A REVIEW ON NEW METHODS FOR INCREASING THE AMPACITY OF UNDERGROUND POWER CABLES: COOL AND PHOTOVOLTAIC PAVEMENTS

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PREGLED NOVIH METODA ZA POVEĆANJE TRAJNO DOZVOLJENOG OPTEREĆENJA PODZEMNIH ELEKTROENERGETSKIH KABLOVA: HLADNI I FOTONAPONSKI TROTOARI

A REVIEW ON NEW METHODS FOR INCREASING THE AMPACITY OF UNDERGROUND POWER CABLES: COOL AND PHOTOVOLTAIC PAVEMENTS

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Uvođenje hladnih i fotonaponskih trotoara u tehniku podzemnih elektroenergetskih kablova može doprineti smanjenju globalnog zagrevanja i naše zavisnosti od fosilnih goriva. U tom slučaju, hladni ili fotonaponski trotoar bi snizio temperaturu površine trotoara iznad nekog podzemnog kablovskog voda, što bi otvorilo mogućnost za značajno povećanje njegovog trajno dozvoljenog opterećenja. Hladni trotoar bi samo ublažio efekat gradskog toplotnog ostrva, dok bi fotonaponski trotoar ublažio ovaj efekat i istovremeno proizvodio električnu energiju bez emisije gasova staklene bašte. U ovom radu su predstavljene i razmatrane različite postojeće i nove metode za povećanje trajno dozvoljenog opterećenja podzemnih kablovskih vodova. Na osnovu uporedne procene, istaknute su njihove prednosti i nedostaci. Takođe, identifikovani su faktori koji utiču na izbor metode.

Ključne reči: *elektroenergetski kabl; fotonaponski trotoar; hladni trotoar; trajno dozvoljeno opterećenje*

The introduction of cool and photovoltaic pavements in underground power cable engineering can contribute to reducing global warming and our dependency on fossil fuels. In this case, a cool or photovoltaic pavement would decrease the temperature of the pavement surface above an underground cable line, which would leave open the possibility for a significant increase in its ampacity. A cool pavement would only mitigate the Urban Heat Island effect, while a photovoltaic pavement would reduce this effect and at the same time generate electricity without emissions of the greenhouse gases. In this paper, the various existing and new methods for increasing the ampacity of underground cable lines are presented and discussed. By means of a comparative evaluation, their advantages and disadvantages are highlighted. In addition, the factors that determine the selection of the method are identified.

Key words: *ampacity; cool pavement; photovoltaic pavement; power cable*

1 Introduction

According to [1-3], surface temperatures of conventional asphalt-pavements can be up to 48-71.1 °C in summer. Cool pavements, i.e. cement-based grouting materials utilizing recycled ceramic waste powder, high-reflectance pavements and white pavement coatings were found to reduce these temperatures by 10-20 °C [2,4]. In addition, by means of numerical simulations, it was found in [1,2] that these temperatures can be reduced by much more than 20 °C, which certainly remains possible. It is shown in Figure 1 how the surface radiation properties (emissivity and absorptivity) affect the surface temperature of an asphalt road. Thermal infrared and visible images of the asphalt road (with light and dark segments) are shown on the left and right sides of the Figure 1, respectively. It is evident from this figure that the temperature of the light segment is about 17 °C lower than the temperature of the dark segment.

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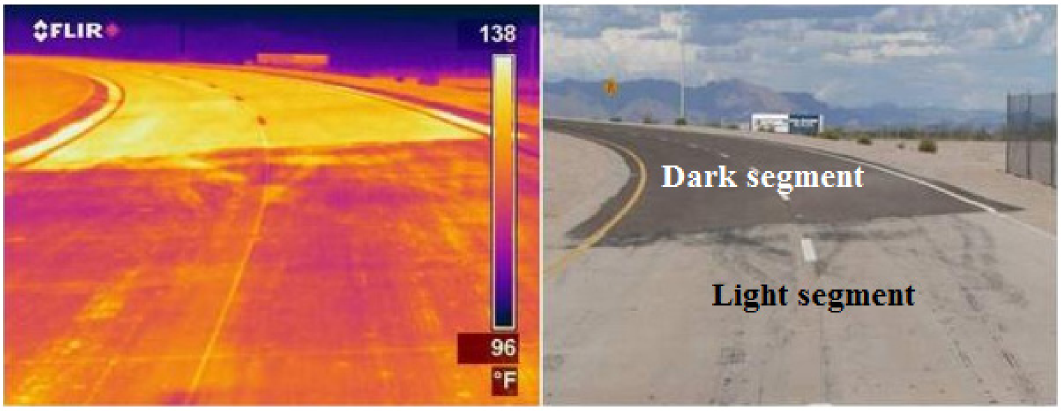

