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Application of Different ANN Methods to Provide Electrical Safety in High Voltage Underground Cable Lines

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ABSTRACT

High voltage underground cables has an insulation layer, so high voltage underground cables are preferred instead of overhead lines in indoor, indoor areas, city center, crowded neighborhoods and between buildings. However, cable faults are very important problem, and the sheath current is one of the most important factors for cable faults and electroshock risk. Thus, metallic sheath is grounded to prevent the sheath current effects in high voltage underground cables. In literature, single point bonding, solid bonding and cross bonding methods are used to ground metallic sheath of cable, but primarily the sheath current must be determined to select the most suitable bonding method. In this study, the sheath current of high voltage cable line is forecasted by using different type artificial neural networks (ANN) and hybrid ANN methods. Hybrid ANN methods are developed by using PSO (particle swarm optimization), DEA (differential evolution algorithm) and iPSO (inertia weight PSO). It is seen that training and forecasting errors of hybrid ANN methods are lower than the other ANN network types. Hybrid ANN methods are iPSO-ANN, PSO-ANN and DEA-ANN methods. Also, training and forecasting errors of iPSO-ANN are lower than the other hybrid ANN methods.

Keywords: High voltage cable, the sheath current, artificial neural network (ANN), hybrid ANN, bonding methods, cable faults and electroshock.

1. INTRODUCTION

Power loss is an important issue for electrical networks, so voltage level of transmission line is raised to decrease power loss of long transmission and distribution lines. Transmission and distribution of high voltage are made by using overhead and underground cable lines. High voltage creates some insulation problems, and these problems affect electrical safety. Especially, providing of electrical safety of overhead lines is major problem in cities or crowded areas. Hence, underground cable lines are used instead of overhead lines in indoor, indoor areas, city centre, the crowded neighbourhoods and between buildings because high voltage underground cable has an insulation layer, so electrical insulation level of underground cable line is more than overhead line in narrow spaces. Also, insulation layer is cowered by metallic sheath to protect insulation layer against to environmental damages. In Fig. 1, a high voltage underground cable is shown [1].

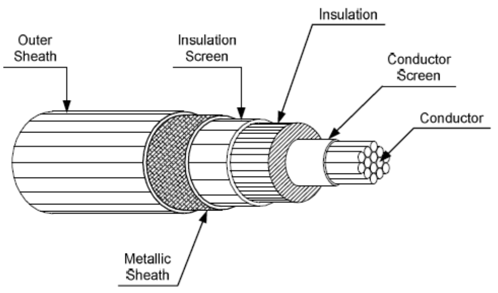

Fig. 1. High voltage underground cable

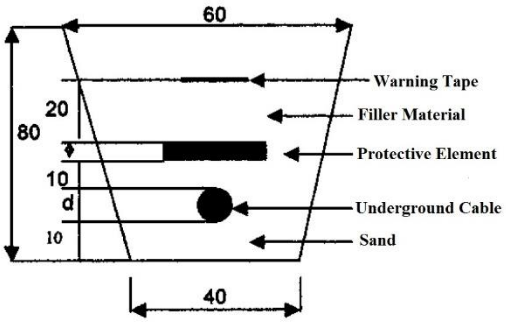

Fig. 2. Standard high voltage underground cable

Also, underground cable channel is used for installation of high voltage underground cable line. This channel protects high voltage cables against heavy working conditions and environmental effects. In Fig. 2, a standard cable channel is shown for single high voltage underground cable line. If cable number is more than 1, the cable channel which is shown in Fig. 3 is used. G is bottom width of the channel, and it is calculated with Equation (1).

$$G = 3 \times d + 2 \times l + 2 \times a \tag{1}$$

High voltage underground cable is protected by the cable channel, and insulation layer is protected by metallic sheath, but the sheath current generates on metallic sheath.

