Computer Aided Arc Flash Risk Assessment According to IEEE and DGUV Standards

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Abstract—**This paper presents an arc flash risk assessment procedure using different computer tools from different countries. Different computation methods according new requirements in NFPA 70E (2018), IEEE 1584 and DGUV I 203-077 standard. Three different software are used and compared incident energy (E_I) or full energy (W_E), arc flash boundary and the level of Personnel Protection Equipment (PPE). Arc flash risk assessment is today a mandatory part of each risk assessment for electrical workplaces and several recommendations exist in different countries. National OSHA rules in USA, EN 50110-1 in Europe and PPE Directive in Europe. A short circuit analysis is performed to calculate the values of arching currents and compute arc flash energy dissipated at busbars at HV and LV voltage busbars. Worst case scenario approach is used to examine what is highest level of Arc Thermal Performance Value (ATPV). There different software tools where used in computation: "EasyPower Arc Flash" (USA), BSD Arc Calculator (Germany) and RENblad 1710 (Norway). A practical sample case is presented and arc flash energy is computed and PPE recommended for high and low voltage busbars in one stone pit facility in Slovenia and biomass power plant in Croatia.**

***Index Terms*—Arc flash, risk assessment, short circuit, incident energy, personnel protection equipment**

I. INTRODUCTION

Risk assessment for the occurrence of arc flash that can have very damaging consequences for personnel and equipment in electrical facilities is increasingly applicable in advanced countries such as USA, Canada and the EU. These countries have regulations and norms to regulate legislative issues and obligations regarding risk assessments as well as the mandatory use of PPE for personnel that may be exposed to such risks [1-4]. Croatia has EU adopted standards [5-8], Croatian legislation [9-11], EN/HRN standards [12-13] and IEC standards [14-16] that regulate this field. Germany uses a standard and recommendations [17-18]. The Electricity Section of the International Social Safety Association ISSA published guidelines for users to select PPE against the thermal hazards of electric fault arcs [19].

The problem is that the protection techniques and methods and the use of protective equipment are not implemented in countries such as Slovenia, Croatia and especially in other countries in Southeast Europe, the aim of this paper is therefor to present computer tools for arc flash calculations, safety distance assessment for personnel and the use of prescribed appropriate personal protective equipment as a measure of protection for staff carrying out live work.

There is a great deal of literature on risk assessment for arc flash in low voltage, medium voltage and high voltage networks and installations, as well as methods to eliminate the consequences of arc flash and the selection of protective equipment [20-44]. The most important literature from the field of arc flash energy assessment is from 1980s from *Ralph Lee* [20], followed by a comprehensive book by *Jay C. Das* [21], providing complete theoretical and practical basis for the calculation of arc flash energy, short-circuit current and arc flash risk assessment.

For the purpose of this paper three tools for the assessment of arc flash, arc flash boundary and PPE will be used. The first tool "EasyPower Arc Flash" is described in [28] and it complies with IEEE 1584 and NFPA 2018 standards. The second tool "BSD Arc Calculator" is described in [35-37] and uses the German approach according to the DGUV I 203-077 norm. The third tool RENblad 1710 is also based on IEEE 1584.

II. INTERNATIONAL NORM AND RECOMMENDATION

European and worldwide OSHA regulations require the selecting of appropriate PPE in order to the arc energy level at the working place for people who work on or in the vicinity of live equipment. It exists two different arc assessment methods therefor it's up to the manager to decide which assessment method is the proper one.

The arc assessment on the basis of NFPA 70E [2] and IEEE 1584 [1] is the worldwide most common method. The second method is the German based assessment on the DGUV standard 203-077 [17] which slightly start to get more attention outside of Germany. Both arc assessment methods are strictly bonded to the associated PPE arc rating method.

In North America the situation is since 2002 quite clear with the publishing of IEEE 1584. The user could select the right PPE level (ATPV) on the basis of the results of arc flash risk assessment according to IEEE 1584 or NFPA 70E tables.

In Europe the situation was unclear for more 10 years. According to European OSH regulation it is necessary for people in charge to select appropriate PPE in order to the estimated hazard risk level at the working place [35]. On the one hand the user has the choice of PPE of the arc protection class 1 or 2. On the other hand there was up to 2012 no standard or algorithm which supports the user to select proper electric arc protective equipment [35].

With the German national report DGUV I 203-077 [17], exist the first practical advice for user of PPE to select proper arc protection PPE. For first this report is valid only in Germany. Now the user and people in charge have the possibility to calculate the arc energy and choose from this basis the arc protection level of the PPE [35]. Following test standards exist (Open arc test (e.g. IEC 61482-1-1) [14], Box test (e.g. IEC 61482-1-2) [15]) for arc rating of electricians clothing. The open arc tests result in an arc thermal performance value (ATPV in cal/cm²) for a tested object (fabrics, clothing). PPE which is tested in box test will classified in two different arc protection classes (APC class 1 or class 2). Finally, each tested PPE product will get a value or a class to specify its arc protection level.

For face shields and gloves exist national and company standards for arc rating these PPE either to test it in open arc test or in the box. Finally, the user has the choice of a lot of arc rated products with different protective levels in the PPE market.

On this basis it is possible to comply with OSH regulations and convert it into the practice. Following questions, you have to answer [35]:

1. Who needs arc rated PPE?
2. For which operations and type of work your electricians need Arc rated PPE?
3. Which type and arc protection level of PPE your electricians need?
4. How you can convert the calculated arc protection level in practical and useful products?

