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Developing Non-traditional Electrical Power Sources for Remote Monitoring Systems

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Abstract. *Potential autonomous energy sources for remote monitoring devices installed on high-voltage overhead power lines (HVOPL) are considered. Experiments were conducted to evaluate the induction of electromagnetic energy from live conductors into metallic elements of transmission towers. Furthermore, simulation-based theoretical analysis was carried out to identify technical solutions for stabilizing power supply systems of local monitoring units powered by energy induced in the ground wire.*

Keywords: *high-voltage overhead power lines, non-traditional power sources, induced energy, ground wire, supercapacitor.*

Introduction

Reliable and efficient transmission of electricity on high-voltage overhead transmission lines is an urgent task in the electricity sector of Kazakhstan. Current analyses point to several dominant causes of emergency incidents, including harsh weather events, inadequate or delayed preventive maintenance, deterioration of support structures, and leakage currents affecting conductors and insulators. Addressing these challenges requires the introduction of remote monitoring technologies to enhance the safety and efficiency of high-voltage overhead power lines.

One of the critical challenges in deploying monitoring technologies lies in ensuring a stable power supply for electronic equipment located on overhead transmission structures. This issue is exacerbated by the present absence of optimized, energy-saving control algorithms. The diagnostic system itself is organized as a network of local modules situated on transmission supports. These modules execute the functions of initial data collection from measurement and indication sensors, archiving of results, and transmission to the dispatch center through hybrid communication methods. To ensure the fault-free functioning of such distributed modules, one of the foremost tasks is the development of a reliable and stable power source.

Research Methods

The creation of HVOPL monitoring systems requires particular emphasis on the development of effective power supply schemes for electronic devices positioned on transmission line supports. Direct utilization of the energy from live conductors to feed local information units is not cost-effective. Instead, the design of autonomous supply systems for these modules incorporates the electrical component of the electromagnetic field of energized conductors together with solar radiation [1] as the primary sources of energy [2]. The main requirements for the power supply of the local units are:

- provision of round-the-clock uninterrupted power supply to the electronic equipment of the local unit under any climatic conditions;
- required power for 20-30 W power supply;
- the voltage of the power supply is 4-50 V;
- the autonomy of the energy source.

One of the requirements for the energy consumer is to minimize the power consumption by the load by optimizing the operating time intervals of the controller and the receiving and transmitting equipment.

In [3], two variants of the structural scheme of an unconventional remote monitoring power source are presented and fully described. In the first, two solar panels were used, and in the second, induced energy between lightning rods from live wires in power transmission lines. The block diagram of the power supply source is presented in [3].

For the second type of conversion of induced energy into a lightning discharge into a power supply source for energy storage, it will be necessary to conduct theoretical studies of the characteristics of induced energy and select equipment, as well as determine the static characteristics of its energy consumption.

In order to develop a stable power supply source for the equipment of local units based on induced energy, theoretical studies using simulation tools were carried out in the thunderstorm discharge.

The objective of the experimental investigation was to evaluate the performance parameters of the supercapacitor incorporated in the second design of the autonomous power supply. The analysis was carried out with reference to the specific characteristics of the HVOPL section as well as the operational requirements of the connected load. The results of theoretical studies will allow us to determine the optimal parameters of the supercapacitor, thereby ensuring uninterrupted power supply to the local unit.

Scientific Results

The design and the scheme of replacement of the research object of a gantry-type support for a 500 kV overhead power line was described in [4-5].

Experimental research program.

Theoretical studies of the operation of the power supply unit based on induced energy in a thunderstorm discharge should be performed in accordance with the program presented below.

Simulation models for studying the energy characteristics of a power source with a supercapacitor as a buffer energy storage device should be developed for the following number of supports: 8, 16, 24 and 32.

In the course of simulation experiments, take the average length of the inter-support distance equal to 300 m. The ground wire resistance corresponding to the inter-support distance is assumed to be 0.43 Ohms. The operating time of the local unit's transceiver equipment is assumed to be 300 s.

The scheme of replacement of the research object is shown in Figure 1.

