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# Flicker Propagation in Power Networks with Hybrid and Parallel Overhead Transmission Lines

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**Abstract.** The growth of the energy generation from renewable sources necessitates the construction of new overhead transmission lines for the energy transport over long distances. The use of common right of ways (ROW) for several overhead lines becomes more and more popular. The construction of combined AC/DC hybrid power lines is one of possible solutions. The spatial proximity of several power lines in the common ROW intensifies electromagnetic interferences between the lines. These interferences can cause deteriorations of power quality parameters in power grids containing parts with common ROWs. The influence of electromagnetic interferences on the flicker propagation in power networks with hybrid and parallel overhead transmission lines is considered in the offered paper.

## Key words

Transmission lines, electromagnetic interference, power quality, voltage fluctuations, wind energy integration, HVDC transmission.

## 1. Introduction

According to German Renewable Energy Act it is planned to increase the installed offshore wind energy capacity in Germany from 6.5 GW by 2020 up to 15 GW by 2030 [1]. It requires the realisation of a number of measures for power grid optimisation, reinforcement and expansion. A row of new EHV transmission overhead lines must be built to transmit electricity from northern Germany, rich in wind energy, to the main centres of consumption in the south of the country. The construction of HVDC transmission lines is foreseen according to the actual Grid Development Plan.
The use of combined EHV AC/DC hybrid power lines is one of possible solutions for the network development and wind energy integration into the grid.
The use of HVDC power connections in power grids can increase the voltage stability and the power quality due to the reduction of conducted disturbances in electrical networks [2 – 4].
On the other hand the use of common ROW for several overhead lines intensifies electromagnetic interferences between electrical networks containing parts with common ROWs [5 – 13].
The electromagnetic interferences can cause deteriorations of power quality parameters in electrical networks. In [14] was shown that the influence of nearby EHV power lines can cause the violations of international power quality requirements for the voltage unbalances and voltage deviations. Interruptions in function and damages of connected electronic devices can be caused by the influence of nearby EHV power lines.
The offered paper is focused on the analysis of the influence of electromagnetic interferences on the flicker propagation in power networks with hybrid and parallel overhead transmission lines.

## 2. Power grid under study

The analysis of the flicker propagation in power grid was carried out for an example of the 380 kV double-circuit overhead line connection containing two common ROWs.
First ROW is 50 km length and shared by ±500 kV DC line and 380 kV AC line. Both power lines are positioned on the same hybrid tower as it is shown in Fig. 1. The HVDC line is equipped with the metallic return wire (MR), the tower has two ground wires (GW) for lightning protection and two grounded metallic aerial self-supporting cables (MASS) for data transmission as it is shown in Fig. 1.
Second common ROW is shared by 380 kV double-circuit power line and 0.4 kV overhead line as it is shown in Fig. 2. The length of this ROW with parallel lines is 2.5 km.
Fig. 3 illustrates the structure of the MATLAB model of the power grid under study. Each common ROW was simulated as a distributed parameter line block which was parametrized by the function *power_lineparam* [15].

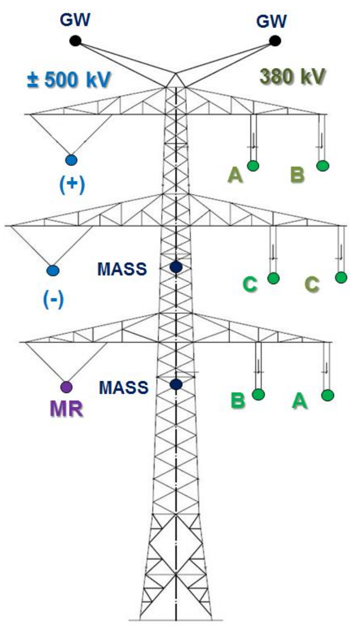


Fig. 1. Hybrid DC/AC tower in the common ROW (50 km)

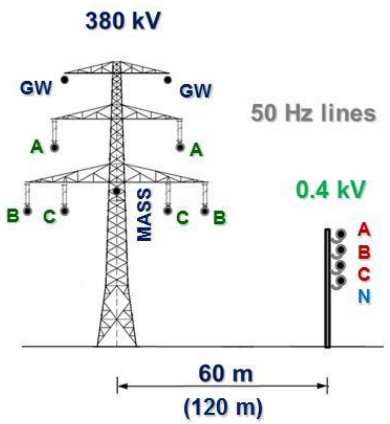


Fig. 2. Parallel OHL in the common ROW (2.5 km)

