Thermal and Arc Flash Analysis of Electric Motor Drives in Distribution Networks

Preliminary Communication

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Abstract *– The paper presents thermal analysis and arc flash analysis taking care of protection relays coordination settings for electric motor drives connected to the electrical network. Power flow analysis is performed to check if there are any voltage and loading violation conditions in the system. Fault analysis is performed to check the short circuit values and compute arc flash energy dissipated at industrial busbars to eliminate damage to electrical equipment and electrical shocks and hazard to personnel. Computers enable the use of smart algorithms used by electrical engineers in providing accuracy of these actions. A fast and accurate procedure for proper incident arc flash energy computation and overcurrent relays coordination in distribution networks is presented. The paper presents the use of the Arc Flash module for arc flash energy computation during the short circuit on LV and HV busbars with soft motor starters. A sample case of one real network is presented which uses soft motor starters as well as the influence on arc flash energy in one transformer station supplying the industrial network in Bosnia and Herzegovina.*

Keywords *– arc flash, distribution network, electric motor drive, power flow, protection, short circuit, thermal analysis*

1. INTRODUCTION

The paper presents computer modeling and arc flash hazard analysis of the distribution network with an industrial consumer with electric motor drives of one technological facility [1]. Protection coordination is essential in industrial facilities in order to avoid damage due to an arc flash produced by short circuit currents. Also, power flow analysis is very important to thermal analysis to check if some part of the system is overloaded [2]. An arc flash is dangerous because it produces the following effect: 80 % of all electrical injuries are burns resulting from the electric arc flash. Section 2 deals with thermal analysis and power flow computations. Section 3 presents arc flow analysis. Measures for reducing arc flash risk using proper protection coordination are presented in Section 4. The arc flash causes an explosion of electrical equipment resulting in an arc plasma ball. Also, solid copper vaporizes and expands to approximately 67,000 times its original volume. The temperatures exceed 12,000 Co and sound levels can reach up to 141.5 dB. In addition, the force can produce a pressure wave and light can be very bright including a plasma ball. The pressure of toxic smoke can be very dangerous [3]. Arc flash analysis and a hazard assessment are normed differently in the USA and the EU countries. In the USA, IEEE 1584-2002 entitled "IEEE Guide for Performing Arc-Flash Hazard Calculations" is a standard. It provides a methodology for computing prospective arc flash hazards [4]. Based on the test data, the IEEE 1584 Committee developed empirical equations to calculate arc flash incident energy for AC systems. The Occupational Safety and Health Administration has two parts, i.e. OSHA 1910.132 (d), and 1926.28 (a). According to the NFPA 70E industry standard [5], an employer is responsible for:

- Conducting a hazard assessment in the workplace;
- Choosing and using the proper personal protective equipment; and

- Documenting the risk assessment.

OSHA considers arc flash assessments that follow the NFPA 70E standard. They have to be in line with OSHA requirements and protect workers from electrical safety hazards [6-7]. In the EU, the IEC standard does not pay special attention to arc flash energy calculation but it has a personal protection equipment (PPE) standard for arc flash protection equipment testing. The IEC 61482-1 and the similar EN 61482-1 are split into two parts, which cover the methods for testing of clothing fabrics and garments designed to protect personnel against arc flash.

IEC and identical EU standards, which have superseded ENV 50354, are now known as the "box test". There are two test method versions: the "material box test", which includes heat transfer measurements and thermal curve differential analysis, and the "garment box test", which requires only a visual assessment of garment performance [8].

The box-test standard defines two testing conditions, namely Class 1 and Class 2:

- Class 1 tests at the arc current of 4 kA and arc duration of 500 ms;
- Class 2 tests at the arc current of 7 kA and arc duration of 500 ms.

A sample case considered in the paper are the industrial facilities supplied by the 10 kV overhead transmission line connected to the transformer station TS 10/0.4 kV [9]. The modeled network consists of overhead distribution lines, a transformer station, molded-case circuit breakers, digital relays, cables and electric motors modeled in the software which can perform power flow, short circuit and arc flash modules.

2. THERMAL ANALYSIS OF AN ELECTRICAL NETWORK AND AN ELECTRIC MOTOR DRIVE

Supply feeder rated voltage 10 kV is connected to TS Plješevac 10/0.4 kV transformer station. The length of line is 11.5 km and it is composed of Al/Fe 50 mm2 conductors and some parts with older Al/Fe 25 mm2 conductors. The feeder line of 10 kV is connected to TS 110/35/10 kV Kiseljak supply transformer station. The main motor data are given in Table 1.

Table 1. Motor data

Motor data Function	Type	Rated power (kW)	Voltage (V)	PF
Mill 1 and Mill 2	AHR	200	380	0.85
Crusher 3 and Crusher 4	AHR	132	380	0.85
Colander	AHR	132	380	0.85
Transport track	AHR	132	380	0.85

Power flow analysis shows that there is no overload of any element in the network and the technological process which will be presented with computed results and thermal measurements and images. A summary report is shown in Table 2.