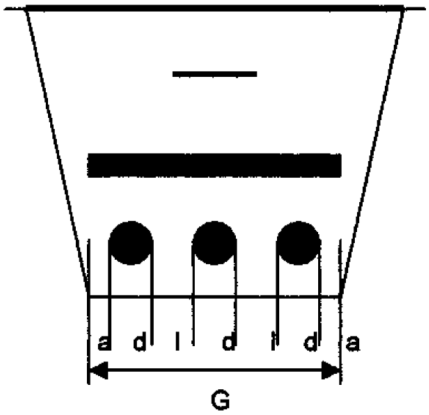

Fig. 3. Multiple high voltage underground cable channel

The sheath current increases cable temperature, so cable insulation life and performance are reduced by the sheath current. Also the sheath voltage increases due to the sheath current, and electroshock risk occurs due to high sheath voltage. It is seen that the sheath current must be reduced to provide electrical safety.

Thus, bonding methods are used to reduce sheath voltage and current [2,5]. Single point bonding, solid bonding and cross bonding methods are used as bonding methods in IEEE 575-1988 standard. These bonding methods are shown in Fig. 4, Fig. 5 and FiG. 6.

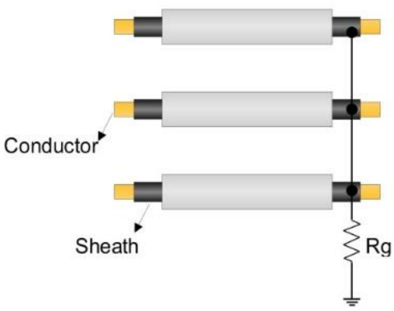

Fig. 4. Single-point bonding

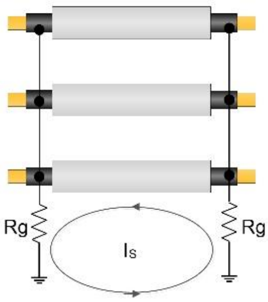

Fig. 5. Solid bonding

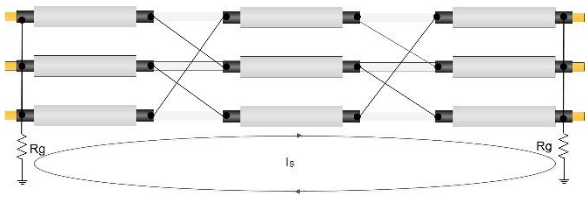

Fig 6. Cross bonding

If cable line length is short, single point bonding is used. If cable length is long, solid bonding or cross bonding are used. Also amount of the sheath current has important role to determine bonding method type. Namely, if the sheath current of high voltage cable line is known, the most suitable bonding type can be determined, so cable faults and electroshock risks can be prevented. Especially, if the sheath current of high voltage cable line which will be installed as a new line is known at the project phase of high voltage underground cable line, the most suitable bonding method and the required precautions can be determined before high voltage underground line is installed. Hence, cable faults and electroshock risks are prevented during electric transmission or distribution. Forecasting methods can be used to determine the sheath current of high voltage underground line. Artificial neural network (ANN) can be used for forecasting studies because ANN is very useful method for forecasting studies, also ANN is used to solve many engineering problems. However, inputs are necessary for ANN to forecast the sheath current. Therefore knowing of the sheath current forming factors are very important for forecasting of the sheath current.

Three phase systems is generally accepted as balanced, and total magnetic field is accepted as zero because vectorial sum is zero in the balanced three phase system. However, total magnetic field is not zero in unbalanced three phase systems. Thus the sheath current occurs on metallic sheath. Namely, the most important factor is unbalanced phase current for forming of the sheath current [6]. Underground cable lines are installed according to certain cable configuration. These cable configurations are trefoil and flat formations. The sheath current of trefoil configuration is lower than flat formation, but flat formation is generally used [7,8] in high voltage underground cable lines. These formations are shown in Fig. 7.