Power sources of industrial frequency with a voltage of 500 kV, respectively, phases A, B and C are represented by elements G_A, G_B and G_C. The electric capacity of the current-carrying wires of the entire controlled section of the HVOPL distributed along the length of the HVOPL relative to the ground is represented by concentrated elements C_A, C_B and C_C. Electric capacitances C_{B1}-C_{BN} represent the capacitance on the inter-support section between the current-carrying wire of phase B and the ground wire. Similarly, the capacitances C_{C1}-C_{CN} represent the capacitance on the inter-support section between the current-carrying wire of phase C and the ground wire. Resistor R_1 performs the load functions for the induced energy in the lightning rod, taking into account the selected number of reference spans. Resistors R_2-R_N represent the active resistances of the ground wire section corresponding to the inter-support span in the replacement scheme.

As part of the simulation study, a number of characteristics were evaluated. These included the voltage at the rectifier output, the charging voltage of the supercapacitor for configurations of 8, 16, 24, and 32 supports, and the corresponding charging times for each case. The assessment was carried out with reference to the predetermined capacitance of the supercapacitor.

Energy accumulation within a supercapaci-

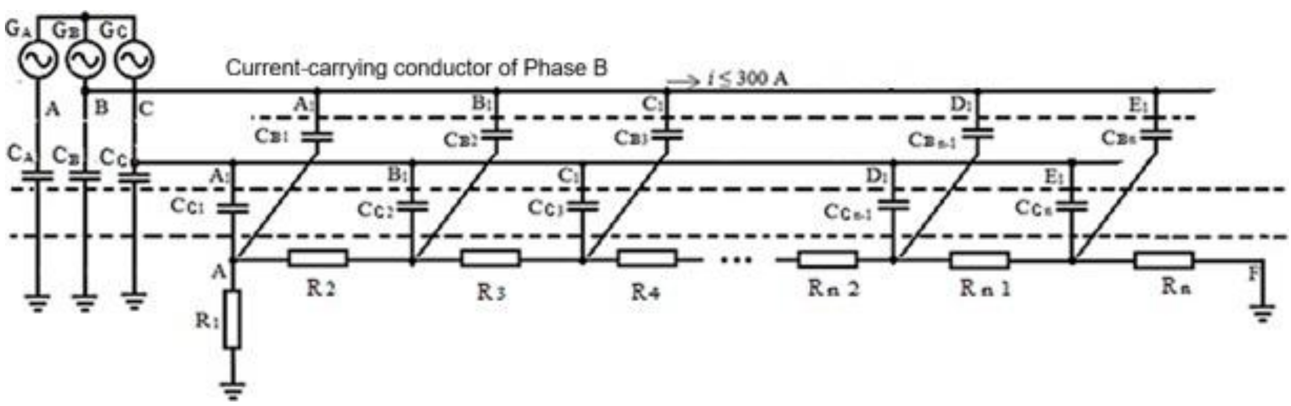

Figure 1 – Scheme of replacement of the controlled section of the overhead transmission line

tor module is essential, as the induced energy in the ground wire is not uniform but distributed along its length, leading to fluctuations in voltage and current with respect to the number of HVOPL supports. Owing to their high energy performance, supercapacitors provide an efficient and economically viable solution for medium-power ranges, particularly in cases where autonomous operation requires buffer storage. These devices are characterized by minimal losses, long operational lifespan, and remarkable endurance to repeated cycling, reaching several hundred thousand charge–discharge cycles, in contrast to only a few thousand cycles for conventional lead-acid batteries.

An essential stage of the study involved determining the specifications and number of supercapacitors necessary to provide stable energy supply for the complete system. For this purpose, the required energy demand of the local unit was calculated, based on the initial conditions of 0.5 A current consumption and a 12 V supply voltage. As the potential on the ground wire depends on the number of inter-support spans, the voltage across resistor R1 was determined through a simulation model developed in accordance with the technical requirements and equivalent circuit representation.

Using MATLAB simulation MATLAB tools, a simulation model was developed with a different number of sections of inter-support spans with registration devices.

