Methods to Determine Overhead Ground Wire Sizes in Distribution Systems

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ABSTRACT

This paper presents an approach to analyze the overhead ground wire (OHGW) sizes in distribution system focus on the i2t of line to ground fault current. For line to ground fault, the fault current and duration time when fault take place as well as the relay operating time have been concerned. The Line Type 1, OHGW not connected to the neutral of substation power transformer, give the short circuit current magnitude which is less than the current from Line Type 2, OHGW connected to the neutral of substation power transformer. So the Line Type 1 gives the smaller OHGW sizes than Line Type 2.

To find the suitable OHGW sizes, the fault current magnitude, the duration time when fault take place and the relay operating time have to be considered. For the short circuit current is not greater than 3 kA, the 25 mm^2 can be used. For the short circuit current is not greater than 7 kA, the 35 mm^2 should be used for distance of 500 m from the substation, 25 mm^2 for line beyond that location should be used. For the short circuit current is not greater than 12 kA, the 50 mm2 should be used for 500 m from substation, 35 mm^2 should be used between 500 m-3 km and 25 mm^2 for line beyond that location should be used.

Keywords: Overhead Ground Wire, Distribution System, Substation, Short Circuit Current, Relay

1. INTRODUCTION

OHGW's are grounded conductors placed above the phase conductors to intercept lightning strokes which would otherwise directly strike the phases. Lightning current is diverted to ground through a pole ground lead. The approach to analyse the OHGW wire size has been shown in [1]. The lightning surge current is the first concern in this approach and the line to ground fault is the other one. The other methodology rating the OHGW size is described in [2] which presents results showing the effect of various system parameters on OHGW fault current requirements. The effect of grounding impedances, generator excitation systems, dc offsets and fault location. Current splitting between OHGWs in one span is examined, and OHGW capabilities are presented.

To find the suitable OHGW sizes, the fault current magnitude, the duration time when fault take place and the relay operating time have to be concerned. The relation between the current and time is shown in (1).

$$t = \left[\frac{kcm}{C'i}\right]^2 \times 2.459 \times 10^5 \qquad (1)$$

t = time, sec
kcm = conductor cross sectional area, kcm
(1 cmil = 5.067×10^{-4} mm^2)
C'= constant as shown in Table 1

Table 1: *Constant C' of Three Materials as Temperature Varied*

Temp (°C)	50	100	200	300	500	1,000	Fusing (°C)
Cu	10	7.78	5.59	5.13	4.36	3.62	1084
Al	16.7	12.2	9.21	7.92	6.70	5.51	657
Fe	29.2	21.6	16.5	14.3	12.2	10.2	1,600

Table 2: *i^2t of OHGW Sizes*

OHGW Size	i^{2}t Weaken (A^2-s)	i^{2}t Melt (A^2-s)
25 mm^2	2.35×10^6	4.81×10^6
35 mm^2	4.69×10^6	9.60×10^6
50 mm^2	1.00×10^7	2.05×10^7
70 mm^2	2.25×10^7	4.60×10^7
95 mm^2	3.84×10^7	7.86×10^7

The duration time concerns with weaken and melting time for any conductors when fault occurred.

1.1 Case 1 : Conductor Weaken

When the temperature goes up to 300°C the conductor begin to weaken. Let consider the OHGW of five different sizes, 25 mm^2, 35 mm^2, 50 mm^2, 70 mm^2 and 95 mm^2. From (1) and C' (14.3) from Table 1, the value of i^{2}t can be found as shown in the second column of Table 2.

1.2 Case 2 : Conductor Melting

The melting point of Iron is 1600°C. From (1) and C' (10) from Table 1, the value of i^{2}t can be found as shown in the third column of Table 2. The value in Table 2 would be useful when consider the different sizes of OHGW.

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The Provincial Electricity Authority (PEA) uses the relay operating time which is less than 0.1 s for the distance of 500 m from substation, less than 0.5 s for the distance of 500 m-3 km from substation and less than 1.0 s for the distance beyond 3 km from substation.

2. SYSTEM MODELING

A section of a typical 22 kV overhead distribution line has been modelled using ATPDraw [3] version of EMTP. The configurations studied are shown in Fig. 1. Two line types have been investigated.