III. Computer Program for Arc Flash Analysis

The IEEE 1584 method is based on empirical formulas for arc flash current calculations based on three phase short-circuit current. Because of the existing transient impedance of arc flash, arc current is smaller than the calculated current of the three phase short circuit. For low voltage systems (<1 kV), arc current is given by the equation (1).

$$I_{arc} = 10^{\{K+0.662 \cdot \log(I_k)+0.0966\,V+0.000526\,G+0.5588\,V \cdot \log(I_k)-0.00304\,G \cdot \log(I_k)\}} \quad (1)$$

Where are: log = $\log_{10}$, I_a = arcing current (kA), K = – 0.153; open configuration, K – 0.097; box configuration, I_k = bolted fault current for 3-phase faults (kA), V = system voltage (kV), G = gap between conductors (mm).

Arc current for medium-voltage systems is given by the equation (2).

$$I_{arc} = 10^{\{0.00402 \cdot 0.983 \log(I_k)\}} \quad (2)$$

Estimated normalized arc flash energy for arc flash duration of 0.2 sec and a distance of 610 mm from the arc is given by the equation (3).

$$E_n = 10^{\{K1+K2+1.081 \cdot \log(I)+0.0011\,G\}} \quad (3)$$

Where are: E_n = incident energy normalized for time and distance (J/ cm^2), K_1 = – 0.792; open configuration, K = – 0.555; box configuration, K_2 = 0; ungrounded and high resistance grounded systems, K = – 0.113; grounded systems, G = gap between conductors (mm).

The normalized energy above is used to assess arc flash energy at a flat surface of distance “D” with the arc current duration “t” as given by the equation (4).

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

Where are: E = incident energy (J/cm^2), C_f = calculation factor = 1.0; voltage > 1 kV, C = 1.5; voltage < 1 kV, t = arcing time (seconds), D = working distance from arc (mm), x = distance exponent as shown in Table I.

Table I. Distance factor x for various voltages and enclose types

Enclosure type	0.208 to 1 kV	> 1 to 15 kV
Open air	2	2
Switchgear	1.473	0.973
MCC and panels	1.641	
Cable	2	2

Arc fault current us calculated with the integrated method, which takes into account the decreasing currents from motors and generators and also from multiple sources being switched out through protective devices tripping. The Integrated method is the closest to a realistic scenario (Fig. 1).

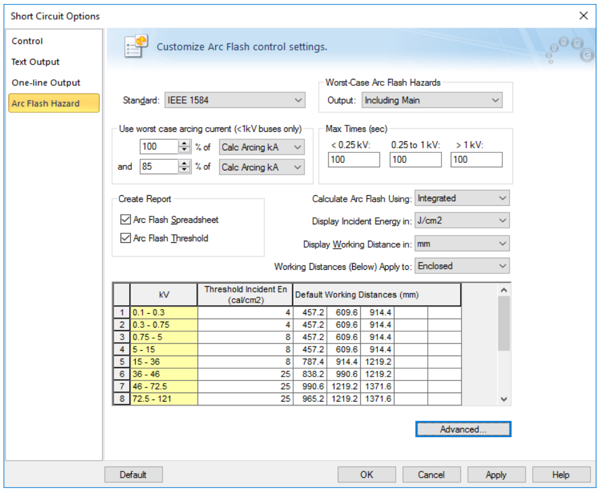

Fig. 1. Arc Flash option in EasyPower Arc Flash module

RENblad 1710 Arc Flash Calculator is also based on the American IEEE-standard 1584 (Fig. 2). The purpose is to easily calculate the incident energy, given the short circuit characteristics and the working position. It can also be used to verify that you are in possession of the right PPE.

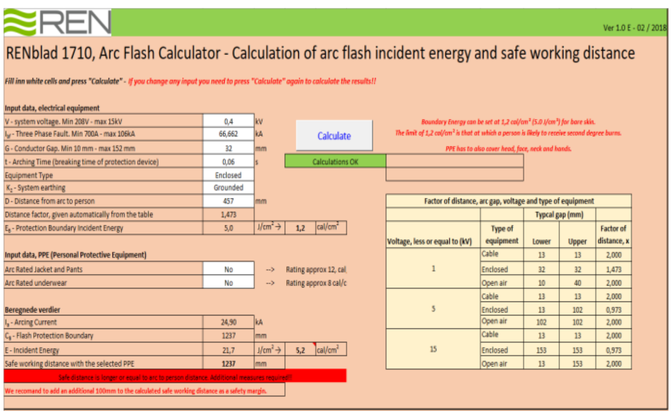

Fig. 2. RENblad 1710 Arc Flash Calculator

The calculator lets you enter whether you are wearing two layers of arc flash protection, only one layer or no arc flash protection at all. To simplify for the user, the outer layer of PPE is preset to an ATPV rating of 12 cal/cm^2 and the inner layer is preset to an ATPV rating of 8 cal/cm^2. Based on this, the calculator will tell you if you are at a safe working distance. If not, the working distance can be increased and/or layers of arc rated PPE can be added. A green result line will occur when sufficient safety is met.

The algorithm published in DGUV I 203-077 bases in principle on same physics like IEEE 1584. The analysis sets up of calculating the bolted three-phase short circuit current at each working place in the system. Then the arc fault current is calculated at each relevant location. As well as in IEEE for low voltage systems, the DGUV method is considering the arc impedance which leads to an arc fault current which will be lower than the bolted fault current. The arc fault current is the basis for calculating the clearing time of the protective devices (fuses or circuit breakers) which is necessary to know about the arcing time.

