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Study on the Performance of Light Sources under Voltage Sag and the Compensation Method

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***Abstract*—All kinds of light sources are sensitive to the power supply, which may be shut down when the grid voltage sag or cut off. It will take more than ten minutes for gas discharge lamps to restart due to their cold start features. In this paper, several typical light sources are selected to do voltage drop tests under different amplitude and phase angle, in which the performance of lamps are carried out. Then a compensation method is presented for HID lamps.**

Keywords-gas discharge lamp; voltage sag; compensation device; drop amplitude; phase angle

I. INTRODUCTION

Voltage Sag refers to the phenomenon that RMS voltage declines from 90% to 10% of the rated voltage rapidly, with a typical duration from 0.5 to 30 cycles. Short circuit faults of transmission and distribution lines, transformer excitation and large-capacity induction motor starting may cause voltage sags with different phenomenon [1-4], which can be solved from system side [5]. This paper presents a compensation method from user side based on the study of performance of lamps under the voltage sag.

High-intensity discharge (HID) lamps such as sodium and metal halide lamps are voltage-sensitive loads. Lamps will sustain a little time before going out when power grid voltage drops or suddenly power off. And due to their cold start characteristics, it needs more than ten minutes to restart [6].

To fulfill the specific requirements of important political users for lighting load, a compensation device for HID lamps should be studied based on analysis of their characteristics under voltage sag to reach the 'Non-flicker' goal. When power grid voltage fluctuates or fails, the light sources should keep on till the emergency power supply starts operating to prevent restarting HID lamps.

In this paper, a voltage drop generating device is used to study the characteristics of typical lamps under voltage sag. Then a compensation method for the single HID lamp is proposed to avoid its going out.

II. MEASUREMENT OF LIGHT SOURCES' CHARACTERISTICS UNDER VOLTAGE SAG

A. The Set-up of the Measurement

In this paper, a voltage drop generating device is applied to measuring typical lamps, whose schematic and principle shown in Figure I. . In the measurement, voltage drop amplitude, initial phase angle, interval time, repetitions etc. can be programed. For instance, the drop amplitude can be set from 0% to 100%, duration time can be programed from 1ms to 5min with resolution of 1ms, drop phase angle can be set from 0° to 359° with resolution of 1° and the output current is programed as 200A. The device can simulate three-phase three-wire (three-phase four-wire) system synchronous voltage sag or a single phase voltage sage, and control the difference of drop time between three phases accurately.

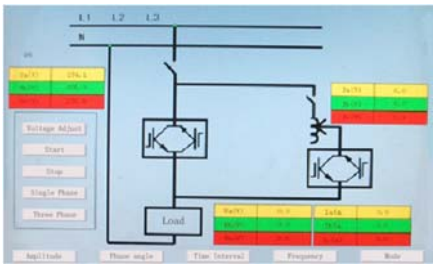

FIGURE I. SCHEMATIC OF VOLTAGE DROP GENERATING DEVICE

The combined measurements can be made by adjusting the following three parameters: dropping amplitude, duration time and falling phase angle. The measurement is repeated three times for each combination. The minimum interval time between two contiguous tests depends on characteristics of the load under test. And the test should be done when the lamp is stable.

The recorded parameters of the lamp include voltage and current waveforms, dropping phase, amplitude, duration time, and restart time for the lamp to recover.

Figure II. shows schematic diagram of a voltage drop. Drop amplitude is defined as the range of the power grid RMS voltage drops, and marked by 1%-90% of the rated value. Drop phase is the initial phase when the voltage start dropping. And duration time means the time while voltage stays low.

B. Measurement Results

Sodium lamps, metal halide lamps, CFL (Compact Fluorescent Lamp), incandescent lamps, and LED lamps are selected to do the voltage drop test. The startup characteristics and voltage drop response performance of above lamps is shown in TABLE I. . TABLE I. illustrates that LED lamps, incandescent lamps and CFL start up quickly and restart immediately. And on the contrary, sodium lamps and metal halide lamps have relatively poor startup characteristics. They

take more time to start up, and require about 10 minutes to fully cool down before restarting. However, these lamps are very sensitive to voltage drop.

