# Dimming of High Pressure Discharge Lamps

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*Abstract* - **The paper discusses a low cost approach for dimming of high-pressure discharge lamps (HPDL) used for street and tunnel lighting. Possibilities of utilizing of variable inductance reactor for reducing the discharge lamps flux are analyzed. The results are compared with three other methods used for group dimming.**

*Keywords* - **high-pressure discharge lamps, dimming, reactor**

## I. Introduction

It is a useful practice to reduce the luminous flux of the street lighting late at night. The traffic during these late hours is low and luminance approximately 30-50 % of the rated is necessary to provide for safety traffic. Saving of 30-50 % of electric energy is realized in consequence of dimming. There is another profit in dimming – the exploitation of lighting devices with reduced supply voltage prolongs the life of the HPDL and its starting devices.

Different methods for dimming ware applied – control device with variable autotransformers, device with thyristor switch, transistor inverters with PWM. It was analyzed [1,2] that utilization of inverters with PWM gives best performance characteristics and stability of the high-pressure discharge lamps. This method may be chosen as a best decision for high-power lighting systems, but the relatively high price of the inverter makes it too expensive for application with relatively low power. Approximately the same characteristics are obtained at dimming devices with variable autotransformers but they are with very big weight and dimensions. In the present paper a method for dimming is proposed with utilization of variable inductance reactor and the performance characteristics of HPDL are simulated and compared to the other methods.

## II. Dimming Methods

Dimming devices utilizing booster transformer and variable autotransformer to control the voltage supply of the street lighting are known. The devices are produced to control the luminous flux for single-phase and three-phase power supply in wide range [4]. With the aid of the autotransformer the device can increase or reduce the voltage supply.

The three-phase version includes three booster transformers in series with the load and three single-phase variable autotransformers, connected across the corresponding line wire and neutral – Fig.1.

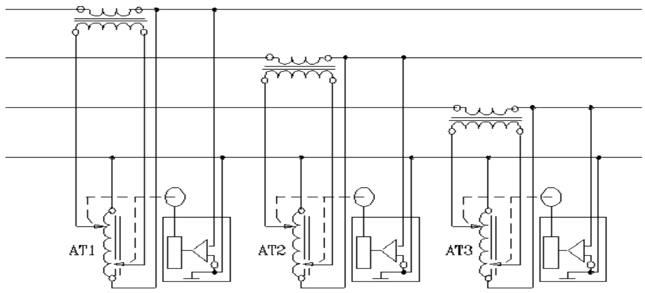


Fig.1. Dimming device for variation of voltage supply with booster transformers and variable autotransformers

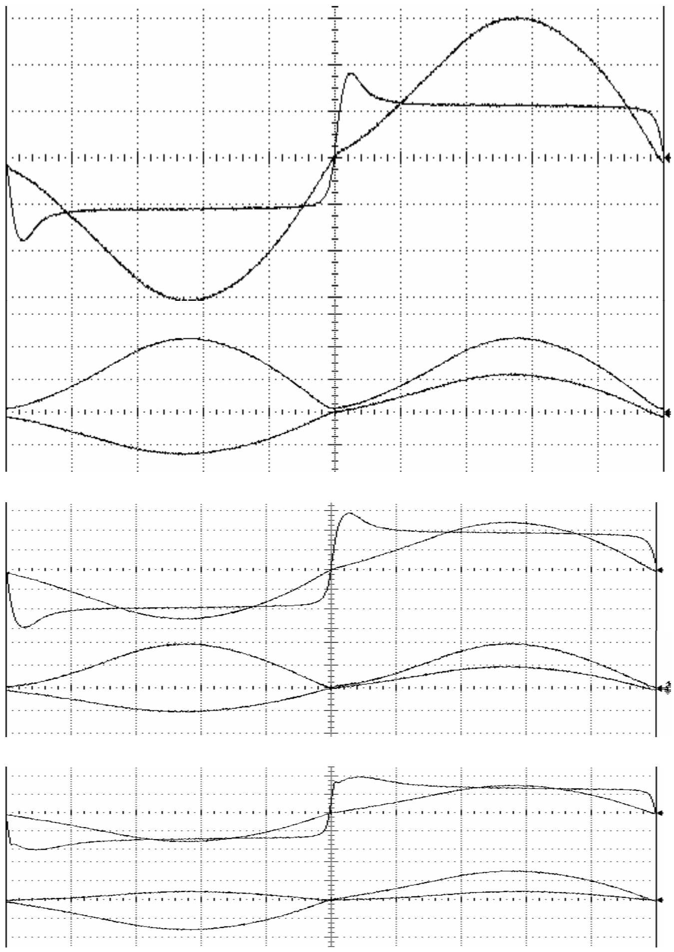

Fig. 2. $U_{supply}$- $I_{lamp}$ , $U_{lamp}$ -$I_{lamp}$ and $\Phi$- $I_{lamp}$ oscillographies for 400W HPDL at dimming with boost and autotransformer at 230, 180 and 120V~