Together will following technical data it is possible to calculate the arc energy W_{LB}:

- electrode gap (distance between electrodes, (necessary for precise calculation, not necessary for worst-case calculation),
- bolted fault current I''_{kmax},
- clearing time t_k,
- R/X ratio of fault effected part of network.

$$W_{LB} = k_p \cdot \sqrt{3} \cdot U_{Nn} \cdot I''_{kmax} \cdot t_k \qquad (5)$$

In contrast to IEEE method the DGUV method is calculating not the incident energy but the arc energy W_{LB}. This is the mostly thermally active energy generated by the electric arc.

The normalized arc power k_p is the relationship of electric arc power to the short-circuit power at the fault location. It depends on R/X ratio, voltage level and electrode gap (for precise calculation).

To consider the realistic working distance and equipment geometry for the relevant working places it is necessary to calculate for every arc protection class (class 1 and class 2) the protection level of the PPE ($W_{LBä}$). After calculation the person in charge shall compare W_{LB} and $W_{LBä}$. When $W_{LB} < W_{LBä}$ the selected PPE is providing sufficient arc protection for the dedicated working place.

In contrast to IEEE the document DGUV I 203-077 has no limit of scope regarding voltage level or fault current. But with the current document there are no clear indications how to proceed for the situation:

$$W_{LB} > W_{LBä}(Class\ 2) \qquad (6)$$

The lower limit for using PPE will be in the next revision of this standard an arc energy of 50 kJ. That means for arc energies lower than 50 kJ there is no need of using PPE (comparable to E_i = 1.2 cal/cm²). For that reason, for all working places protected by fuses with rating 63 A or lower there is no need for calculation.

In the DGUV document were mentioned two methods of calculating arc energy W_{LB}.

- precise calculation,
- worst-case calculation.

The worst-case calculation is considering as a simplified method, easy to use with a spreadsheet (e.g. Excel). The precise calculation is more sophisticated but leads to lower arc energy values and that's why in some cases to lower arc protection classes. To apply this precise calculation method, it is recommended to work with the special software tool "BSD Arc Calculator Software" (Fig. 3 - Fig. 4).

With BSD tool the user is able to calculate with limited amount of time the arc energy and the proper arc protection level for relevant working places.

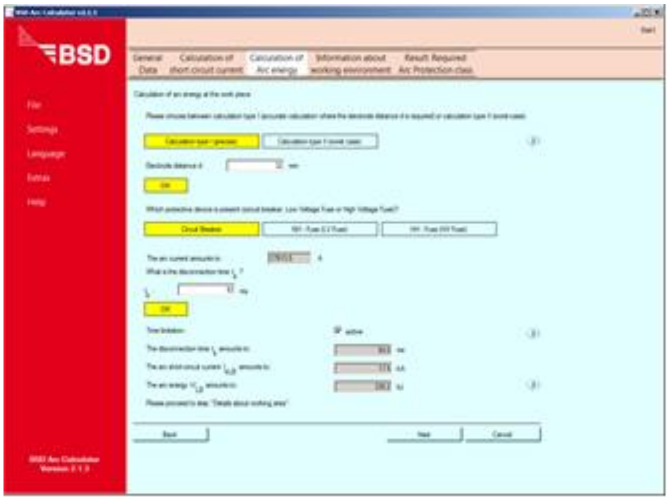

Fig. 3. User Interface of BSD Arc Calculator

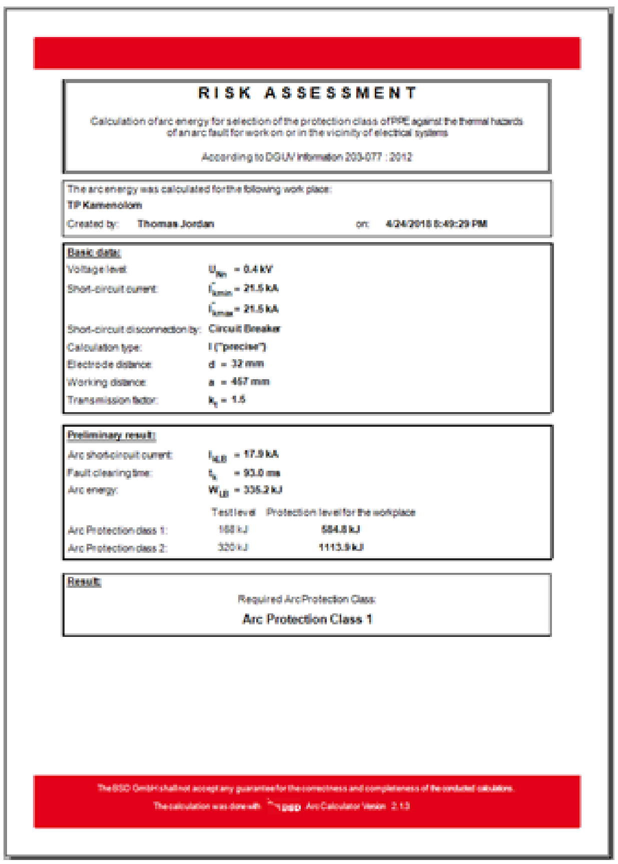

Fig. 4. Print Report of BSD Arc Calculator

The software has following features [35]:

1. Arc energy with the precise calculator according to DGUV I 203-077,
2. Short-circuit current calculation for simple radial networks,
3. Database of more than 600 digitized time-current-charts of LV and MV fuses (TCC plots),
4. Easy printing of labels for working places,
5. Safe and re-edit of calculations,
6. Calculation of arc test energy for arc hazard risk higher class 2.

