ARC FLASH IDENTIFICATION FOR SELECTION OF PERSONAL PROTECTION EQUIPMENT IN THE REAL INDUSTRIAL POWER SYSTEM USING LEVENBERG MARQUARDT BACKPROPAGATION

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ABSTRACT

Arc flash hazard is an important concern for who works on an industrial electrical system. Arc flash hazard incident energy can lead damage to equipment and injury to workers. Therefore, arc flash identification required to determine category of personal protective equipment (PPE) based on NPFA 70E. Calculations of Arc flash hazard incident energy using numerical techniques based on IEEE std. 1584. However, the calculations just determine value of arc flash incident energy. Therefore, in this paper, proposes Levenberg Marquardt Backpropagation (LMBP) for identification of Arc flash. The proposed method applied in HESS Indonesia Corporation. In the simulation result demonstrates that the proposed method presents high accuracy in identification of arc flash for selection of PPE.

Keywords: *Arc Flash, personal protective equipment, NPFA 70E, Identification, Levenberg Marquardt Backpropagation*

1. INTRODUCTION

The phenomena to hazards associated with arc flash is a topic of significant interest to engineer and scientist. In the industrial power system, the explosion of Arc flash causes damage to equipment and severe injury to anyone who work on an electrical system [1]. The standards and regulations focus on study of arc flash in low and medium voltage especially reducing of arc flash hazard incident energy. NFPA 70E-2004: standard for electrical safety in the workplace [2] and IEEE standard 1584-2002: IEEE for performing arc flash hazard calculation [3] give guidelines to protecting persons who work on electrical system. The value of incident energy obtained by collection of existing test data and the equations presented by NFPA 70E and IEEE 1584.

To be aware the arc flash hazard then required the arc flash hazard analysis. In the many papers have used to arc flash hazard analysis [4]-[9]. Ravel F. Ammerman *et al* [4], proposed arc flash hazard incident energy calculations using IEEE 1584 and NFPA 70E. Tom A. Short *et al* [5], discussed analysis of arc flash on medium voltage distribution with compare of 4 techniques. Gerald T. Homce *et al* [6], presented arc flash hazard analysis implemented in the mining industry. H. W. Tinsley *et al* [7], discuss a technique for arc flash calculations for specific area in the power distribution system. A. C. Parsons *et al* [8], used simplified ach flash hazard analysis using energy boundary curves to obtain reductions in data collection and analysis time. M. Lang *et al* [9], presented the result of testing of arc flash event to evaluate effort to prevent arc flash hazard exposures to operators.

Literatures [4]-[9] focus on calculation of arc flash hazard incident energy using numerical methods. However, the results of arc flash hazard incident energy calculations are not used to selection of personal protection equipment (PPE) from arc flash identification. Moreover, the complexity of electricity system in industrial applications cause the calculation of arc flash hazard incident energy becomes more complicated and requires a long time.

Artificial intelligence can be used to identification, classification, modelling, control and prediction [10], [11], [12]. it mostly used is supervised neural network [13]. One of supervised neural network is adaptive learning rate and momentum (BPAM) [14], conjugate gradient [15]. These methods have a weakness are accuracy and convergence rate [16]. To increasing accuracy and learning process, levenberg marquardt backpropagation can be used [17]-[18].

Therefore, in this paper, propose to develop arc flash identification to selection of PPE using levenberg marquardt backpropagation (LMBP). The results under different numbers of neurons are compared to obtain the accurate arc flash identification. In this paper, the proposed method implemented in HESS Indonesia Corporation.

2. ARC FLASH INCIDENT ENERGY CALCULATIONS

The calculation of the incident energy is one of the important parameters of an arc flash hazard analysis. The amount of energy during an arc flash is obtained from this calculation. Incident energy is delivered in J/cm^2 (joule) or cal/cm^2 (calories). To obtain the value of incident energy with equations from NFPA 70E and IEEE 1584-2002. The initial steps to get incident energy with using calculations of arc fault. The equations (1) – (3) show calculations to obtain arc fault with voltage under 1000 V.

