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Highway lighting system simulations using the DIALux evo software to increase the energy efficiency

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Abstract. The design of the highway lighting system involves two essential stages, namely: the lighting system itself and the electrical power supply installation including the protection system. The LED technology that has evolved in recent years offers significant advantages in terms of energy efficiency and obviously for the intelligent control of the lighting system. Special attention is paid to the protection system because LED lighting fixtures contain electronic components that are extremely sensitive to surges, mainly atmospheric ones but also switching ones. These surges will affect the power drivers and LED components, having a negative effect on them by reducing their lifetime. Another aspect is related to the inrush current because in the first half-period the current is variable, after which they stabilize at normal operating conditions. Thus, transient phenomena occur during the switching process. In this sense, to have complete protection, an integrated system composed of miniature circuit breaker, surge protection device and voltage threshold tripping device will be used.

Keywords: LED, highway, system lighting, electrical installation, energy efficiency, overvoltages.

1. Introduction

DIALux software is considered the market leader for interior and exterior lighting design and is available for free. This software offers multiple advantages such as: planning, calculating and visualizing lighting for interior and exterior areas, from entire buildings and individual rooms to parking areas or street lighting. DIALux allows a realistic visualization of road lighting planning as it is an improved version. It also offers multiple additional functions and a good visualization of the results. Dialux automatically calculates the road lighting quality parameters: average illumination, average luminance, general and longitudinal uniformity, surrounding ratio and threshold increment. DIALux offers the following workspaces to create a new project:

- Outdoor and building planning
- Import plan of IFC
- Room planning

- Street lighting
- Simple indoor planning

2. Simulation of the highway lighting system with DIALux

The following are the main steps of the algorithm for designing the lighting system with DIALux software:

1. In the main DIALux window, select the Street lighting option
2. Selection of the planning standard (EN 13201:2015) and description of the highway (expressway) profile
3. Design of the highway (expressway) profile
4. Selection of the lighting class
5. Configuration of the lighting system
6. Selecting and importing luminaires. LED technology for the analyzed case studies is ALT3-168L-385-27K8-5W-CLR.
7. Optimisation of the lighting system
8. Documentation of the highway (expressway) plans

The case studies considered for example are presented as follows:

- Figure 1 shows the simulation of the lighting system for a highway consisting of three lanes in each direction with the arrangement of the opposite poles
- Figure 2 shows the simulation of the lighting system for a highway consisting of two lanes per direction with the arrangement of the two-sided poles (staggered lighting)
- Figure 3 shows the simulation of the lighting system for a highway consisting of two lanes per direction with the arrangement of the median mode

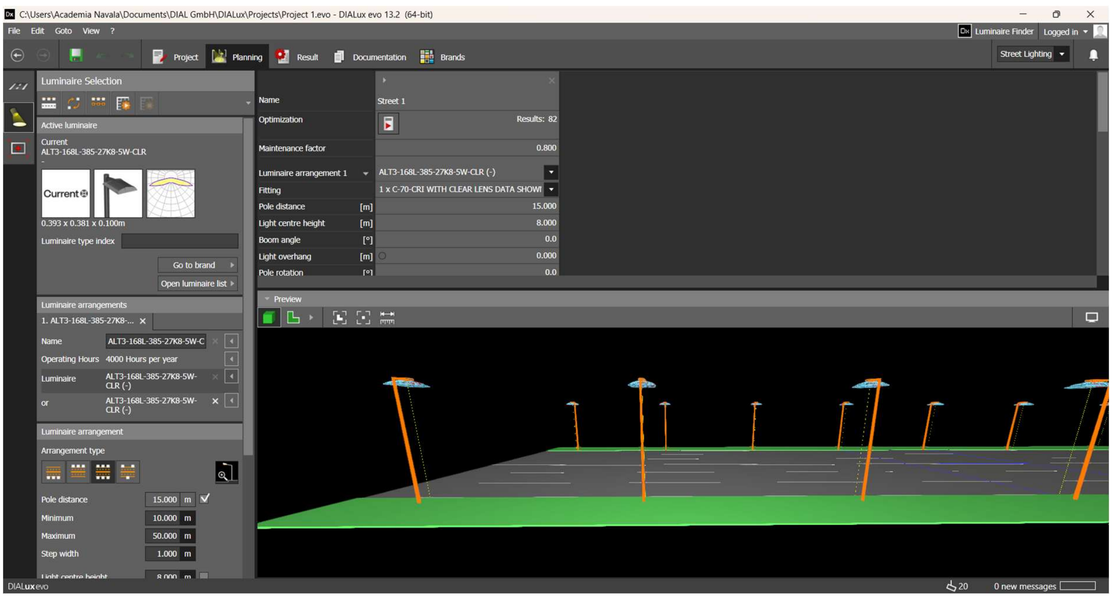

Figure 1. Lighting system simulation in opposite mode

For the case analyzed in figure 1, Dialux automatically calculates the following results:

- Valuation field
- For observer
- For energy efficiency indicators (table 1)

Table 1. Results for energy efficiency indicators

	Symbol	Calculated	Energy Consumption
Street 1	D_p	0.028 W/lx*m²	–
ALT3-168L-385-27K8-5W-CLR (both sides opposite)	D_e	9.6 kWh/m² yr	3096.0 kWh/yr

