# COMPARISION BETWEEN UV ELECTRIC'S LW SERIES ELECTRONIC BALLASTS WITH OTHER BALLASTING ALTERNATIVES FOR HIGH-POWER UV DISCHARGE LAMPS

## INTRODUCTION

Historically, conventional magnetic ballasts were the only choice in high-power UV applications. However, today there are additional choices: UV Electric's LW Series and SCR controlled electromagnetic ballasts [1].

Before discussing the pros and cons of the competing technologies, a brief overview is presented. A ballast is required to adapt the gaseous discharge lamp, in this instance the UV source, to the mains. The ballast ignites and drives the lamp at a desired power level as long as the output specifications are met or the lamp doesn't fail. For optimal operation and long lamp life, it is important that the ballast provides adequate open circuit ignition voltage, quick glow-to-arc transition, and low current crest in normal operation [2].

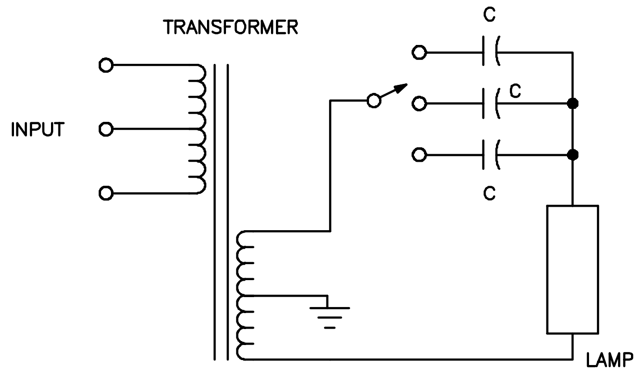
The first part of this report focuses on the performance comparison and the second part covers the cost/benefit analysis.

## PERFORMANCE

### Overview of the Traditional Electromagnetic Ballasts

Today nearly all high-power UV systems in the North American market are relying on electromagnetic (EM) ballasts. The pros and cons of EM ballasts are well known: they are inexpensive, reliable and efficient -- and that is why they have been around for over sixty years. Nevertheless, they have some inherent limitations, namely: poor regulation with the line and load variations. At the multi-kilowatt power level, the size and weight of EM ballast can be particularly cumbersome.

There are several ways that EM ballast can be regulated. One method involves saturating the magnetic core, a ferroresonant approach, which degrades efficiency. Another method involves switching capacitors. This can cause extremely high currents in the capacitors and switches having the effect of reduced reliability [1].

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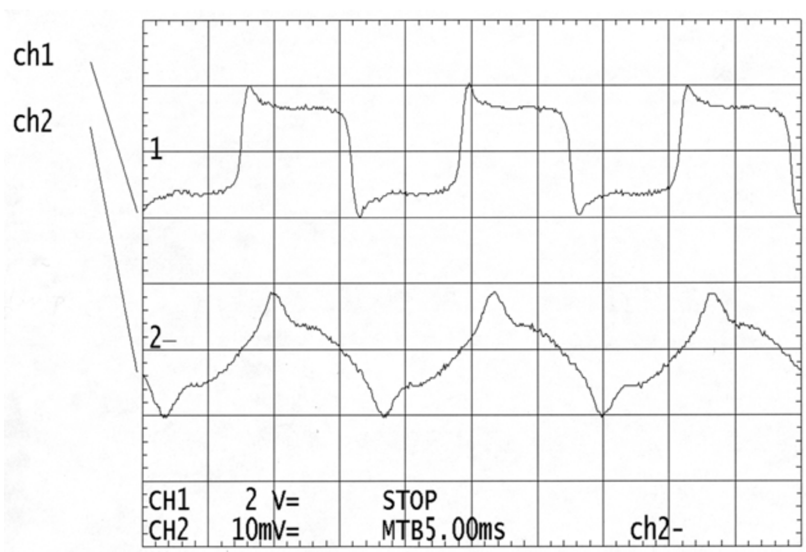