Arcing Fault calculations

$$l_g I_a = K + 0{,}662 \lg I_{bf} + 0{,}0966V + 0{,}000526G + 0{,}5588V(\lg I_{bf}) - 0{,}00304G(\lg I_{bf}) \quad (1)$$

Where
I_g = log$_{10}$
K = - 0.153 for open configurations and
-0.097 for box configuration
I_{bf} = bolted fault current in three phase fault (kA)
V = system voltage (kV)
G = gap between conductors (mm) (table 1)

Whereas for system voltage over 1000 V using equation (2) as follow

$$l_g I_a = 0{,}00402 - 0{,}983(l_g I_{bf}) \quad (2)$$

$$I_a = 10^{lg(I_a)} \quad (3)$$

Incident energy calculations

$$I_g E_n = K_1 + K_2 + 1{,}081 l_g I_a + 0{,}0011G \quad (4)$$

$$E_n = 10^{\lg(En)} \quad (5)$$

Where
E_n = normalized incident energy (J/cm^2)
K_1 = - 0.792 for open configurations and
-0.555 for box configurations
K_2 = 0 for ungrounded system and high resistance grounder
-0.113 for grounded system
G = gap between conductors (mm) (table 1)

$$E = 4{,}184 C_f E_n \left(\frac{t}{0{,}2}\right)\left(\frac{610^x}{D^x}\right) \quad (6)$$

Where
E = Incident energy (J/cm^2)
C_f = calculation factor based on 1 for voltage system over 1 kV and 1.5 for voltage system below 1 kV
t = duration of arcing fault (second)
D = distance between person with arcing point (mm) (table 2)
x = distance factor (table 1)

Table 1. Factor for equipment and voltage classes

System voltage (kV)	Equipment type	Typical gap between conductors (mm)	Distance exponent (x)
0,208–1	Open air	10–40	2
	Switchgear	32	1,473
	MCC and panels	25	1,641
	Cable	13	2
>1– 5	Open air	102	2
	Switchgear	13–102	0,973
	Cable	13	2
>5–15	Open air	13–153	2
	Switchgear	153	0,973
	Cable	13	2

Table 2. A typical working distance

Equipment	Typical working distance (mm)
15 kV switchgear	910
5 kV switchgear	910
Low-voltage switchgear	610
Low-voltage MCC and panel	455
Cable	455

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Figure 1. PPE based on hazard category

3. SELECTION OF PERSONAL PROTECTIVE EQUIPMENT (PPE)

The result of arc flash incident energy calculations can be classified to determine of personal protective equipment, which it applied by anyone who work in the electrical system.

In the table 3, shows PPE based on NFPA 70E-2004. PPE applied suitable for risk category shown by fig. 1.

Table 3. Summary of protective clothing categories

Risk Category	Minimum PPE Rating (cal/cm^2)	Clothing Required
0	Up to 1,2	Shirt (Long-Sleeve), Pants (Long), Safety Glasses, V-Rated Gloves, Insulated Tools
1	1,2 – 5	FR Shirt (Long-Sleeve), FR Pants (Long), FR Safety Glasses, V-Rated Gloves, Insulated Tools, FR Hard Hat
2	5 – 8	Category 1 requirements, Extra Layer of Untreated Natural fiber (Shirt & Pants), Leather Work Shoes
3	8 – 25	Category 2 requirements, Coveralls up to 2 Sets, Double Layer Switching Hood, Hearing Protection
4	> 25	Category 3 requirements, Flash Suit

4. LEVENBERG MARQUARDT BACKPROPAGATION

LMBP is used to identification of arc flash for selection of PPE. Hidden layer uses different number of neurons, which used to evaluate performance LMBP. The number of neurons in the hidden layer are 10 neurons and 5 neurons. The number of input neuron into LMBP depends on the data of equipment in the electrical system.

In the paper, data of equipment involve numbers of generators, voltage level, thevenin impedance, time delay relay and fault clearing time.

In the LMBP method, the change (Δ) in the weights $(\vec{\omega})$ are obtained by solving

$$\alpha\Delta = -\frac{1}{2}\nabla E \quad (7)$$

Information E is the mean-squared network error

$$E = \frac{1}{N}\sum_{k=1}^{N}[\vec{y}(x_k) - \vec{d}_k]^2 \quad (8)$$

Information N is the number of examples, $\vec{y}(x_k)$ is the network output appropriate to the example x_k and $\vec{d}_k$ is the desired output for that example. The elements of the α matrix are given by

$$\alpha_{ij} = (1+\lambda\delta_{ij})\sum_{r=1}^{P}\sum_{k=1}^{N}\left[\frac{\partial y_r(x_k)}{\partial \omega_i}\frac{\partial y_r(x_k)}{\partial \omega_r}\right] \quad (9)$$

Information p is the number of outputs of the network.