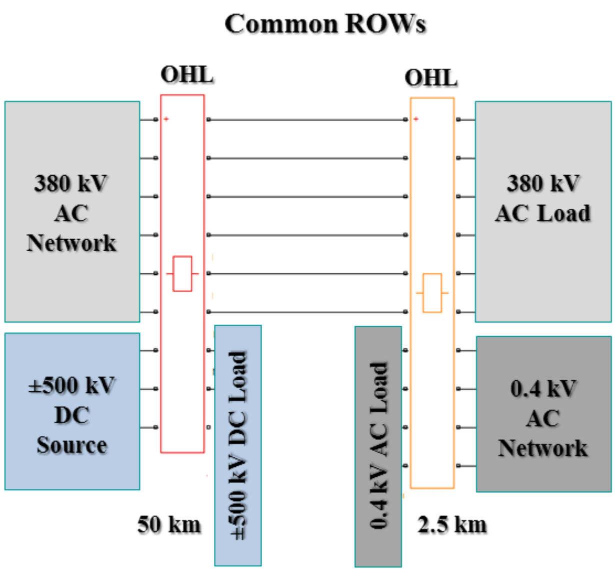


Fig. 3. Structure of the MATLAB model of the power grid under study

This is a standard MATLAB function which computes parameters of parallel or hybrid overhead multi-conductor lines from characteristics of their phase, neutral and grounded conductors and geometry of towers. Self and mutual resistances, inductances, potential coefficients terms are determined taking into account conductor and ground skin effects (depending on the considered earth resistivity).
Fig. 4 illustrates the representation of the ROW with parallel 380 kV and 0.4 kV OHL as the MATLAB model block.

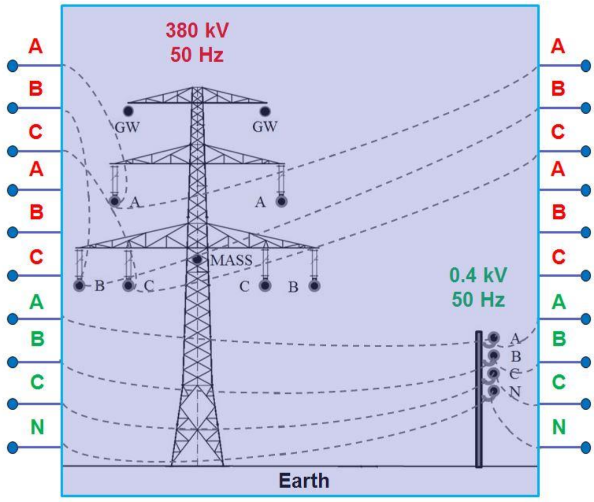


Fig. 4. Representation of the common ROW containing parallel 380 kV and 0.4 kV OHL as the MATLAB model block

The ROW with hybrid DC/AC towers was represented at the model in a similar way.
Grounded wires were considered according to their characteristics in the model blocks intern.
The load current of the modelled 380 kV AC power line is 1800 A in each phase, the load current of the ±500 kV DC power line is 2000 A. The load of the 0.4 kV OHL is 7 kW.
The ±500 kV DC power source was simulated as an ideal DC voltage source. The DC load was simulated as resistances.

## 3. Simulation of flicker sources

### *A. Flicker source in the HVDC power line*

The flicker in HVDC power lines is not a case of consideration in actual standards for power quality. The DC voltage can be very good stabilized by converter control systems and there are no direct galvanic connections of lighting installations to the HVDC power circuits.
On the other hand the use of HVDC connections for the transmission of wind energy over long distances is characterized by permanent changes of the transmitted power due to the significant dependence of the wind farm output active power on the changeable wind speed. It means permanent changes of currents and active power in DC power circuits.

In [16] is shown at an example that the changes of the wind speed can cause the active power oscillations in the DC power circuit within the range of approx. ±12 % of the average value of the considered active power. More intensive DC active power oscillations caused by the changes of the wind speed are presented in [17].
In [17, 18] are shown the fluctuations of currents in the DC power circuits, caused by the changeable wind speed. The DC current oscillations up to approx. ±60 % of the average value of the considered DC current are presented in [17, 18].
The current and active power oscillations in the DC power circuits result from the maintaining constant DC voltage values due to the effect of converter control systems throughout the changes of the input active power from wind generators.
The oscillation frequencies of DC currents and DC active power presented in [16- 18] are within the flicker relevant range.
Taking into account considerations [16- 18] the flicker source in the HVDC power line was simulated. Fig. 5 shows the model of the flicker source on the load side of the HVDC power line. The current and active power oscillations in the DC power circuit were created through the implementation of an ideal AC current source into the model as it is shown in Fig. 5. Fig. 6 and 7 show the simulated current and active power oscillations.