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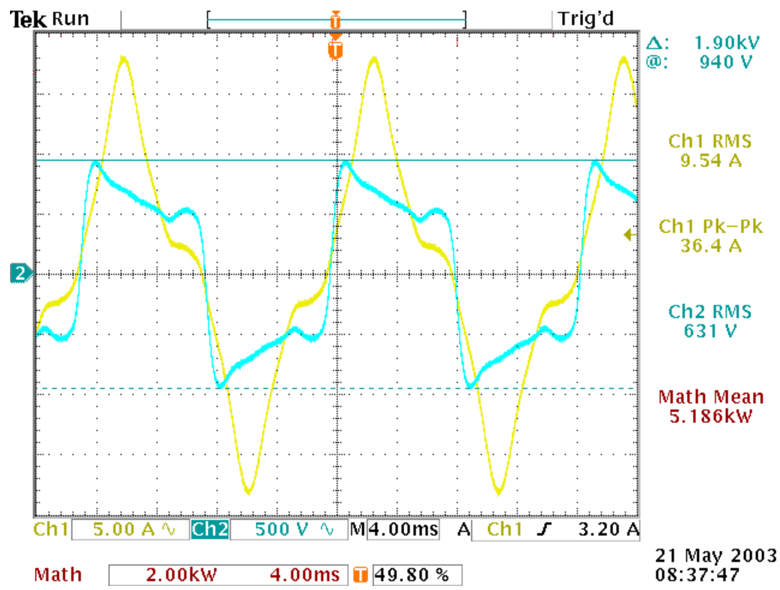
**Fig. 1 Series capacitor EM ballast a) schematic and b) accompanying lamp, Philips HK-70 medium pressure (MP) UV lamp, voltage (channel 1, 2000V/div) and current (channel 2, 5A/div) waveforms**

Figure 1 shows a schematic of a) a traditional ballast with a series capacitor and b) lamp voltage and current waveforms. Note typical reignition voltage peaks and non-sinusoidal lamp current. Current crest factor (crest factor defined as a ratio between the peak and the rms value) is approximately 1.7.

Figure 2 shows typical waveforms of lamp voltage and current on a series capacitor ballast for lamp running at a) full power and b) at about 20% power. Note the additional current reversals, ones beyond the expected mains frequency related reversals, an artifact of this typical ballast circuit arrangement, leading to additional increase in plasma cooling leading to a limited power regulation range.

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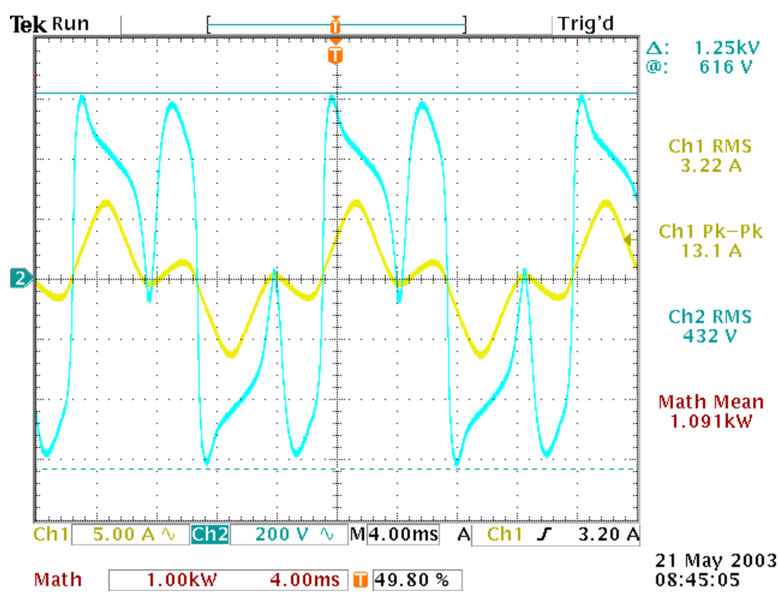


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**Fig. 2 Series capacitor EM ballast with SQP 5.4 kW MP lamp voltage (channel 2, 200V/div) and current (channel 1, 5A/div) waveforms for a) full power and b) about 20% nominal power**

**Overview of the SCR Controlled EM Ballasts**

A block diagram of an SCR controlled magnetic ballast is shown in Figure 3 [1]. In this arrangement, the mains voltage is connected to the appropriate primary tap of a transformer through an SCR module (anti-parallel combination of SCRs). Simply, an SCR module is added to an EM ballast to continuously control lamp power by means of controlling ballast input voltage. Operation is similar to a incandescent dimmer.