In comparison to EasyPower Arc Flash Software the BSD Arc calculator is dedicated to the Arc Flash calculation only. The software has no more features like protection device settings load analysis etc. Therefore, the software is smart and simple to use.

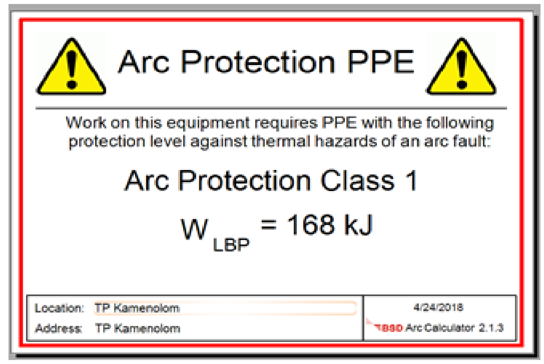

Fig. 5. Arc Flash PPE label generated by BSD Arc Calculator

IV. Case Samples

Before purchasing new arc protection PPE it is necessary to know the appropriate arc protection level for your personnel. Regarding ATPV-rated PPE exist with NFPA 70E and IEEE1584 two standards to assess arc hazard risks. For the European Box-Tested PPE exist since 2012 the German report DGUV I 203-077 for selecting proper arc flash PPE classes. Based on the mentioned algorithm it is possible to calculate the arc energy or the incident energy for each working place as a function of short circuit current, voltage level, tripping time of protective devices, R/X ratio, arc gap, working distance and the volume of the electrical installation. The calculation methods are quite accurate. But for its high accuracy it needs time and it is not quick and easy enough to do it before each job [35]. Table II shows arc flash risk assessment categories with the necessary protective equipment and minimal thermal permissible values of arc flash energy (ATPV) in cal/cm^2.

Table II. Personal protection equipment according to NFPA 70E

Hazard Risk Category	Clothing Description (Number of clothing layers given in parenthesis)	Total Weight (oz/yd^2)	Minimum Arc Thermal Performance Exposure Value (ATPV) (cal/cm^2)
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

The first analysis was carried out for TS Kamenolom (Fig. 6), which consists of a supply grid, cables, 20/0.4 kV transformer station, 630 kVA transformer, low voltage busbar, 0.4 kV cable and a busbar cabinet that powers a crusher with a power output of 90 kW and 75 kW and local consumption.

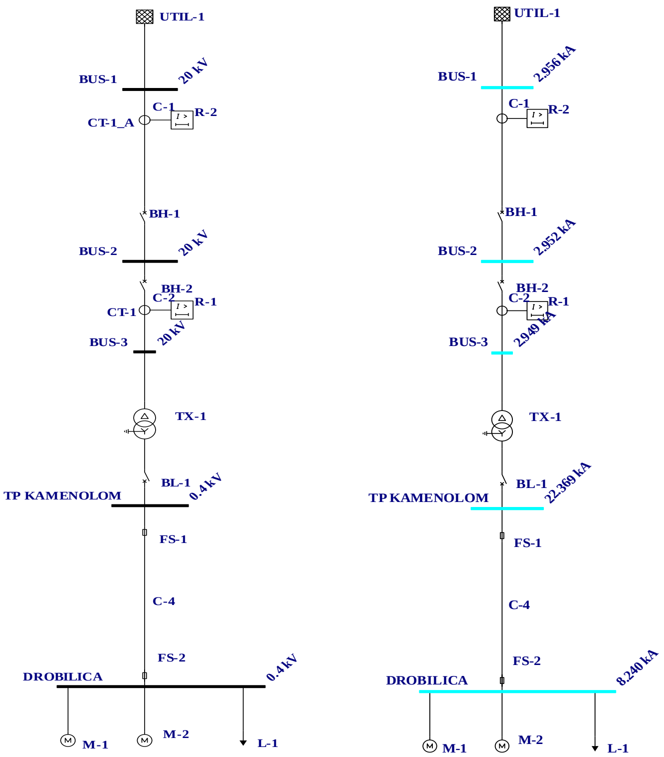

Fig. 6. TP Kamenolom single line diagram and 3 phase fault currents results

The scheme includes known overcurrent protection for VN cables and transformer, as well as all data for low-voltage switches and low-voltage fuses.

All this data were entered into the EasyPower Arc Flash toolkit and a calculation of incident arc flash electricity was carried out in accordance with III 1584 and NFPA 70 E 2018 standards.

An integrating method was used and 100 % and 85 % probabilities of arc flash current were calculated. Based on these, the permitted personnel distances were calculated and the selected level of personal protective equipment for personnel working on these busbars was calculated.

The results of the calculation of arc flash energy, the boundary distance of the personnel and the levels of protective equipment that was used are shown in Table III.

The Table III shows that the incident arc flash energy is the highest at the BUS-1 busbar, because it does not have any protective device to disconnect the current if a fault arises and to cut off the arc flash electricity. On 20 kV busbar BUS-2, the arc flash energy is lower and the level of protection is class 2 because a numeric relay disables a fault for 0.116 s.