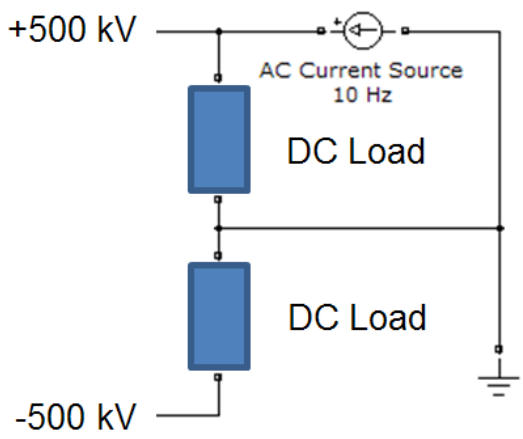


Fig. 5. Model of the flicker source in the DC power circuit

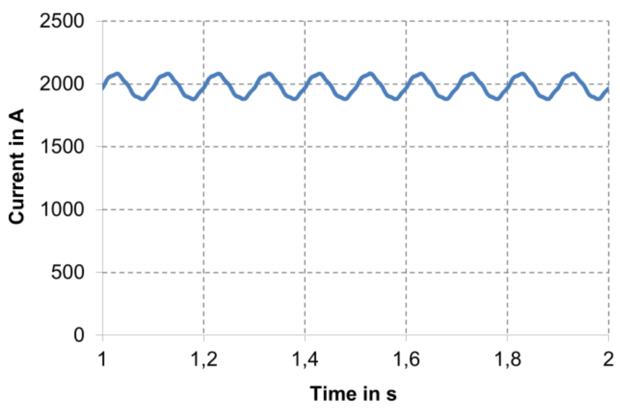


Fig. 6. Current oscillations in the DC power circuit

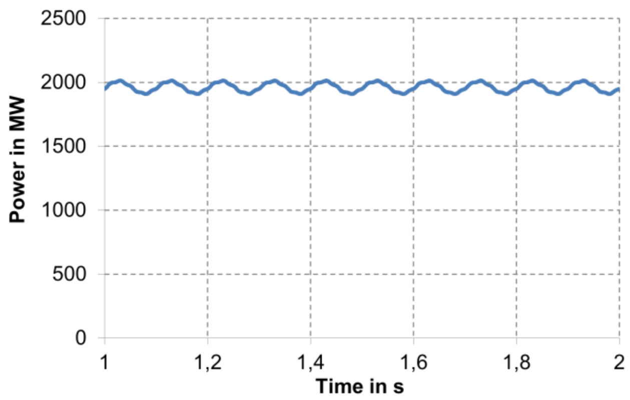


Fig. 7. Active power oscillations in the DC power circuit

From Fig. 6 and 7 it can be seen that the DC active power oscillations are within the range of ±2.5 % of the average value of the considered active power and the DC current oscillations are within the range of ±5 % of the average value of the considered current.
The oscillation frequency of 10 Hz was chosen for a simplified representation of the modulation impact within the flicker relevant frequency range.

*B. Flicker source in the 380 kV power network*

The approach described above was used for the modelling of the flicker source in the 380 kV power network under study. Fig. 8 shows the model of the flicker source in the 380 kV power grid. As it can be seen from Fig. 8 an ideal AC current source was implemented in each phase of the three-phase network on the load side. The frequency of 10 Hz was chosen for each simulated AC current source.

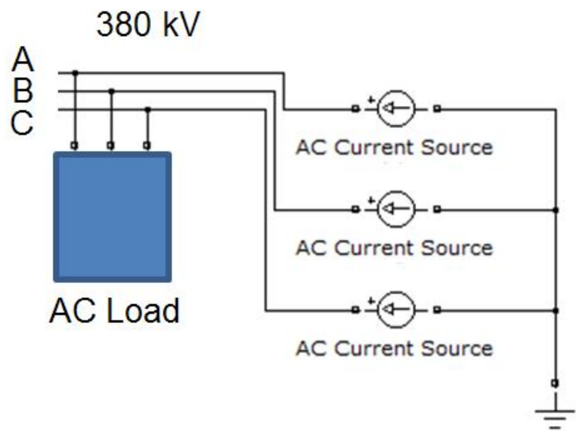


Fig. 8. Model of the flicker source in the 380 kV power grid

## 4. Computational results

*A. Flicker source in the HVDC power line*

In the simulations described below the flicker source was presented only in the HVDC power connection.