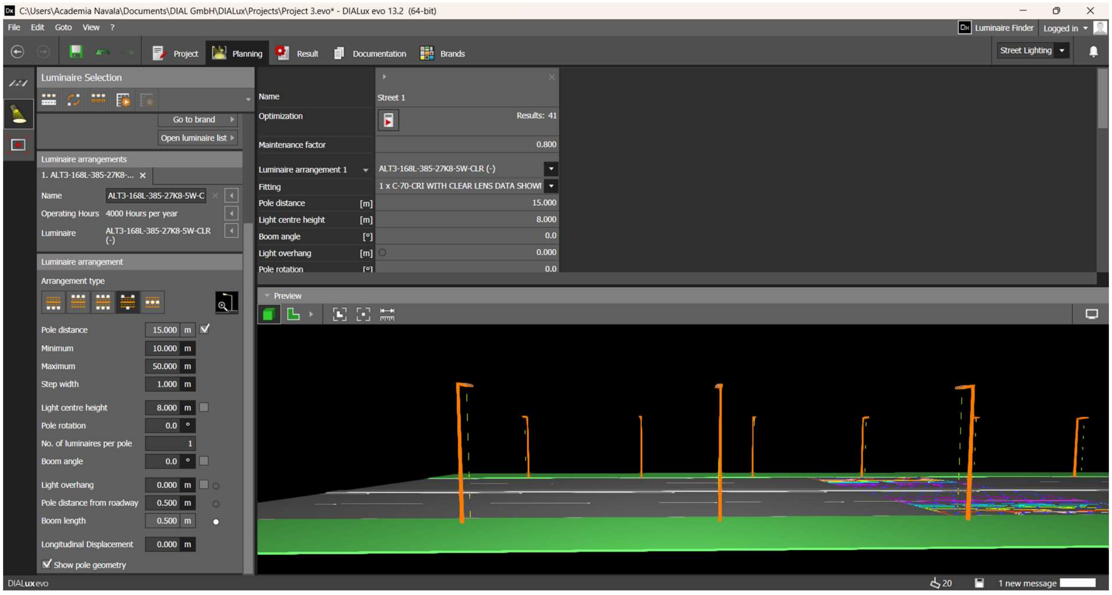

Figure 2. Lighting system simulation in staggered mode

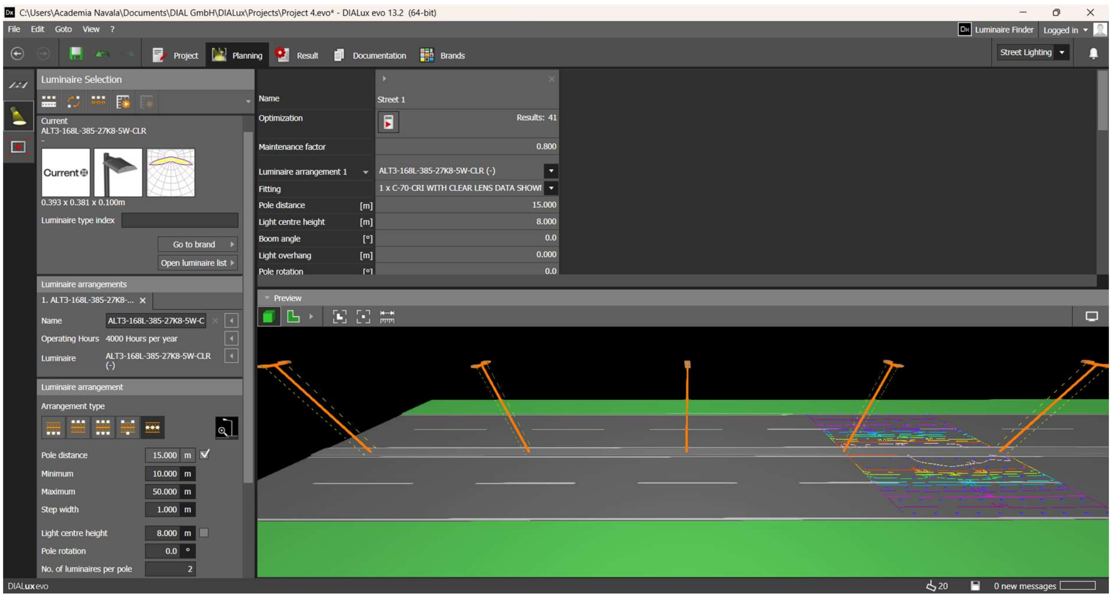

Figure 3. Lighting system simulation in median mode

In table 2 are presented the results for valuation fields (according to EN-13201:2015). A maintenance factor 0f 0.80 was used for calculating for the installation.

Table 2. Results for valuation fields

	Symbol	Calculated	Target	Check
Roadway 1 (M4)	L_{av}	5.95 cd/m²	≥ 0.75 cd/m²	✓
	U_o	0.67	≥ 0.40	✓
	U_l	0.96	≥ 0.60	✓
	$TI^{(3)}$	–	≤ 15 %	
	R_{EI}	0.92	≥ 0.30	✓
Roadway 2 (M4)	L_{av}	5.95 cd/m²	≥ 0.75 cd/m²	✓
	U_o	0.67	≥ 0.40	✓
	U_l	0.96	≥ 0.60	✓
	$TI^{(3)}$	–	≤ 15 %	
	R_{EI}	0.92	≥ 0.30	✓

In figure 4 are presented the pole characteristics and type of LED lamp.

