Power Distribution Feature of Coil-based Power-Tapping from Ground Wire of Typical HV Overhead Transmission Line

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Abstract. Power-tapping from ground wire is an ideal method to power on-line monitoring devices of HV overhead transmission line. And the way with bus-like power-tapping coil plays an important role for its simple engineering and excellent lightning protection performance. The key to the PTC way is whether enough power is available from ground wire. Study has revealed that for PTC of certain size and material the available power from ground wire is variable. Hence, to study the distribution performance of power from ground wire bears great reference value for the power-tapping design and installation of on-line monitoring device. In view of the power is in proportion to square of ground wire current, the power distribution performance is obtained through analyzing ground wire current of power-tapping circuit. Besides, effects of concerned factors on it are analyzed using EMTP-ATP program. Results show that the available power increases from the vicinity of terminal tower to middle zone of line, and tends to be stable when it is about 10 spans away. Besides, conductors transposition could reduce the current evidently while others show little impacts. Finally, on-cite measurements verified the above-said analysis.

Introduction

Currently solar battery and PTC-based power-tapping from ground wire are the usual way to power on-line monitoring devices of HV overhead transmission line[1,2]. For the former, the available power is too small and the device is bulky, while for the latter the way isn't applicable to devices at earth potential. As an ideal on-line powering method, power-tapping from ground wire becomes a hotspot in this field.

Usually a typical line includes two ground wires, of which one is optical power ground wire (OPGW) continuously grounded at each tower, the other is ordinary ground wire segmented with one point grounded within each section. The ground wire power originates from electromagnetic induction of the transmission line, as shown in Fig. 1[1,3].

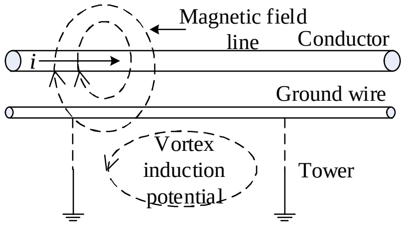

Fig. 1 Electromagnetic induction scheme of overhead transmission line

Vortex magnetic field induction-based GWPT involves two methods, namely electrical method and magnetic method. For the former a power-tapping load (recorded as Z_l) is connected in the power-tapping circuit including ground wire, for the latter PTC is used. Compared to the electrical method, the PTC based method bears advantages of immunity to lightning strike because of its non-indirect contact with ground wire, and of great installation convenience. However, its available power is quite small, hence the key to the PTC way is whether enough power is available from ground wire. Researches showed that the available GW power isn't constant, but variable with certain factors. Therefore, to study the GWPT power distribution feature is of important reference value for design of GWPT design as well as installation of on-line monitoring devices of transmission lines.

Paper on GWPT power distribution is seldom reported in open literatures. In paper [4], PTC based power is tapped from ground wire to power obstruction indication lights. In paper [5], induced GW voltages and currents are measured respectively on single-circuit and double-circuits transmission lines and compared with theoretical calculations. In [6], GW voltages and currents of 750 kV transmission line under several GW operation modes are calculated as well as GW power loss. Obviously, no specialized research on distribution of power available from GW is conducted yet.

In view of PTC-based power is in proportion to square of OPGW current, in this paper the PTC-based power from ground wire is studied mainly through analysis and calculation of GW current.

Calculation of PTC-based power from Ground wire

To tap power from GW with PTC, the GW should form a closed circuit together with other paths such as tower, the earth, etc. first to produce induction current. For typical overhead transmission line, only OPGW could form closed current. Hence, only OPGW is considered for tapping power.

For the PTC as shown in Fig. 2:

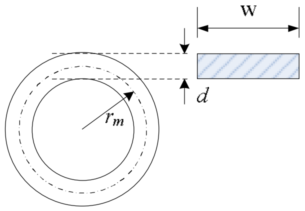

Fig.2 PTC size diagram

We could have:

$$P_{CT} = p\, f \frac{mS}{l} I_1^{2} \sin(2q)$$

(

1)

where P_{CT} denotes PTC power, μ , $S(=w*d)$, $l(=2\pi r_m)$ respectively denotes permeability, section area and magnetic path length of PTC, I_1 the OPGWcurrent, θ the included angle of I_1 and PTC excitation current.