Figure 1. Effect of the surface radiation properties on the surface temperature of an asphalt road (the source of these images: https://heatisland.lbl.gov/coolscience/cool-pavements).

Moreover, a photovoltaic pavement can reduce the temperatures by almost 11-15 °C [3]. Thus, the effect of the photovoltaic pavement on the thermal environment of underground power cables could be identical to the effect of any cool pavement. This means there is a possibility that photovoltaic pavements may be used in a similar manner as cool pavements to increase the ampacity of underground power cables.

2 Conventional methods

The ampacity of an underground power cable is very sensitive to changes in the surrounding thermal environment. The soil parameters affecting the cable ampacity are thermal conductivity, thermal diffusivity and soil temperature [1]. It is possible to control the thermal conductivity and diffusivity of soils using special cable beddings, the soil temperature using systems for forced cooling, and all the three parameters using systems for irrigation [1]. These conventional methods are illustrated in Figure 2. It should be noted here that the systems for forced cooling of underground power cables can be realized as water or oil cooling. Figure 2b shows only water pipe cooling systems.

3 New methods

After studying the results reported on the Urban Heat Island effect [3,4], the authors of the references [1,2] came to the idea that cool pavements can be used to increase the ampacity of underground power cables. In this manner, according to [1], the ampacity of a 110 kV underground cable line can be increased up to 26.7 % for the most unfavorable summer conditions. Moreover, according to [2], the ampacity of the same cable line adjacent to heating pipeline can be increased up to 25.4 % for the most unfavorable summer conditions and up to 8 % for the most common winter conditions. The percentages for which the ampacities of these cable lines can be increased are very large in relation to the increases that can be obtained using the conventional methods.

In comparison with the conventional methods, new methods do not use systems for forced cooling of the cables or systems for irrigation of the cable bedding. The new methods are based on the radiation properties of the earth's surface above the cables, and for their successful implementation the following is necessary: (i) to completely fill the trench along the entire cable route with thermally stable bedding or quartz sand, (ii) to pave the trench along the entire cable route with a cool pavement or to coat the top surface of the trench along the entire cable route with a high-reflectance coating, and (iii) to use solid materials and white coatings that have absorptivity-to-emissivity ratios of below 0.6, i.e. materials whose surfaces absorb less heat from the Sun than they emit to the environment. These innovative methods for increasing the ampacity of underground power cables are illustrated in Figure 3.

