

Automatic On Load Voltage Regulating Technology and Energy-saving HID Lamps

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Abstract. This report analyses the current typical non-contact On-Load Tap Changer(OLTC) thyristor products, poses the circumfluent calculating formula, and points out the main problems existed. The paper also introduces the highly-performed and highly-reliable thyristor OLTC technology and products. Compared with the current technology, high power thyristors will be decreased to half in amount, the high power current limiting resistances or reactors will no longer be used. The current can be continuous without impact, over-voltage or voltage drop phenomena when changing the transformer taps. This kind of technology will have positive significance on High-Intensity Discharge(HID) lamps energy saving, lamps service life extending and non-contact OLTC performance improving of the intelligent power grid.

Introduction

Power electronic technologies have extremely important effect on electric energy saving. High intensity discharge lamps (HIDs) belong to those energy-efficient lamps, including high pressure sodium lamps, high pressure mercury lamps and metal halide lamps. For HID lamps, appropriate voltage reduction will not only save energy efficiently, but also can lengthen lamps' service life. This automatic voltage regulator can be adjusted to meet the voltage applied to the lamp at different times during the day and extreme weather the demand for different road illumination^[1]. Related experimental research report has pointed out that when the voltage of the lamp surpasses by 10%, a lamp's life span decreases to half; when the voltage of the lamp remains to be 90% of the rated one, a lamp's life span will be double.

On-load voltage regulating transformer on load adaptive regulation is the common used method of voltage control in power grid, People have published many papers and monographs about some studies suggest that the OLTC transformer is considered to be one of the important factors causing voltage collapse^[2-10]. Especially in the inductive load, the thyristor element prone to malfunction cause the regulator to fail, seriously affected the reliability of the transformer load tap^[11].

For HID lamps, current discontinuity with Millisecond level is likely to cause unstable voltaic arc, what will lead to lights out or lamps' life span decreasing. As a result, OLTC devices with mechanical contacts or non-contact current limiting resistances are not fit for HID lamps. With using these kinds of products, the lamps are easy to be lighted out and broken down. The reason is that the voltage causes the HID lamps' discontinuous current when the transformer taps are changed, and even impact current, as well as instant over-voltage and voltage dropping can be caused probably, what is easy to cause HID lamps lighting out or re-lighting. It will accelerates HID lamps' aging and decreases the lamps' life span, the new problems such as energy saving but money wasted will be brought at the same time.

In conclusion, it is significant to research on highly-performed, highly-reliable and rapid OLTC devices which will be able to avoid current discontinuity, current impact and over-voltage when changing the transformer taps^[12].

Current Typical OLTC Thyristor Product Analysis

Non-contact OLTC technology has an easy principle, but if the core techniques do not reach the standard, transition resistance or transited inductance components must be united in series in the thyristor loop, to limit the current impact occurred in taps change, which is hard to consider high performance and high reliability.

This kind of products not only occupies many high-power components and high cost, but also leads to poor property as well as impact current and output-voltage dropping while changing the transformer taps. Current products are almost in this mode, and the analysis comes as following.

A. The Main Electric Loop of the OLTC

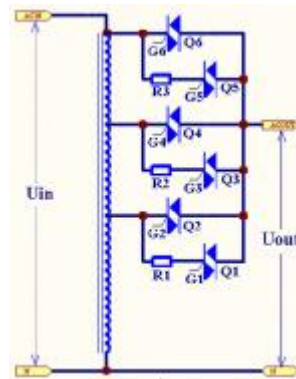


Fig. 1. The schematic diagram of the Main electrical Loop of current typical OLTC thyristor

Fig. 1 is the schematic diagram of the Main electrical Loop of current typical OLTC thyristor^[12], there are 3 taps which can be adjusted, the 3 sets of non-contact switches are used on Fig. 1, every set of non-contact switch are comprised of 2 high-power and two-ways thyristors and 1 high-power resistance which is the transition resistance like R1,R2,R3.

B. Controlling Method of Taps Change

Take an example of the changing process from Q1, Q2 to Q3, Q4, the details as following:

1) The original state is that Q1 and Q2 gates on, the load wades the resistance to get electricity from the bottom of the triac through Q2. It starts to change.

2) Trigger Q3, and stop triggering Q2, so that Q3 and the resistance R2 go through the circulation formed by the on-load current and Q2 form a circulation. After half circle, the natural current of Q2 shuts at zero. Q1/Q3 carries the on-load current together and the circulation decreases half. After stopping tripping Q2 for 15 milliseconds, trip Q4, and leave Q1 to natural shut after stopping tripping. The whole changing process ends and Q4 provides the whole on-load current.