The highest current of the three phase short circuit is on low-voltage busbars of 0.4 kV TS Kamenolom, it is 21.546 kA and the current of arc flash is 10.221 kA. Incident arc flash energy is 12.9 J/cm^2. The safety distance is 867.4 mm and the level of personal protective equipment is class 1. An example of labeling according to NFPA 70E 130.7 (C) 15 (c) for LV busbar for TS Kamenolom is shown in Fig. 7.

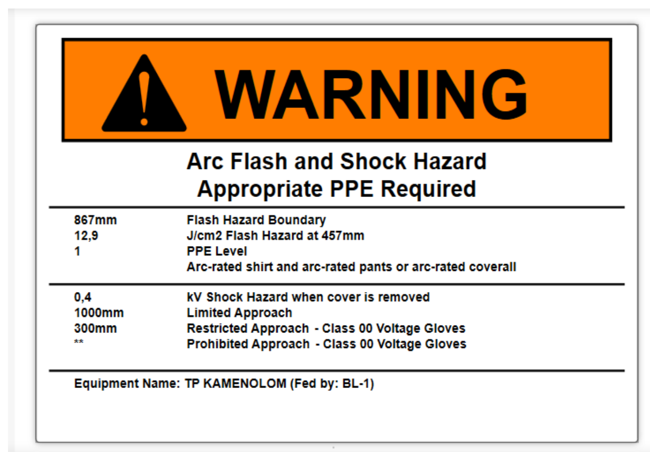

Fig. 7. Arc Flash label for busbar 0.4 kV Kamenolom

Table III. Arc Flash analysis report for TS Kamenolom

EasyPower calculation								REN Calculation				BSD Calculation		
Arc Fault Bus Name	Arc Fault Bus kV	Bus Bolted Fault (kA)	Bus Arc Fault (kA)	Est Arc Flash Boundary (mm)	Working Distance (mm)	Incident Energy (cal/cm^2)	Required Clothing	Flash protection boundary (mm)	Bus Arc Fault (kA)	Incident energy (cal/cm^2)	Required layers of arc flash rated PPE	Bus Arc Fault (kA)	Arc Time (sec)	APC
BUS-1	20	2.931	2.931	2240	787.4	9.7	3	Can not compute	Can not compute	Can not compute	Can not compute	2.9	0.20	1
BUS-2	20	2.937	2.937	1709.2	787.4	5.7	2	Can not compute	Can not compute	Can not compute	Can not compute	2.9	0.11	1
BUS-3	20	2.935	2.935	1708.6	787.4	5.7	2	Can not compute	Can not compute	Can not compute	Can not compute	2.9	0.11	1
DROB ILICA	0.4	7.405	3.743	348.7	457.2	0.3	1	389.0	4.404	0.9	Outer layer	6.2	0.01	0
TP KAM	0.4	21.546	10.221	867.4	457.2	3.1	1	857.0	10.221	3.1	Outer layer	17.9	0.09	1

Note: To compare PPE results please consider, that common PPE with NFPA 70E clothing class 3 rating and Arc protection class 2 (IEC 61482-2) rating require two layer for arc flash clothing.

The second case study is a complex biomass 2 MW power plant, which is connected to a 10 kV distribution network via a 2 MVA transformer block (Fig. 8).

The power plant also has a back-up power supply with a 400 kVA diesel generator that is automatically switched on when the network or generator power supply is disconnected to enable power supply of its own consumption with important DC drives, mains pumps, boiler pumps and fans and a mandatory 0.4 kV low-voltage power supply.

The analysis of short circuits on high-voltage and low-voltage busbars in the cabinets was carried out and the arc fault energy was calculated.

Everything necessary was done for the installation of protective devices in the power plant.

As this is a low voltage and a relatively large unit, the power generator of 2 MW short circuit current on the generator and low voltage busbars is extremely large at 64 kA.

The short-circuit current computation results for all LV busbars are shown in Table IV.

Table IV. LV Momentary Report

3 Phase Fault		**Total Fault Currents**			
Bus Name	**Bus kV**	**Sym (A)**	**X/R Ratio**	**Mult Factor**	**Asym (A)**
ATS-1	0.40	63873.0	6.22	1.33	84784.0
BUS-4K	0.40	64892.0	6.74	1.35	87504.6
BUS-BIO	0.40	64696.1	6.76	1.35	87278.9
BUS-DG	0.40	4434.0	17.62	1.55	6884.0
BUS-VP	0.40	61564.6	4.71	1.25	77177.7
BUS-VP2 BUS-VP3 BUS-VP4 BUS-VP5 BUS-VP6 BUS-VP7 BUS-VP8	0.40	19630.2	0.38	1.00	19630.3
BUS-VP8 BUS-VP9 BUS-VP10 BUS-VP11	0.40	45713.4	1.40	1.02	46679.0
BUS-VP12 BUS-VP13 BUS-VP15	0.40	54372.5	3.38	1.17	63531.3
BUS-VP14	0.40	52692.8	2.53	1.10	58124.6