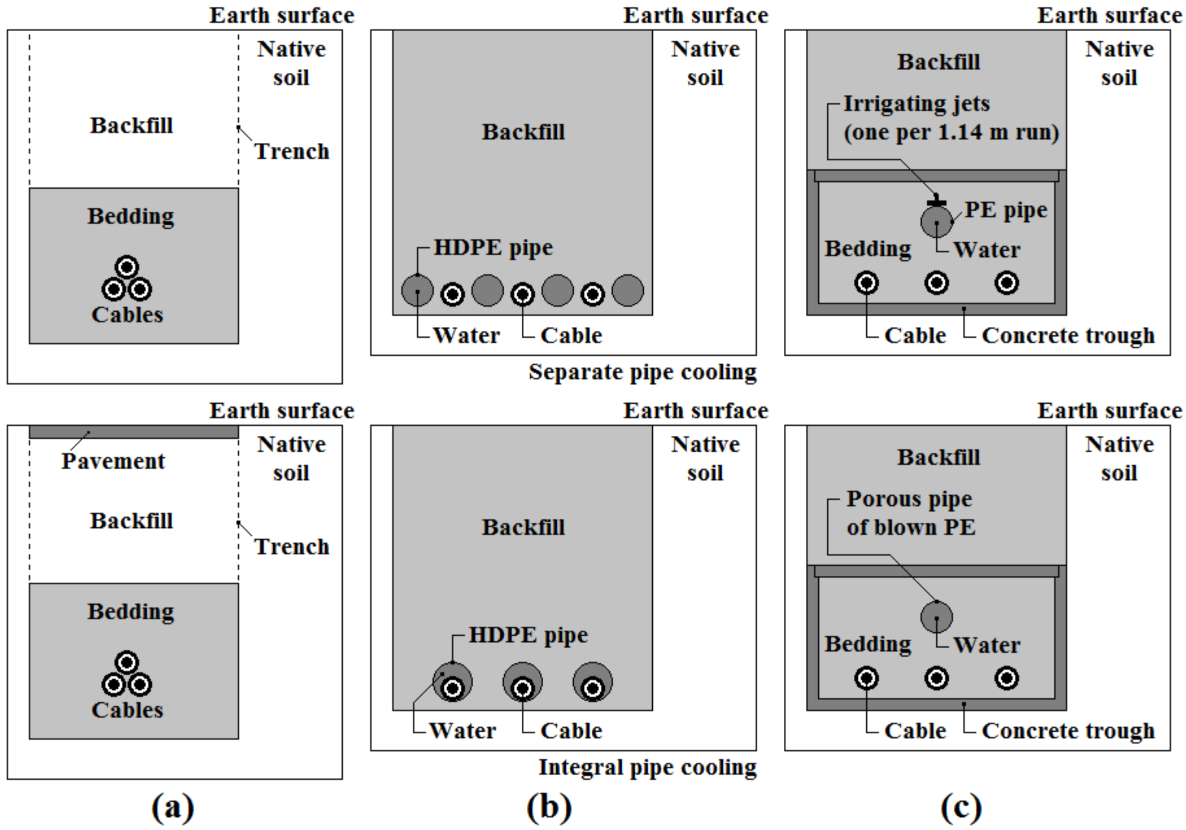

Figure 2. Conventional methods for increasing the ampacity of underground power cables: (a) special cable beddings, (b) systems for forced cooling, and (c) systems for irrigation; where HDPE and PE denote high-density polyethylene and polyethylene, respectively.

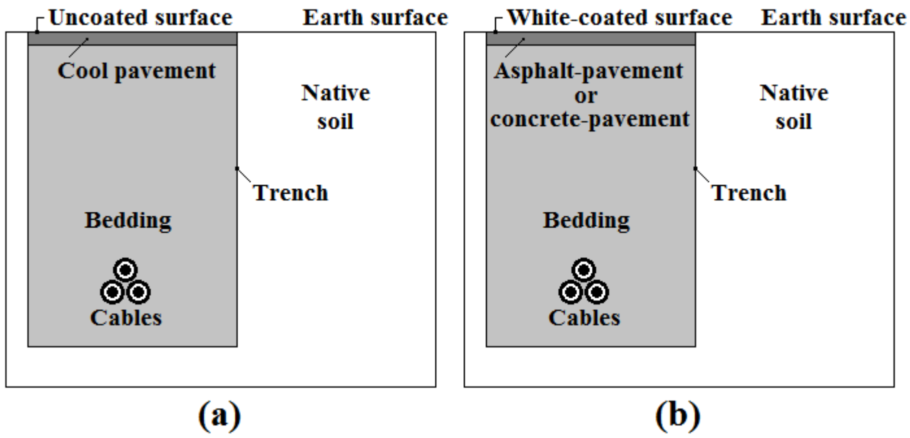

Figure 3. New methods for increasing the ampacity of underground power cables: (a) cool pavement with uncoated surface, and (b) asphalt- or concrete-pavement with white-coated surface.