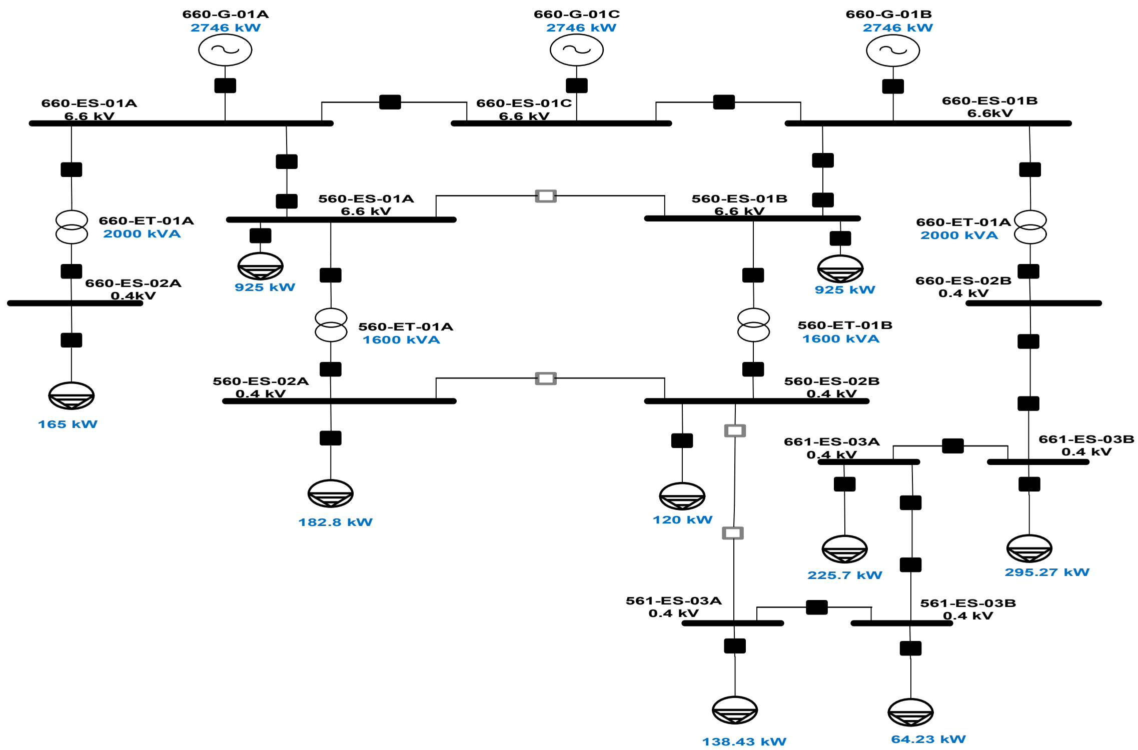

Fig. 2. Single Line Diagram Of Electrical System In The HESS Indonesia Corporation

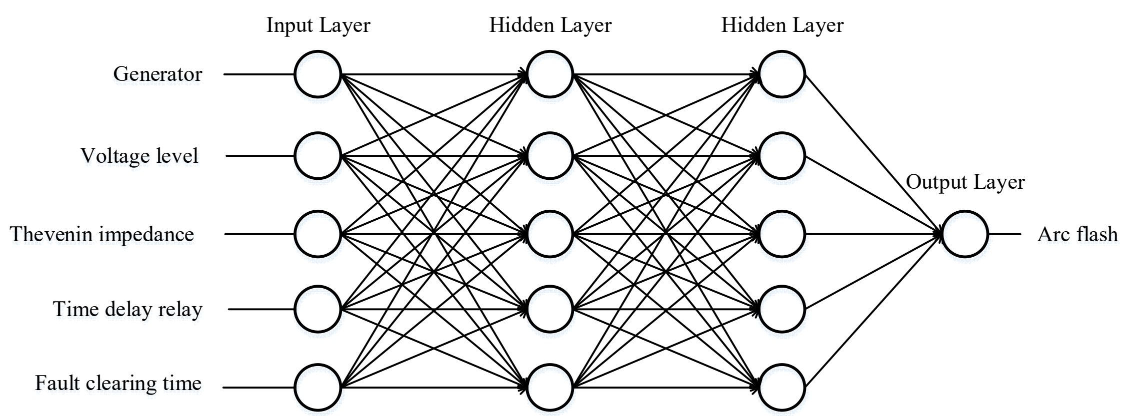

Fig. 3. Architecture Of 5 Neurons LMBP

5. FLOWCHART OF ARC FLASH IDENTIFICATION

In this paper, application in the industrial power system is discussed to evaluate arc flash identification for selection of PPE using LMBP. Application is performed in the HESS Indonesia Corporation. Data is obtained from Single line diagram in the electrical system of HESS Indonesia Corporation, which it is shown in the fig. 2. Single line diagram used to arc flash hazard incident energy calculations. The electrical system of HESS Indonesia Corporation using radial system. The electrical system installed three generators with capacity of 2.746 MW, four transformers to step down with capacity of 2 MW, 1.6 MW, 1.6 MW and 2 MW, respectively. Moreover, there are 9 motor loads and 13 buses. Grounding system of equipment using solid and NGR 50 A.

