sensors are placed along the busbar. Designing based research perfectly need to follow the IEC standards and codes [8]. Software used to calculate fast evaluation for optimizing values implemented to operating fast response of every component in switchgear part, panel boards, and switch boards.Random phenomenon of electric circuit is Arc flash which highly depends upon the arc resistance, Protection system for Current limiting approach involved in the electric circuit. The operation time of the circuit breaker, arc extinguishing time, released incident energy calculations are needed to analyse and examine the reduction of arcing current.InitiallyI_f is a short circuit current and it is calculated as:

$$I_f = \frac{k\, V_{L-L}}{1.732\ Z''} \quad (5)$$

k- Voltage factor;V_{L-L}- system voltage (line-line);Z''-sub transient reactance of the network [9].Basic fundamental equation related to ohm's law for D.C I=V/R; A.C I=V/Z;Z=R+jX, R is resistance, X is reactance in electrical network AC circuits, inductive circuit X will act as positive, capacitive circuit X will act as negative. The following methods used to calculate for fault currents in power system. Ohmic method, percentage impedance methods, per unit methods. Ohmic methods to calculate source impedance at HV in ohms:

source impedance ZΩ =KV/ (√3*HV fault current);

Transformer impedance ZΩ= (Z%*KV)/KA;

To calculate LV fault current =LV/(√3*ZΩLV);

Fault value of
MVA =E^2/X;
X=$E^2/Fault\ value\ in\ MVA$;

For percentage reactance method Fault value in MVA=$\frac{100(MVA\ rating)}{X\%}$;

X%=$\frac{100\ (MVA\ rating)}{Fault\ value\ in\ MVA}$;

For per unit method ,
Per unit impedance =$\frac{actual\ impedance\ in\ ohms}{Base\ impedance\ in\ ohms}$;

Base current $I_b = \frac{Base\ KVA}{1.732*Base\ KV}$;

Base impedance$Z_b = \frac{Base\ V}{1.732*Base\ A}$;

Power systems depending upon the complexity at fault condition use any one method to calculate.

$$P_i = \frac{V_I^2}{R} \quad (6)$$

$$W_i = \frac{\Delta t}{R} v_i^2 \quad (7)$$

PD level of Energy (W_i) can be solved by apparent charge values and as follows,

$$W_i = q_i V_s = q_i V_m sin\emptyset_i;$$

Where qi is apparent charge of a single discharge [11].

Incident energy calculation should be followed by IEEE 1584-2002 standards [12]. Fault current Calculation is

$$I_{bf} = \frac{V_t}{|Z_{sc}|*1.732} \quad (8)$$

I_{bf} *is the maximum bolted fault current*, V_t *− system voltage in kv*, Z_{sc} *− is the magnitude of the short circuit impedance.*

The faulted current calculation followed by using equation (8).

$$I_{sa} = 10^{K+0.622logI_{bf}+0.0966v+0.000526G+0.5588V(logI_{bf})-0.00304G(logI_{bf})} \quad (9)$$

$$I_{sa} = 10^{0.00402\ +0.983log\,I_{bf}} \quad (10)$$

Where:
$I_{sa}$is a RMS short circuit current in KA.
K is -0.097 for configurations.
I bfis the 3ph bolted fault current in KA.
V is the system nominal voltage in KV.
G is the conductor's gap in millimetres.

IEEE standards followed by the incident energy levelclearing time for 0.2secs distance from arc for 610 millimetres. At any working distance from the incident energy level can be calculated by using equation (11) as follows:

$$E_n = 10^{K_1+K_2+1.08log\,I_a+0.0011G} \quad (11)$$

Incident energy En measured by $\frac{joules}{cm2}$standardized for time and distance.
Arcing current Ia
For configurations k1is -0.555
Ungrounded and high resistance grounded systems are K2
Grounded systems-0.113.
Between conductors gap (G) in millimetres.
Incident energy formula in joules (i.e.)

$$E = 4.184(Cf)\ (En)\ (\frac{t}{0.2})\left(\frac{610^x}{D^x}\right) \quad (12)$$

Calculation factor (C_f) (>1KV =1.0,<1KV= 1.5).
Arc duration in seconds (t)
Distance from the arc (d) in mm
Distance exponent(x).

The fastest detection system in uses as light is the primary component including

- Detection of Light
- Current detection

- Combined current and light detection [11]. Ac flash safety and considerations are more reliable and effective.

IV. CONCLUSION

Maintenance schedules for generators, motors, transformers should be followed by scheduled manner, switchgear components time settings are more important for safe and secure reliability of the system. The available fault current exceeds over limit interrupt rating for very short durations for bus tripping, circuit breaker open and closing time period is important. In this paper give the solution for calculation methods for fault currents and need to improve the time setting calculations for CB's at bus bar compartment, panel board compartment, switch boards. The risks of large power systems fault current evaluated and identified values for implementation and designing components of future expansion of the power system.

REFERENCES

[1]. Robert A. Wilson (ABB Inc.), Rainer Harju, Juha keisala , sethuraman ganesan ," Tripping with speed of light Arc flash protection"1mrs756426;2006.

[2]. David Bisel and mike metro, "Methods to reduce Arc-Flash Hazards", Schweitzer Engineering laboratories, Inc 2015.

[3]. Modular arc fault protection system DEHNarc Siegfried bombik ,09/2010

[4]. Safety requirements for electrical equipment for measurement, control and laboratory use –part 031: safety requirements for hand-held probe assemblies' for electrical measurement and test, Jun 2008.

[5]. IEC 6482-1-2: Live working –protective clothing against the thermal hazards of an electric arc –part 1-2: test methods –Method 2: determination of arc protection class of material and clothing by using a constrained and directed arc. January 2007.

[6]. IEC 60947-3:low-voltage switchgear and control gear –part 3: switches, disconnectors, switch- disconnectors and fuse – combination units, August 2008.

[7]. Steven Abaray, *Senior Member, IEEE*, and Stan Beaver "Switchgear Main-Tie-Main Closed-Transition Transfer Design Strategy for High Levels of Available Fault Current", IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS, VOL. 54, NO. 2, MARCH/APRIL 2018.

[8]. Young-woo, hyun-wook lee, yang-seop sin, young-keun Kim, "solution for internal arc flash hazards in air insulated switchgear',21st international conference on electricity distribution, Frankfurt, 6-9 June 2011.

[9]. IEC standard 909,"short circuit current calculation in three phase A.C. systems". Secondimpression, IEC, 1989.

[10]. Simms.J and G.Johnson,"Protective Relaying Methods for Reducing Arc Flash Energy",IEEE trans.ina.appl.vol:49.no.2,pp.803-813, March-April 2013.

[11]. William Knapek,"Verify performance and safety of Arc-Flash Detection systems" OMICRON Electronics crop, Mark Zeller, Schweitzer Engineering Laboratories, Inc.