Pole distance	15.000 m
(1) Light spot height	8.000 m
(2) Light point overhang	0.000 m
(3) Boom inclination	0.0°
(4) Boom length	0.650 m
Annual operating hours	4000 h: 100.0 %, 387.0 W
Wattage / route	51858.0 W/km
ULR / ULOR	0.00 / 0.00
Max. luminous intensities Any direction forming the specified angle from the downward vertical, with the luminaire installed for	≥ 70°: 374 cd/klm ≥ 80°: 80.2 cd/klm ≥ 90°: 0.00 cd/klm
Luminous intensity class The luminous intensity values in [cd/klm] for calculation of the luminous intensity class refer to the luminaire luminous flux according to EN 13201:2015.	G*4
Glare index class	D.2
MF	0.80

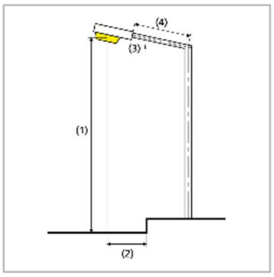

Figure 4. Pole characteristics and type of LED lamps

3. Electric power supply system analysis

Street lighting networks can be considered balanced and with a uniformly distributed load on the line, due to the large number of consumers supplied, located at short distances (figure 5 and figure 6 single respective three phase solution for power supply system).

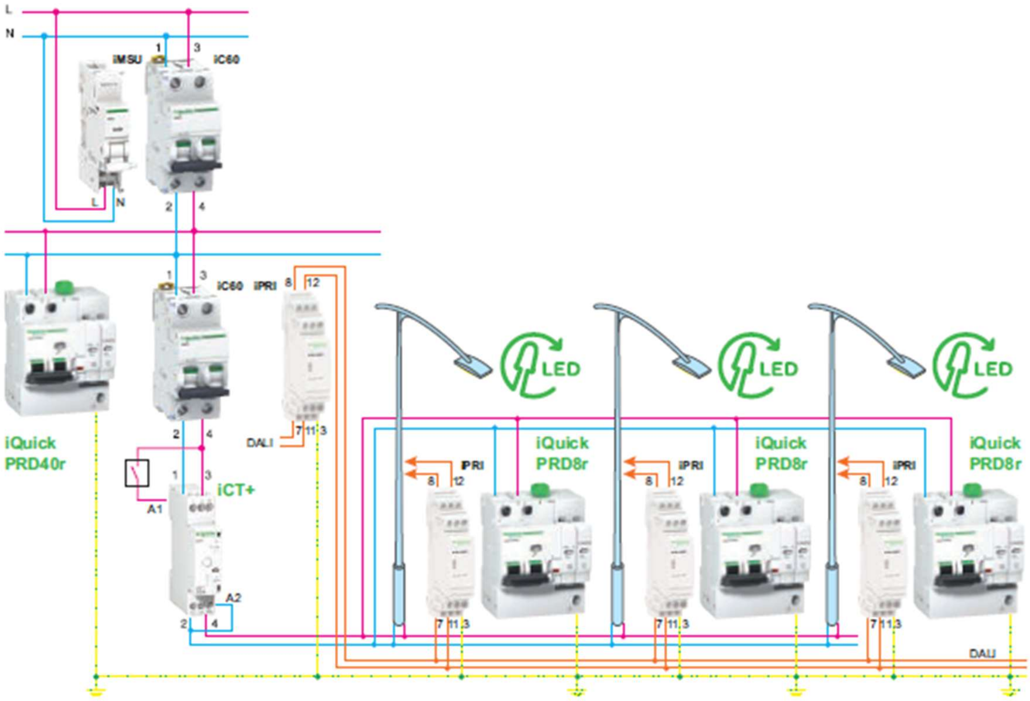

Figure 5. Single-phase alternating current power line with uniformly distributed load:

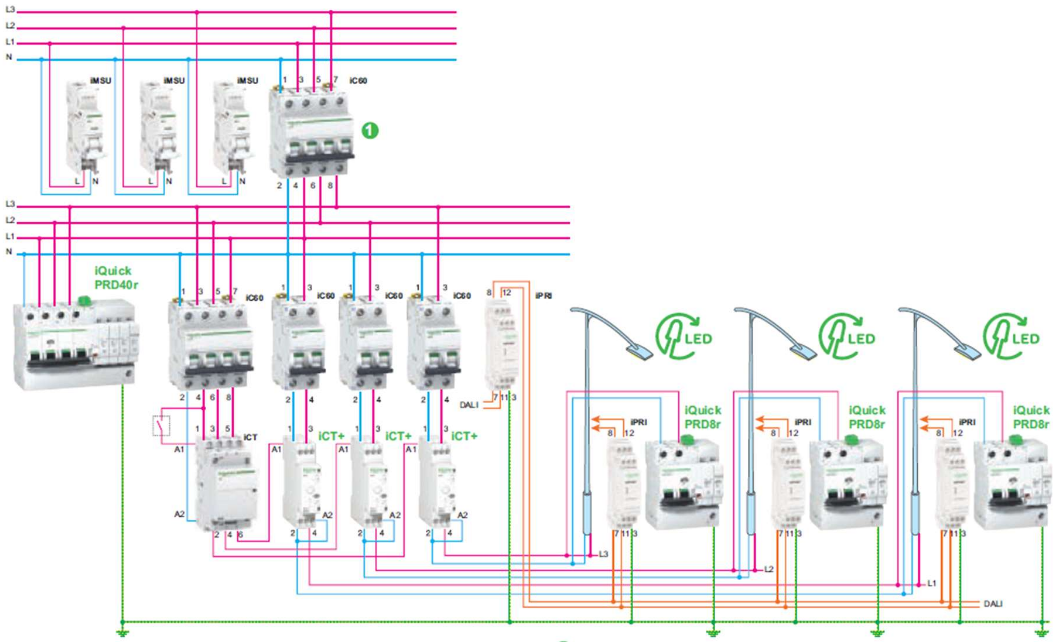

Figure 6. Three phase alternating current power line with uniformly distributed load

Networks that supply such consumers usually have the same cross-section along their entire length and a power factor close to unity. The load of these lines is expressed by the linear load density i_0 [A/m] or p_0 [W/m].