C. The Simplified Equivalent Circuit

The simplified equivalent circuit of the OLTC thyristors is showed as Fig. 2, $\Delta U = k_1 U_i$, $0 < k_1 < 1$.

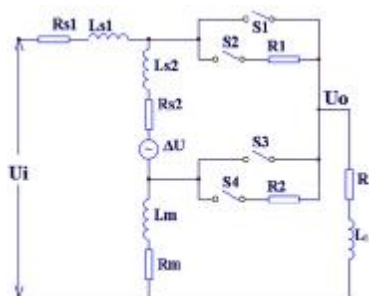


Fig. 2. The simplified equivalent circuit of the OLTC thyristors

D. The Formation of OLTC

The transformer usually works closely to the saturation segment of the magnetization curve, with the nonlinear characteristics of its dynamic regulating properties, which makes it hard to do quantitative analysis during work process.

Suppose the voltage of transformer's voltage regulating winding is $\Delta u = \Delta U_m \sin(\omega t + \theta)$, it as the circular current caused by Δu in the loop of $R_{S2}, L_{S2}, S_2, R_1, S_3$ and ΔU during the switching process of S_2 and S_3 being closed, set the loop equation as following^[13]:

$$(R_1 + R_{S2})i_h + L_{S2} \frac{di_h}{dt} = \Delta U_m \sin(\omega t + q) \quad (1)$$

Solve it, get :

$$i_h = I_{hm} \sin(\omega t + q - a) + A e^{-\frac{R}{L_{S2}}t} \quad (2)$$

In which

$$R = R_1 + R_{S2}$$

$$a = \arctan(\omega L_{S2} / R)$$

$$I_{hm} = \frac{\Delta U_m}{\sqrt{(\omega L_{S2})^2 + R^2}} \quad (3)$$

E. Analysis

Usually, the number of windings is small, so R_{S2} and L_{S2} have few functions. Circular current is bound to exist among the transformer's secondary windings. According to the transformer's principle, it will definitely run through the primary windings and form impact current in the net's side. This impact current will inevitably lead to an abnormal drop of output voltage. If the supply line is longer, and transformer's power is larger; it will impact the surrounding electrical appliances also. If changing taps in quick succession, it will lead to the thyristor and its series resistor or transformer burned out. From equation (3) and the equivalent circuit diagram we can see that the smaller the resistance values of R_1 and the greater the circular current it caused, when the value becomes as close as zero, the huge circular current can easily burn out switching devices instantaneously.

Researches we have done on HID lamp's energy saving

The ideal thyristor OLTC technology is the one without transition resistance or reactor components as current limiting element. It regulates the output voltage by the instant change thyristor devices connected to different transformer tap.

When the core technology is good enough, it will be possible to regulate the voltage shift without interruption of output current, no current impact, and no over-voltage or voltage drop phenomenon. Because there is no current limiting resistors or reactors in electrical main circuit, the regulator shows the best performance and its' manufacturing cost is low. However, as the change in voltage and current is difficult to predict, it is rather difficult to make this ideal program into highly-performed and highly reliable products. There are still some university professors conducting related researches.

We have made breakthrough progress in this area, have accessed to a number of national patents and have gotten the support by the Innovation Fund For Technology Based Firms. Products have been developed and put into use in road lighting. They also have played a positive role in lighting energy, increasing lamp life and reducing lighting maintenance workload.

Products are developed with intelligent monitoring software and have undergoing long-periods of harsh tests in a variety of loads (including no-load, high pressure sodium lamp load, high-pressure mercury lamp, metal halide, mixed lighting load, resistive load) with the cumulative frequency shift over 200,000,000 times. Following is its brief.

A. Autotransformer triac voltage regulation

Fig. 3 is the schematic diagram of the Main electrical Loop of Autotransformer triac voltage regulation. Only 4 two-ways triac switches are used, the transition resistance is not needed any more by non-contact switch.