2.1 Line Type Model

Line type 1 : OHGW not connected to the neutral of substation power transformer. Line Type 2 : OHGW connected to the neutral of substation power transformer as found in [4]. The grounding impedances of the line are 5 and 25 Ω and the ground grid resistance is 1 Ω. The line span 40 m (100 poles) has been modelled.

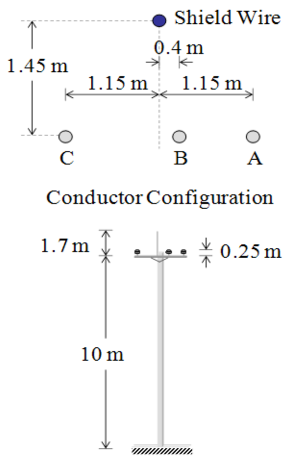

Fig.1: *Typical 22 kV Overhead Distribution Line Section*

2.2 Power Transformer Model

The wtrafo3.exe and BCTRAN in ATPDraw have been used for transformer model. The parameters of power transformer used for the simulation is shown in Table 3.

Table 3: *Parameters for Substation Power Transformer*

Short Circuit Test						Open Circuit Test
Impedances			Losses(kW)			Losses (kW)
HV-LV	HV-TV	LV-TV	HV-LV	HV-TV	LV-TV	23.6
15.13%	26.21%	8.7%	143.5	201.17	201.17	

2.3 Phase to Ground Fault Model

The single line to ground fault on phase A has been simulated along the 22 kV overhead distribution line by using ATPDraw. The pole number 1, 2, 3, 5, 8, 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100 are the fault pole locations. Fig. 2 shown the fault current path, I_f is the total fault current from phase A to pole, I_{GndImp} is the current pass through grounding impedance , $I_{GwRight}$ is the current flow to the right through the overhead ground wire, I_{GwLeft} is the current flow to the left through the OHGW.

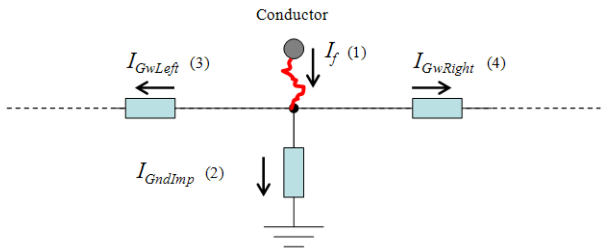

Fig.2: *Current Flow Direction of Phase to Ground Fault on Overhead Distribution Line Section*

3. RESULTS

3.1 Short Circuit Current from Simulation

Fig. 3-6 shown the results of each current path from the simulation using ATPDraw.

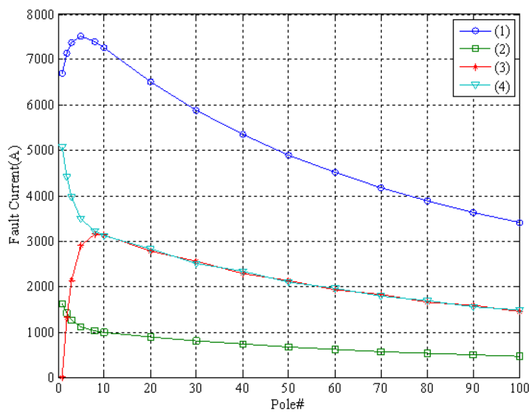

Fig.3: *Phase to ground fault current along the line, Line Type 1, 5 Ω grounding impedance*

In Fig. 3 and 4 which is the case of Line Type 1, the I_f and I_{GwLeft} currents go uphill when the fault locations are placed on pole number 1 to 5 and go downhill when the fault locations moved beyond the pole number 6. Unlike the I_{GndImp} and $I_{GwRight}$ currents which go downhill from the substation to the end of line. The grounding impedance plays a significant role to the fault current though. The fault current decreases as the grounding impedance increase.