Table 2. Summary system report

Motor data	Type	Rated power	Voltage	PF
Generation in the system	750	209	779	0.963
Load in the system	687	154	704	0.976
Losses in the system	63	55		

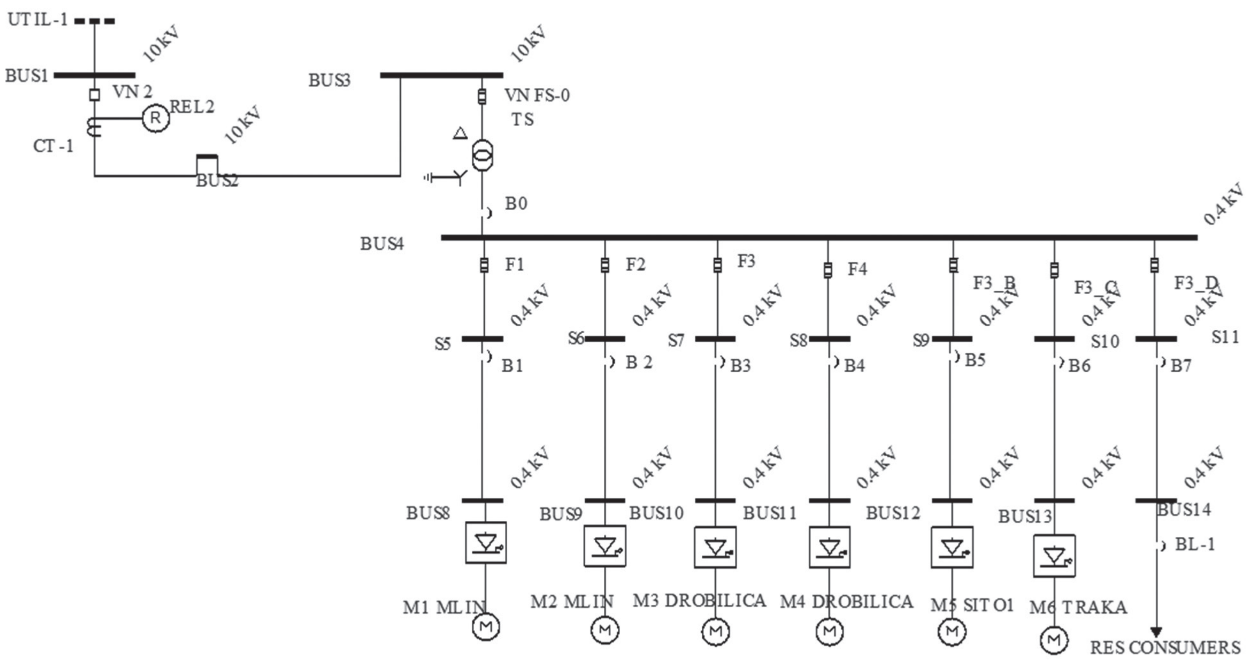

Fig. 1. A single-line diagram of the electric motor drives connected to the TS [11]

With a thermal image of the medium voltage (MV) line pole in Fig 2, it is indicated that there are no overloaded elements on distribution conductors, isolators and connection elements. The working temperature of Al/Fe conductors is 65°C. The cables on the primary side can withstand a working temperature of 75°C and the transformer temperature for cooling IEC class for the ONAN transformer is 65-85°C.

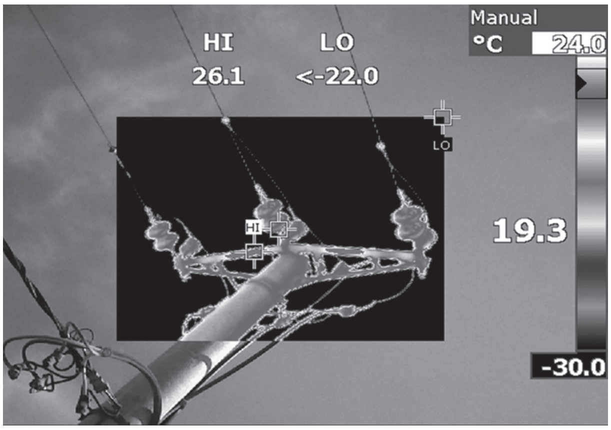

Fig. 2. Thermal image of a 10 kV pole of the distribution line

Element overloads are presented in Tables 3 and 4.

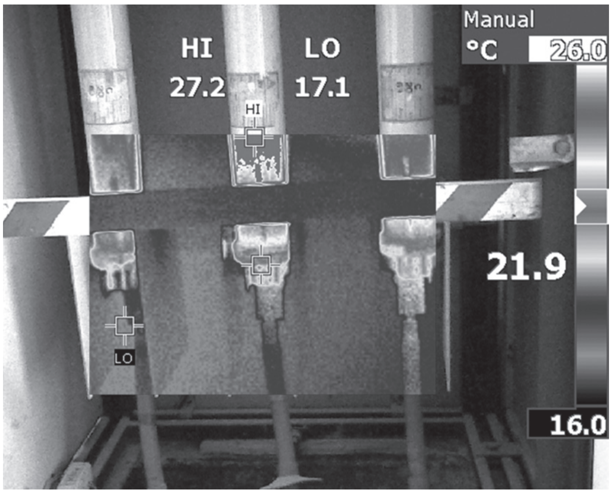

Fig. 3. Thermal image of MV fuses in the transformer station

Table 3. Transformer loading report

	Transformer			Load		
Name	From Bus	To Bus	Rated (A)	Load (A)	Loaded %	Over-loaded %
TS	BUS3	BUS4	66.4	45.0	67.7%	-32.3%

Figures 3-5 clearly illustrate that there are no overloaded elements in the transformer station TS Plješevac and its components, busbars, fuses and isolators. Also, power flow computation shows that there are underloaded elements. All thermal images show that there is no heat radiation.