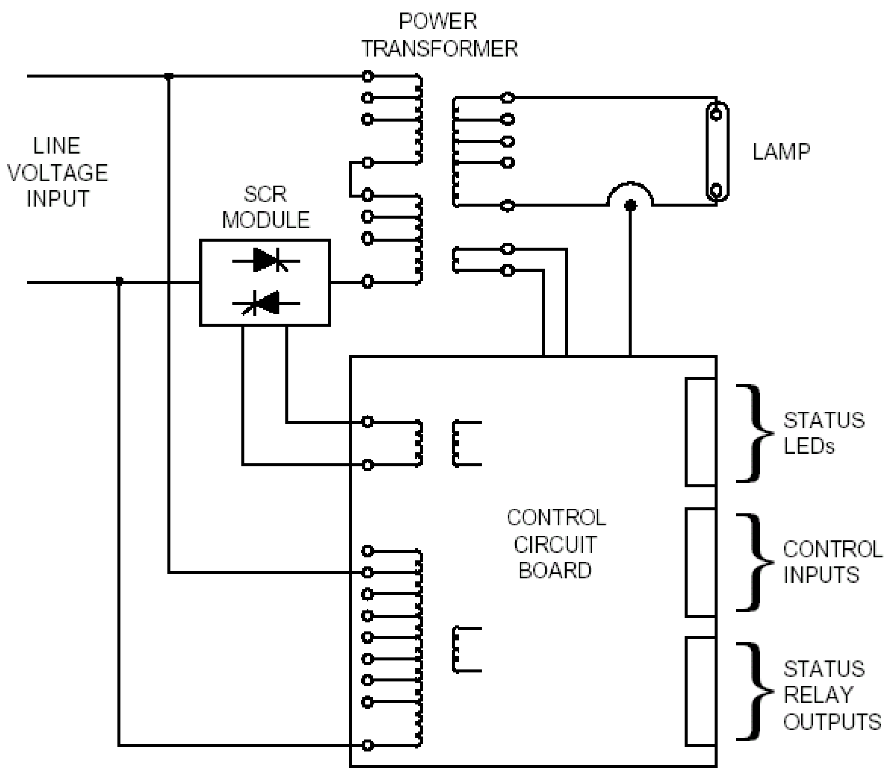


**Fig. 3 SCR controlled EM ballast**

Applying phase-control to an EM ballast does have its limitations. From the side of the power mains, the control process produces lagging currents and considerable harmonics in a single-phase power circuit. This lowers power factor, increases kVA requirements, causes harmonics to flow in the unprotected neutral line, creates potentially unbalanced load condition, and degrades power quality. Adding power factor capacitors will improve power factor, but will not help to reduce harmonic content. Power factor correction capacitors in these types of applications are common source to reliability problems since they can sink unknown system harmonics. From the load side, phase-control increases current crest factor and raises lamp reignition voltage, factors leading to shorter lamp life.

Similar to conventional EM ballasts, the SCR controlled ballasts are designed to address the power conditioning portion (ignition and normal operation) only. For interfacing with the external world, these ballasts require external an on/off switch or contactor to meet safety codes and external power factor correction capacitors to mitigate low power factor of a phase-controlled SCR circuitry. In terms of size and weight, SCR controlled EM ballasts are nearly the same or somewhat smaller than conventional EM ballasts.

For applications were regulation is needed, the SCR controlled approach improves the power conversion efficiency when compared to ferroresonant solutions and improves reliability when compared to switched capacitor solutions.

## Overview of the UV Electric's LW Series Electronic Ballasts

The LW Series electronic ballast powers high and low intensity discharge lamps with a medium-frequency, 400 Hz current square-wave. Excitation at this frequency assures stable, acoustic resonance free lamp operation. The series covers 37 models, ranging from 3.3 to 30 kW. These air-cooled, rack-mountable ballasts (standard 19" racks, 3 to 9 rack units, 5.125" to 15.375" high) weigh between 74 to 365 lbs.

The underlying technology, a combination of high and medium frequency power processing, shrinks package size and weight and raises ballast performance to a level that is unmatched in high-power discharge lamp applications.