4 Other possible methods

According to [5], a conventional photovoltaic pavement consists of: (i) a transparent layer made of high-strength and textured glass material, on which different vehicles can drive on and that can be walked upon, (ii) an optical layer with air gaps/compartments to transmit the load around the PV (photovoltaic) cells, and (iii) an insolating/base layer that is further used to transmit the load to the subgrade structure. From the transparent and optical layers sunlight will reach up to the PV cells. The transparent layer is made rough enough to ensure great traction in order to prevent the vehicles from skidding, as well as water-proof so that it can prevent PV cells, other electronics (light-emitting diodes, microprocessors, sensors etc.) and heating elements beneath it. Sunlight is passed through the air gaps of the optical layer to the PV cells embedded within the gaps. The insolating/base layer distributes energy collected from the electronics, as well as data from various signals. Dezfooli et al. [6] developed and tested a prototype of photovoltaic pavement consisting of the PV cells embedded between two porous rubber layers, of which the upper layer is made of transparent rubber. The layout and number of layers of the photovoltaic pavement designed by Dezfooli et al. [6] are identical to the conventional one. Figure 4 shows the general design of conventional photovoltaic pavements.

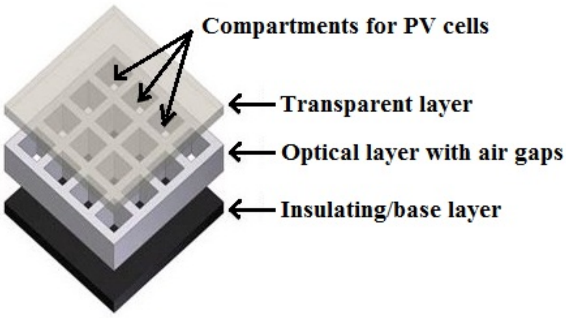

Figure 4. General design of conventional photovoltaic pavements.

In order for this emerging technology to be used for increasing the ampacity of underground power cables, the equivalent thermal conductivity of a photovoltaic pavement (between the lower surface of the subgrade structure and the upper surface of the transparent layer) should be greater than or approximately equal to the thermal conductivity of the cable bedding. Moreover, the photovoltaic pavements must be combined with a system for forced cooling, a hybrid energy system or a ventilation channel. If this can be ensured, then four manners of applying this technology in underground power cable engineering are possible, such as: one with a system for forced cooling (Figure 5a), one with a hybrid energy system (Figure 5b) and two with a ventilation channel (Figure 5c). The applicability of this technology will be considered and experimentally confirmed in the nearest future. In another paper prepared for this conference, it will be demonstrated through numerical simulations that this technology can be used for increasing the cable ampacity.