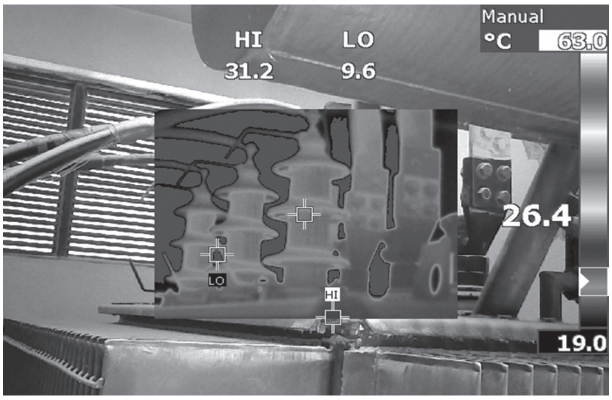

Fig. 4. Thermal image of an MV connection of the transformer

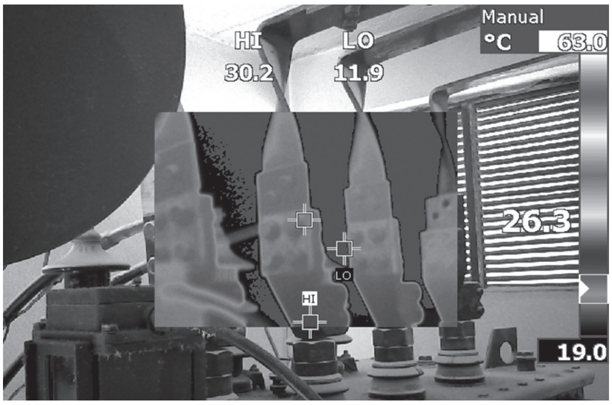

Fig. 5. Thermal image of an LV connection of the transformer

Table 4. Line overload report

		Load		
Branch Name	**Rated (A)**	**Load (A)**	**Loaded %**	**Over-loaded %**
L-2	170.0	44.9	26.4%	-73.6%
L-1	125.0	45.0	36.0%	-64.0%
C-3	585.0	225.2	38.5%	-61.5%
C-5	585.0	225.2	38.5%	-61.5%
C-6	585.0	279.9	47.9%	-52.1%
C-1	675.0	341.3	50.6%	-49.4%
B-2	1250.0	341.3	27.3%	-72.7%
B-4	1250.0	225.2	18.0%	-82.0%
B-5	1250.0	225.2	18.0%	-82.0%
B-6	1250.0	279.9	22.4%	-77.6%

Load flow analysis shows that there are no overloaded elements, line and cables, their fuses or breakers in LV motor panels and switchboards. As illustrated in Table 5, loss analysis indicates that losses are permissible; hence the elements are underloaded.

Table 5. Branch losses report

From Bus		To Bus		Losses	
Name	**Base (kV)**	**Name**	**Base (kV)**	**kW**	**kVAr**
BUS1	10.00	BUS2	10.00	36.3	23.4
BUS2	10.00	BUS3	10.00	21.4	7.3
BUS3	10.00	BUS4	0.400	4.2	23.9
BUS10	0.400	S7	0.400	0.2	0.1
BUS12	0.400	S9	0.400	0.2	0.1
BUS14	0.400	S11	0.400	0.3	0.2
S5	0.400	BUS8	0.400	0.4	0.2
S5	0.400	BUS4	0.400	0.2	0.0
S7	0.400	BUS4	0.400	0.2	0.0
S9	0.400	BUS4	0.400	0.2	0.0
S11	0.400	BUS4	0.400	0.2	0.0
Total Losses				**63.8**	**55.2**

It can also be seen that busbars are all within the permissible temperature limits, but only on one 200 kW motor connection it can be seen that there is a higher temperature of 62.3°C and the warming process on the contact at phase C, as can be seen in Fig.7. It could be a signal for the maintenance department to check this contact point. Cables from the substation supply electric motor drives owned by W&P Beton Ltd Company, Sarajevo.

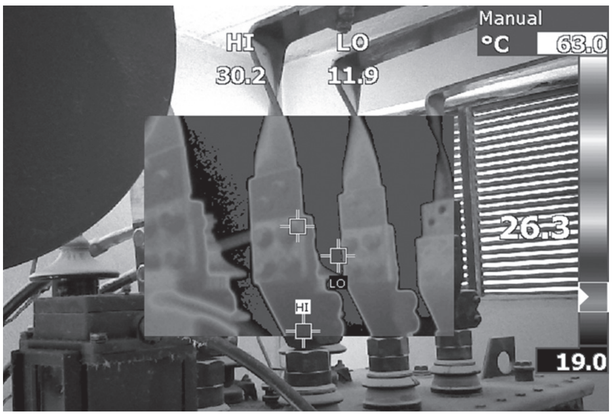

Fig. 6. Thermal image of LV busbars for a 200 kW motor

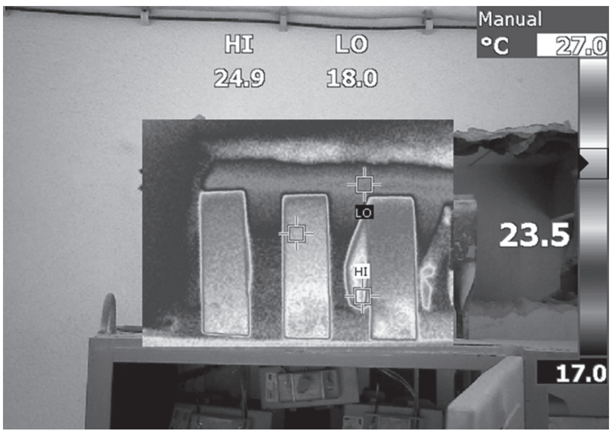

Fig. 7. Thermal image of LV main busbars

The temperature at LV busbars is good, as shown in Fig 7. Table 6 points to voltage drops, which are within permissible levels of +/- 10%.

Table 6. Voltage drop report

From Bus		To Bus		Drop
Name	**Base (kV)**	**Name**	**Base (kV)**	**%**
BUS1	10.00	BUS2	10.00	5.3%
BUS2	10.00	BUS3	10.00	2.9%
BUS3	10.00	BUS4	0.40	-3.3%
BUS10	0.40	S7	0.40	-0.2%
BUS12	0.40	S9	0.40	-0.2%
BUS14	0.40	S11	0.40	-0.2%
S5	0.40	BUS8	0.40	0.2%
S5	0.40	BUS4	0.40	-0.0%
S7	0.40	BUS4	0.40	-0.0%
S9	0.40	BUS4	0.40	-0.0%
S11	0.40	BUS4	0.40	-0.0%

3. ARC FLASH ANALYSIS

The Software Arc Flash module enables computation of incident energy on busbars during the three-phase bolted short circuit faults [5]. Arc flash hazards can result from many factors, e.g. dropped tools, accidental contact with electrical parts, corrosion and improper work procedures. An arc is produced by the flow of electrical current through ionized air after an initial flashover or short circuit, resulting in a flash that can cause significant heating and burn injuries to occur. Hazard effects of arch flash can be very harmful and dangerous for personnel.