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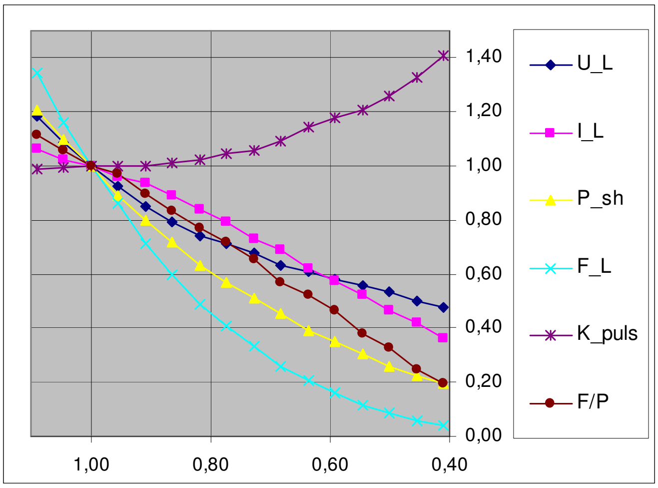
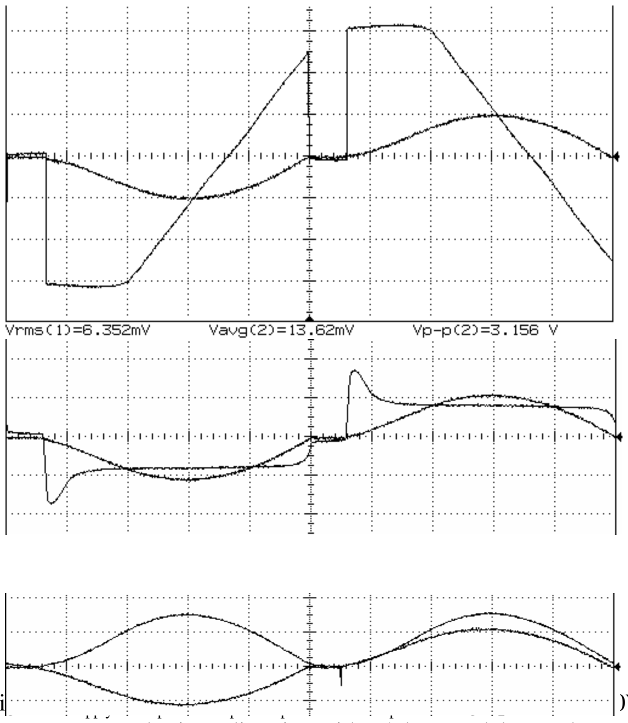



Fig. 3. Performance characteristics of 400W HPDL with inductive ballast at dimming with variation of the supply voltage amplitude via boost transformer and autotransformer

In the figure:
U_L is the voltage across the lamp, I_L is the lamp current, P_sh is the load power, F_L is the luminous flux, K_puls is the flux pulsation coefficient , F/P is the luminous flux yield.




Fi )W
HPDL at thyristor dimming with 75 degrees delay angle

Dimming devices with thyristor switch has been widely used due to its simplicity and low price. Different level of dimming is achieved controlling the delay of firing angle. An experimental example for application of this method is shown in Fig.4. The delay of firing angle is 75 degrees. It is seen that the current flowing through the lamp is equal to zero for a certain period of time, which causes corresponding pulsation in the luminous flux.

The bigger is the delay angle the bigger is luminous flux pulsation and this is main disadvantage of the method (Fig. 5). Recently some frequency converters with PWM (Fig. 6.) were developed and applied for dimming tunnel lighting [3].

Simulations and experimental investigations for 400 W HPDL with inductive ballast were made. The frequency converter supplies the lamp with a variable frequency AC voltage. Controlling the frequency between 50 Hz and 140 Hz the luminous flux were reduced from the rated value to approximately 10-20 % of the rated. The results of simulation and experimental investigations prove very smooth and lossless dimming process.