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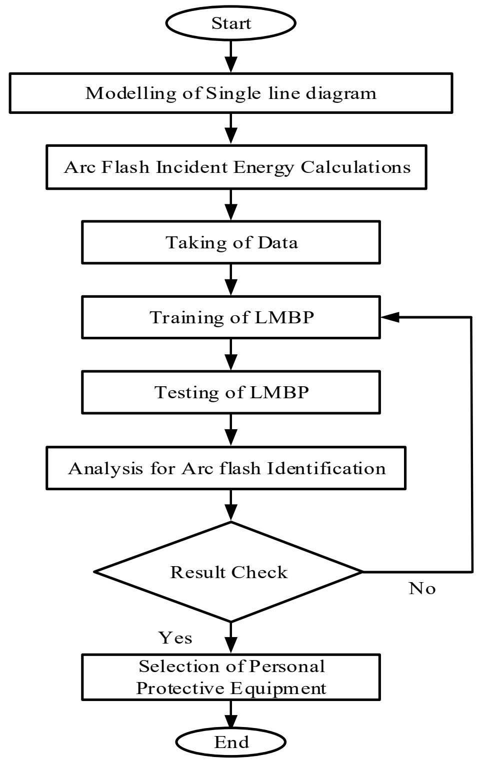

Fig. 4. Flow Chart Of The Proposed Algorithm

Data is obtained in form of numbers of generators, voltage level, thevenin impedance, time delay relay and fault clearing time, which they are used as input of LMBP. Whereas, arc flash used as output of LMBP. The architecture of 5 neurons LMBP is shown by fig. 3. LMBP is simulated by different numbers of neurons to evaluate the performance of LMBP. In the table 4, demonstrate example of data for training of LMBP.

The results of LMBP to arc flash identification used to selection of PPE. In the fig. 4, show the complete flow chart of the proposed algorithm.

6. SIMULATION RESULT AND ANALYSIS

Application in the electrical system of HESS Indonesia corporations used to evaluate arc flash identification using LMBP, which it used to selection of PPE. LMBP is implemented using different numbers of neurons and each case is trained for 100 iterations. LMBP is trained using data from Single line diagram in the electrical system, which it involves numbers of generators, voltage level, Thevenin impedance, time delay relay and fault clearing time. Moreover, for output data is arc flash incident energy. Training of LMBP using combination input data with matrix 5x336 and output data with matrix 1x336.

Training of the 5 neurons LMBP has performace of mean square error is 1.32×10^{-7}, which the result of training of 5 neurons LMBP is shown by fig. 5. Moreover, Training of the 10 neurons LMBP has performace of mean square error is 6.95×10^{-8}, which The result of training of 10 neurons LMBP is shown by fig. 6. The detailed results of arc flash identification are listed in the tables 5 and 6.

The results show that the average percentage error of the arc flash identification for selection of PPE under different numbers of neurons. For category 1, the 10 neurons LMBP obtains more accurate results compared by the 5 neurons LMPB with average percentage error is 0.061 % and 0.321 %, respectively. For category 2, the 10 neurons LMBP obtains more accurate results compared by the 5 neurons LMPB with average percentage error is 0.206 % and 0.558 %, respectively. For category 3, the 10 neurons LMBP obtains more accurate results compared by the 5 neurons LMPB with average percentage error is 0.022 % and 0.048 %, respectively.

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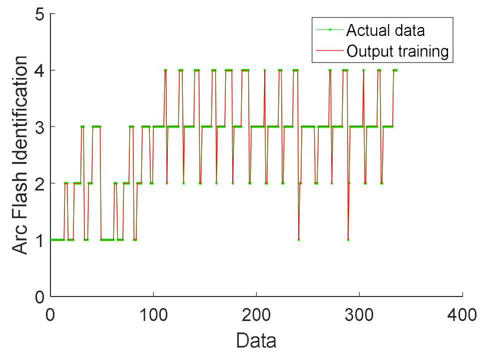

