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Electromagnetically Coupled Charging for Monitoring Devices near 110 kV High-Voltage Transmission Line

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The possibility and efficiency of wireless electromagnetic charging near 110 kV high-voltage transmission line is studied. For monitoring devices that are used to measure various physical parameters near transmission lines or in electrical substations, it is necessary to provide sufficient power supply according to device specifications. In some cases, it is necessary to use additional back-up charging because photovoltaic panels do not provide enough power to charge the built-in battery pack during the day especially in winter season. One of the possible additional methods of back-up charging is the wireless electromagnetic charging. We propose a design of such charging system and we study the efficiency of the system as the parameter of design and distance from the transmission line. The distance above the ground was in the range between 10 cm and 200 cm for our experiments. The orientation of the coil was another parameter the influence of which on the charging system was analyzed. A model situation of such charging system is provided and modelled situation is verified by experimental measurements at power distribution network frequency of magnetic field. First approximation input parameters for design and placement of the charging system were requirements placed by overall measurement module design.

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1. Introduction

There are cases when photovoltaic panels in combination with built-in batteries fail to provide power supply and there is no possibility to connect the power supply of the device to supply network due to, e.g., restrictions placed by regulations or unavailability of the supply network. In such cases the on-line monitoring devices that are used to measure, acquire, and transmit various physical parameters placed near transmission lines or in electrical substations still need to be supplied by power according to device specifications. As a fallback, additional back-up charging is needed such as wireless electromagnetic charging [1, 2]. However, this method is usable only for special cases as electromagnetically coupled charging can contravene national regulations or regulations stated by the operator of the transmission line (if the area near transmission line is public, for the case of substations other terms of agreement may exist).

2. Theoretical background

As it is known, current flowing through any wire and transmission power line creates an electric and magnetic field with magnetic field intensity H around that wire. Furthermore, magnetic field is characterized by magnetic flux lines, where the density flux lines determine the magnetic field intensity. The flux density B strongly depends on material in the environment around the conductor, which is characterized by the permeability of the material. As seen in the modeled situation in Fig. 1, the value of magnetic intensity decreases with the distance from the wire. In addition, the magnetic flux is determined by the flux density and the surface area, as shown by the following equation:

$$\Phi = BA = \mu HA. \quad (1)$$

The effect of electromagnetic induction means that a kind of force is created by time-varying flux. This situation is shown in Fig. 2, and expressed by

$$F = -\frac{\mathrm{d}\Phi}{\mathrm{d}t} = -\frac{\mathrm{d}}{\mathrm{d}t}\int_A B\,\mathrm{d}A. \quad (2)$$

To be able to estimate and model the capability of the magnetic field to give enough power to charge a measurement system we have to express the power belonging to the magnetic field. Therefore,

$$P_m = \int H\left(\frac{\delta B}{\delta t}\right)\mathrm{d}V. \quad (3)$$

By multiplying this equation by $\mathrm{d}t$ the power expression becomes energy expression. By integrating such an expression, we can get the energy assigned to a magnetic field. After substitution and simplification operations, the energy density $\frac{\mathrm{d}W_m}{\mathrm{d}V}$ $\left[\frac{\mathrm{J}}{\mathrm{m}^3}\right]$ in the environment can be expressed as

$$\frac{\mathrm{d}W_m}{\mathrm{d}V} = \frac{\mu}{2}H^2 = \frac{\mu_0}{2}\left(\frac{I^2}{2(2\pi r)^2}\right). \quad (4)$$

The modelled values of energy density are shown in Table I. These values were calculated depending on the distance of the receiving coil from the wire and on DC current flowing through the wire. Note that these are only theoretical values. The real value of extracted

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TABLE I

Modelled values of energy density.

r [m]	$\mathrm{d}W_m/\mathrm{d}V$ [μJ/m^3]								
	100 A	150 A	500 A	650 A	700 A	750 A	800 A	850 A	900 A
0.1	15.9×10^3	35.8×10^3	397.9×10^3	672.4×10^3	779.9×10^3	895.2×10^3	1018×10^3	1149×10^3	1289×10^3
1	159.15	358.10	3978.87	6724.30	7798.59	8952.47	10185.92	11498.94	12891.55
5	6.37	14.32	159.15	268.97	311.94	358.10	407.44	459.96	515.66
7	3.25	7.31	81.20	137.23	159.15	182.70	207.88	234.67	263.09
10	1.59	3.58	39.79	67.24	77.99	89.52	101.86	114.99	128.92
15	0.71	1.59	17.68	29.89	34.66	39.79	45.27	51.11	57.30
20	0.40	0.90	9.95	16.81	19.50	22.38	25.46	28.75	32.23