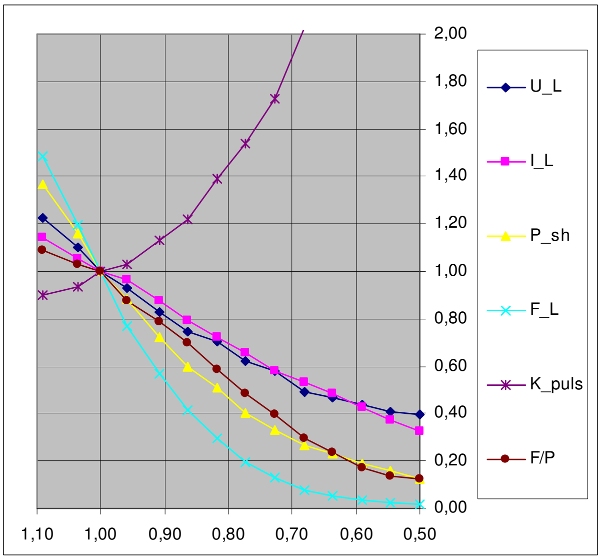



Fig. 5. Characteristics of HVDL 400W at thyristor dimming

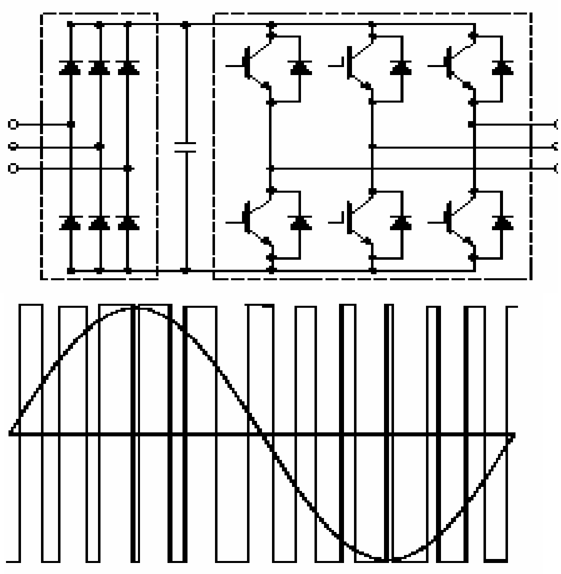


Fig.6. Sinusoidal inverter output voltage via PWM

The disadvantage of this tape of dimming device is its relatively high price, compared to the other components of the system. For this reason it can be used for applications in long tunnels or streets with high-power lighting systems. It is possible to use conventional frequency converters (manufactured for AC motor drives) for applications in low power lighting systems to avoid the development expensive application oriented inverter. Unfortunately the conventional three-phase inverters have been developed for symmetrical machines and do not have neutral wire. In case of non-symmetrical load the neutral will "float" and it is pretty possible some lamps to operate at supply voltage bigger than the rated. This will result in shorten lamps life and will increase the exploitation costs of the lighting.

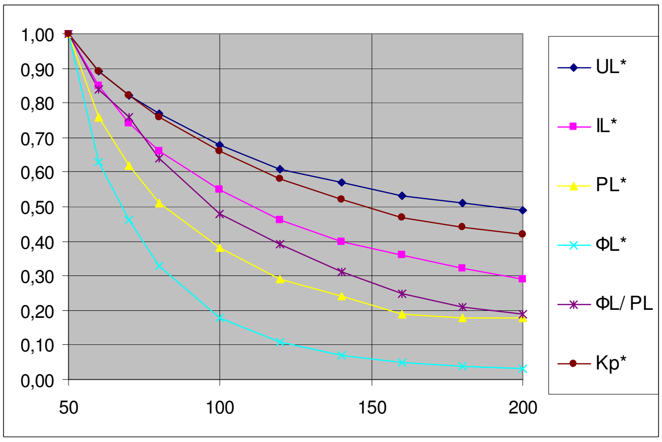



Fig. 7. Characteristics of 400 W HVDL at frequency dimming

The performance characteristics of the HPDL under operation with autotransformer dimming device are like characteristics with frequency converter as it is shown in Fig.3 and Fig.7. A comparison of pulsation for the three dimming methods is given in Fig. 8. It is clearly seen that the frequency inverter dimming makes less pulsation – the increase in frequency of the supply voltage leads to pulsation coefficient reduction while the thyristor switch makes pulsation to increase rapidly.