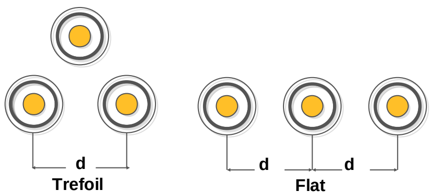

Fig. 7. Trefoil and flat formations

In this study, different high voltage cable line is generated in PSCAD/EMTDC simulation program, and the sheath currents of these high voltage lines are obtained after many simulation studies. It is seen at the end of simulation studies that cable length (L), distance of between phases (d), unbalanced phase current (I_{UB}), cable formation and grounding resistance (Rg) are the most important factors for formation of the sheath current in high voltage underground cable line [9,12].

In literature, generally hybrid ANN methods are used to forecast the sheath current, but other network types of ANN are not compared with hybrid ANN [13]. Thus in this study, simulation results are used as input data of ANN, and the results of these different ANN network types are compared with hybrid ANN methods.

2. MATERIAL AND METHOD

Simulation of high voltage underground cable is made by using electromagnetic transient program [14,15]. In this study, simulation studies for high voltage underground cable lines are used PSCAD/EMTDC as electromagnetic transient program. In simulation studies of high voltage cable, primarily high voltage cable is modelled. In this study, the modelled cable is shown in Fig. 8.

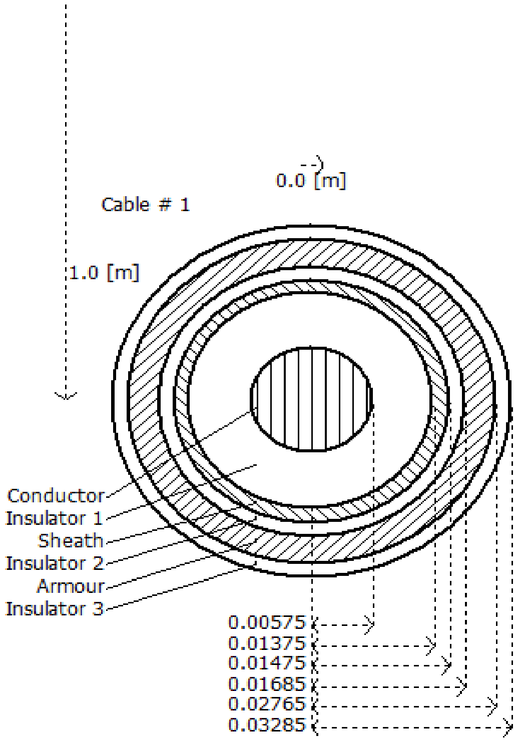

Fig. 8. The modeled high voltage underground cable

Cable length, distance of between phases, unbalanced phase current and grounding resistance are the most effective factors in formation of the sheath current of the high voltage underground cable lines. These factors are used to generate different high voltage cable lines, and simulations of these cable lines are made in PSCAD/EMTDC to obtain sheath currents of these lines. Hence, these factors and the real values of sheath current of different lines are used for training process of ANN.

Working principle of ANN is based on mathematical model of human learning, and the basic element of ANN is neuron. Also ANN occurs from input layer, hidden layer and output layer [16,18]. The basic schema of ANN is shown in Fig. 9.

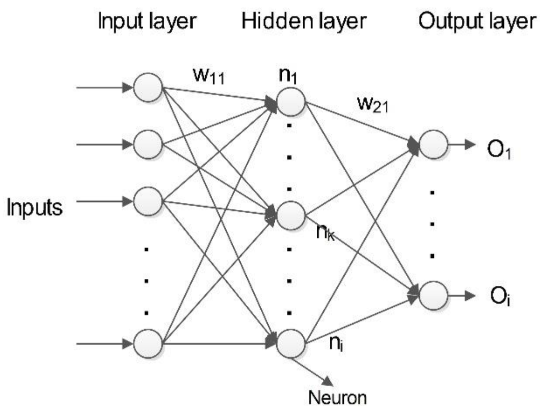

Fig. 9. The basic schema of ANN

Neurons work as a transfer function. This transfer function is shown in Equation (2), and a neuron working schema is shown in Fig. 10.

$$y_i = f_i(\sum_{j=1}^{n} w_{ij} \times x_j + b_i) \tag{2}$$

Where, x_j is input, w_{ij} is weight, b_i is bias, f_i is transfer function, and y_i is output of the neuron.