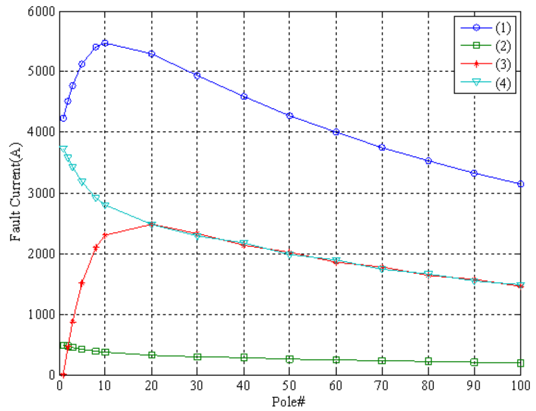

Fig.4: *Phase to ground fault current along the line, Line Type 1, 25 Ω grounding impedance*

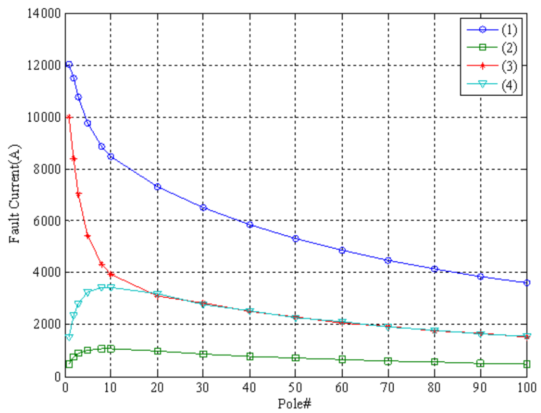

Fig.5: *Phase to ground fault current along the line, Line Type 2, 5 Ω grounding impedance*

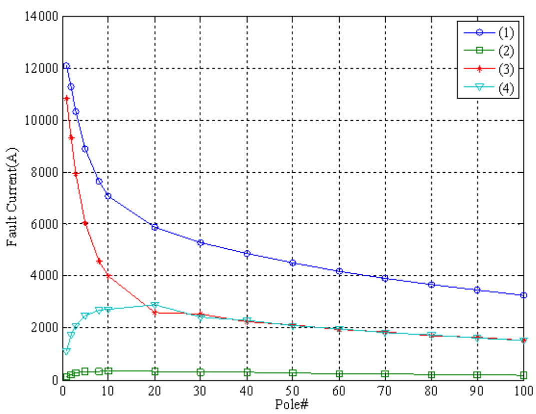

Fig.6: *Phase to ground fault current along the line, Line Type 2, 25 Ω grounding impedance*

In Fig. 5 and 6, Line Type 2, the fault current go downhill except for the I_{GndImp} and $I_{GwRight}$ which goes uphill when the fault locations are placed on pole number 1 to 5 and go downhill when the fault locations moved beyond the pole number 6. The grounding impedance affect to the fault current in the manner that the I_{GndImp} and $I_{GwRight}$ currents decrease as the grounding impedance increase. The decreasing of currents pushes the I_{GwLeft} current increase instead.

From Table 2, the relation between the current and weaken time can be shown in Fig. 7 and Fig. 8 for the relation between the current and melting time.