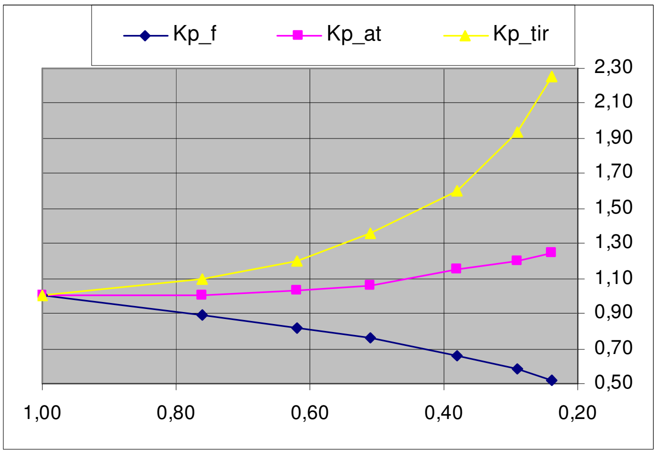



Fig. 8. Pulsation coefficient at dimming with autotransformer (at), thyristor switch (tir) and frequency inverter (f)

The voltage across the lamp for the three dimming methods is given in Fig. 9. It is seen that under thyristor switch dimming the reduction of the luminous flux increases the voltage across the lamp (arc discharge voltage). This causes intensive disintegration the lamp electrodes and shortens the lamp life. According this feature dimming with reduction the voltage supply with booster transformer and autotransformer is superior to frequency inverter dimming. The luminous flux yield for both methods is equal (Fig. 10).

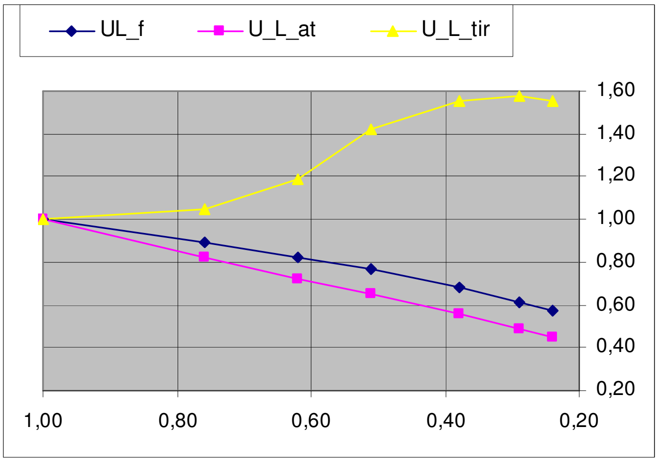



Fig. 9. Voltage of the discharge lamp at dimming

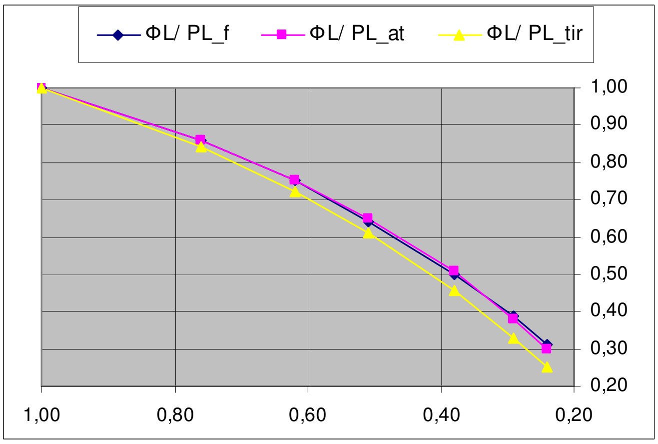



Fig.10. Luminous flux yield at dimming with autotransformer (at), thyristor switch (tir) and frequency inverter (f)

According to the analysis and comparison given above it is reasonable to conclude that the method with reduction of the supply voltage with booster transformer and variable autotransformer can be chosen for dimming the street and tunnel lighting. An approach to reduction the price of the dimming device is proposed in the present paper – to replace the booster transformer and variable autotransformer with a variable reactance reactor for group dimming of a set of lamps.

## III. Reactor Dimming

Normally the dimming is used to make the illumination operate with voltage equal to the rated and lower than the rated. There is no need to increase the voltage supply. This makes possible to simplify the dimming device and use only a variable reactor connected in series with the lamps. With a control of the reactor's reactance the current flow through the lamps is controlled similar to the autotransformer's device. Simulations for a set of six HPDL were made. Each lamp is with power of 400 W and is equipped with 146 mH inductive ballast and 45 uF capacitive compensation. The results are shown in Table 1 and Fig. 11. It was found that a single reactor with 70 mH reactance can provide dimming of the luminous flux from rated value to 20 % of the rated for the whole set of lamps.