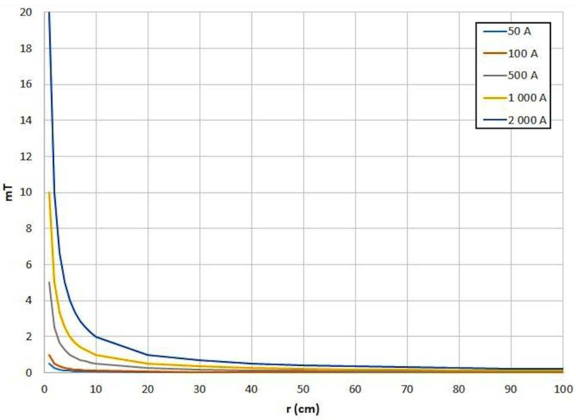

Fig. 1. Modelled values of magnetic intensity.

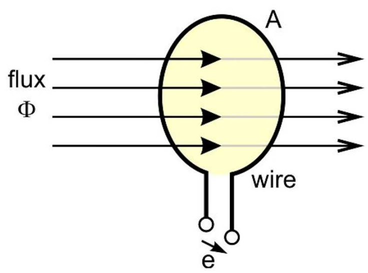

Fig. 2. Electromagnetic induction through the wire loop.

field energy will be different due to flux changes caused by power line operating frequency of 50 Hz and power line configuration (usually there is more than 1 wire near such proposed measurement places). There is also a difference between the position in and out of electrical substation (in electrical substation the situation is much more complicated because of different high voltage device proximity) [3–5].

3. The receiving coil

For our experiments, we have proposed a receiving coil with construction diagram shown in Fig. 3. This coil has core material type N87 with $\mu_e = 1590$ and

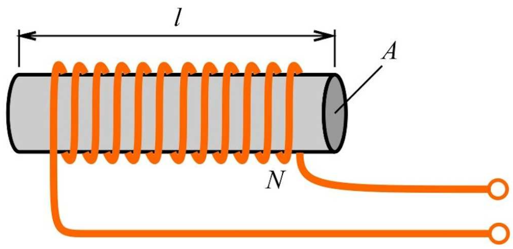

Fig. 3. Diagram of receiving coil construction.

$BS = 320$ mT and it has a linear shape with dimensions: length $l = 15$ cm and area $A = 0.00785$ m^2. The number of coil windings is proposed to be 2000. However, this is just a first order approximation of receiving coil and it is based on requirements from charging module construction conditions such as maximum size and weight. Alternatively, the parameters of the receiving coil should be adjusted to the values outgoing from the measured values of energy density of magnetic field in proposed position and orientation of the coil.

4. Experimental setup

We have made a set of experiments in real world situation under the 110 kV high-voltage transmission line. The experimental setup diagram is depicted in Fig. 4.

We have measured the induction B and the electric field intensity in position directly under the power line (position 1) at distances from the ground of 1 m, 1.5 m, and 2 m, at positions misplaced by 5 m to both sides from the power line in perpendicular direction (positions 2 and 3). The distance from the ground to the position of the lower power wires was 15 m. Above-mentioned measurement positions were determined by possible positions of measurement modules [6], which need to be powered and charged. Usually this position is at minimum of 1.5 m from the ground and should be higher due to security reasons. However, for this measurement we have chosen the worst cases for the possible energy exploit. We also suppose that the position is seldom directly under the power line. Measured values can be seen in Table II. Table III shows the calculated values of energy density at measurement positions.

TABLE II

Values of B measured in experimental positions, and distance h from the ground.

	Position 1			Position 2			Position 3		
h [m]	1	1.5	2	1	1.5	2	1	1.5	2
B_x [nT]	15.5	49.26	35.49	51.17	20.33	24.07	71.74	44.33	73.69
B_y [nT]	606.9	702.1	628.4	335.6	426.1	306.3	646.8	714.4	678.7
B_z [nT]	205.3	237.4	292.4	402.9	466.1	548.5	382.9	401.9	375.2

TABLE III

Calculated values of energy density in nJ/m^3 according to the values of B and positions from Table II.