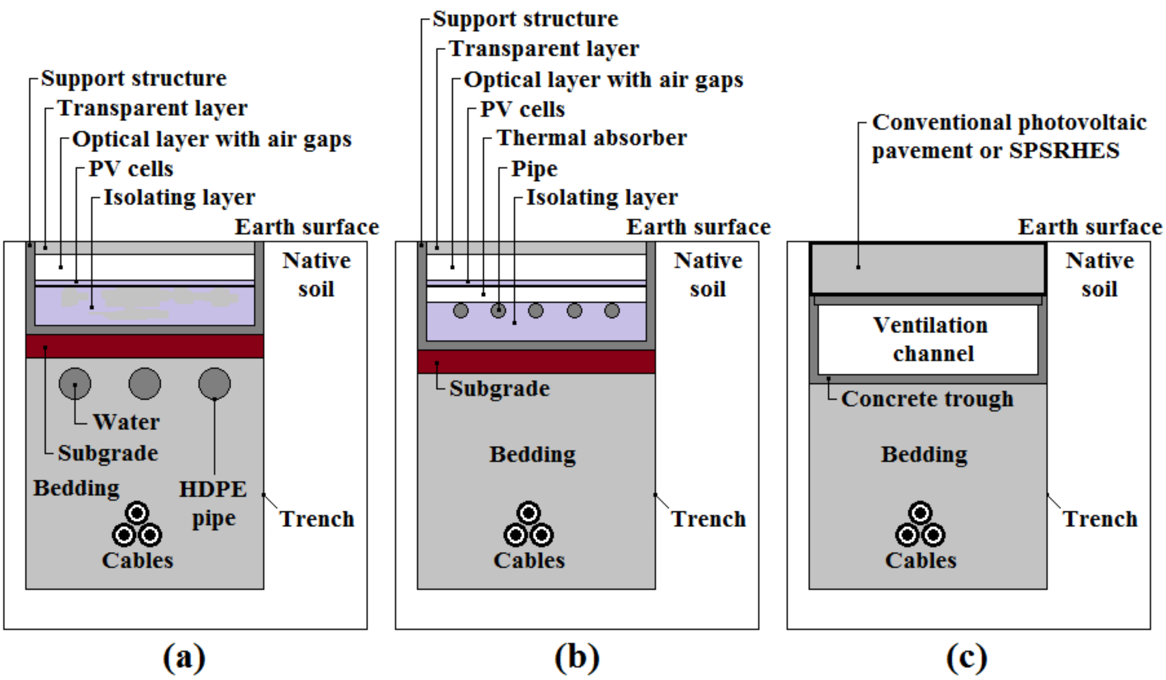

Figure 5. Other possible methods for increasing the ampacity of underground power cables: (a) conventional photovoltaic pavement combined with a system for forced cooling, (b) solar-pavement and soil-regenerator hybrid energy system, abbreviated as SPSRHES, and (c) conventional photovoltaic pavement or SPSRHES combined with a ventilation channel.

5 Advantages and disadvantages of new methods

5.1 Advantages

The advantages of methods for increasing the ampacity of underground power cables using the cool pavements are as follows:

- For the same price of the cables and all the associated equipment, an increase of up to 26.7 % in the cable ampacity compared to the corresponding base case can be provided [1,2].
- These methods do not have to be too expensive, they can be easily implemented within current practice and they would result in significant economic benefits [1,2].
- Any cost for periodic cleaning, maintenance or resurfacing will be quickly paid back by these methods [2].
- Application of these methods would lead to the elimination of all possible hot spots caused by unfavorable conditions in the soil along a cable line route [1,2].
- The cool pavements above the cables can contribute to mitigation of the Urban Heat Island effect.

5.2 Disadvantages

The disadvantages of methods for increasing the ampacity of underground power cables using the cool pavements are as follows:

- These methods will require periodic maintenance and cleaning to preserve the pavement surface radiation properties. Compared with the dimensionally-optimized cable bedding, the methods require up to 2.5 times higher volume of the bedding material, and up to 2.5 times higher volume of the native soil must be transported to other places [1,2]. Such methods will definitely increase the costs of construction and maintenance, i.e. the initial costs [1,2].
- The cool pavements do not produce electricity.
- The life span of cool pavements with white-coated surfaces is the same as the life span of conventional asphalt-pavements.

6 Advantages and disadvantages of other possible methods

6.1 Advantages

The advantages of methods for increasing the ampacity of underground power cables using the photovoltaic pavements would be as follows:

- The main advantage of these methods is that they can significantly increase the ampacity of underground power cables.
- The photovoltaic pavements above the cables can contribute to almost 0.8 °C decrease of the ambient temperature compared to the conventional asphalt-pavements, which could mitigate the effect of Urban Heat Island [3].
- Electricity produced by a photovoltaic pavement can be capable to cover a part of the energy demand, for example, for electric lighting in the outdoor urban areas or for ventilation purposes in the channels, which would reduce consumption of fossil fuels and pollution from the conventional electricity generation processes [3].
- The life span of photovoltaic pavements is 2.5-4.3 times greater than the life span of conventional asphalt-pavements [7].
- The photovoltaic pavements are modular, so repairs will be much easier and quicker. In case of defect, the photovoltaic panels could be swapped out and reprogrammed quickly and then can be inserted back [7].
- The elimination of all possible hot spots in the soil along a cable line route.

6.2 Disadvantages

The disadvantages of methods for increasing the ampacity of underground power cables using the photovoltaic pavements would be as follows:

- Each method would have a very high initial cost. The construction cost of a photovoltaic pavement above the cables is about three times higher than the construction cost of any conventional asphalt-pavement.

- Surfaces of photovoltaic pavements accumulate dust, rubber, salt and so on, which block the sunlight. Accordingly, each method would require proper and regular maintenance services, and therefore also maintenance costs.
- By placing the PV cells between the transparent (a polycarbonate sheet or porous rubber) and isolating (porous rubber) layers, the conventional photovoltaic pavements showed up to 50 % reduction in power conversion efficiency [6].