The MATLAB simulations have shown that the current oscillations in the DC power circuit can cause the voltage fluctuations in AC power circuits due to the electromagnetic interferences in common ROWs.

Fig. 9 illustrates the oscillations of the phase-to-ground voltage in the 380 kV node caused by the electromagnetic interferences in the common ROW containing HVDC power circuit. It can be clearly seen from Fig. 9 that the instantaneous values of the phase-to-ground voltage are modulated by the frequency of 10 Hz.

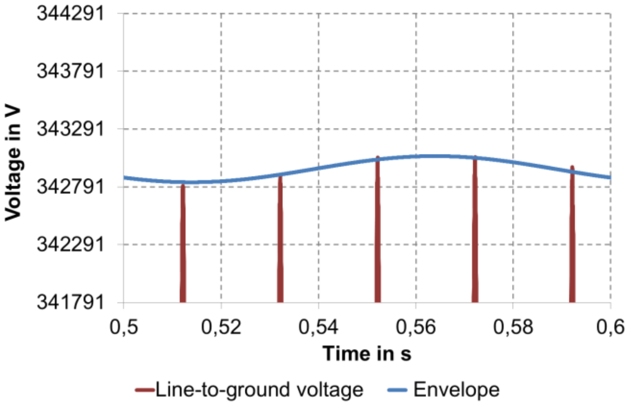


Fig. 9. Voltage fluctuations in the 380 kV network node (flicker source in the HVDC power line)

The relative voltage change caused by the modulation presented in Fig. 9 is ΔU /U = 0.066 %. The relative voltage change ΔU /U was computed according to Annex B in [19]. The voltage oscillations presented in Fig. 9 are characterized by the short-term flicker severity value $P_{st}$ = 0.18. Solcept Open Source Flicker Measurement-Simulator [20] was used for the calculation of the short-term flicker severity value $P_{st}$.

It must be noted that the voltage fluctuations caused by the electromagnetic interferences with HVDC line are practically the same for each phase of the 380 kV line. Therefore the voltage oscillations of phase-to-phase voltages are very small and can be neglected.

Actually there are no established compatibility flicker severity levels for EHV networks. In [21] is noted that planning voltage flicker levels are specified by the system operator or owner. Indicative planning voltage flicker levels for EHV network $P_{st}$ = 0.8 and $P_{lt}$ =0.6 are suggested in [21].

Taking into account the estimation of flicker planning levels from [21] it can be concluded that the simulated operating states of the HVDC transmission line are not critical with respect to the flicker levels in the 380 kV network.

Flicker is defined as an impression of unsteadiness of visual sensation induced by a light stimulus whose luminance or spectral distribution fluctuates with time. From this point of view it is important to estimate the flicker propagation into LV networks which normally contain lighting devices.

Fig. 10 shows the phase-to-ground voltage fluctuations induced in the 0.4 kV overhead line in the power grid presented in Fig. 3.

From Fig. 10 can be seen that the instantaneous values of the phase-to-ground voltage are modulated by the frequency of 10 Hz.

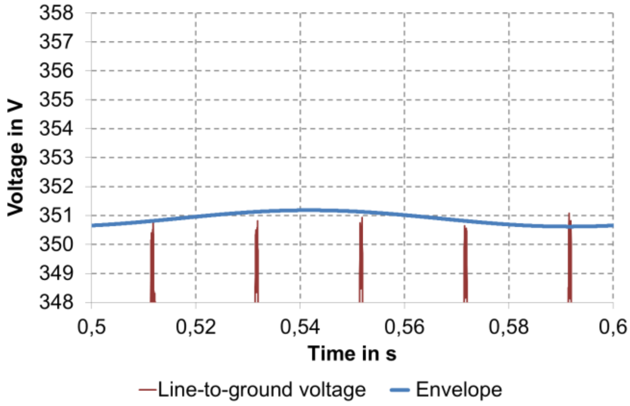


Fig. 10. Voltage fluctuations in the 0.4 kV network node (flicker source in the HVDC power line)

It means that the flicker caused by the current oscillations in the HVDC line under study can propagate into the LV network without direct galvanic connection to the LV power circuits.

