Sectional Solid Bonding for Grounding of High Voltage Underground Cables to Reduce the Sheath Current Effects

Bahadır AKBAL
Electrical and Electronic Engineering
Department, Selçuk University,
Konya, Turkey,

ABSTRACT
The sheath current effects are major problems for electrical network and facilities. The sheath voltage is increased by the sheath current. Thus the sheath voltage exceeds touch voltage, and electroshock risks and cable faults occur. Also, cable temperature is increased by the sheath current, so cable ampacity reduces. In literature, single-point bonding, solid bonding and cross bonding are used to reduce sheath voltage and current. However, if the unbalanced phase current is high, the sheath voltage is not dropped under touch voltage by using these bonding methods. Therefore, sectional solid bonding method is developed to solve this problem in this study. When sectional solid bonding is used to reduce the sheath voltage and current, the sheath voltage drops under touch voltage although unbalanced phase current is high. Also, optimum parameters for sectional solid bonding are determined by differential evolution algorithm.

Keywords
Sheath current, bonding methods, high voltage underground cable line, grounding, differential evolution algorithm.

1. INTRODUCTION
Electrical safety is a major issue for electrical network and facilities. In electrical networks, overhead and underground cable lines are used for distribution of electrical energy, and safety level of overhead lines are lower than underground cable lines. Hence high voltage underground cable lines have been used for electric distribution in city center and neighborhoods. XLPE insulation material is used for high voltage underground cable insulation, and metallic sheath is used to protect XLPE insulation from environmental factors. High voltage underground cable is shown in Figure 1 [1].

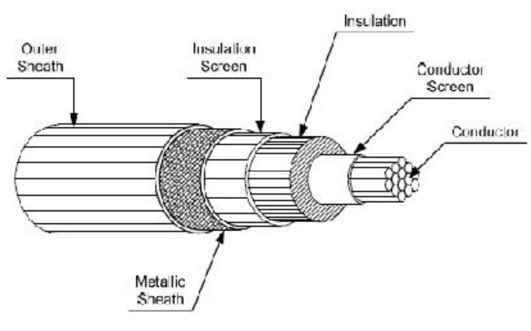

Figure 1: High voltage underground cable

However, the sheath current generates on metallic sheath, and the sheath current causes major insulation faults and electroshock risk for human. Also, cable temperature is increased by the sheath current, so ampacity of cable reduces because of the sheath current. There are various factors in formation of the sheath current. The most effective factor in formation of the sheath current is unbalanced phase current [2]. If currents of phases is not equal each other, unbalanced phase current generates, and voltage induces on metallic sheath. Hence the sheath current generates on metallic sheath because of unbalanced phase current. Also, if unbalanced phase current amount increases, the sheath current increases. High voltage underground cable is installed as trefoil and flat configurations [3,4]. These configuration types affect the sheath current amount. Trefoil and flat formations are shown in Figure 2.

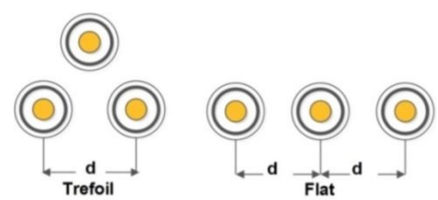

Figure 2: Formations of cables

Where, d is distance of between phases. The sheath current amount of trefoil configuration type is less than flat configuration. However, flat configurstionn type is generally used due to geometric conditions. Eddy and hysteresis losses generate on metallic sheath but these losses are lower than the sheath current loss, so eddy and hysteresis losses are generally ignored in the sheath current studies [5]. Also, magnetic flux is effect to formation of the sheath current [6]. If metallic sheath of high voltage cable is grounded, the sheath current effects reduce. Single-point bonding, solid bonding and cross bonding methods are used for grounding of metallic sheath of high voltage underground cable [7]. These bonding methods are respectively shown in Figure 3, Figure 4 and Figure 5.