Fig. 8. Accidents involving arc flash [7]

An arc flash hazard assessment is useful for those places where workers are exposed to arc flash during their work. So it may not be necessary to perform a risk assessment for every part of equipment in the network. All switchboards in which LV breakers, fuses and reclosers are installed had to be included in the assessment if there is a possibility that an arc flash injury might occur. Incidents may occur when operating breakers or fused disconnects, even with the door closed.

The first action is arc prevention and it includes the following: de-energize equipment if at all possible, label equipment and train personnel, minimize risk with good safety practices, move people further away, design the hazard out (Safety by Design), reduce available fault current, and faster clearing times. What is important to realize is that the level of fault current changes clearing times of all protective relays. These changes can have a significant impact on the arc flash hazard and the Personal Protection Equipment requirements (PPE) for each part of equipment.

Fig. 9. Using protection equipment when working with voltage [10]

Working distance is a very important part of an arc flash hazard assessment. The arc flash boundary and associated protection requirements are based on the incident energy levels available to the person's chest or face. The hands or arms are not included. A degree of injury depends on the percentage of person's burned skin since the head and chest areas are more critical to survival than fingers or arms. During live working, the hand and head regions are particularly at risk of being burnt by arc faults. National regulations valid in the country of use must be observed. Employers must provide tested personal protective equipment (PPE) in compliance with Directive 89/686/EEC to their employees. PPE must be certified by an accredited test institute. Employers must ensure that PPE is used properly.

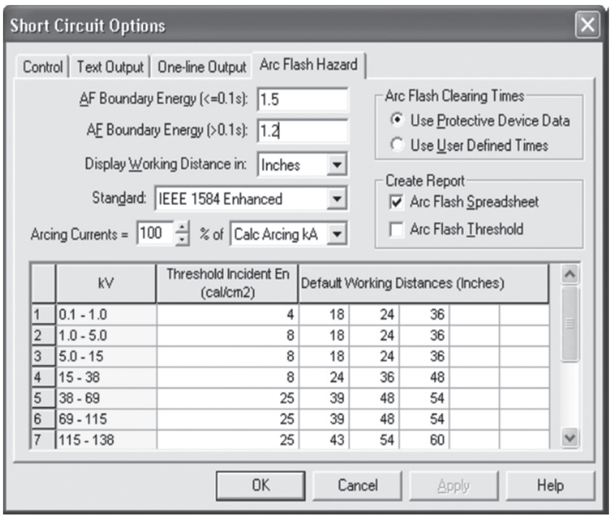

Fig. 10. Software module for Arc Flash [11]

Software enables analysis including multiple graphical tools to solve overcurrent relay coordination problems to reduce arc flash effects. The program enables up to five working distances for each voltage level. The user can use a safety program where distances can be modified for a specific operation and maintenance function. This also allows easy standardization of personal protecting equipment and clothing levels for safety benefits. For higher voltage levels, greater distances may be used to indicate hot stick operations.

Determination of the arc energy is given by the equation:

$$W_{arc} = k_p \cdot \sqrt{3} \cdot U_n \cdot I''_{k3p} \cdot t_k \quad (1)$$

where:

W_{arc} - electrical arc energy (expected value)

k_p - arc power in relation to the short-circuit power

U_n - nominal voltage

I''_{k3p} - three-phase fault current

t_k - tripping time of the overcurrent relay

The amount of energy impressed on a surface at a specific distance away from the source during an electrical arc event is defined as incident energy. Incident energy is measured in joules per centimeter squared (J/cm2) or in calories per centimeter squared (cal/cm2). Software provides a threshold incident energy level for different voltage ranges. If the incident energy level of a particular device is above the threshold, the device will be highlighted on the one-line as immediate danger. Electrical workers and safety managers can use this threshold to immediately identify areas where current Personal Protective Equipment (PPE) standards will not provide the required safety margins. Traditional infrared thermograph survey inspection that can be used for preventive checking using infrared windows and viewports for visual inspection in regular scheduled maintenance intervals is shown in Fig. 11.

Fig. 11. Infrared visual thermography inspection [10]

The selection and overcurrent coordination of the system protective relays are very important. Each protective device needs to be determined by plotting the device TCC (Time-Current-Curves) operating characteristic for a given feeder supply. Adequate separation of protective relays depends on the type of device and the desired safety factor. At the beginning of a 0.4 kV feeder there is a secondary overcurrent relay Energoinvest. At the primary side of the distribution transformer is an MV fuse. Protection relays used to protect the secondary side of the transformer in TS Plješevac is an LV breaker with the LSI characteristic. On the cables, there are fuses and LV breakers with LSI characteristics and relays for electric motor soft start. Protection input data for relay presetting from the Distribution System Operator (DSO) Company and the W&P Beton Ltd Company are given in Table 7.