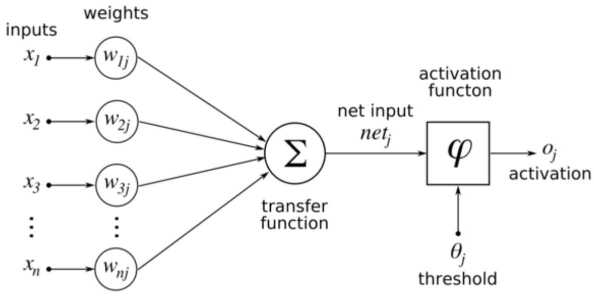

Fig. 10. Neuron working schema

Activation functions can be sorted as step function, linear function, log-sigmoid function, tan-sigmoid function, softmax function, and gaussian function. Primarily, training process is implemented in ANN, and training error is calculated. Mean square error (MSE) method is used in calculation of training error. MSE is shown in Equation (3).

$$E(t) = \frac{1}{n}\sum_{i=1}^{n}(p(i) - o(i))^2 \tag{3}$$

Where, E(t) is estimation error at t^{th} iteration, p(i) is the desired value for i^{th} output, o(i) is the actual value for i^{th} output. Weights of ANN should be updated to reduce training error, so Equation (4) is used to update weights in classic ANN.

$$w_i\left(t+1\right)=w_i\left(t\right)+\Delta w_i\left(t\right) \tag{4}$$

There are many ANN network types in literature. In this study, feedforward backpropagation (FFBP), Elman backpropagation (EBP) and layer recurrent (LR) network types are used. Also hybrid ANN method is used to obtain the most accurate results. In hybrid ANN method, weights of ANN are optimized with optimization methods according to training and forecasting errors. In this study, differential evolution algorithm (DEA), particle swarm optimization (PSO) and inertia weight particle swarm optimization (iPSO) are used as optimization method to determine the most suitable weights. Namely, in classic ANN, weights are updated by Equation (4), but in hybrid ANN, weights are updated by optimization methods. Flow chart of hybrid ANN method is shown in Fig. 11.

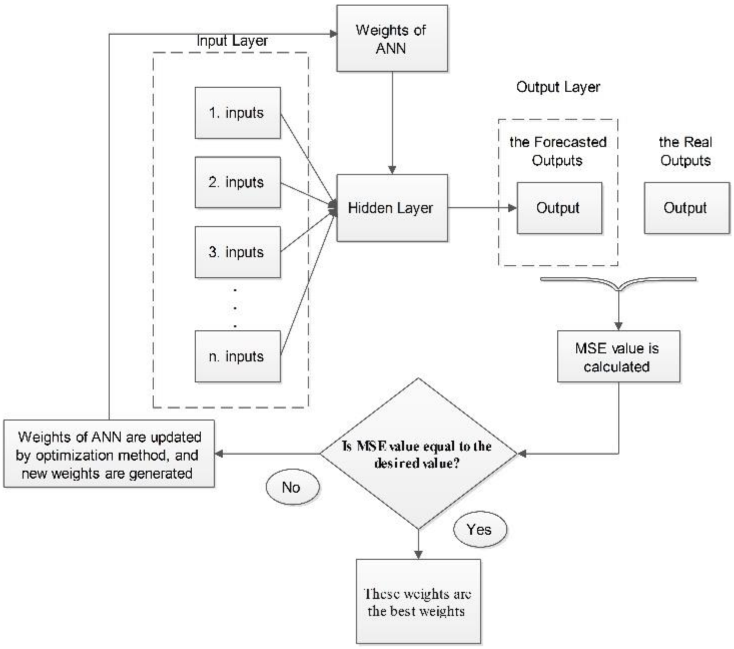

Fig. 11. Hybrid ANN flow chart

3. EXPERIMENTAL STUDIES

59x5 data matrix is used for training of ANN and 12x5 data matrix are used for test of ANN. In these matrices, unbalanced phase current (I_{UB}), cable length (L), distance of between phases (d), grounding resistance (Rg) and the sheath current are used as variables. Values of these variables are obtained in PSCAD/EMTDC.