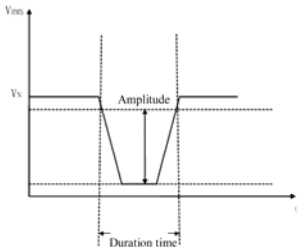

FIGURE II. SCHEMATIC DIAGRAM OF VOLTAGE DROP

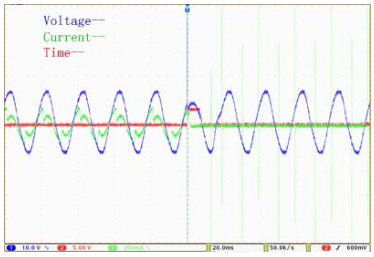

FIGURE III. WAVEFORM OF SODIUM LAMP: VOLTAGE DROPS TO 67% FOR 6ms (LIGHTS OUT)

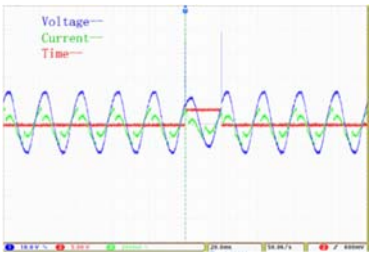

FIGURE IV. WAVEFORM OF SODIUM LAMP: VOLTAGE DROPS TO 81% FOR 20ms (LIGHTS ON)

TABLE I. THE STARTUP CHARACTERISTICS AND THE VOLTAGE DROPRESPONSE PERFORMANCE OF THE LAMPS

Item	Power	Startup characteristics	voltage drop response performance
Sodium Lamp (Philips)	150W	Cold start, about 5 minutes into steady state Restart over 20s Recover after about 3.5minutes	Keeps on for 5ms when voltage drops to zero When voltage drops more than 5ms, whether it goes out depends on the dropping amplitude and duration time
Sodium Lamp (Philips)	1000W	Cold start, about 2 minutes into steady state Restart about 2-3 minutes Recover after about 3minutes	Keeps on for 22ms when voltage drops to zero When voltage drops more than 22ms, whether it goes out depends on the dropping amplitude and duration time
Metal Halide Lamp (GE)	150W	Cold start, about 3 minutes into steady state, Long time cooling after goes out Recover after 8-10 minutes	Keeps on for 5ms when voltage drops to zero When voltage drops more than 5ms, whether it goes out depends on the dropping amplitude and duration time
Metal Halide Lamp (Philips)	150W Double End	Cold start, about 3 minutes into steady state, Long time cooling after goes out Recover after7-9 minutes	Keeps on for 8ms when voltage drops to zero When voltage drops more than 8ms, whether it goes out depends on the dropping amplitude and duration time
Metal Halide Lamp (Philips)	250W	Cold start, about 2 minutes into steady state, Long time cooling after goes out Recover after 8-10minutes	Keeps on for14ms when voltage drops to zero When voltage drops more than 14ms, whether it goes out depends on the dropping amplitude and duration time
Metal Halide Lamp (Philips)	400W	Cold start about 3 minutes into steady state, Long time cooling after quench Recover after 9-13 minutes	Not off after voltage dropping to zero for 7ms(visible) Whether light off or not after 7ms is related to dropping amplitude and time
Metal Halide Lamp (Philips)	1000W	Cold start about 2 minutes into steady state, Long time cooling after quench Recover after 10-11 minutes	Not off after voltage dropping to zero for 12ms(visible) Whether light off or not after 12ms is related to dropping amplitude and time
Metal Halide Lamp (Philips)	1000W Double End	Cold start about 2 minutes into steady state, Long time cooling after quench Recover after 6-10 minutes	Not off after voltage dropping to zero for 37ms(visible) Whether light off or not after 37ms is related to dropping amplitude and time
Energy-saving Lamp (OSRAM, import, domestic)	18W, 42W	cold start less than 1 second, recover instantly after quench	Visible after voltage dropping to zero for 5ms
Incandescent Lamp	100W	Startup instantly, recover instantly after quench	Visible after voltage dropping to zero for 5ms
LED Lamp (OSRAM)	5W	Startup instantly, recover instantly after quench	Not off after voltage dropping to zero for 80ms (Non-visible)

Figure III. and Figure IV. are waveforms of the sodium lamp when voltage drops to 67% and 81% respectively with a duration time of 6ms. In which we can see that sodium lamps put out 6ms later when the voltage drops to 67%, while stay on for 20ms when the voltage drops to 81%. Table II–VI are measurement results for typical sodium lamps (SON-T150W, SON-T1000W) and metal halide lamps (HPI-T250W, HPI-T400W, HPI-T1000W) respectively.