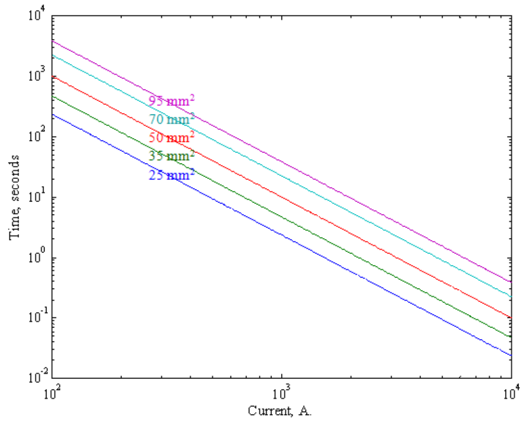

Fig.7: *Threshold of Damage Curves (weaken)*

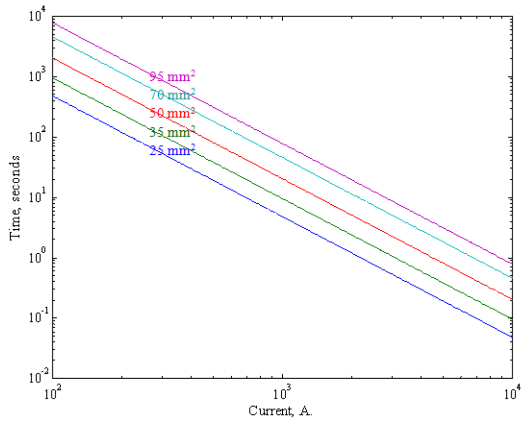

Fig.8: *Threshold of Damage Curves (melting)*

Table 4 shows the melting current magnitude for different OHGW sizes of Line Type 1 and 2 at 5 Ω footing impedance from the simulation. Table 5 shows the melting duration time correspond to the melting current from Table 4. Table 6 shows melting current magnitude for different OHGW sizes of Line Type 1 and 2 at 25 Ω footing impedance from the simulation. Table 7 shows the melting duration time correspond to the melting current from Table 6.

From Table 4-7, the Line Type 1 gives the short circuit current magnitude which is less than the short

Table 4: *Melting Current Magnitude at 5 Ω Grounding Impedance*

Line Type	Melting Current Magnitude (kA) for Different OHGW Sizes				
	25 mm^2	25 mm^2	50 mm^2	70 mm^2	95 mm^2
1	7.26	10.25	14.79	22.43	29.34
2	14.29	20.18	29.46	44.14	57.73

Table 5: *Melting Duration Time at 5 Ω Grounding Impedance*

Line Type	Melting Duration Time (s) for Different OHGW Sizes				
	25 mm^2	25 mm^2	50 mm^2	70 mm^2	95 mm^2
1	0.0913	0.0458	0.0215	0.0096	0.0056
2	0.0236	0.0118	0.0055	0.0025	0.0014

Table 6: *Melting Current Magnitude at 25 Ω Grounding Impedance*

Line Type	Melting Current Magnitude (kA) for Different OHGW Sizes				
	25 mm^2	25 mm^2	50 mm^2	70 mm^2	95 mm^2
1	5.35	7.55	11.02	16.51	21.60
2	15.48	21.86	31.92	47.83	62.55

Table 7: *Melting Duration Time at 25 Ω Grounding Impedance*

Line Type	Melting Duration Time (s) for Different OHGW Sizes				
	25 mm^2	25 mm^2	50 mm^2	70 mm^2	95 mm^2
1	0.1682	0.0845	0.0396	0.0198	0.0103
2	0.0201	0.0101	0.0047	0.0021	0.0012

circuit current from Line Type 2. So the Line Type 1 gives the smaller OHGW sizes than Line Type 2. For Line Type 1, as the grounding impedance getting higher, the duration time increase. On the other hand, for Line Type 2, the duration time decrease when the grounding impedance increase. Both of them are the minimum duration time for the maximum fault current flow through the OHGW.

3.2 OHGW Sizes from Calculation

Table 8 shows OHGW sizes at different constant short circuit current magnitude (3, 7, 10 and 12 kA) for the different distance from substation and also the melting time in seconds (numbers in parenthesis). The 500 m from substation corresponds to the relay operating time which is less than 0.1 s. The 500 m-3 km from substation corresponds to the relay operating time which is less than 0.5 s. The 3 km from substation corresponds to the relay operating time which is less than 1.0 s.

Table 8: *OHGW Sizes from Calculation Using Constant Short Circuit Current*

Short Circuit Current (kA)	OHGW Sizes (mm^2) at Different Distance from Substation [time]		
	500 m	500 m-3 km	> 3 km
3	25 [0.5350]	25 [0.5350]	35 [1.0665]
7	35 [0.1959]	70 [0.9377]	95 [1.6093]
10	50 [0.2046]	95 [0.7859]	-
12	50 [0.1421]	95 [0.5458]	-

For the short circuit current is not greater than 3 kA, the 25 mm^2 can be used for the distance of 3 km from substation and 35 mm^2 from that location should be used. For the short circuit current is not greater than 7 kA, the 35 mm^2 should be used for distance of 500 m from the substation, 70 mm2 between 500 m-3 km and the 95 mm^2 beyond that location should be used. For the short circuit current is not greater than 12 kA, the 50 mm2 should be used for 500 m from substation, 95 mm^2 should be used between 500 m-3 km and the OHGW size greater than 95 mm^2 for line beyond that location should be used.