Figure 7 and 8 shows the single-wire electrical power supply diagram for calculating short-circuit currents, choosing the cable conductor cross-section, calculating short-circuit currents, and choosing the circuit breakers (main upstream circuit breaker and downstream circuit breaker).

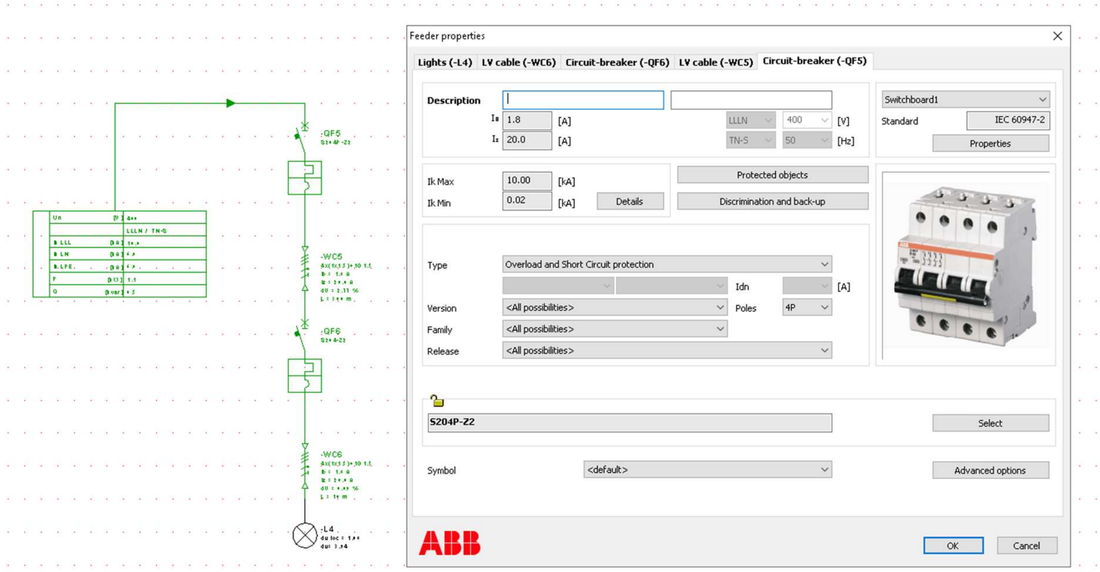

Figure 7. Single-line diagram and characteristics of the upstream circuit breaker for one circuit

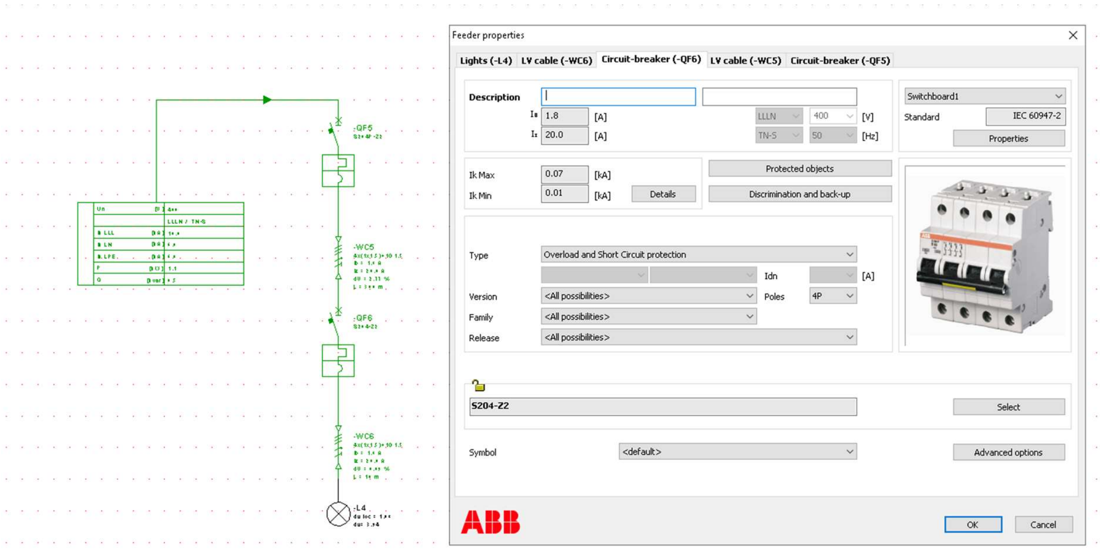

Figure 8. Single-line diagram and characteristics of the pole circuit breaker for one circuit

When an LED luminaire is powered up, it requires a variable inrush current for the first second, and then it stabilizes as soon as the rated operating conditions are reached.

When an LED luminaire is powered up, it requires a variable inrush current for the first second, and then it stabilizes as soon as the rated operating conditions are reached. During the power-up process, three transient phenomena occur: energizing up the luminaire, turning on the dimmer, and powering up the LED module (the light is on).