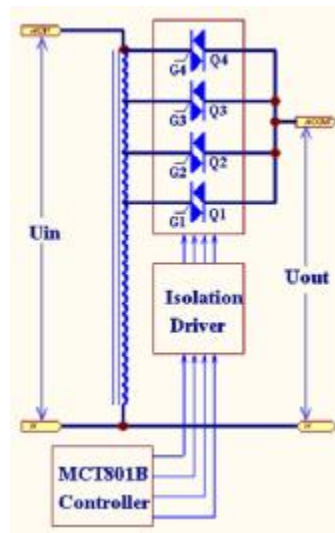


Fig. 3. The main circuit of autotransformer triac voltage regulation

B. The regulated voltage supply regulated by the combination of two transformers

Fig. 4 is the schematic diagram of the Main electrical Loop of voltage regulation of the combination of two transformers^[14], there are totally 15 taps which can be adjusted, the transition resistance is not needed by non-contact switch. It has the Higher precision.

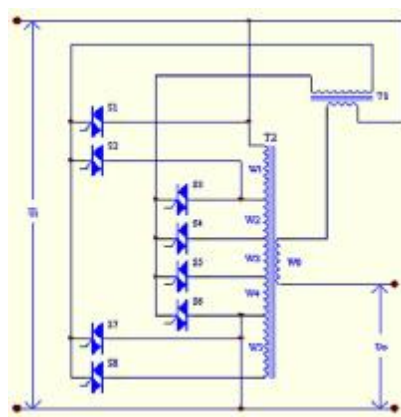


Fig. 4. The main circuit of double voltage regulating transformer combination

The regulated voltage supply is equipped with quite complete monitoring software functions. For the same product, just a few mouse clicks, it can freely switch among "all taps rapid cycling test - fixed regulator - regulation according to energy-saving curve - automatic delay energy-saving ". When it is used as energy-efficient lighting, its voltage accuracy is better than $\pm 1\%$, and its' saving proportion is over 20%. It can actually prolong the lamp's life and reduce lighting maintenance rate.

C. Non-contact OLTC waveforms

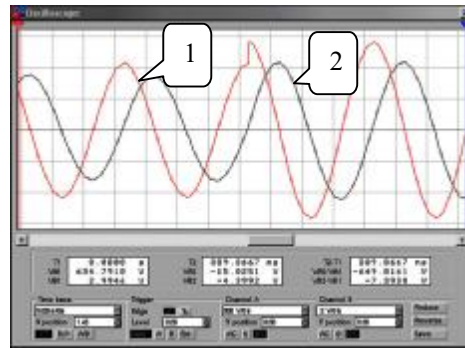


Fig. 5. The simulation of voltage and current waveforms when the inductive load voltage regulation switches

Fig. 5 shows the simulation of voltage and current waveforms of computer when the inductive load voltage regulation switches, the red curve 1 is the voltage waveform, the black curve 2 is the current waveform. Fig. 6 shows the output voltage and output current waveform of high-pressure sodium lamp load regulator, which is shot by an oscillograph on the spot. the yellow waveform 1 is the output voltage waveform; the blue waveform 2 is the output current waveform. Seen from the Fig. the load is an inductive nonlinear load, during the period of switching the output current is continuous and non-impact, there is no output over-voltage or voltage dropping phenomenon.

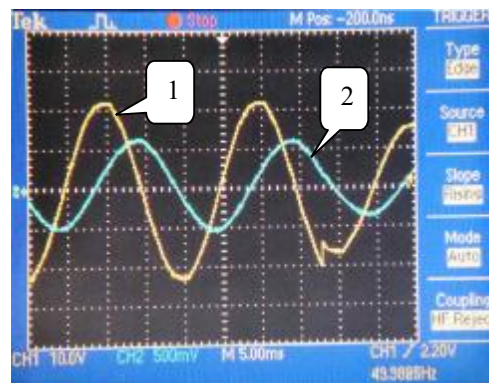


Fig. 6. The output voltage and output current waveform when high-pressure sodium lamp load regulator switches

Conclusion

High-performance and high reliable non-contact OLTC needs no series resistance or inductance current limiting element in its' main electrical circuit. When changing the transformer taps the current is continuous and non-impact. Besides, it has no over-voltage or voltage drop phenomenon. So the advantages are obvious. Compared with existing technologies, in the same capacity and voltage regulation accuracy, the innovative technology not only has greatly improved the product performance and reliability, but also halves the number of high-power thyristors and makes it no longer need to use high-power current-limiting resistor or reactor. For non-contact OLTC, HID lamps is a rather severe load; in this regard we have accumulated some successful experience. In the next step we are ready to deeper into the research about high voltage system, trying to make a greater contribution to the construction of smart grid.

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