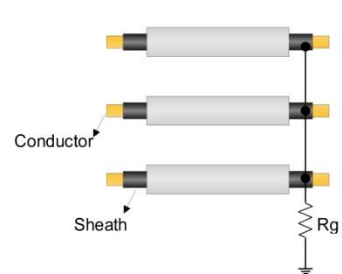

Figure 3: Single-poind bonding

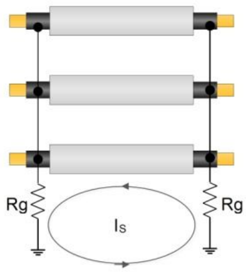

Figure 4: Solid bonding

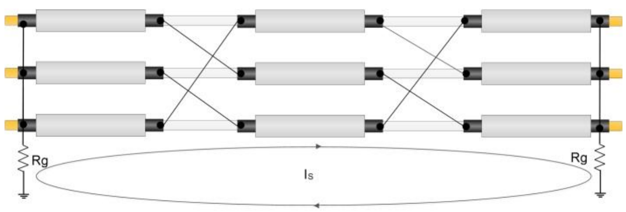

Figure 5: Cross bonding

High voltage cable line is planned before it is installed, and this phase is called as project phase. If the sheath current is detected before high voltage underground cable line, the required precautions and the most suitable bonding method are implemented. Namely determining of the sheath current of high voltage underground cable line at project phase is a big advantage to reduce the sheath current effect. Hence in this study, simulations of high voltage underground cable line which will be installed as new high voltage underground cable line are made, and the sheath current of new high voltage underground cable line is detect in simulation program. It is seen at the end of simulation studies that the current bonding methods are not enough to eliminate the sheath current effects in some cases. Thus, sectional solid bonding method is developed as new bonding method to eliminate sheath current effects on high voltage underground cable, and differential evolution algorithm (DEA) is used for optimization of sectional solid bonding method.

2. MATERIAL AND METHOD

Electrical simulation programs are generally used in high voltage underground cable studies [8,9]. In this study, PSCAD/EMTDC simulation program is used for simulation studies of high voltage underground cable lines. Primarily high voltage underground cable is modelled in PSCAD/EMTDC, and it is shown in Figure 6.

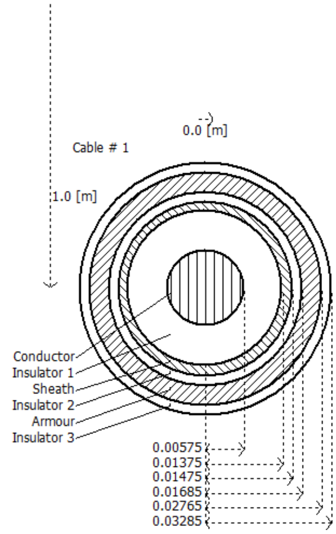

Figure 6: The modelled high voltage undergorund cable

If the sheath current increases, the sheath voltage increases on metallic sheath of high voltage underground cable, so electroshock risk occurs for humans. Therefore the sheath voltage must be under touch voltage limit for safety of human. Also sheath current causes major cable faults and increasing of cable temperature. Thus, metallic sheath must be grounded to reduce the sheath current and voltage. Single-point bonding, solid bonding and cross bonding are used for grounding of metallic sheath of high voltage underground cable according to IEEE 575-1988 standard. When single-point bonding is used for grounding of high voltage underground cable, the sheath current does not generate because sheath circuit is open. However, single-point bonding should not be used for long high voltage underground cable lines because high voltage generates on metallic sheath due to long length of high voltage cable, so electro shock risk and cable faults occur due to high voltage. Solid bonding and cross bonding can be used for long high voltage underground cable line. The sheath current value of cross bonding is lower than solid bonding sheath current, but the sheath voltage value of solid bonding is lower than cross bonding sheath voltage [10-13]. Also, it is seen in simulation studies that if grounding resistance is increased, the sheath current reduces. Hence solid bonding method can be used for grounding of high voltage underground cable line. However, the sheath voltage does not reduce under touch voltage although grounding resistance increased. In this case, some important precautions can be taken, and these precautions are sorted as follows;

- If distance of between phases is increased, the sheath current reduces. However, high voltage underground cables are installed in cable channel, but dimension of cable channel is limited, and dimensions of cable channel may be increased. Thus, distance of between phases must be minimum value.
- If grounding resistance (Rg) is increased, the sheath current reduces, but the sheath voltage does not change. Thus, the sheath voltage does not reduce under touch voltage although the sheath current reduces because grounding resistance is increased as well, so the sheath voltage is constant.
- If phase current reduces, the sheath current and voltage reduce. However, phase current is based on load working conditions, so it is not controlled.

- If cable length is reduces, the sheath current and voltage reduce because metallic sheath length reduces as well, but phase conductor length of cable must not be reduced. Thus, in this study, sectional solid bonding is developed as new bonding.