From Eq. 1 it can be seen that with a definite PTC size and material, P_{CT} is in proportion to I_1 square,. Therefore , the power distribution feature could be obtained from the analysis of I_1.

Analysis of OPGW current distribution feature

1.1 Equivalent calculation circuit reduction of OPGW current

The equivalent circuit is shown in Fig. 3 as follows:

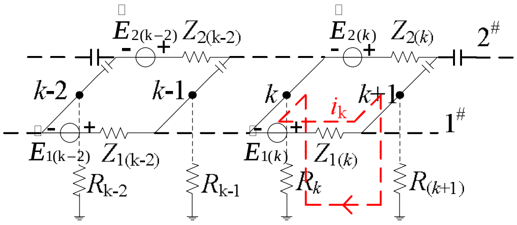

Fig.3 Equivalent calculation circuit for OPGW current

where line $1^{\#}$ and $2^{\#}$ respectively denotes OPGW and ground wire, $Z_{1(k)}$, $Z_{2(k)}$, $E_{1(k)}$, $E_{2(k)}$ respectively denotes theself-impedance and vortex induction potential of the kth span (between $k^{\#}$ and $(k+1)^{\#}$ tower) of OPGW. R_k the resistance of the kth tower, i_k the OPGW current of the kth span. $k = 1, 2, 3, \ldots ,$.

Without losing generality, i_k is calculated, as reamrked in red line in Fig. 3.

Supposing Z_l is located in the kth span as labeled in red, then the calculation of i_k could be done through its Thevenin's equivalent circuit. And therefore the equivalent circuits respectively towards the left side of node k, and right dide of node (k+1) need to be calculated. Denoting $\dot{U}_{e(k)}$ and $Z_{e(k)}$ as the equivalent voltage and impedance towards the left side of node k, $\dot{U}_{e(k+1)}$ and $Z_{e(k+1)}$ the right side of node (k+1) , we get:

$$\begin{cases} \dot{U}_{e(k)} = R_k(\dot{U}_{e(k-1)} + \dot{E}_{1(k-1)}) / (Z_{e(k-1)} + Z_{1(k-1)} + R_k) \\ Z_{e(k)} = R_k(Z_{e(k-1)} + Z_{1(k-1)}) / (Z_{e(k-1)} + Z_{1(k-1)} + R_k) \\ \dot{U}_{e(k+1)} = R_{(k+1)}(\dot{U}_{e(k+2)} + \dot{E}_{1(k+1)}) / (Z_{e(k+2)} + Z_{1(k+1)} + R_{(k+1)}) \\ Z_{e(k+1)} = R_{(k+1)}(Z_{e(k+2)} + Z_{1(k+1)}) / (Z_{e(k+2)} + Z_{1(k+1)} + R_{(k+1)}) \end{cases} \tag{2}$$

From Fig. 3 and Eq. 2 we could have the Thevenin's equivalent circuit of Z_l:

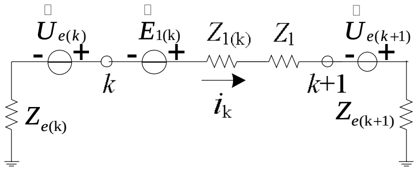

Fig.4 Simplified equivalent calculation circuit of ground wire

Then we get:

$$i_k = |\dot{U}_{e(k)} + \dot{U}_{e(k+1)} + \dot{E}_{1(k)}| / |Z_{e(k)} + Z_{e(k+1)} + Z_{1(k)}| \tag{3}$$

1.3 Analysis of OPGW current distribution feature

From Fig. 3 and Eq. 2 it can be seen that $Z_{e(k)}$ is the parallel combination of R_k and series connection of $Z_{e(k-1)}$ and $Z_{1(k)}$. Considering $Z_{1(k)}$ is the OPGW resistance of the kth span, just a value of about 0.1 Ω, $Z_{e(k)}$ could be approximately regarded as the shunting resistance of R_k and $Z_{e(k-1)}$, which signifies $Z_{e(k)}$ is less than $Z_{e(k-1)}$. Hence, $Z_{e(k)}$ decreases as k increases.