The relative voltage change caused by the modulation presented in Fig. 10 is ΔU /U = 0.161 %. The short-term flicker severity level caused by the voltage oscillations presented in Fig. 10 is $P_{st}$ = 0.44.

The way of the flicker propagation in the case under study is: HVDC line – EHV line – LV line. So the flicker in the EHV network is the direct origin of the flicker in the LV network.

The comparison of the flicker values in both EHV and LV networks shows that the flicker value in the LV network is significantly higher than the flicker value in the EHV network. It is an unusual relation. In case of the conventional conductive flicker transfer from EHV to LV network the flicker values in both networks must be the same or slightly different [22, 23].

*B. Flicker source in the 380 kV power network*

The influence of the flicker generated direct in the 380 kV network on the flicker values in the 0.4 kV network in case of the flicker transfer through a common ROW was studied in the simulations described below. The flicker source was simulated only in the 380 kV network as it is shown in Fig. 8.

Fig. 11 shows the simulated voltage fluctuations in the 380 kV network node.

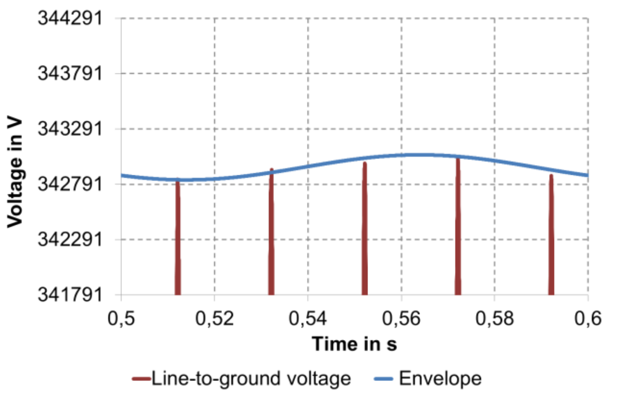


Fig. 11. Voltage fluctuations in the 380 kV network node (flicker source in the 380 kV power grid)

As it can be seen from Fig. 11 and Fig. 9 the flicker source in the 380 kV network was so parametrized that the simulated voltage fluctuations in the 380 kV network node were practically identical in both cases under study.
The relative voltage change in case of oscillations presented in Fig. 11 is ΔU /U = 0.066 %. The short-term flicker severity level caused by the voltage oscillations presented in Fig. 11 is $P_{st}$ = 0.18.
Fig. 12 shows the voltage fluctuations in the 0.4 kV network node caused by the electromagnetic interferences in the common ROW with the 380 kV line.

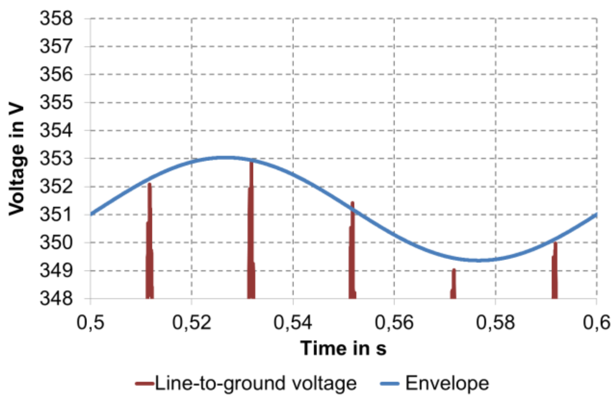


Fig. 12. Voltage fluctuations in the 0.4 kV network node (flicker source in the 380 kV power grid)

The relative voltage change caused by the modulation presented in Fig. 10 is ΔU /U = 1.047 %. The short-term flicker severity level caused by the voltage oscillations presented in Fig. 10 is $P_{st}$ = 2.86.
For the calculation of the short-term flicker severity value $P_{st}$ was used Solcept Open Source Flicker Measurement-Simulator [20].
The established compatibility level for the short-term flicker severity value for LV networks is $P_{st}$ = 1 [24]. With respect to the simulated case it means the violation of the flicker severity limit in the 0.4 kV network due to the electromagnetic interferences with 380kV line in the common ROW.
The different effects of the flicker transfer from EHV to LV network through the same common ROW in case A (flicker source in the HVDC power line) and in case B (flicker source in the 380 kV power grid) can be explained by the different values of 10 Hz currents in the 380 kV line in both cases. The induced 10 Hz currents in the 380 kV line in case A are smaller in comparison with the injected 10 Hz currents in case B.
Practically it means the significant dependence of the flicker propagation from EHV to LV network caused by electromagnetic interferences on the origin of the flicker in the EHV network and on the electrical parameters of both networks under study.