The model diagram is shown in Figure 2.

Within the developed simulation model, the three-phase power supply of the HVOPL, operating at a line voltage of 500 kV, is described by block A1. The capacitive properties of the phase conductors, the length of which is defined by the spacing between the generating and receiving substations, are simulated using capacitors C1-C3. Resistors R1-R3 represent the internal active resistance of these conductors. The capacitive coupling between phase B and the lightning protection cable is modeled by capacitors C4-C10, whereas the interaction between phase C and the same cable is modeled by capacitors C11-C17. The active resistance of the ground wire between successive supports is represented by resistors R4-R10. The conversion of alternating current into direct current is achieved through macroblock A7, which models a full-wave bridge rectifier. The system load is emulated by resistor Rn.

By means of the key S1, the load resistance is switched off during the charge period of the supercapacitor C19. Reactive elements L1, C18 simulate an LC filter that smooths ripples at the rectifier output, and element C19 simulates a block of supercapacitors. Recording of transients at the supercapacitor terminals is performed with an A8 oscilloscope.

The results of the simulation experiment are presented in Table 1.

For a different number of supports, the capacity of the supercapacitor block is calculated. The unit consists of several series-connected supercapacitors. From formula (1), we obtain formula (2), which determines the block capacity:

$$E = \frac{C_{eq} \cdot U_{gr}^2}{2}, \qquad (1)$$

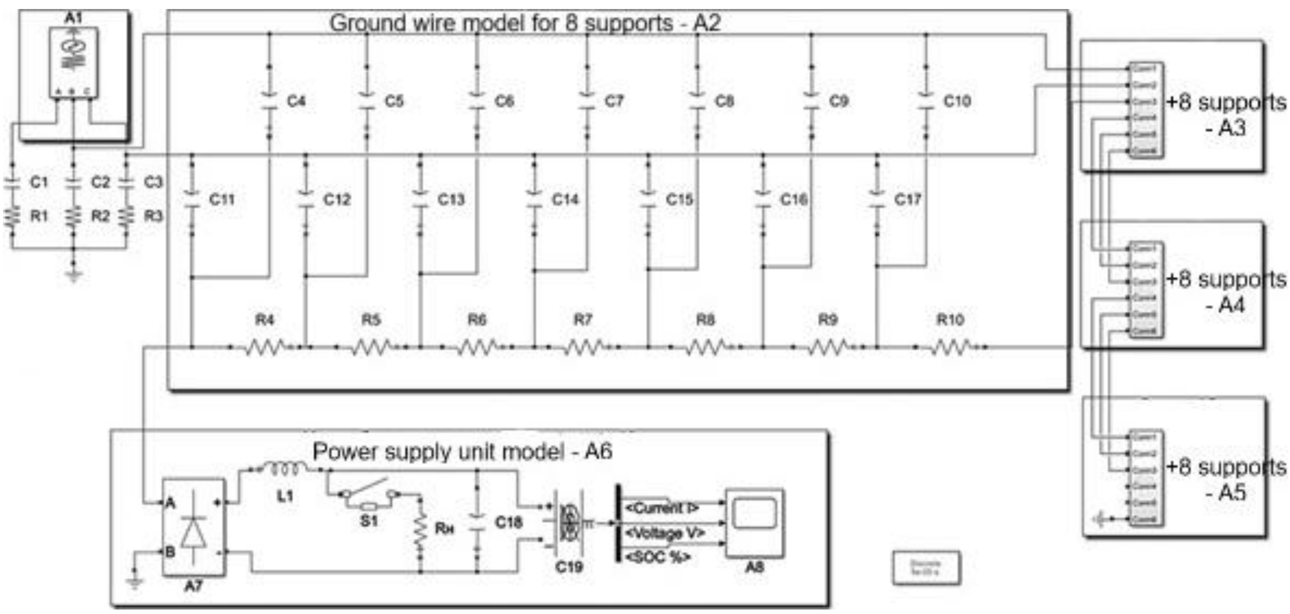

Figure 2 – Simulation model with different number of sections of inter-support spans

$$C_{eq8} = \frac{2E}{U_{gr}^2} = \frac{gr2}{2.25} = \frac{2 \cdot 1800}{2.25} = 1600\ F, \quad (2)$$

where C_{eq} – is the capacity of the supercapacitor block; U – is the lightning line voltage; E – is the required energy to power the controller and transceiver equipment of the local block. Similar formulas are used to calculate the capacity for 16, 24, and 32 supports: $C_{eq16} = 44.4\ F$, $C_{eq24} = 9\ F$ and $C_{eq32} = 2.9\ F$.