Now let's turn to $\dot{U}_{e(k)}$. With even span and R_k, term $R_k/(Z_{e(k-1)}+Z_{1(k-1)}+R_k)$ should increases as k increases (because $Z_{e(k)}$ decreases as k increases). With a constant $\dot{E}_{1(k-1)}$ superimposed, it is easy to deduce that $\dot{U}_{e(k)} > \dot{U}_{e(k-1)}$. therefore $\dot{U}_{e(k)}$ must increases as k increases.

Further calculation shows that for line with even span and R_k, both $\dot{U}_{e(k)}$ and $Z_{e(k)}$ will eventually tends to a constant value when k increases. Calling these constants respectively $\dot{U}_{e(\infty)}$ and $Z_{e(\infty)}$ and substituting them into Eq. 2 and 3, it can be calculated that:

$$i_{k(\infty)} = |\dot{E}_{10} / Z_{10}| \tag{4}$$

where $i_{k(\infty)}$ is the stable value of i_k. $\dot{E}_{10}$ and Z_{10} are respectively the even value of $\dot{E}_{1(k)}$ and $Z_{1(k)}$.

Summing up the above analysis, it's clear that, as i_k behaves, the PTC-based power increases as k increases, and eventually towards to be stable. In other words, the power is relatively small near the terminal tower, while in the middle zone is great and stable. What needs to be mentioned is that in the incoming transmission line, two ground wires are grounded which differs from outside the incoming section, but the distribution feature of ground wire current as well as PTC power are similar.

Effect of concerned factors on GW current distribution feature

Research shows that for GW current distribution feature, concerned influential factors mainly include distribution of line span and R_k near Z_l, conductor transposition. Analysis is based on an example of 220 kV line, whose longitudinal geometrical structure is shown in Fig. 5:

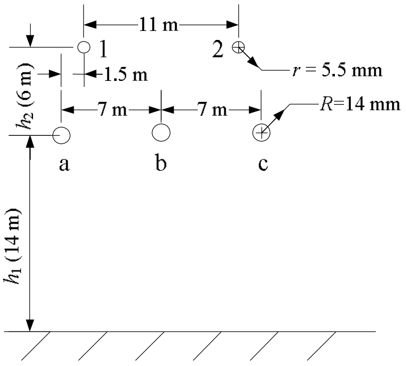

Fig. 5 Longitudinal construction scheme of the line example

where 1 and 2 respectively denotes OPGW and ground wire, R the radius of conductor (LGJ-400, 0.08 Ω/km), r_1 of OPGW (OPGW-120, 0.3 Ω/km), r_2 of ordinary ground wire (GJ-70, 1.7 Ω/km), ρ=300Ω.m. In convenience, conductorcurrent is set to be 100 A, $\cos\varphi$=0.95.

The ananlysis is implented through simulation with EMTP-ATP. To eliminate the effects of the distance between terminal tower and the measuring spot, the spot is selected at middle zone of line.

For line span and R_i, concerned parameter value variation is designed in Table 1.

Table 1 Variation of span and R_i (footing resistance of tower)

No	R_i [Ω]	R_{i+1} [Ω]	R_{i+2} [Ω]	R_{i+3} [Ω]	N [o]	S_i [M]	S_{i+1} [m]	S_{i+2} [m]	S_{i+3} [m]
1	50	40	30	25	3	1000	900	800	700
2	2	5	8	10	4	100	150	250	250

where S_i~S_{i+3} respectively denotes the *i*th ~ *(i+3)*th span of the line, *i* is the tower number.