In sectional solid bonding, conductor length of high voltage underground cable is not changed, but metallic sheath of high voltage cable is sectioned. In this case, total length of metallic sheath of cable is called as major part, and major part is divided to minor parts. Sectional solid bonding is shown in Figure 7.

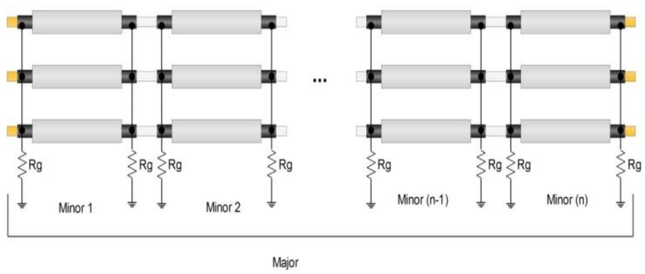

Figure 7. Sectional solid bonding

In sectional solid bonding, maximum metallic sheath length, minimum distance of between phases and minimum grounding resistance must be detected. Thus in this study, DEA is used to detect optimum values of these parameters.

2.1 Differential Evolution Algorithm (DEA)

DEA is generally used to solve optimization problems in electrical engineering. Each variable is called as vector in DEA, and there are four type vectors. These vectors are target, base and different two vectors. Namely at least 4 vectors are necessary for DEA. DEA works as follows [14];

Step 1: Vector population is randomly generated.

Step 2: Target, base and different two vectors is selected in population. Each vector is respectively selected as target vector in vector population. Base and different two vectors are randomly selected.

Step 3: Difference of between the selected difference two vectors is taken, and base vector is added, so mutant vector is generated.

Step 4: Mutant vector and target vector are used for crossover process. A new trial vector is generated after crossover.

Step 5: Fitness values of target and new trial vectors are calculated, and these values are compared. If fitness value of new trial vector is better than target vector, new trial vector is changed as target vector. Otherwise, target vector is not changed.

Step 6: These processes are implemented each vector, and new vector population is generated.

If the desired fitness value is obtained, or iteration number reaches maximum value, algorithm is stopped. Otherwise, the steps between 2 and 6 are repeated.

3. EXPERIMENTAL STUDIES

In this study, solid bonding is suggested for grounding of metallic sheath of high voltage underground cable to reduce the sheath current and voltage. However, if unbalanced phase current is high, the sheath voltage does not drop under touch voltage limit although the sheath current reduces. Thus, sectional solid bonding method is developed, and its applications are made by PSCAD/EMTDC in this section. Touch voltage is 50 V rms for human, and this value is accepted as 70.5 V peak value in AC systems. In this section, primarily simulations of solid bonding are made by using PSCAD/EMTDC simulation program for new high voltage underground cable line in project phase. In simulation studies, different high voltage underground cable lines are designed, and the sheath currents and voltages of these cable lines are measured in PSCAD/EMTDC. The designed high voltage underground cable parameters and simulation results are shown in Table 1. In Table 1, I_{UB} is unbalanced phase current, L is high voltage cable length, d is distance of between phases, R_g is grounding resistance, I_S is the measured sheath current, and V_S is the measured sheath voltage in PSCAD/EMTDC.

Table 1. The simulation results of solid bonding for different lines

Line	I_{UB}	L	d	R_g	I_S(A)	V_S(V)
1	224.63	250	0.1	6	3.61	21.66
2	224.63	500	0.1	10	3.30	33.00
3	224.63	500	0.1	40	1.08	43.20
4	224.63	500	0.5	9	4.42	39.78
5	224.63	250	0.5	6	3.34	20.04
6	464.12	250	0.5	10	4.48	44.80
7	464.12	400	0.1	35	2.20	77.00
8	464.12	700	0.1	40	3.32	132.8
9	464.12	500	0.5	35	2.54	88.90
10	464.12	500	0.5	40	1.97	78.80
11	464.12	1000	0.5	50	3.48	174.0
12	224.63	1000	0.1	50	1.71	85.50

It is seen in Table 1 that the sheath voltages of line 1-6 do not exceed touch voltage limit, but the sheath voltages of line 7-12 exceed touch voltage limit. Namely, solid bonding method is not enough for line 7-12. Thus, sectional solid bonding can be implemented to line 7-12. For example, the sheath voltage of line 11 is 174 V peak value, and this value exceeds touch voltage. In this section, application of sectional solid bonding is made for line 11. When solid bonding is used for grounding of line 11, the results are shown in Figure 8. In sectional solid bonding, maximum minor part length, minimum distance of between phases and minimum grounding resistance must be determined according to touch voltage limit. Hence DEA is used to determine these parameter limits for line 11. Where underground cable length borders for each minor part are between 100 m and 1000 m, borders of distance of between phases are between 0.1 m and