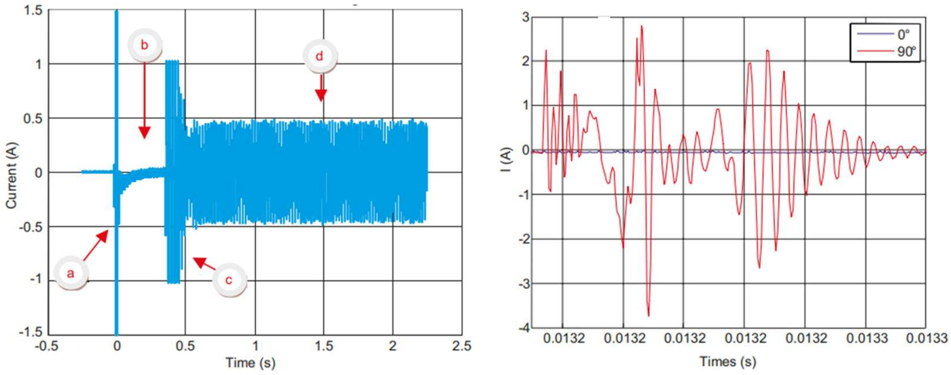

Figure 9. Transient phenomena during LED power-up and the variation of inrush current

The four transient states in Figure 9 have the following meaning: (a) initial power supply, (b))driver power on, (c) energizing the LED module and (d) steady-state operating conditions. When calculating voltage drops, it is known that sections with uniformly distributed load can be replaced with a concentrated load equal to the total load of the respective section and located halfway through it. Figure 10 presents the optimization of the calculation of the entire lighting system supply network where overload and short-circuit protection with circuit breakers and differential devices was chosen.

It results that when calculating voltage drops, sections with uniformly distributed load can be replaced by a concentrated load equal to the total load of the respective section and located halfway there. If the uniformly distributed load is expressed in terms of active powers, the analytical expression of the voltage drop is given by the relation.

$$\Delta U[V] = r_0 \cdot \frac{P \cdot L}{U_n \cdot 2} = r_0 \cdot \frac{P}{U_n} \cdot \left(L_0 + \frac{L'}{2} \right) \quad (1)$$

Where:

r_0 is the specific resistance in Ω / km

$P = p_0 \cdot L$ represents the total load of the electric line, in kW.

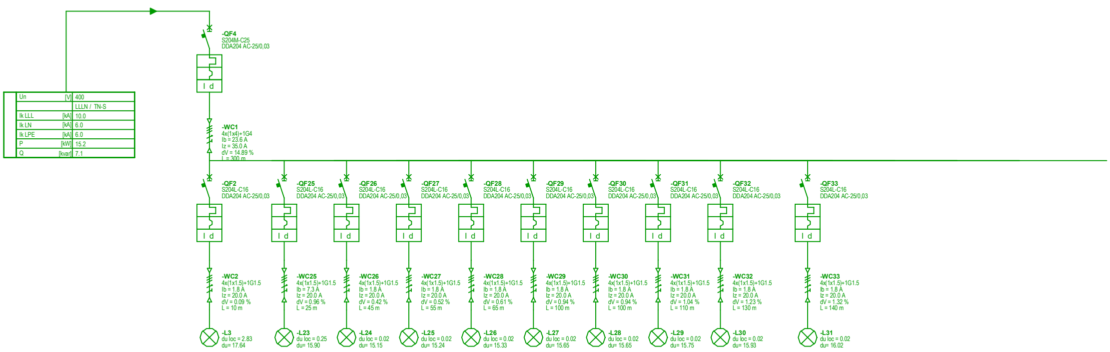

Figure 10. Single-line diagram for the entire analysed network

To study the selectivity of the protections based on the single-line diagram of the electrical power supply network in figure 10, the DocWin software was used.

The selectivity analysis between upstream and downstream switching equipment (the last lighting pole was taken into account) is presented in Figure 11.

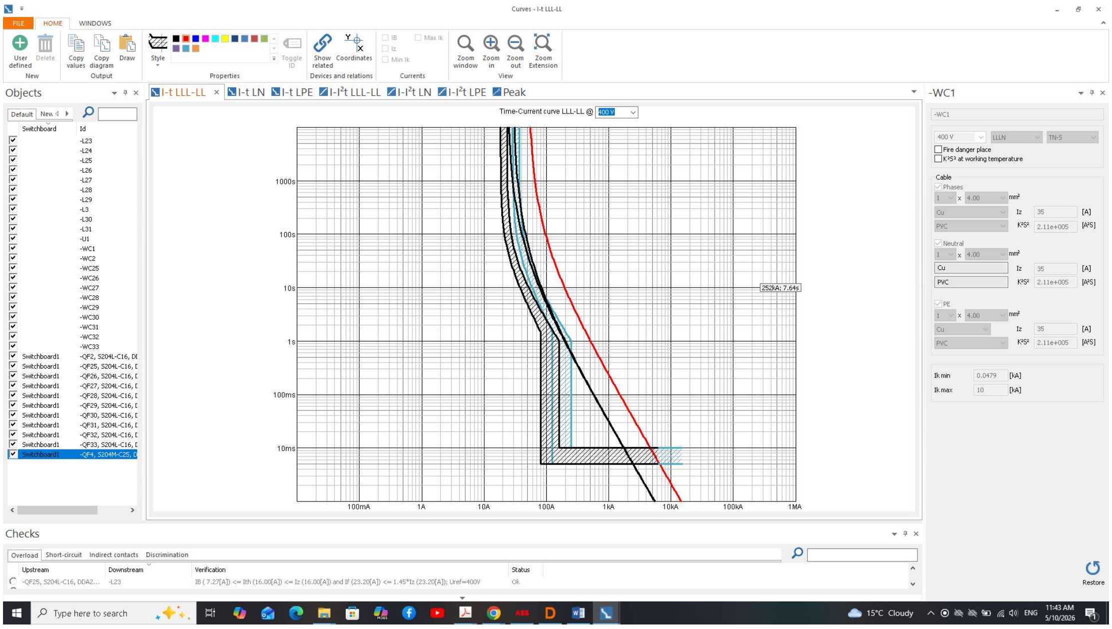

Figure 11. Tripping characteristic for the selectivity between two circuit breakers and residual current devices