Table 7. Protection relay settings

Relay	Protection relay settings			
	Type of relay	Function	Setting	Setting
REL 2	Energoin. Overcurrent	I>120 A, Very inverse IEC	I>> 330 A, time deal=11	I>>>570 A, t=0.5 s
FS0	HV Fuse	63 A IEC standard		
B4	SIEMENS LV breaker	LSI I>1280 A	I>>4800 A, LT band A StT delay B	I>>>12800 A
F1, F2	LV Fuses	500A IEC standard		
F3	LV Fuse	400A		
B1-B2	SIEMENS LV breakers	LSI I>400 A	I>>2400 A, LT band B StT delay A	I>>> 4800 A
B3	SIEMENS LV breaker	LSI I>300 A	I>>1600 A, LT band B StT delay B	I>>> 3200 A

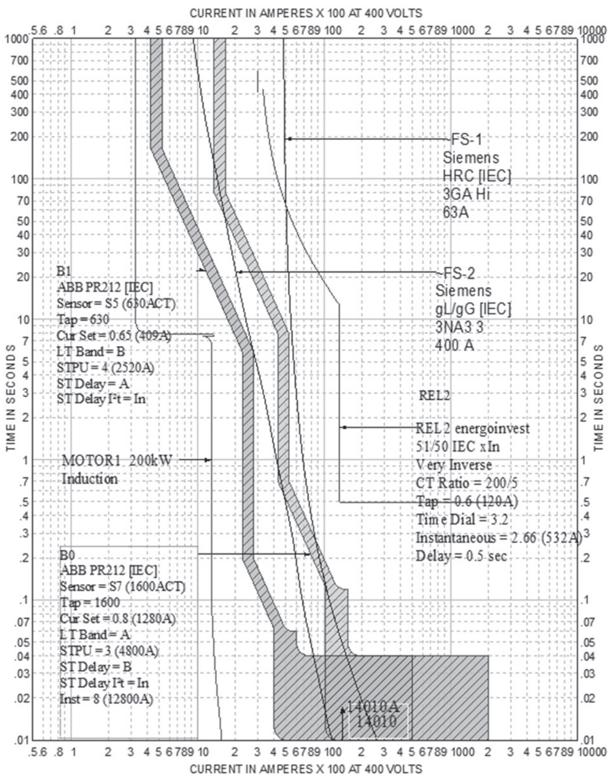

Fig. 12. Protection coordination for a 3-phase fault at bus 8 for a 200 kW soft start motor [11]

Overcurrent coordination for a three-phase fault at bus 11 for a 200 kW motor is shown in Fig. 12. From the TCC curves shown in Fig. 12 it can be concluded that protection relay coordination is well performed. In the case of three-phase faults, motor LV breaker B3 will trip first. If it fails to trip, then the LV fuse will trip. The last to be activated is breaker B0 on the LV secondary side of the transformer.

All motors at LV busbars with rated power 200 kW and M3 132 kW are equipped with a soft starter adjustable frequency device to adjust starting of the motor. In this case, the soft starter manufactured by Allen-Bradley is used, and its soft start curve is presented in Fig. 13. [8]

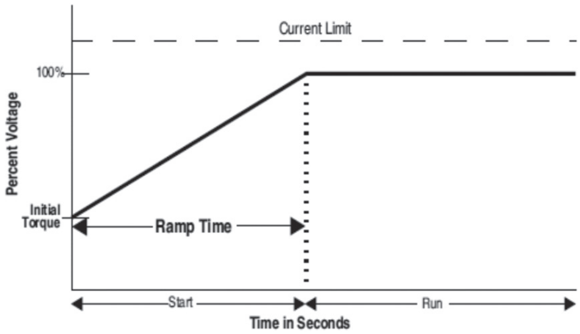

Fig. 13. Soft start curve of the SMC Flex adjustable controller

Arc flash hazard analysis is performed in the short circuit focus. The analysis yields results as required by NFPA-70E. NFPA requires a specification of the arc flash boundary and the incident arc energy at a probable working distance. Various analysis options are available such as the type of the calculation method, working distances, units, the type of enclosure for equipment, and the use of arcing time. Results may be viewed on the one-line as well as in spreadsheet reports. The arc flash report is an interactive spreadsheet, in which users can change some values and the results will change automatically.

Work permits for working on energized equipment recommending the appropriate PPE based on arc flash hazard analysis and the nature of work can be created. The IEEE 1584 equations are applicable up to 15kV. Above 15 kV, the program uses the Ralph Lee method and the distance X factor and the gap from the library do not apply. This method has the distance exponent of 2. Software obtains "Worst-Case Arc Flash Hazards", the arcing time from the upstream protective device of the faulted bus. Some circuit breakers have an additional instantaneous trip setting that can be turned on during maintenance work. In the case of faults, this results in fast tripping, limiting the arc flash incident energy.

During normal operation, this trip is set to "Off" for selective coordination. This additional trip may be known as Maintenance Mode or have commercial names such as ARMS, Quick-Trip, or RELT. As specified in Short Circuit Options, when 100% of calculated arc current or the upper value yields greater arc flash incident energy, then the text results are displayed in *black* in the Arc Flash Report spreadsheet. When 85% or the lower value yields greater incident energy, the texts are displayed in *pink*.

When short circuit analysis is performed for all buses, we get results for incident arc flash energy for all buses. It is very high in the main 0.4 kV busbar, and at all motor panel busbars, incident energy is over permissible levels and marked *red*. Arc flash hazard reports are generated in the form of a spreadsheet. Fig. 14. shows a report for a faulting "BUS-4".