AVX supercapacitors were used to build the buffer drive. Their parameters are shown in Table 2.

Due to the fact that the voltage at the ground wire terminals depends on the number of support spans, and the voltage of the selected brand of supercapacitor is 2.7 V, it is necessary to dial them into the battery connected in series. The value is rounded up to an integer. In this case, the capacity of one supercapacitor in a block is determined from expressions (3):

$$C_{SC8} = \frac{C_{eq8}}{N_S} = \frac{1600}{1} = 1600\ F, \quad (3)$$

where C_{SC} – is the capacity of one supercapacitor; and N_S – is a number of supercapacitors in a series-connected unit. Similar formulas are used to calculate the capacity for 16, 24, and 32 supports: $C_{SC16} = 3.25\ F$, $C_{SC24} = 1.125\ F$ and $C_{SC32} = 0.52$. To gain the calculated capacity of the supercapacitor, taking into account the required voltage, it is necessary to turn on in parallel the series-connected supercapacitor blocks C_{SC8}, C_{SC16}, C_{SC24}, C_{SC32}.

As a result of simulation experiments, dynamic characteristics are obtained – the charge time of the supercapacitor for a different number of reference spans. The simulation results are presented in Table 3.

As part of the simulation study, the dependencies of the load voltage on the load current were analyzed for several configurations characterized by varying numbers of reference spans.

The dependence of the load current on the voltage at the ground wire terminals is shown in Figure 3.

From the results of simulation experiments (Figure 3), it follows that the voltage as a function of the load current changes in a quadratic dependence on the number of supports in the inter-tank span.

The conducted research led to the devel-

Table 1 – Ground wire stress for different number of inter-support spans

Number of inter-support spans	8	16	24	32
Lightning rod voltage, V	1.5	9	20	35

Table 2 – Technical characteristics of supercapacitors

Number of supports	The brand of the supercapacitor	U, V	I, A	C, F	E, W*hour
8	SCCZ1EB308SCB	2.7	2165	3000	3.0375
16	SCCX50B227SSBLE	2.7	144	128	0.18
24	SCCW50B127SSBLE	2.7	83	120	0.12
32	SCCV40B506SRBLE	2.7	39	50	0.05

Table 3 – Simulation results

Number of supports	U, V	I, A	Supercapacitor capacity, F	Charging time, s	% of remaining charge during transmission
8	1.5	0.3	1600	17926780 (298780 minutes)	-
16	9	0.57	13	9273 (155 minutes)	28
24	20	0.82	9	2610 (44 minutes)	37
32	35	1.1	6.8	1091 (18 minutes)	49