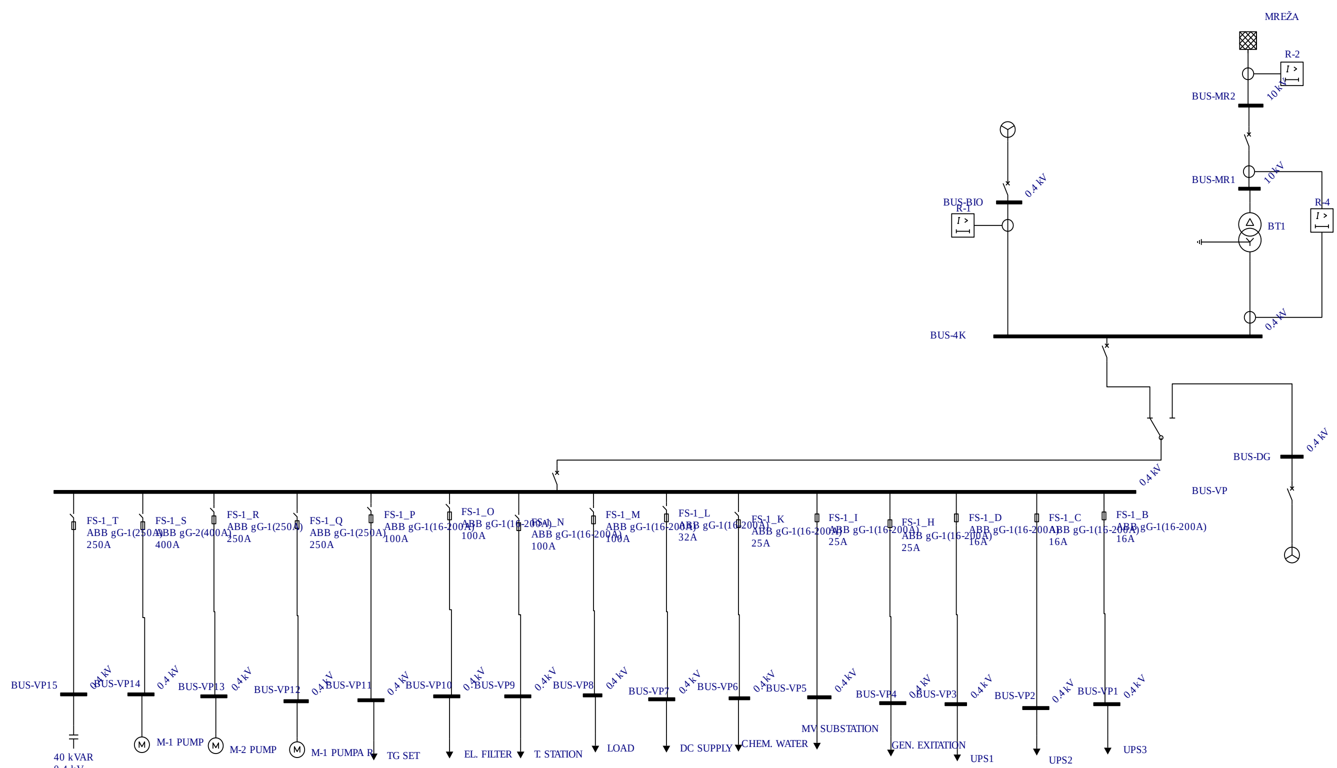

Fig. 8. The single-circuit scheme of the biomass power plant

Table V. Arc Flash analysis report for biomass power plant

EasyPower calculation									REN Calculation		BSD Calculation		
Bus Name	Arc Fault Bus (kV)	Arc Gap (mm)	Bus Bolted Fault (kA)	Bus Arc Fault (kA)	Est Arc Flash Boundary (mm)	Working Distance (mm)	Incident Energy (cal/cm^2)	Required Clothing Class	Incident Energy (cal/cm^2)	Required layers of arc flash rated PPE	Bus Arc Fault (kA)	Arc Time (sec)	APC
ATS-1	0.4	32	63.873	24.071	1203	457.2	5.4	**2**	5.4	**Outer layer**	53.2	0.06	**2**
BUS-4K	0.4	32	64.892	24.373	1073	457.2	4.3	**2**	18.1	**Inner+outer layer***	54.1	0.05	**1**
BUS-BIO	0.4	32	64.696	24.315	1596	457.2	7.6	**2**	18.0	**Inner+outer layer***	53.9	0.09	**2**
BUS-DG	0.4	32	4.434	2.94	976	457.2	3.7	**1**	2.8	**Outer layer**	4	0.33	**1**
BUS-MR1	10	153/ 152	3.796	3.746	168	457.2	0.5	**1**	0.1	**Not required**	3.8	0.04	**1**
BUS-MR2	10	153/ 152	3.798	3.747	475	457.2	1.3	**1**	0.3	**Not required**	3.8	0.11	**1**
BUS-VP	0.4	32	61.565	23.383	1178	457.2	4.9	**2**	5.2	**Outer layer**	51.3	0.06	**2**
BUS-VP1 BUS-VP2 BUS-VP3 BUS-VP4 BUS-VP5 BUS-VP6 BUS-VP7	0.4	32	19.63	9.497	237	457.2	0.5	**1**	0.5	**Not required**	No calculation needed		**0**
BUS-VP8 BUS-VP9 BUS-VP10 BUS-VP11	0.4	32	45.713	18.492	386	457.2	0.9	**1**	1.0	**Outer layer**	34	0.01	**1**
BUS-VP12 BUS-VP13 BUS-VP15	0.4	32	54.373	21.202	427	457.2	1.1	**1**	1,1	**Outer layer**	45.2	0.01	**1**
BUS-VP14	0.4	32	52.693	20.684	420	457.2	1.1	**1**	1.1	**Outer Layer**	39.2	0.01	**1**

Note: To compare PPE results please consider, that common PPE with NFPA 70E clothing class 3 rating and Arc protection class 2 (IEC 61482-2) rating require two layer for arc flash clothing.