Fig. 5. The result of training of 5 neurons LMBP

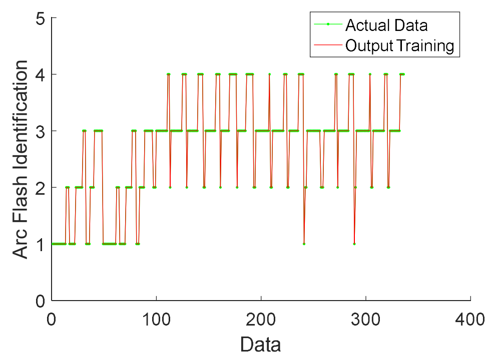

Fig. 6. The result of training of 5 neurons LMBP

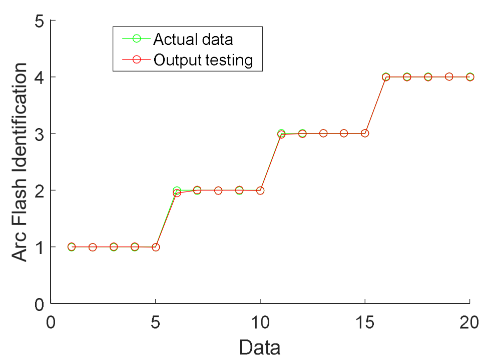

Fig. 7. The result of testing of 5 neurons LMBP

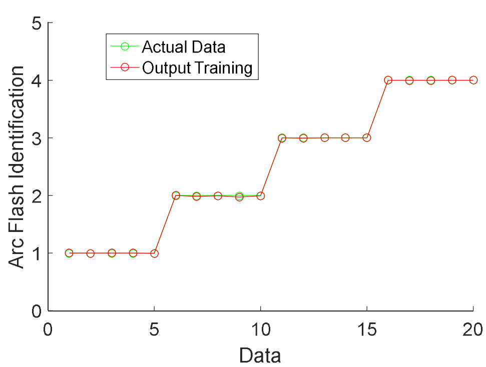

Fig. 8. The result of testing of 10 neurons LMBP

Table 4. Example data is used as input of LMBP

Bus	Input					Energy (cal/cm²)
	Generator	kV	X thev	Time CB	FCT	
660-ES-01B	1	6,6	2,5	0,1	0,2	1,198
	1	6,6	2,5	0,2	0,3	1,704
	1	6,6	2,5	0,25	0,35	1,989
	1	6,6	2,5	0,3	0,4	2,273
	1	6,6	2,5	0,35	0,45	2,557
	1	6,6	2,5	0,4	0,5	2,841
	1	6,6	2,5	0,45	0,55	3,125
	1	6,6	2,5	0,5	0,6	3,409
	1	6,6	2,5	0,55	0,65	3,693
	1	6,6	2,5	0,6	0,7	3,977
	1	6,6	2,5	0,65	0,75	4,261
	1	6,6	2,5	0,7	0,8	4,545

Table 5. Identification result for selection of PPE with 5 neurons

Testing	Err. Category 1 (%)	Err. Category 2 (%)	Err. Category 3 (%)	Err. Category 4 (%)
1	0.017	0.042	0.017	0.006
2	0.018	0.263	0.008	0.008
3	0.119	0.039	0.077	0.003
4	0.004	0.352	0.001	0.032
5	0.147	0.335	0.006	0.002
Average	0.061	0.206	0.022	0.010

Table 6. Identification result for selection of PPE with 10 neurons

Testing	Category 1	Category 2	Category 3	Category 4
1	0.357	0.414	0.009	0.040
2	0.363	0.410	0.096	0.038
3	0.104	0.415	0.119	0.040
4	0.358	0.390	0.009	0.037
5	0.422	1.159	0.009	0.040
Average	0.321	0.558	0.048	0.039

For category 4, the 10 neurons LMBP obtains more accurate results compared by the 5 neurons LMPB with average percentage error is 0.01 % and 0.039 %, respectively.

In all cases, the arc flash identification for category 4 using 10 neurons LMBP yiels a very minimum average percentage error of 0.01%. The average percentage errors of arc flash identification for selection of PPE are less than 1 %, which it demonstrate the proposed algorithm is accurate and encouraging.

The results also demonstrate the average percentage errors of arc flash identification for selection of PPE using LMBP decreases when the number of neurons increases. Therefore, in the industrial power system, arc flash identification for selection of PPE using LMBP can be developed become smart meter to prevent injury to workers.

7. CONCLUSION

In this paper, the proposed algorithm used to arc flash identification for selection of PPE, which it is performed in the industrial power system of HESS Indonesia corporation. To evaluate arc flash identification, the proposed algorithm developed using different numbers of neurons and each case is trained for 100 iterations. The results show that the average percentage errors of arc flash identification for selection of PPE are less than 1 %. Therefore, the proposed algorithm to arc flash identification is accurate and encouraging. Future research focus on develope of real time implementation of smart meter for arc flash identification.

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