According to the measurement results of various kinds and

different power of gas discharge lamps, it is obvious that the voltage drop response performance of a lamp is related to its power. The higher the power of gas discharge lamp is, the better its voltage drop response performance is.

TABLE II. MEASUREMENT RESULT FOR SODIUM LAMP (SON-T150W)

Voltage drop %	0	69	70	73	76	78	79	80	81	82	83	84
Duration time (ms)	5	6	11	12	13	14	15	19	21	37	65	400

TABLE III. MEASUREMENT RESULT FOR SODIUM LAMP (SON-T1000W)

Voltage drop %	0	5	10	15	20	25	30	35	40	45	50	55	60	65
Duration time(ms)	23	25	23	25	24	25	25	24	24	25	26	27	64	Not extinguished in 1 minute

TABLE IV. MEASUREMENT RESULT FOR METAL HALIDE LAMP (HPI-T250W)

Voltage drop %	0	5	10	15	20	25	30	35	40	45	50	60	65	75	80
Duration time(ms)	15	14	15	13	14	14	13	14	12	18	13	24	25	120	Not extinguished in 200ms

TABLE V. MEASUREMENT RESULT FOR METAL HALIDE LAMP (HPI-T400W)

Voltage drop %	0	15	20	30	35	40	45	50	55	60	65	70
Duration time(ms)	8	11	13	14	14	15	15	14	21	25	42	Not extinguished in 380ms

TABLE VI. MEASUREMENT RESULT FOR METAL HALIDE LAMP (HPI-T1000W)

Voltage drop %	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70
Duration time(ms)	13	14	17	17	18	17	19	19	18	23	25	28	41	103	700

III. LAMP COMPENSATION FOR VOLTAGE DROP

A. *Principle of Compensation Device*

According to above results of the lamp test under a voltage drop, a compensation device for lamps under voltage drop is proposed in this paper. A capacitor is adopted in the compensation device for storing energy. When the grid voltage is operating normally, the lamp is powered by the grid and the capacitor can be charged from the grid by a rectifier. When the power grid voltage drops to 60% of the rated value, the energy stored in the capacitor will go through an inverter circuit, changing the voltage to AC 220V and outputting to the lamp. The lamp will be powered by the compensation device.

A DSP is adopted in the system to monitor the real-time power grid voltage and control the circuit. Figure V. illustrates the structure diagram of the compensation device.

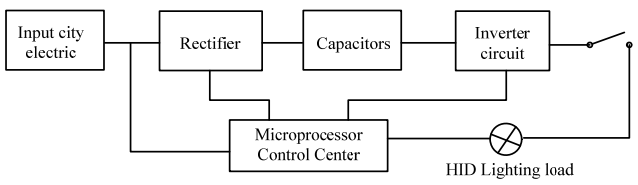

FIGURE V. STRUCTURE DIAGRAM OF COMPENSATION DEVICE

Figure VI. is the main circuit diagram of the compensation device. The structure of the inverter is a single phase bridge. And an electrolytic capacitor is adopted as the energy-storing device in DC side of the inverter, supplying voltage in DC side (u_d). While the power grid voltage operating normally, the bidirectional thyristor VT1 turns on. And when the power grid voltage drops to less than 40%, the capacitor in DC side is charged though the anti-parallel diodes of IGBT and the inductance, the current through VT1 breaks and isolates the load from the power grid. Meanwhile, VT2 turns on and the inverter outputs AC voltage for the load.