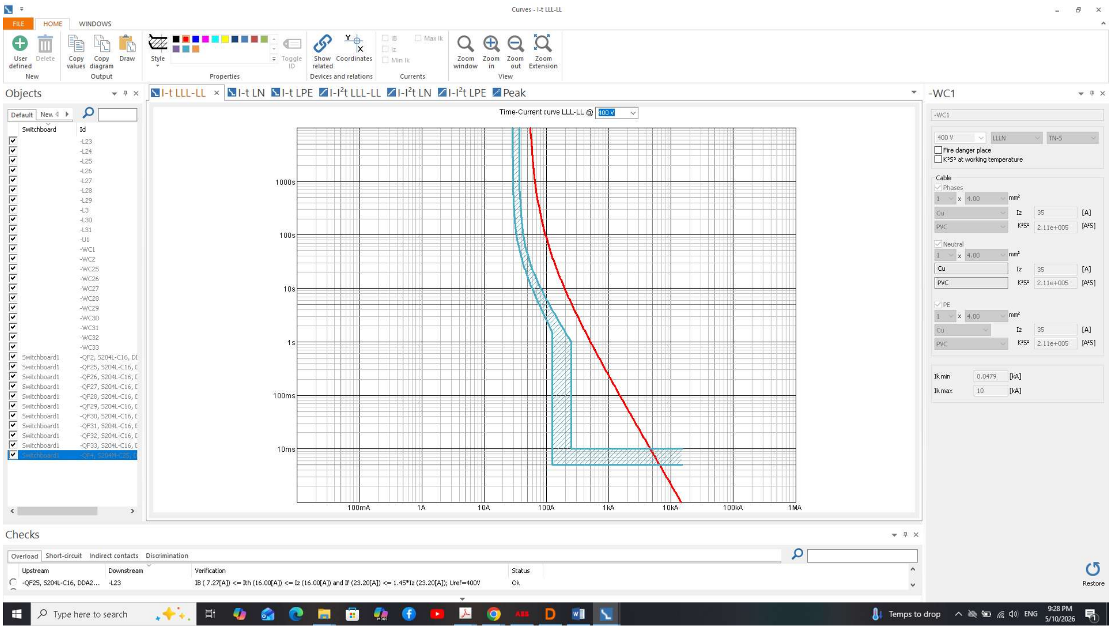

Figure 12. Time-current diagram LLL-LL

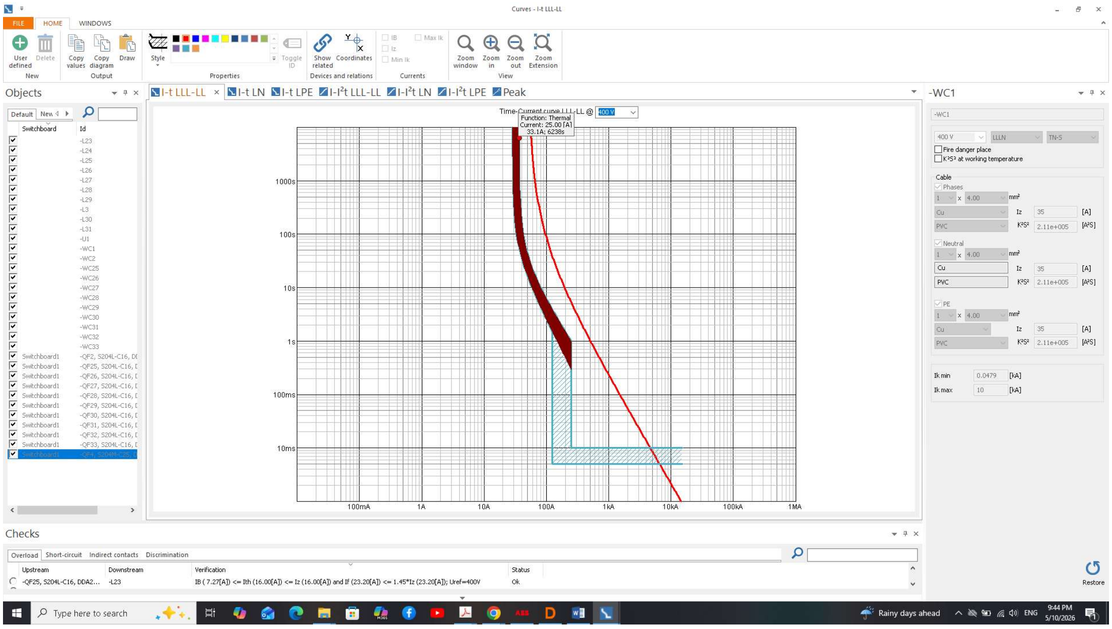

Figure 13. Overload tripping characteristic

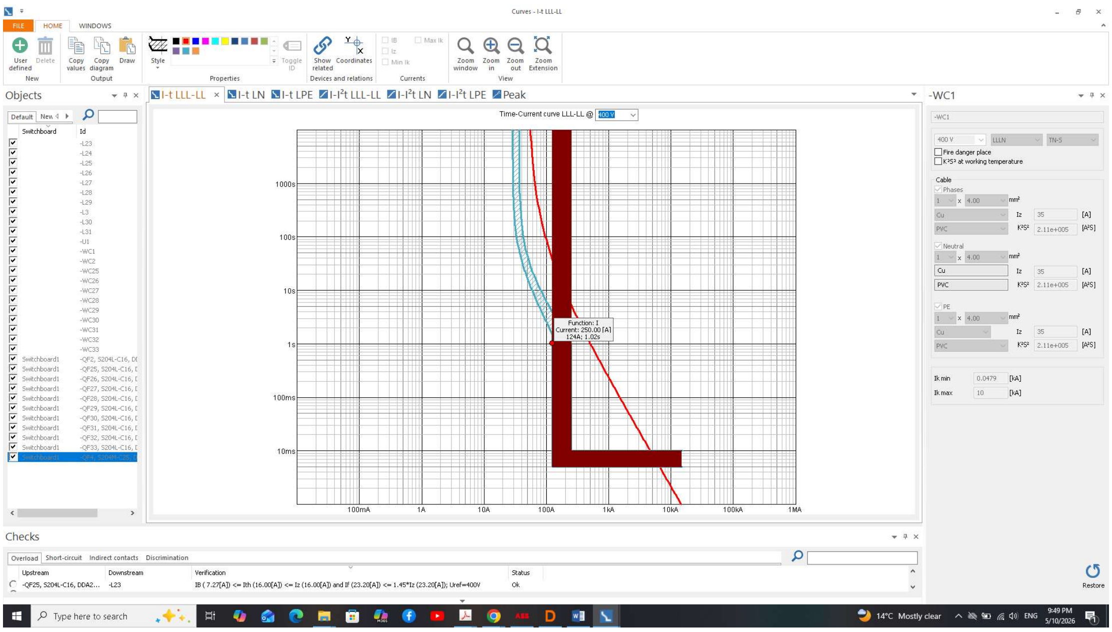

Figure 14. Short-circuit tripping characteristic

Thus, the following diagrams were obtained from e-design with DocWin, namely: figure 12 - time-current diagram LLL-LL, figure 13 – overload tripping characteristic, figure 14 – short-circuit tripping characteristic, figure 15 - time-current diagram L-PE (L-N) (earth fault or indirect contacts), figure 16. specific let-through energy