These electronic ballasts, block diagram shown in Figure 4, are based upon a current fed, three stage design: 1) power from the mains is converted to a dc voltage with a three-phase rectifier, 2) the dc bus is converted to a controlled dc current with a poly-phase chopper, and 3) the dc current is inverted and isolated with a current fed inverter and transformer. The lamp is connected directly to the mid-frequency, 400 Hz square-wave transformer. For safety purposes, the mid-point of the output transformer is connected to ground.

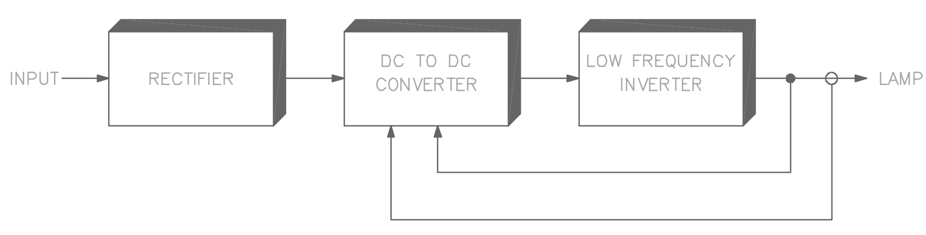


**Fig. 4 Block diagram of the LW Series electronic ballast**

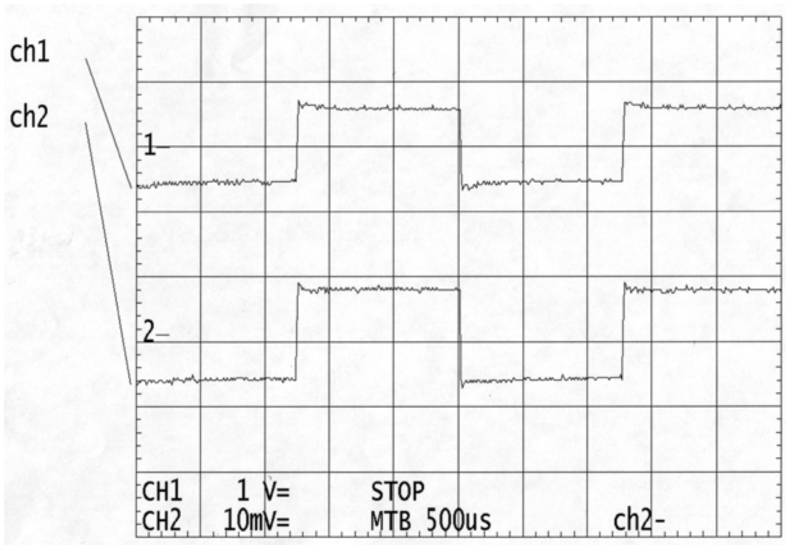


**Fig. 5 13 kW MP Lamp voltage (channel 1, 1000V/div) and current (channel 2, 5A/div) waveforms while operated on LW 1450-14 ballast**

Figure 5 shows lamp voltage and current. Due to fast current reversal (di/dt) and 400 Hz operation, the gaseous discharge lamp operates without cycle-by-cycle reignition. Furthermore, square-wave operation means a unity current crest factor that is ideal for minimizing electrode wear during warm-up, normal operation and dimming. For comparison, a typical conventional electromagnetic ballast is considered adequate if its current crest factor is less than 1.7 [2]. Note, lamp manufacturers data implies operation on conventional EM ballast hence a lamp power factor around 0.9 (power factor is defined as a ratio of average power and apparent power). However, when the lamp is operated on LW Series ballast the power factor is one, therefore it requires less current to run at the same power level than required while operating on EM ballasts.

In terms of electrical input, the LW Series is designed to be permanently connected to either 3-phase 50/60 Hz 208/240V mains (standard), a 380/415V mains, or a 440/480V mains. Its input stage is designed to comply with applicable safety and compliance regulations in mind: it has an EMI filter, fuses, step-start dual contactor arrangement, three-phase rectifier, input choke, and dc bus capacitor. This arrangement limits inrush current to below nominal and assures power factor over 90%.