0.5 m, grounding resistance borders are between 10 ohm and 50 ohm for DEA. Afterwards, values of L_{MAX}, d_{MIN} and R_g are determined by DEA for line 11. L_{MAX} is determined as 334 m, and d_{MIN} is determined as 0.235, and Rg is determined as 18.5 ohm by using DEA for each minor part. Total length of line 11 is 1000 m, and L_{MAX} is determined by DEA as 334 m. Thus metallic sheath of line 11 can be divided as three minor parts. Length of minor 1 can be 333 m, length of minor 2 can be 333 m, and length of minor 3 can be 334 m. Values of these parameters are used in PSCAD/EMTDC, and simulations of sectional solid bonding for line 11 are made to verify DEA results. These simulation results are shown in Figure 9.

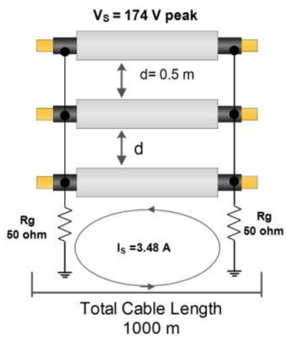

Figure 8: The results of solid bonding for line 11

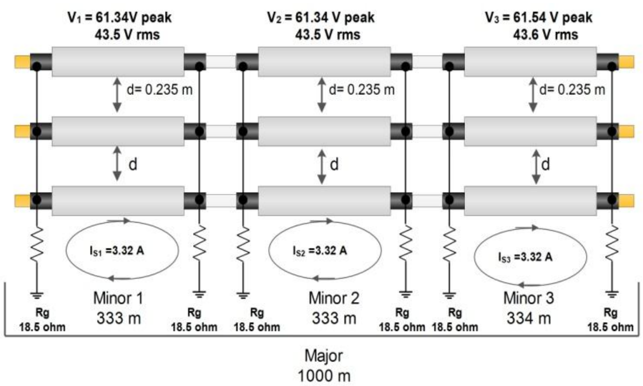

Figure 9: Sectional solid bonding result of DEA for line 11

It is seen that if solid bonding is used for grounding line, the sheath voltage is 174 V peak (123.4 rms). This value exceeds touch voltage. If sectional solid bonding is used for grounding of line 11, maximum value of the sheath voltage is 43.6 rms. This value does not exceed touch voltage. Thus, the sheath voltage problem is solved by sectional solid bonding with DEA. After this stage, if reducing of the sheath current is desired, grounding resistance is increased. Minimum value of grounding resistance is determined with DEA as 18.5 ohm. If grounding resistance is bigger than 18.5 ohm, the sheath current is under 3.32 A. for example, if grounding resistance is 45 ohm, the sheath current is 1.36 A, but the sheath voltage does not change seriously. This simulation result is shown in Figure 10.

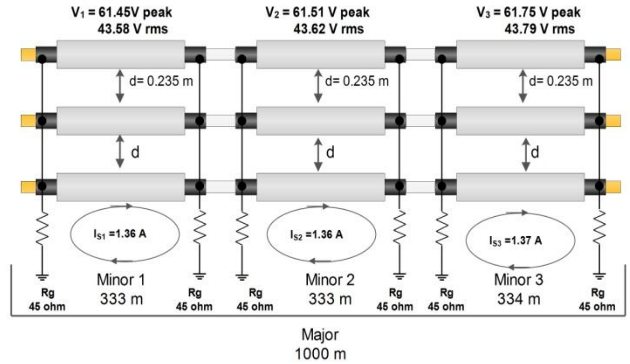

Figure 10: Sectional solid bonding result of DEA for line 11

4. CONCLUSION

The sheath voltage and cable temperature are increased by the sheath current, and the sheath voltage must be under touch voltage. In literature, single-point bonding, solid bonding and cross bonding are used to reduce the sheath current and voltage. However, if unbalanced phase current is high, the sheath voltage exceeds touch voltage. Therefore, sectional solid bonding method is developed as a new bonding method for grounding of high voltage underground cable lines in this paper. It is seen that when sectional solid bonding is used at high unbalanced phase current values, the sheath voltage drops under touch voltage. Hence electroshock risks and cable faults can be eliminated in high voltage underground cable lines.

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