This 12x5 data matrices is shown in Table 1. In Tables, I_{SA} is defined as real value of the sheath current. I_{SA} is obtained from simulation studies in PSCAD/EMTDC. I_{SA} is used in training and test studies to obtain errors. In Table 2, I_{SF} is defines as the forecasted sheath current of different network type ANN and hybrid ANN models.

Table 1. Test matrices

Line Type	I_{UB}(A)	L(m)	d(m)	Rg(Ω)	I_{SA}(A)
Line 1	224.630	250	0.1	6	3.61
Line 2	224.630	500	0.1	10	3.30
Line 3	224.630	500	0.1	40	1.08
Line 4	224.630	500	0.5	9	4.42
Line 5	224.630	250	0.5	6	3.34
Line 6	464.120	250	0.5	10	4.48
Line 7	464.120	400	0.1	35	2.20
Line 8	464.120	700	0.1	40	3.32
Line 9	464.120	500	0.5	35	2.54
Line 10	464.120	500	0.5	40	1.97
Line 11	464.120	1000	0.5	50	3.48
Line 12	224.630	1000	0.1	50	1.71

Table 2. the Forecasted Sheath Current of Different Type ANN Models

L	I_{SA} (A)	I_{SF} (A)					
		FFBP	LR	EBP	iPSO	PSO	DEA
1	3.61	3.49	2.33	2.56	3.63	3.22	3.62
2	3.30	3.49	1.19	1.22	4.45	3.67	4.45
3	1.08	3.49	3.76	3.80	0.90	3.66	0.91
4	4.42	3.49	2.71	2.66	4.55	3.66	4.59
5	3.34	3.49	1.90	1.81	3.62	3.22	3.64
6	4.48	3.49	1.35	1.26	4.35	1.87	4.39
7	2.20	3.49	0.81	0.75	2.18	2.13	2.20
8	3.32	3.49	4.33	5.45	3.12	2.67	3.17
9	2.54	3.49	2.26	2.97	2.68	2.32	2.74
10	1.97	1.35	3.92	5.48	2.08	2.31	2.15
11	3.48	1.35	2.00	3.00	3.47	3.20	3.58
12	1.71	1.35	1.055	1.41	2.28	4.54	2.34

Table 3. Training and Forecasting Errors of Different Type ANN Models

ANN type	Training Errors	Forecasting Errors
Feedforward backpropagation	1.1493	0.7732
Layer recurrent	0.5380	0.6877
Elman backpropagation	0.5608	0.8863

iPSO-ANN	0.1307	0.1139
PSO-ANN	0.2285	0.3998
DEA-ANN	0.1653	0.2373

It is seen in Table 3 and Table 3 that generally, errors of hybrid ANN method is lower than the other errors of ANN network types. Also errors of iPSO-ANN is lower than the other hybrid ANN methods. Thus, iPSO-ANN method is proposed for the sheath current forecasting studies. After the sheath current of high voltage underground cable line is accurately forecasted, the most suitable bonding method can be selected. If cable length is shorter than 200 m, generally single point bonding method can be used. However, if ground resistance is very small, the sheath current value can be high. If the sheath current value is high, cross bonding should be used even if cable length is short (less than 200m). If the sheath voltage value is high, solid bonding should be used even if cable length is short (less than 200m). Thus, determination of the sheath current is very important before installation of high voltage cable line.

4. CONCLUSION

If the sheath current of high voltage underground cable line which will be installed as a new line can be determined at project phase before installation of this line, the required precautions and the most suitable bonding method can be detected. This way is economic and reliable. Thus, in this study, different ANN networks and hybrid ANN methods are used to forecast the sheath current. It is seen according to the results that iPSO-ANN method will be very useful to forecast the sheath current of a new high voltage underground cable line. Hence, the most suitable bonding method is selected, and cable faults and electroshock risks can be prevented as economically and reliably.

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