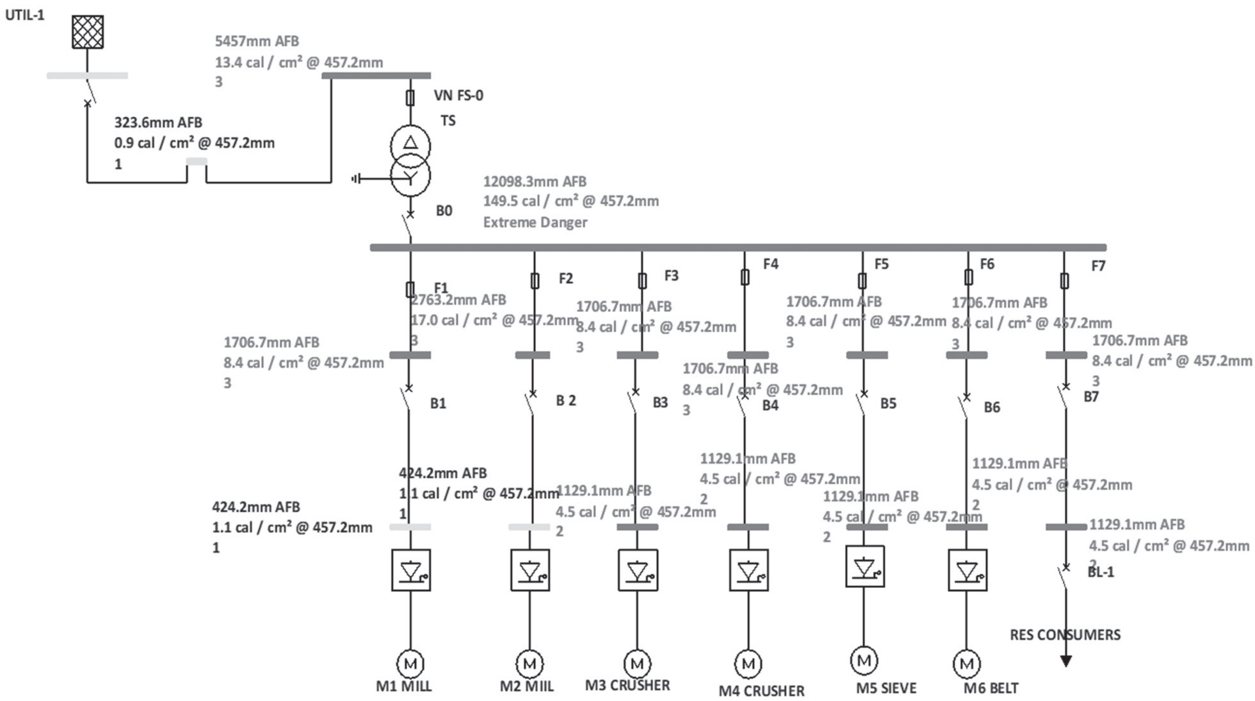

Fig. 14. Arc flash incident energy is over permissible limits on the main 0.4 kV and motor busbars. [11]

From Fig. 14 it can be seen that incident arc flash energy is over limited values and can be dangerous for personnel working at the main HV and LV transformer busbars BUS3 and BUS4, all motor panel busbars S5 to S11 and busbars on motors BUS10 to BUS14.

Table 8. Arc flash report

Arc Fault Bus	Arc Fault Bus (kV)	Up-stream Trip Device Name	Up-stream Trip Device Function	Arc Gap (mm)	Bus Bolted Fault (kA)	Bus Arc Fault (kA)	Trip Time (sec)	Arc Time (sec)	Est Arc Flash Bound-ary (mm)	Work-ing Dis-tance (mm)	Inci-dent Energy (cal/cm2)	Required Clothing Class
BUS2	10	REL2	51/50 IEC	153	0.763	0.774	0.5	0.54	323.6	457.2	0.9	#1
BUS3	10	REL2	51/50 IEC	153	0.516	0.526	12.76	12.8	5,457	457.2	13.4	#3
BUS4	0.4	B0	LSI	32	9,248	4,46	11,117	11,117	12,098.3	457.2	149.5	Ext Danger
BUS8	0.4	B1	LSI	32	8,726	4,26	0.084	0.084	424.2	457.2	1.1	#1
BUS9	0.4	B2	LSI	32	8,726	4,26	0.084	0.084	424.2	457.2	1.1	#1
BUS10	0.4	B3	LSI	32	8,654	4,98	0.3	0.3	1,129.1	457.2	4.5	#2
BUS11	0.4	B4	LSI	32	8,654	4,98	0.3	0.3	1,129.1	457.2	4.5	#2
BUS12	0.4	B5	LSI	32	8,654	4,98	0.3	0.3	1,129.1	457.2	4.5	#2
BUS13	0.4	B6	LSI	32	8,654	4,98	0.3	0.3	1,129.1	457.2	4.5	#2
BUS14	0.4	B7	LSI	32	8,654	4,98	0.3	0.3	1,129.1	457.2	4.5	#2
S5	0.4	F1	Fuse	32	9,182	4,435	0.625	0.625	1,706.7	457.2	8.4	#3
S6	0.4	F2	Fuse	32	9,182	4,435	1,271	1,271	2,763.2	457.2	17	#3
S7	0.4	F3	Fuse	32	9,182	4,435	0.625	0.625	1,706.7	457.2	8.4	#3
S8	0.4	F4	Fuse	32	9,182	4,435	0.625	0.625	1,706.7	457.2	8.4	#3
S9	0.4	F5	Fuse	32	9,182	4,435	0.625	0.625	1,706.7	457.2	8.4	#3
S10	0.4	F6	Fuse	32	9,182	4,435	0.625	0.625	1,706.7	457.2	8.4	#3
S11	0.4	F7	Fuse	32	9,182	4,435	0.625	0.625	1,706.7	457.2	8.4	#3

In Table 8, it can be seen that without eliminating arch flash hazard we will have extremely dangerous requirements for PPE clothing and a high amount of incident arch flash energy which can cause a serious risk to personnel security and health.