V. CONCLUSION

This paper describes a comparative analysis of three risk assessment tools and a selection of protective equipment due to arc flash, which can occur with short circuits in power grids and installations from the lowest voltage level (0.4 kV) to the highest voltages. The EasyPower Arc Flash software tool provides all the required data for the calculation of arc flash energy according to IEEE 1584 and NFPA 70E standards in the USA. In addition, EasyPower can handle arc flash incident energy calculations using the Duke Power heat flux model for very high voltages used in transmission line settings where it is more likely to be a line to ground fault which is different from IEEE 1584 model addresses.

EasyPower also offers relay protection coordination as a measure for reducing arc flash hazard risk. The software is simple but requires good knowledge of relay protection. The software RENblad 1710 Arc flash calculator used in Norway provides similar results because it uses the same IEEE 1548 standard but is limited to 15 kV voltage level. It is very easy for users to choose PPE on two levels, the outer layer of PPE is present to an ATPV rating of 12 cal/cm^2 and the inner layer is present to an ATPV rating of 8 cal/cm^2.

The BSD Arc Calculator Software from Germany works according to DGUV I 203-077 recommendations. It is easy to use and after arc flash energy calculations and safety distances it is possible to print labels for LV cabinets where arc flash could occur and the personnel carrying out live work is at risk. As shown in Table III and Table V the results regarding necessary PPE is more and less the same protection level. In some cases, exist differences (e.g. Table III Bus-1) which occurs by different calculations algorithms. Especially the different ways of calculation arc fault current lead to different results in PPE. Because of the basis of arc fault current, the arcing time will have calculated which has high influence on incident energy (IEEE method) and arc energy (DGUV method). Note that in Croatia and Slovenia such security risk assessments and calculations are not used for arc flash, unlike USA, Germany and Norway, where they are required and it is recommended that they are implemented in practice.

VI. REFERENCES

[1] Standard IEEE 1584 “IEEE Guide for Performing Arc-Flash Hazard Calculations “, 2002, 10-12 print.

[2] “NFPA 70E, Standard for Electrical Safety Requirements for Employee Workplaces.” Volume 2015 Edition. National Fire Protection Association, n.d.

[3] Occupational Safety and Health Standards, 29CFR, Part 1910, Subpart S, Electrical, Occupational Safety and Health Administration (OSHA

[4] IEEE National Electrical Safety Code Standard C2-2012, 2011.

[5] Council Directive 89/391/EEC of 12 June 1989 on the introduction of measures to encourage improvements in the safety and health of workers at work, Official Journal L 183, 29.6.1989.

[6] Directive 2007/30/EC of the European Parliament and of the Council of 20 June 2007 amending Council Directive 89/391/EEC, its individual Directives and Council Directives 83/477/EEC, 91/383/EEC, 92/29/EEC and 94/33/EC with a view to simplifying and rationalising the reports on practical implementation, Official Journal L 165, 27.6.2007.

[7] Directive 89/686/EEC - personal protective equipment of 21 December 1989 on the approximation of the laws of the Member States relating to personal protective equipment, Official Journal L 399, 21.12.1989.

[8] Regulation (EU) 2016/425 on personal protective equipment of the European Parliament and of the Council of 9 March 2016 on personal protective equipment and repealing Council Directive 89/686/EEC, Official Journal L 81, 31.3.2016.

[9] Occupational Safety Act (OS Act, ZZR), Official Gazette of the Republic of Croatia (Zakon o zaštiti na radu; NN, No. 71/14., 118/14. i 154/14).

[10] Rules of safety and health against electric energy hazard at work (the rules), Official Gazette of Republic of Croatia (Pravilnik o sigurnosti i zdravlju pri radu s električnom energijom, NN, No. 88/12).

[11] Rules of the use of personal protective equipment (Pravilnik o uporabi osobnih zaštitnih sredstava, NN, No. 39/06).

[12] HRN EN 50110-1:2013 Pogon električnih postrojenja - 1. dio: Opći zahtjevi; (EN 50110-1:2013.

[13] HRN EN 50110-2:2010 Pogon električnih postrojenja - 2. dio: Nacionalni dodaci..

[14] IEC 61482-1-1:2009: Live working – Protective clothing against the thermal hazards of an electric arc – Part 1 Test methods, Part 1-1 Determination of the arc rating (ATPV or EBT50) of flame-resistant textile materials. (published also as EN 61482-1-1:2009 and VDE 0682-306-1-1).

[15] IEC 61482-1-2:2014 Live working – Protective clothing against the thermal hazards of an electric arc – Part 1 Test methods, Part 1-2 Determination of the arc protection class of textile material and clothing by using a directed and constrained arc. (published also as EN 61482-1-2:2014 and VDE 0682-306-1-2).

[16] IEC 61482-2:2009: Live working – Protective clothing against the thermal hazards of an electric arc – Part 2 Requirements.

[17] DGUV Information 203-077: Thermische Gefährdung durch Störlichtbögen–Hilfe bei der Auswahl der persönlichen Schutzausrüstung., Edition October 2012, Deutsche Gesetzliche Unfallversicherung e.V. (DGUV) (BGI/GUV-I 5188)

[18] GS-ET-29:2011-05 Test Principles - Face shields for electrical works - Supplementary requirements for the testing and certification of face shields for electrical works, issued by DGUV Test Cologne 2008-02 and 2010-02.

[19] ISSA Guideline for the selection of personal protective equipment when expose to the thermal effects of an electric fault arc, 2nd Edition 2011.