3.3 OHGW Sizes from Calculation and Simulation

Consider the maximum short circuit current, If, along the line from the simulation in Fig. 3-6. The short circuit current decreased when the short circuit location move out from the substation. The reduced short circuit current means the 10 kA short circuit current is reduced to 8.5 kA for the distance of 500 m-3 km from substation and reduced to 4.2 kA for the distance that is greater than 3 km from substation. The reduced short circuit current means the 12 kA short circuit current is reduced to 8 kA for the distance of 500 m-3 km from substation and reduced to 4 kA for the distance that is greater than 3 km from substation. This implies that the OHGW sizes from Table 8 can be reduced to the sizes shown in Table 9.

Table 9: *OHGW Sizes from Calculation and Simulation Using Reducing Short Circuit Current*

Short Circuit Current (kA)	OHGW Sizes (mm^2) at Different Distance from Substation [time]		
	500 m	500 m-3 km	> 3 km
3	25 [0.5350]	25 [0.5350]	25[4.8147]
7	35 [0.1959]	50[0.9263]	35[1.8145]
10	50 [0.2046]	70[0.6359]	50[1.1600]
12	50 [0.1421]	70 [0.7179]	50[1.2789]

For the short circuit current is not greater than 3 kA, the 25 mm^2 can be used. For the short circuit current is not greater than 7 kA, the 35 mm^2 should be used for distance of 500 m from the substation, 50 mm^2 between 500 m-3 km and the 35 mm^2 beyond that location should be used. For the short circuit current is not greater than 12 kA, the 50 mm^2 should be used for 500 m from substation, 70 mm^2 should be used between 500 m-3 km and 50 mm^2 for line beyond that location should be used.

Table 10: *OHGW Sizes from Calculation and Simulation Using Reducing Current along OHGW*

Short Circuit Current (kA)	OHGW Sizes (mm^2) at Different Distance from Substation [time]		
	500 m	500 m-3 km	> 3 km
3	25 [0.5350]	25 [4.8147]	25[19.259]
7	35 [0.1959]	25[0.9102]	25[3.3436]
10	50 [0.2046]	35[0.5999]	25[1.2037]
12	50 [0.1421]	35 [0.5999]	25[1.2037]

To determine the suitable OHGW sizes. Consider the current distribution of I_{GwLeft} and $I_{GwRight}$ along the OHGW from the simulation in Fig. 3-6. The short circuit current decreased when the short circuit location move out from the substation. The reduced short circuit current means the 10 kA short circuit current is reduced to 4 kA for the distance of 500 m-3 km from substation and reduced to 2 kA for the distance that is greater than 3 km from substation. The reduced short circuit current means the 12 kA short circuit current is reduced to 4 kA for the distance of 500 m-3 km from substation and reduced to 2 kA for the distance that is greater than 3 km from substation. This implies that the OHGW sizes from Table 9 can be reduced to the sizes shown in Table 10.

From Table 10, for the short circuit current is not greater than 3 kA, the 25 mm^2 can be used. For the short circuit current is not greater than 7 kA, the 35 mm^2 should be used for distance of 500 m from the substation and 25 mm^2 beyond that location should be used. For the short circuit current is not greater than 12 kA, the 50 mm^2 should be used for 500 m from substation, 35 mm^2 should be used between 500 m-3 km and 25 mm^2 for line beyond that location should be used.

4. CONCLUSIONS

The Line Type 1, OHGW not connected to the neutral of substation power transformer, give the short circuit current magnitude which is less than the current from Line Type 2, OHGW connected to the neutral of substation power transformer. So the Line Type 1 gives the smaller OHGW sizes than Line Type 2.

The suitable OHGW sizes for line to ground fault when concerned with the short circuit current magnitude, duration time and relay operating time can be found. For the short circuit current is not greater than 3 kA, the 25 mm^2 can be used. For the short circuit current is not greater than 7 kA, the 35 mm^2 should be used for distance of 500 m from the substation and 25 mm^2 beyond that location should be used. For the short circuit current is not greater than 12 kA, the 50 mm^2 should be used for 500 m from substation, 35 mm^2 should be used between 500 m-3 km and 25 mm^2 for line beyond that location should be used.

5. ACKNOWLEDGEMENT

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