4. ELIMINATING ARC FLASH HAZARD RISK

It is necessary to eliminate such huge level of risk while working on busbar BUS4 and busbars S5 to S11, so it is necessary to rearrange upstream relay settings of breaker B0 to new lower and faster time settings. The TCC time-current (t-I) characteristics for that case are presented in Fig. 16. For the existing systems, reducing the duration of an arc is the most practical method to reduce incident energy. Arc duration is a function of time-current characteristics of the upstream device that must clear the fault. The arcing time can get reduced in several ways. Some changes in the system of settings may be required for this purpose. Some strategies outlined in this section are as follows:

- Perform or update a protective device coordination study to reduce protective device operating times.
- Implement maintenance mode settings for low voltage breakers and protective relays.
- Implement Zone Selective Interlocking for a low voltage switchgear.
- Implement “Fast Bus Tripping” schemes for a medium voltage switchgear.
- Use bus and transformer differential protection to combine selectivity with instantaneous operation.
- Retrofit time-overcurrent relays with a delayed instantaneous trip (definite-time) element if needed.
- Use optical sensors to rapidly clear faults in the event of arc flash within an equipment enclosure.
- Install remote feeder breakers to reduce arc flash levels for group mounted low voltage switchboards and panel boards.

In this paper, the first strategy is used to update a protective device coordination study to reduce protective device operating times. There are limited options for reducing current significantly, especially on the existing systems. The main tool available for reducing arc flash energy is to reduce the arc time. When coordinating inverse time type relays such as overcurrent relays, circuit breakers and fuses, selectivity is achieved by making each upstream device slower than all downstream relays it must coordinate with. While this slower operation may provide adequate equipment protection, it results in longer arc times and higher arc energy. Protective device coordination is generally a compromise between protection (fast operation) and selectivity (slower operation), and these two goals are quite often directly conflicting. In the past, coordination settings were based on equipment protection boundaries and arc flash levels were not considered.

Significant reduction in incident energy is often possible without sacrificing coordination by simply lowering device settings. To ensure that overcurrent relays in series properly coordinate with each other, it is often necessary to allow a safety margin between the two time-current curves. This is especially true for overcurrent relays and medium voltage circuit breakers. This safety factor is referred to as the Coordination Time Interval or CTI. Traditionally, when coordinating between two overcurrent relays, a CTI of 0.3 to 0.4s was used. This was based on the accuracy and operating characteristics of electromechanical induction disk overcurrent relays. With modern digital relays, this CTI can be reduced to range between 0.2 and 0.25s. This reduction can significantly reduce the incident energy levels.

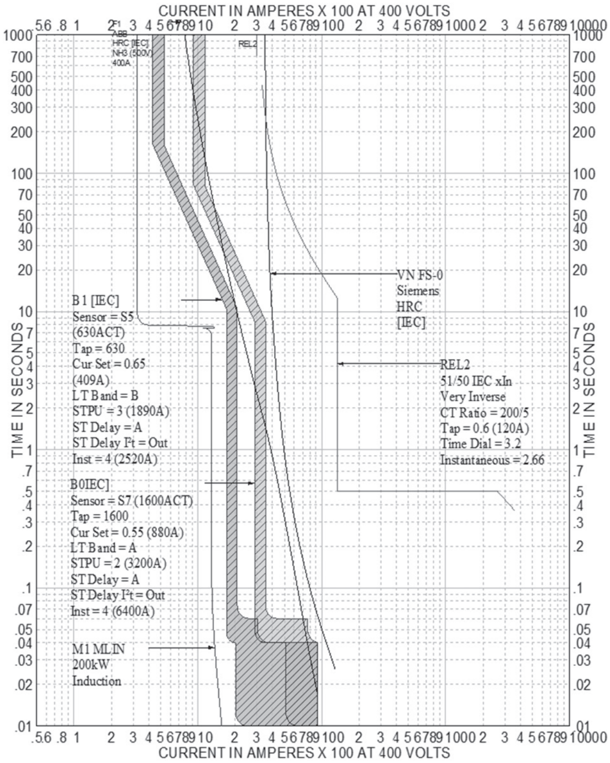

Fig. 15. Protection coordination for a three-phase fault at bus 8 for a 200 kW motor with a soft starter [11]

After arc flash analysis, we can see in the last column in Table 9 that in this case the required clothing classes are 1 and 2.

Table 9. Final relay settings

Relay	Type of relay	Protection relay settings		
		Function	Function	Function
REL2	Energoinv. Overcurrent	I>120A, Very inverse IEC	I>> 330A time deal=11	I>>>532A, t=0.5 s
FS0	HV Fuse	63 A IEC standard		
B4	SIEMENS LV breaker	LSI, I>410 A, LT band A	I>>1,890 A, I2t=out StT delay A	I>>>2,520 A
F1-7	LV Fuse	400A IEC standard		
B1-B2	SIEMENS LV breakers	LSI, I>400 A, LT band B	I>>1,800 A, StT delay A	I>>>2,520 A
B3-B7	SIEMENS LV breaker	LSI, I>300 A, LT band A	I>>1,600 A, StT delay A	I>>>2,400 A