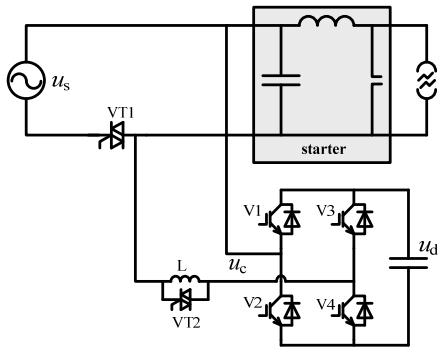

FIGURE VI. THE MAIN CIRCUIT DIAGRAM OF THE COMPENSATION DEVICE

Figure.7 shows the control circuit diagram of the compensation device. The control circuit is based on the DSP digital-analog hybrid structure. The central processing unit DSP samples the power grid voltage (us) for switching judgment, and samples the voltage in DC side (u_d) to control the effective value of output voltage. The PWM unit of DSP outputs four high frequency driving signals to the 4 IGBTs in the inverter bridge and two switching signals to the 2 thyristor switches. The power for circuit control part supplies in two ways. When the power grid operates normally, it is powered by rectifying step-down power grid voltage. And when the power grid is disconnected for abnormal voltage, it is powered by the divided DC voltage.

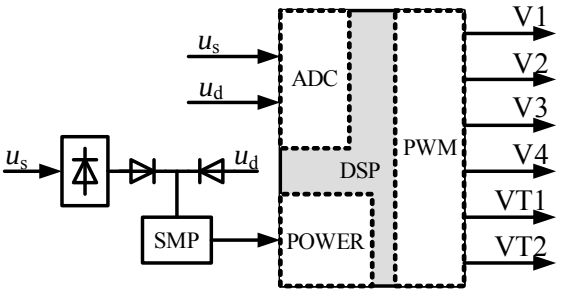

FIGURE VII. CONTROL CIRCUIT DIAGRAM OF THE COMPENSATION DEVICE

B. Results

According to the test, the lamp will quench when the power grid voltage drops to 70% of its rated value considering a 400W metal halide lamp as the load. In this case, the threshold voltage can be set as 70% of the rated value to switch. The device will switch when the grid voltage drops to less than 154V. Supposing the maximum input voltage of the lamp is 120% of the rated value, which is 220*1.2=264V

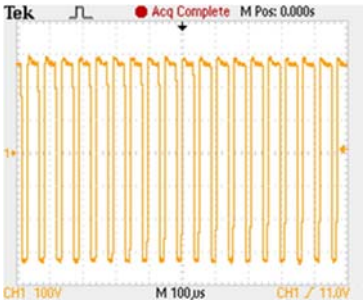

FIGURE VIII. VOLTAGE WAVEFORM OF THE INVERTER OUTPUT

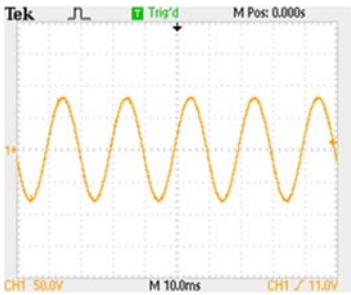

FIGURE IX. LOAD VOLTAGE WAVEFORM OF THE INVERTER OUTPUT

Set the duration time to 100ms when the grid is disconnected, which is also the time that the grid backup power supply needs to secondary switch. The following formula shows the calculation for energy storage capacitor.

$$C = \frac{2Pt}{V1^2 - V2^2} = \frac{2*400*100}{264^2 - 154^2} = 1.74mF = 1740\mu F \quad (1)$$

In practical applications, taking into account a certain margin, select two 400V/1000μF capacitor. Figure VIII. illustrates the voltage waveform of the inverter output. And Figure IX. shows the load voltage waveform of the inverter output. Connect the compensation device to a 400W metal halide lamp. When the grid is disconnected for 100ms, the lamp stays on. And when the grid voltage drops to 60%, the lamp stays on over 10s.

IV. CONCLUSION

In this paper, several typical lamps from the market are selected to do the voltage drop test. The experiment shows that metal halide lamps, sodium lamps and other gas discharge lamps are relatively sensitive to voltage, and have poor starting characteristics. Finally, according to the test results, this paper presents a compensation device for a single lamp to ensure that the lamp can be compensated rather than extinguished when the power grid voltage drops or power off suddenly.

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