		Position 1			Position 2			Position 3		
h [m]		1	2.5	2	1	2.5	2	1	2.5	2
$\mathrm{d}W_m/\mathrm{d}V$ [μJ/m^3]	x axis	0.10	0.97	0.50	1.04	0.16	0.23	2.05	0.78	2.16
	y axis	146.55	196.14	157.12	44.81	72.24	37.33	166.46	203.07	183.28
	z axis	16.77	22.42	34.02	64.59	86.44	119.71	58.34	64.27	56.01

TABLE IV

Calculated values of current flowing through secondary coil.

		Position 1			Position 2			Position 3		
h [m]		1	1.5	2	1	1.5	2	1	1.5	2
I [nA]	x axis	0.93	2.94	2.12	3.05	1.21	1.44	4.28	2.65	4.40
	y axis	36.22	41.90	37.50	20.03	25.43	18.28	38.60	42.64	40.51
	z axis	12.25	14.17	17.45	24.05	27.82	32.74	22.85	23.99	22.39

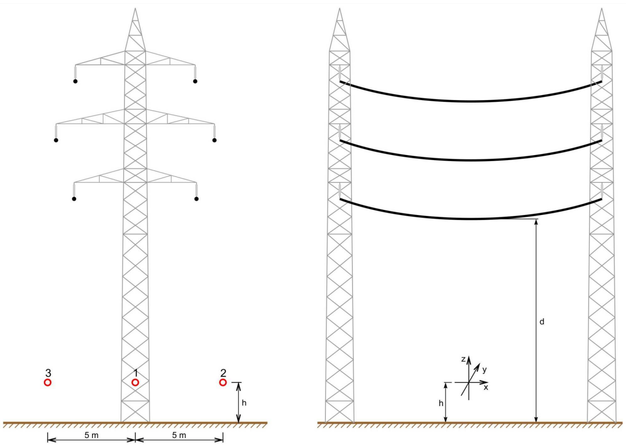

Fig. 4. Experimental setup diagram and measurement positions.

Furthermore, using

$$I = \frac{lB}{\mu N}, \tag{5}$$

where μ is the permeability of the coil core, l is the length of the coil core, B is the magnetic field induction at measured position, and N is the number of coil windings, we can calculate the values of current flowing through receiving coil (Table IV). However, these calculated values assume simplified conditions, where we neglect the winding and core geometry and winding density for this model.

5. Discussion

In real world, the situation is much more complex compared to the modelled parameters. The electric and magnetic field near power line depend strongly on power line wire configuration, distance between poles, number of wires and phase configuration. The proximity of other high voltage devices also deforms these fields. Furthermore, it is often hard to ensure the exact coil orientation according to the power line axis. Therefore, our measurements were made in coil orientation aligned to all dimensional axes. The shape, dimension, material of the coil, and its core also influence the measured values.

6. Conclusions

We studied the possibility and efficiency of wireless electromagnetic charging near 110 kV high-voltage transmission line. We have calculated theoretically achievable values of energy density near such power lines. For our experiments we have proposed a receiving coil with core material type N87 with $\mu_e = 1590$ and $BS = 320$ mT and the number of coil windings 2000. During experiments, we have tested different combination of receiving coil position and orientation according to the power line. Experimentally acquired values of energy density by magnetic field (in the range of nJ/m^3) differ from theoretically calculated values (these values are slightly shifted to the range from nJ/m^3 to μJ/m^3 for comparable distances from the wire), but this difference could be caused by reasons mentioned in the discussion.

Furthermore, during our measurements we did not know the exact value of the current flowing through the power line wires. However, modelled values and measured values show that the current flowing through the receiving coil is not high enough to provide charging capability within reasonable time in reasonable distances from the power line wire. In order to improve the efficiency of such a charging system, we would have to redesign the receiving coil.

Acknowledgments

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References

[1] M. Simic, C. Bil, V. Vojisavljevic, *Proced. Comput. Sci.* **60**, 1846 (2015).

[2] M. Pavlík, L. Kruželák, M. Mikita, M. Špes, S. Bucko, L. Lisoň, M. Kosterec, *Archiv. Electr. Eng.* **66**, 361 (2017).

[3] N. Garraud, A. Garraud, D. Munzer, M. Althar, D.P. Arnold, *J. Phys. D Appl. Phys.* **52**, 449601 (2019).

[4] S. Kang, J. Kim, S. Yang, T. Yun, H. Kim, *Electron. Lett.* **53**, 1134 (2017).

[5] M.M. Samy, A.M. Emam, in: *1st IEEE Int. Conf. on Environment and Electrical Engineering and 17th IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS EUROPE), Milan (Italy), 2017*.

[6] L. Lisoň, I. Kolcunová, M. Kmec, *Acta Electrotechn. Informat.* **14**, 23 (2014).