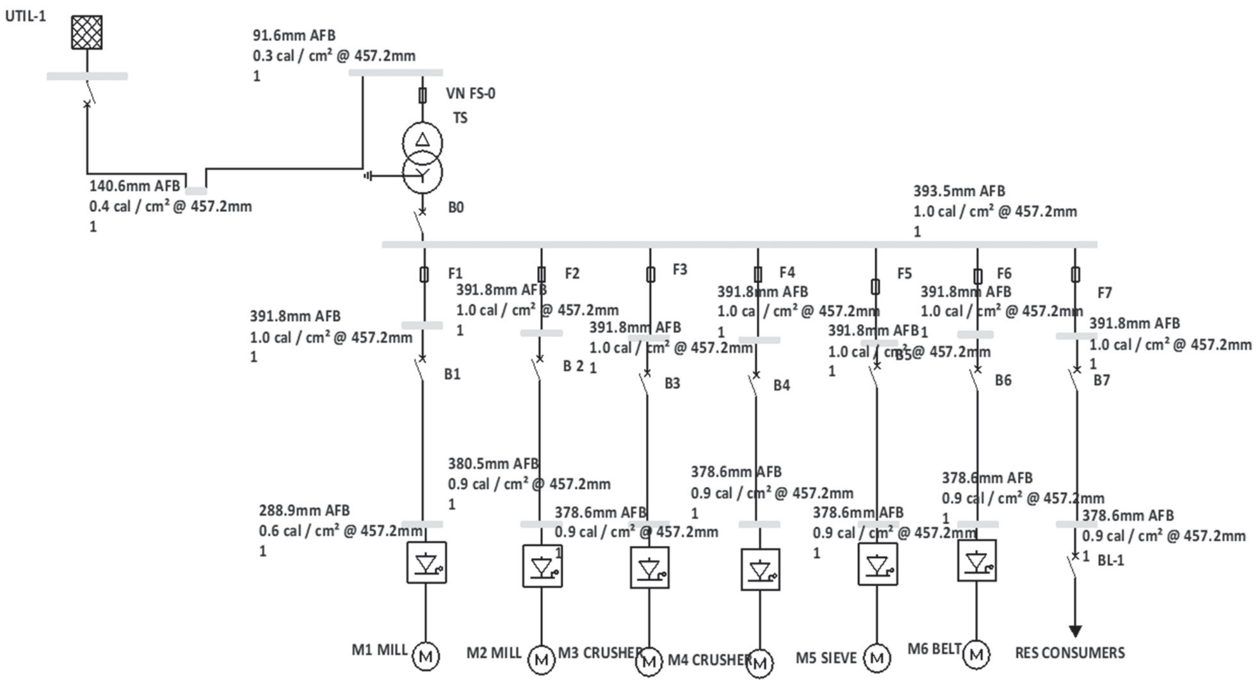

Fig. 15. Arc flash reduction using correct relay settings. [11]

Table 10 presents the final result after rearranging relay settings.

Table 10. Arc flash final report

Bus Name	Bus kV	Device Name	Device Function	Arc Gap (mm)	Bus Bolted Fault (kA)	Bus Arc Fault (kA)	Trip Time (sec)	Arc Time (sec)	Est Arc Flash Boundary (mm)	Working Distance (mm)	Incident Energy (cal/cm2)	Required Clothing Class
BUS2	10	REL2	51/50	153	0.763	0.774	0.05	0.09	51.3	457.2	0.1	#1
BUS3	10	REL2	51/50	153	0.516	0.526	6.056	6.096	2,545.8	457.2	6.4	#2
BUS4	0.4	B0	LSI	32	9.248	5.248	0.06	0.06	393.5	457.2	1	#1
BUS8	0.4	B1	LSI	32	8.726	5.013	0.04	0.04	288.9	457.2	0.6	#1
BUS9	0.4	B0	LSI	32	8.726	5.013	0.06	0.06	380.5	457.2	0.9	#1
BUS10	0.4	B0	LSI	32	8.654	4.98	0.06	0.06	378.6	457.2	0.9	#1
BUS11	0.4	B0	LSI	32	8.654	4.98	0.06	0.06	378.6	457.2	0.9	#1
BUS12	0.4	B0	LSI	32	8.654	4.98	0.06	0.06	378.6	457.2	0.9	#1
BUS13	0.4	B0	LSI	32	8.654	4.98	0.06	0.06	378.6	457.2	0.9	#1
BUS14	0.4	B0	LSI	32	8.654	4.98	0.06	0.06	378.6	457.2	0.9	#1
S5	0.4	F1	IEC	32	9.182	5.218	0.06	0.06	391.8	457.2	1	#1
S6	0.4	F2	IEC	32	9.182	5.218	0.06	0.06	391.8	457.2	1	#1
S7	0.4	F3	IEC	32	9.182	5.218	0.06	0.06	391.8	457.2	1	#1
S8	0.4	F4	IEC	32	9.182	5.218	0.06	0.06	391.8	457.2	1	#1
S9	0.4	F5	IEC	32	9.182	5.218	0.06	0.06	391.8	457.2	1	#1
S10	0.4	F6	IEC	32	9.182	5.218	0.06	0.06	391.8	457.2	1	#1
S11	0.4	F7	IEC	32	9.182	5.218	0.06	0.06	391.8	457.2	1	#1

After arc flash analysis, in the last column in Table 11 it can be seen that in this case the required clothing classes are #1 and #2.

Table 11. Personal protection equipment

Hazard Risk Category	Clothing Description (Number of clothing layers given in parenthesis)	Total Weight (oz/yd2)	Minimum Arc Thermal Performance Exposure Value (ATPV) or Breakopen Threshold Energy Rating of PPE (cal/cm2)
0	Untreated Cotton (1)	4.7-7	1.2
1	FR Shirt and FR Pants (1)	4.5-8	4
2	Cotton Underwear plus FR Shirt and FR Pants (2)	9-12	8
3	Cotton Underwear plus FR Shirt and FR Pants plus Coverall (3)	16-20	25
4	Cotton Underwear plus FR Shirt and FR Pants plus Double Layer Switching Coat and Pants (4)	24-40	40

5. CONCLUSION

In this paper, thermal analysis using an infrared thermal camera and computer power flow analysis is presented to confirm the presence of any element overload in the distribution system and an industrial company. In addition, Arc Flash analysis is introduced followed by a hazard assessment and it is explained how to use a computer program for calculating incident energy; working distance and personal protective equipment can be chosen to mitigate arch flash effects. Protection coordination of numerical relays, LV breakers and fuses is very important and it is one of the ways to mitigate and reduce the risk of arc flash. A sample case was presented where presetting values of time current curves were not chosen and coordinated well so that it caused a high level of incident energy. After rearranging TCC presented in Fig. 15, incident energy was reduced and the risk of arc flash is mitigated.

6. ACKNOWLEDGMENT

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