[20] L. Ralph, "Pressure Developed by Arcs", IEEE Transactions on Industry Applications IA-23. No. 4 july/August 1987 (1987): 760-764.

[21] J. C. Das, "Arc flash hazard analysis and mitigation", IEEE Press, John Wiley & Sons, Inc., Hoboken, New Jersey, 2012.

[22] C. L. Brooks, "Integrating Arc-Flash Analysis: A Look at Protective Device Coordination", IEEE Industry Applications Magazine,, Volume: 20, Issue: 3., 2014.

[23] J. Lagree, "Arc Flash Mitigation Techniques for Considerations for System Design",EasyPower LCC webinar,www.easy/power.com, 2016.

[24] R. Catlett, M. Lang, S. Scala, "Novel Approach to Arc Flash Mitigation for Low-Voltage Equipment", IEEE Transaction on Industry Applicarion, Vol. 52, No. 6, Nov/Dec. 2016.

[25] R. Mahayni, J. Bugshan, R. Pragale, "Arc flash mitigation for 1500 substations: A corporate approach," in Proc. IEEE Petroleum Chemical Industry Conf., 2015, pp. 1–7.

[26] S. Swencki, J. Smith, D. Roybal, D. Burns, G. Wetzel, D. Mohla, "Electrical Safety, Arc Flash Hazards, and 'The Standards' A Comprehensive Overview," in IEEE PCIC Conference Record, 2005, pp 343-357.

[27] 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, IEC 61482-1-2:200.

[28] C. S. Pierre, S. Shrestha, A. Majd, D. Castor, C. Davis, R. Luo, M. Koch, "Practical Solution Guide To Arc Flash Hazards", Second edition, EasyPower, LLC, 2015.

[29] EasyPower User's Manual, EasyPower LLC, version 9.7. Mohawk St, Tualatin, Oregon, 2016.

[30] "Arc Flash - A Guide to standards and requierements for ptotective clothing" http://www.arcflashprotection.co.uk/ assessed on 11th Dec 2016.

[31] T. A. Short, "Arc-Flash Analysis Approaches for Medium-Voltage Distribution", IEEE Transactions on Industry Applications, Volume: 47, Issue: 4, 2011.

[32] A. M. Graham, M. Hodder, G. Gates, "Current Methods for Conducting An Arc-Flash Hazard Analysis", IEEE Transactions on Industry Applications, Volume: 44, Issue: 6: 2008.

[33] C. Inshaw, R. A. Wilson, "Arc flash hazard analysis and mitigation", 58th Annual Conference for Protective Relay Engineers, 2005

[34] S. Nikolovski, P. Marić, Lj. Majdandžić, "Integration of Solar Power Plant in Distribution Network", International Journal of Electrical and Computer Engineering-IJECE Vol. 5, No. 4, August 2015, pp. 656-668.

[35] T. Jordan, M. Kauschke, "Selection of PPE – Practical experience of different arc assessment methods and their comparison", ICOLIM 2017, 12th International Conference on Live Maintenance, Strasbourg, France, 26.-28.4.2017.

[36] T. Jordan, R. Dolata, "Electric Arc Protection – PPE, Selection of PPE, High Performance PPE beyond Class 2", ICOLIM 2014, 11th International Conference on Live Maintenance, Budapest, Hungary, 21.-23.5.2014.

[37] T. Jordan, H. Tänzer, "Class 2 Arc Protection of Electricians Face Shields – BSD ErgoS", ICOLIM 2011, 10th International Conference on Live Maintenance, Zagreb, Croatia, 31.5.-02.6.2011.

[38] S. Nikolovski, P. Marić G. Knežević,"Computer modeling and simulation of overcurrent relay settings of solar power plant", Journal of Basic and Applied Research, International Knowledge Press, Vol.: 11, Issue.1, 2015.

[39] S. Nikolovski, D. Mlakić, E. Alibašić, "Arc Flash Analysis and Techniques for Hazard Reduction Using Smart Protective Devices", Journal of Industrial Electronic, Volume 1, Issue 1, page 1-12, 2017.

[40] S. Nikolovski, D. Mlakić. E. Alibašić, "Thermal and Arc Flash Analysis in Distribution Networks", International Journal of Electrical and Computer Engineering Systems (IJECES), Volume 8, Issue 2, 2017.

[41] V. Lovrenčić, G. Opaškar, "EN 50110-1:2013, Operation of electrical installations–Part 1: General requirements (SIST EN 50110-1:2013 Obratovanje električnih postrojev-1.Splošne zahteve), 36. Posvetovanje o močnostni elektrotehniki in sodobnih inštalacijah, Kotnikovi dnevi, Radenci, 26.-27.3.2015.

[42] V. Lovrenčić, M. Lušin, "Protecting electricians from arc in accordance with recommendations SIST EN 50110-1:2013 Operation of electrical installations (Varovanje električarjev pred oblokom v skladu s priporočili SIST EN 50110-1:2013 Obratovanje električnih postrojev)", 12. konferenca slovenskih elektroenergetikov (CIGRE-CIRED), 25.-27.5.2015, Portorož.

[43] M. Engebrethsen, "Calculation of energy from an arc flash", REN Temadager AUS (Norwegian live work conference), Thon Hotel Rosenkrantz, Bergen, 10.04.18 - 11.04.18.

[44] T. Jordan, "Arc protection", REN Temadager AUS (Norwegian live work conference), Thon Hotel Rosenkrantz, Bergen, 10.04.18 - 11.04.18.