diagram LLL and LL (LLL –three phase short-circuit and LL – two phase short-circuit) and finally and finally in figure 17 the variation diagram for the current limit values is presented.

In order to reduce the over-voltages that occur in the lighting network, an efficient solution consists in connecting all the metal lighting poles to the grounding system that allows the different parts of the lighting system to adjustment at the same potential with respect to the ground.

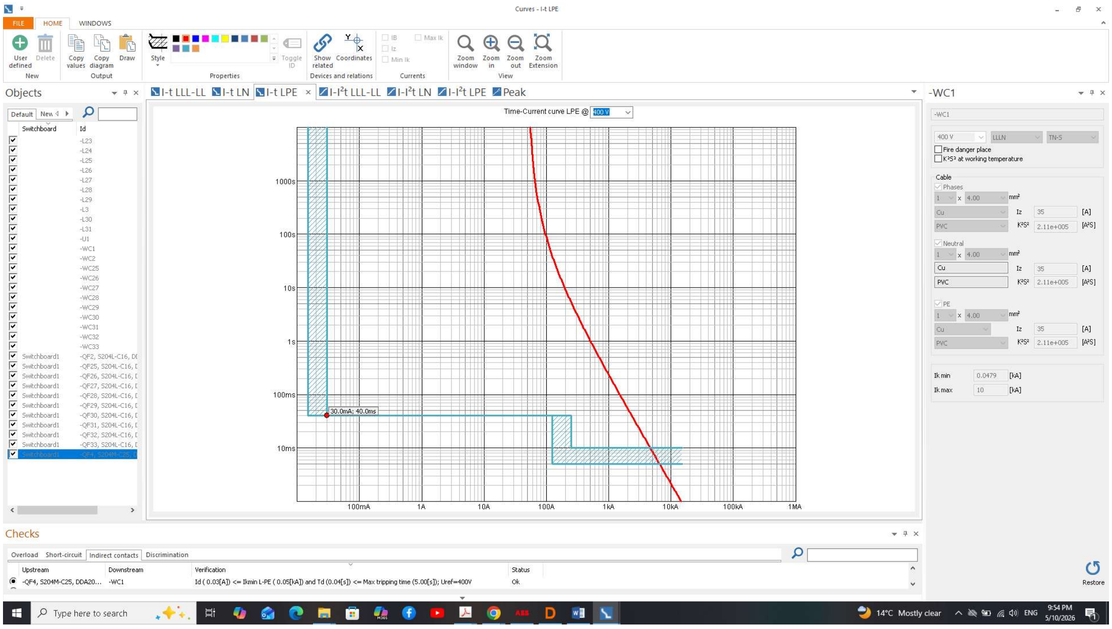

Figure 15. Time-current diagram L-PE (earth fault or indirect contacts)