TABLE 1
DIMMING WITH A VARIABLE REACTOR

| $L_R$ | $U_{supply}$ | $I_{lamp}$ | $U_{lamp}$ | $I^*_{lamp}$ | $U^*_{lamp}$ | $\Phi^*$ |
|---|---|---|---|---|---|---|
| mH | V | A | V | - | - | - |
| 0 | 230 | 4,15 | 110 | 1 | 1 | 1 |
| 10 | 220 | 3,97 | 105 | 0,956 | 0,955 | 0,87 |
| 17 | 210 | 3,79 | 100,5 | 0,914 | 0.914 | 0,76 |
| 23 | 200 | 3,62 | 96 | 0,872 | 0,872 | 0,66 |
| 29,5 | 190 | 3,44 | 91 | 0,828 | 0,827 | 0,57 |
| 36 | 180 | 3,25 | 86 | 0,784 | 0,784 | 0,48 |
| 43 | 170 | 3,06 | 81 | 0,737 | 0,737 | 0,40 |
| 49 | 160 | 2,89 | 77 | 0,697 | 0,697 | 0,34 |
| 57 | 150 | 2,71 | 72 | 0,652 | 0,652 | 0,28 |
| 64,5 | 140 | 2,53 | 67 | 0,610 | 0,610 | 0,23 |
| 70 | 134 | 2,42 | 64 | 0,582 | 0,582 | 0,20 |

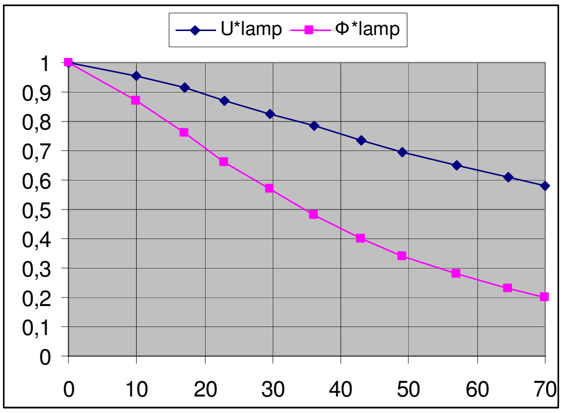



Fig.11. U_lamp and F_lamps at dimming with reactor 0-70 mH

These results were compared to the experimental investigations made with autotransformer's dimming device. The per-unit luminous flux versus per-unit lamp voltage is shown in Fig.12 for both methods. The relative difference is given as "eps" in the same figure.

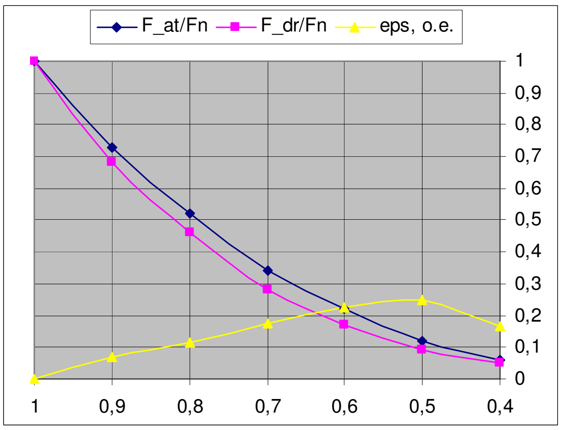



Fig.12. F_lamps/F_nom_lamps as function of supply voltage at dimming with an autotransformer (at) and with a variable reactor (dr)

The advantage of reactor dimming is the possibility for lamps to operate with individual capacitive compensation, which makes the line current approximately 50 % of the current through the lamp and allows reducing the supply wire's cross section. For comparison it should be mentioned that at dimming with frequency converter, group power factor capacitive compensation for the whole set of lamps is used as the capacitors are included in the inverter circuit.

Some problems have to be solved for practical application of the proposed method:

- to chose the type of reactor – multi-tap reactor or direct-current controllable reactor;
- to implement adequate feedback for keeping the constant voltage across the set of lamps in case of accidental change load, e.g. disconnecting one of the lamps.

Utilization of multi-tap reactor is cheaper decision but the tap-changing should provide continuous current flow through the lamps. Application of direct-current controlling reactor will make the device to operate smooth and safe but this reactor is more expensive. Additional economic calculations and experiments should be made to make the final decision.

## IV. CONCLUSION

Methods for dimming the street and tunnel lighting are analyzed and compared in the paper. It is obtained that dimming with reduction of the supply voltage amplitude is expedient method for application at relatively low power lighting systems. A method for group dimming with reduction of the supply voltage amplitude is proposed. Variable reactance reactor is used to control the level of dimming for a set of HPDL with individual inductive ballast and capacitive compensation. Simulation of the lamp's performance characteristics is made and compared to the experimental results for dimming device with booster transformer and variable autotransformer. Good agreement in the results is obtained. Both methods provide smooth and reliable operation of the lighting but the proposed dimming device with variable reactor is with reduced dimensions, weight and price.

## REFERENCES

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