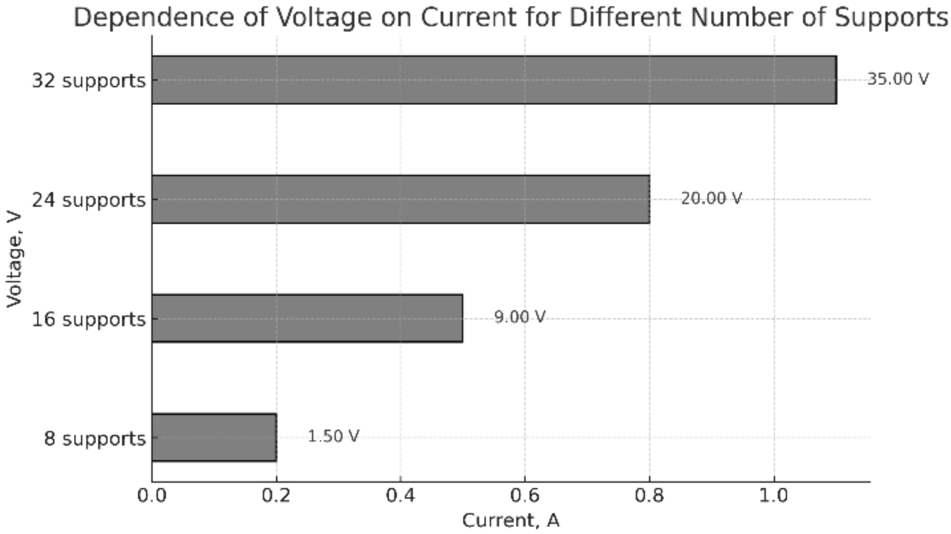

Figure 3 – Dependence of the load current on the voltage at the ground wire terminals

opment of energy-efficient control algorithms for local unit power sources that minimize consumption and rely on renewable energy inputs. Requirements were established for power supply devices structurally integrated into transmission line supports, and two practical technical configurations of such devices were implemented. The necessity of employing supercapacitors was substantiated in order to ensure the reliable operation of transceiver modules in systems with high internal resistance. To analyze the energy characteristics of induced currents generated during lightning discharges, substitution schemes and simulation models of a 500 kV transmission line section with portal-type supports were constructed. Additionally, a methodology for determining the technical parameters of supercapacitors and for selecting their appropriate types was proposed for line sections containing 8, 16, 24, and 32 spans.

Conclusions

Analyzing the results obtained, we can conclude that the induced voltage from 8 poles is not enough to ensure a stable power supply to the local unit. When the number of supports is 16, the supercapacitor unit is fully charged in 155 minutes. After the end of the receiving and transmitting energy cycle, 28% of the charge remains in the supercapacitor. The most suitable and optimal results on the charge of the supercapacitor block were obtained using induced voltage from 24 and 32 supports. In both experiments, the supercapacitor was charged almost to its full charge level (98%) in 19 minutes. After the end of the transmit-receive cycle, 37% and 49% of the energy remains in the supercapacitor, respectively.

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Қашықтан бақылау жүйелері үшін дәстүрлі емес электрқуат көздерін әзірлеу

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***Аңдатпа.** Зерттеуде жоғары вольтты әуе электр желілерінде (ЖВЭБӘЖ) орнатылған қашықтықтан бақылау құрылғылары үшін автономды энергия көздерінің зерттелгені қарастырылады. Электромагниттік энергияның өткізгіштерден трансмиссиялық мұнаралардың металл элементтеріне индукциясын бағалау бойынша тәжірибелер жүргізілді. Сонымен қатар, жерге қосу сымында индукцияланған энергиямен жұмыс істейтін жергілікті бақылау қондырғыларының электрмен жабдықтау жүйелерін тұрақтандырудың техникалық шешімдерін анықтау үшін модельдеуге негізделген теориялық талдау жүргізілді.*

***Кілт сөздер:** жоғары вольтты электр беру әуе желілері, дәстүрлі емес қуат көздері, қоздырғыш энергия, жерге қосу сымы, суперконденсатор.*

Разработка нетрадиционных источников электропитания для систем удаленного мониторинга

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***Аннотация.** Рассматриваются потенциальные автономные источники энергии для устройств дистанционного мониторинга, установленных на высоковольтных воздушных линиях электропередачи (ВВЛЭП). Были проведены эксперименты по оценке индукции электромагнитной энергии от проводов грозотросов, находящихся под напряжением, к металлическим элементам опор электропередачи. Кроме того, был проведен теоретический анализ, основанный на моделировании, для определения технических решений для стабилизации систем электроснабжения локальных блоков мониторинга, питающихся от энергии, индуцируемой в проводе заземления.*

***Ключевые слова:** высоковольтные воздушные линии электропередач, нетрадиционные источники электропитания, наведённая энергия, грозотрос, суперконденсатор.*

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