## 5. Conclusions

The paper is focused on the analysis of the influence of electromagnetic interferences on the flicker propagation in power networks with hybrid and parallel overhead transmission lines.
It was shown that the electromagnetic interferences can cause the flicker transfer from one network to other.
It was shown that the flicker caused by the influence of neighbouring EHV power lines in a LV network can violate the limits established by international power quality standards.
It was shown that the flicker propagation from EHV to LV network caused by electromagnetic interferences depends on the origin of the flicker in the EHV network and on the electrical parameters of networks.

## Appendix

Fig. 13 and 14 present DC and AC electric fields of the AC/DC hybrid line calculated using the WinField software [25].

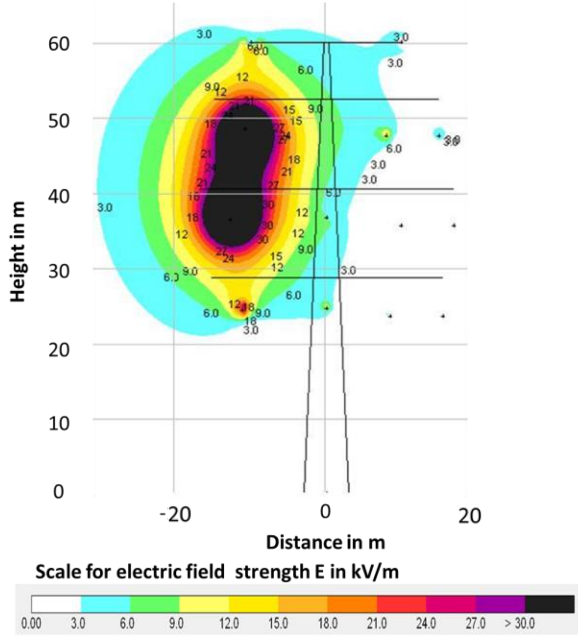


Fig. 13. Electric field strength (stationary DC field)

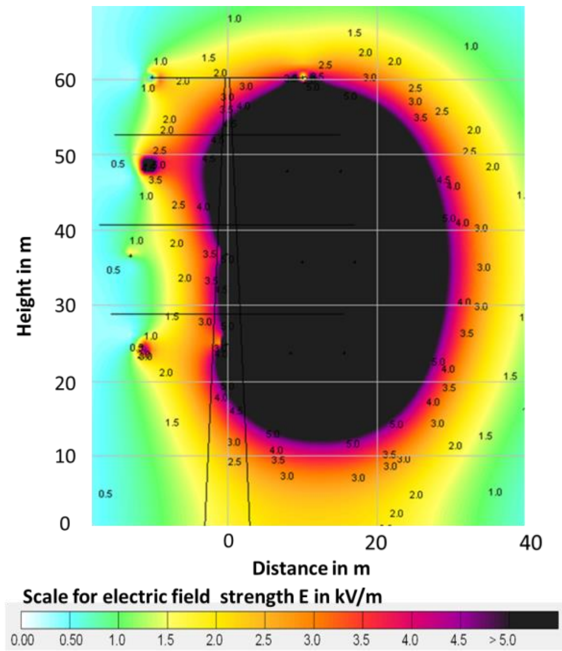


Fig. 14. Electric field strength (50 Hz field)

Taking into account the permissible value of 5 kV/m for the 50 Hz field [26] it can be seen from Fig. 14 that the influence of the 50 Hz electric field must be considered when carrying out the maintenance works on the DC wires of the hybrid AC/DC line. Taking into account the permissible value of 30 kV/m for the DC field [27] it can be concluded from Fig.13 that the influence of the DC stationary electric field can be neglected when carrying out the maintenance works on the AC wires of the hybrid AC/DC line. It must be noted that the influence of the DC corona can increase the DC electric field strength values by a factor of 3 or 4.

Both DC and AC magnetic field have no significant influence on the carrying out of the maintenance works both on DC and AC wires. The corresponding magnetic field values calculated for the AC/DC hybrid line using [25] are all under the limits of 500 µT for DC magnetic field and 100 µT for 50 Hz magnetic field [26].

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