For conductor transposition, the common transposition mode is;

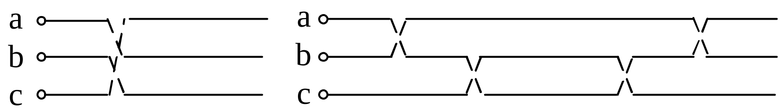

Fig.6 Conductor transposition sketch(left: Traditional; right: Optimal)

The simulation results show that: For R_i and S_i, the OPGW current basically remains unchangeable with the change of them; For conductor transposition, the closer to the transposition spot is the the measuring spot, the more the reduction of the OPGW current value is, with the maximum reduction magnitude up to 40% or above which means a reduction maximum of above 60% for the PTC-based power. For this example, the reduction effect gradually disappear when the measuring spot is about 10 or more spans away from the transposition spot. Further simulation shows that circuits branching of line has the same effect of conductor transposition.

What needs to be mentioned is that conductor current, and current unbalance etc. can affect the OPGW current magnitude, but can't change their distribution feature.

Field verification

As above said, the OPGW current is small near the terminal tower, and gradually increases towards the middle zone of line and eventually get stable. This implies that the error between the adjacent OPGW currents gradually decreases and eventually disappear. The tower earthing current (i_{tw}) is right the error of adjacent OPGW currents, therefore it is great near the terminal tower, and gradually decreases towards the middle zone, and eventually disappear. In view of i_{tw} is easier to be measured, field measurements are conducted on a 110 kV transmission line of State Grid Tibet Electric Power Company Limited, . The results are shown in Table 2.

Table 2 Test results of i_{tw}

Naixi Line I		Naixi Line II		
Measuring spot	i_{tw} [A]	Measuring spot	i_{tw} [A]	Naixi Line I:
$1^{\#}$ Tower	4.18	$43^{\#}$ Tower	0.55	66.652 A
$2^{\#}$ Tower	3.54	$44^{\#}$ Tower	0.88	Naixi Line II:
$3^{\#}$ Tower	0.73	$45^{\#}$ Tower (transposition tower)	1.54	67.852 A
$4^{\#}$ Tower	0.68			

From the Table 2 it can be seen that i_{tw} is small near the terminal tower, and gradually decreases towards the middle zone of line, also that the nearer to the transposition tower, the greater the i_{tw}. In view of all the errors, the above results could be regarded as consistent with the above said distribution feature of OPGW currents. Therefore, the PTC based power distribution feature, which is similar to of OPGW current, is verified indirectly.

Conclusions

(1) With both theoretical deduction and simulation of OPGW current , the PTC based power distribution feature is analyzed;

(2) The analysis result shows that the PTC based power is small near the terminal tower, and gradually increases towards the middle zone of line and eventually get stable. And the conductor transposition as well as circuit branching could evidently reduce the power, and the nearer to the transposition or circuit branching spot, the greater the reduction is.

(3) Field measurements verified the above said analysis.

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References

[1] R.L. Vasquez-Arnez, M. Masuda, J.A. Jardini, E.J.V. Nicodem, Tap-Off Power From the Overhead Shield Wires of an HV Transmission Line, J. IEEE Transactions on Power Delivery, 27(2)986-992.

[2] S. Peungsungwal, B. Pungsiri, K. Chamnongthai, et al., Autonomous robot for a power transmission line inspection, J. Proc. IEEE Int. Symp. Circuits Syst., 2001 (3)121-124.

[3] Kent C. Jaffa, Magnetic Field Induction from Overhead Transmission and Distribution Power Lines on Parallel Fences, J. IEEE Transactions on Power Apparatus and Systems.PAS-100(4)1624-1636.

[4] T. Yamaguchi, S. Takano, O. Naganuma, et al., Development of PowerSupply System for Obstruction Lights Exploiting Induced Current Which Flows Through Overhead Ground Wires, C. Proc. Transmission and Distribution Conference and Exhibition 2002, Asia Pacific: IEEE/PES, 2002: 2176–2180.

[5] Yu Wang, Jianguo Wang, Xiangyang Peng, et al., Overhead Ground Wires Induction Current and Energy Loss of 220 kV Double Circuit Transmission Lines, J. High Voltage Apparatus, 49(5)31 –38. “in Chines”

[6] Dandan Zhao, Zhen Han, Jie Guo, Grounding Modes and Electric Loss of 750 kV Overhead Ground Wire, J. High Voltage Apparatus, 49(2)67 – 73.“in Chines”