7 Selection between the different methods

By controlling the thermal environment, the existing underground cable lines may be able to transmit more electricity. There are several factors that should be taken into account in order to select the appropriate method for increasing the ampacity of an underground cable line. According to [8], the factors that determine the method could be as follows: (i) the condition of the existing assets; (ii) the characteristic of the rating constraint; (iii) the budgetary constraints; (iv) the time constraints; and (v) the transient availability of an underground cable line during outages.

If the existing assets are due for reconstruction within a short period, the upgrading of an underground cable line could be a good choice for the increasing its ampacity. In the case of new assets, this option results in early asset write-off costs.

With respect to the level of the increase in the cable ampacity, the methods differ significantly. One of the two methods illustrated in Figure 5c could achieve the highest ampacity increase due to the ventilation. The methods presented in Figures 5a and 5b can also achieve considerable increases. The increase in the cable ampacity could be impossible by the methods in Figures 5a and 5b if a system for forced cooling or a hybrid energy system is not combined with the photovoltaic pavement. Finally, the methods in Figures 3a and 3b do not require any periodic coating in order to preserve the pavement surface radiation properties. This probably represents the best possible solution. Furthermore, all the methods depend on the weather conditions.

The modifications required for the ampacity increase are related to the budgetary and time constraints, as well as to the availability. The SPSRHES combined with a ventilation channel is the method that requires most modifications in the cable trench. Hence, it is the most expensive method. Each method presented in Figure 5 requires many modifications in the cable trench as well. The methods in Figures 3a and 3b require small modifications which could be quickly paid back.

8 Conclusion

Methods for increasing the ampacity of underground cable lines have been presented. The construction of new cable lines or reconstruction of existing cable lines using the cool and photovoltaic pavements has been described. The applications of systems for forced cooling, hybrid energy systems and ventilation channels in combination with the photovoltaic pavements have also been considered. Finally, the advantages and disadvantages of the new and other possible methods have been listed. All the methods are based on the radiation properties of the pavement surface above the cables. In addition, the factors that determine the selection of the appropriate method have been identified and discussed. Many different factors must be taken into account in the selection of the appropriate method, and the optimal solution varies from project to project.

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10 References

[1] **Klimenta, D., B. Perović, J. Klimenta, M. Jevtić, M. Milovanović, I. Krstić**, Controlling the thermal environment of underground cable lines using the pavement surface radiation properties, *IET Generation, Transmission & Distribution,* Available online: April 5, 2018, DOI: 10.1049/iet-gtd.2017.1298.

[2] **Klimenta, D. O., B. D. Perović, J. Lj. Klimenta, M. M. Jevtić, M. J. Milovanović, I. D. Krstić**, Controlling the thermal environment of underground power cables adjacent to heating pipeline us-

ing the pavement surface radiation properties, *Thermal Science,* Available online: January 7, 2018, DOI: 10.2298/TSCI171103312K.

[3] **Efthymiou, C., M. Santamouris, D. Kolokotsa, A. Koras**, Development and testing of photovoltaic pavement for heat island mitigation, *Solar Energy, 130* (2016), pp. 148–160.

[4] **Mohajerani, A., J. Bakaric, T. Jeffrey-Bailey**, The urban heat island effect, its causes, and mitigation, with reference to the thermal properties of asphalt concrete, *Journal of Environmental Management, 197* (2017), pp. 522-538.

[5] **Xiang, B., X. Cao, Y. Yuan, L. Sun, H. Wu, F. Haghighat**, A novel hybrid energy system combined with solar-road and soil-regenerator: Dynamic model and operational performance, *Energy Conversion and Management, 156* (2018), pp. 376–387.

[6] **Dezfooli, A. S., F. M. Nejad, H. Zakeri, S. Kazemifard**, Solar pavement: A new emerging technology, *Solar Energy, 149* (2017), pp. 272–284.

[7] **Stephy, J., S. J. Keerthi**, A review on solar roadways: The future of roads, *International Journal of Recent Innovation in Engineering and Research, 2* (2017), 3, pp. 104–108.

[8] **Albizu, I., A. J. Mazón, I. Zamora**, Methods for increasing the rating of overhead lines, *2005 IEEE Russia Power Tech*, St. Petersburg, Russia, 2005.