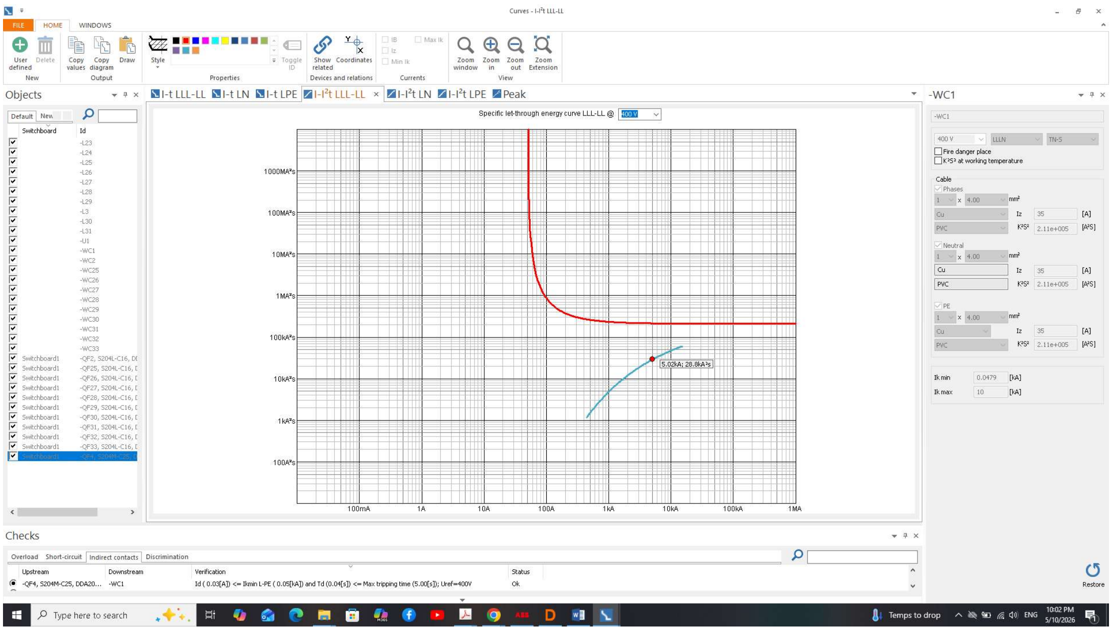

Figure 16. Specific let-through energy diagram LLL and LL

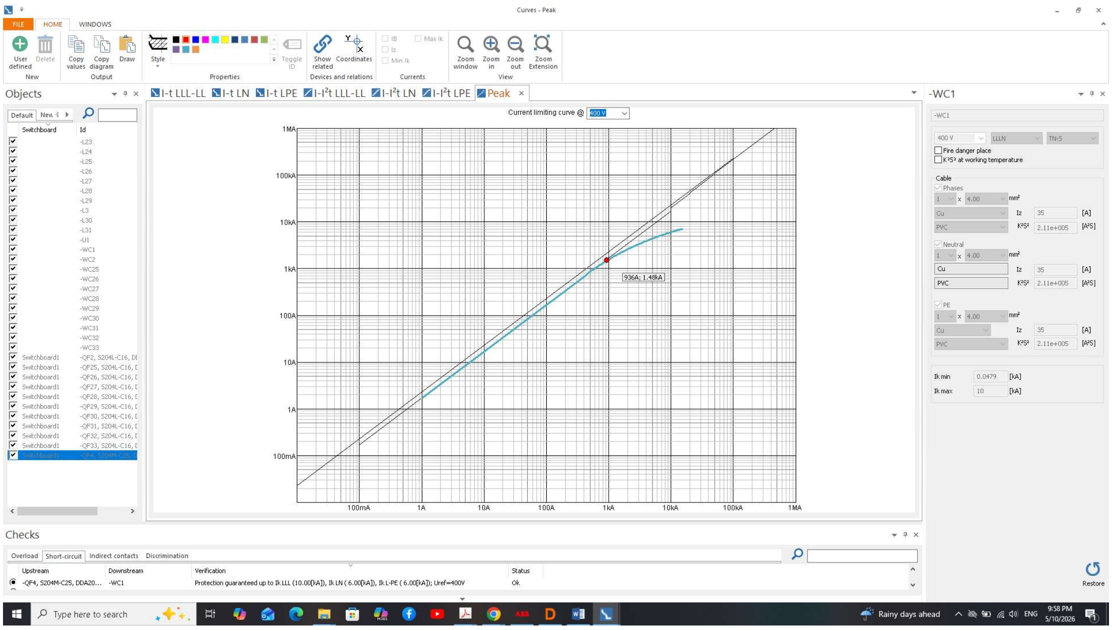

Figure 17. Current limiting diagram

4. Conclusions

The central theme of this work is the design of the lighting system and the electrical power supply network for highways.

In the first part, the simulation mode of highway lighting was presented through three case studies depending on the number of lanes considered. According to the regulations in force, this is an important factor in terms of the location of the lighting poles, namely: median, opposite on both sides and staggered mode.

The type of lamp used is with LED technology with a power of 387W. DIALux automatically calculates the energy efficiency indicators, among which the most important is the annual electricity consumption of 3096 kWh/year.

The second essential problem is the design of the electrical power supply network. Electrical power supply networks for highways are networks with uniformly distributed loads and in the analyzed case studies it resulted that the lighting poles are uniformly placed at a distance of 15 m from each other. The simulation of the electrical supply network was performed with ABB's e-Design for the correct sizing of the cable cross-section, the calculation of voltage losses and short-circuit currents in order to correctly choose the circuit breakers for overload and short-circuit protection.

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