LW Series electronic ballasts have push button start/stop controls. These controls are tied to a mechanical contactor that operate with electronic switches to break the ac mains when stop is commanded. The ballast are fully programmable via resistance, voltage, current, or optional IEEE-488/RS 232. Diagnostic functions are contained directly within the ballasts' control loop. Exclusive circuitry eliminates guesswork about which function has control - voltage, current, or fault condition.

LW Series ballasts have three levels of over current protection: shutdown of controlling insulated gate bipolar transistors (IGBT's), disconnect of main power, and internal fusing. If the fault condition requires user attention, such as open circuit conditions caused by a failed lamp, main power is disconnected and the diagnostic condition is latched into memory. All diagnostic functions are monitored with optical isolators that can be paralleled for master/slave operation. Furthermore, control functions are also set through optical isolators to allow simultaneous control of one or more units. Programming switches in the rear of the ballast enable internal operation of controls, external operation, or both.

## COST/BENEFIT ANALYSIS

From the system integrator, UV curing or water treatment equipment manufacturer, and the end user point of view, ballasts are differentiated by their cost, reliability, and functionality. These costs can be expressed in terms of the following simple sale paradigm:

1. Initial acquisition cost of the system in terms of dollars-per-UVwatt,

2. Lifetime operation costs, and

3. Lamp replacement costs.

In addition to lamp and ballast cost, initial acquisition cost includes the system engineering, enclosure, circuit breakers, relays, cooling, shipping, etc. Ballast efficiency and reliability are key factors in lifetime operation costs; however, ballast diagnostics (or self-diagnostics) and computer control and diagnostics are also a factor in cost of the maintenance [3]. Lamp life is the sole driver of the third cost; these costs include lamp replacement and maintenance.

### Initial Acquisition Costs

There are radical differences how the LW Series Electronic Ballast and conventional and SCR controlled ballast integrate and interface with the remaining parts of an OEM's system. These differences translate into costs.

In terms of mechanical packaging, the LW Series ballasts are self-contained and rack-mountable. In terms of an electrical ac input connection, they are designed to be permanently connected to the power source and require a readily accessible disconnect device incorporated into the fixed wiring.

The input stage of the LW Series design has an EMI filter, fuses, step-start dual contactor arrangement, three-phase rectifier, input choke, and dc bus capacitor. This arrangement limits inrush current to below nominal and assures a power factor over 90%. In short, LW Series ballasts can be simply connected to the mains and lamps and are ready to go. There are no additional costs.

Magnetics at multi-kilowatt power levels and utility line-frequencies are very bulky. Hence for conventional and SCR controlled EM ballasts the mechanical packaging, thermal management, transportation and installation is more involved and costly than for rack-mountable LW Series ballasts. The fact that EM ballasts are designed to address the power conditioning portion (ignition and normal operation) only means that additional external components: the external on/off switch, relays, power factor correction capacitors, internal wiring, etc. needs to be custom engineered for each system. The additional components, assembly and engineering weigh in the overall cost.

**Lamp Replacement Costs**

One of the key differences between UV Electric's LW Series and any EM ballast, SCR controlled unit or otherwise, is the electrical conditions under which discharge lamps are operated. The main cause to UV output decrease is the sputtered electrode material deposition onto the lamp walls. The actual sputtering occurs during ignition, warm-up, and dimming, and at lower rate during normal operation.

400 Hz current square-wave operation is ideal for minimizing sputtering during normal operation and, especially, warm-up and low power operation. The absence of cycle-by-cycle reignition and the unity current crest factor is the optimal condition for minimizing electrode wear and extending lamp life.

Cycle-by-cycle reignition, normal with 50/60 Hz operations, and the high current crest factor, 1.7 or lower in conventional ballasts and higher with SCR controlled ballasts, are detrimental for lamp life.

In terms of ignition, all ballast rely on open circuit voltage and/or an igniter in some cases. Both the LW design and the SCR controlled designs can accommodate fast warm-operation (running up the lamp to full power with more than nominal current). When adequately engineered, neither approach should cause more harm or benefit in terms of lamp life [5].

## Lifetime Operating Costs

### *Reliability*

LW Series electronic ballasts are based on a current-fed design. In turn, the SCR controlled EM ballasts are voltage-fed. The advantage of the current-fed design over voltage-fed design is robustness. In the case of current-fed design, the isolation transformer is driven by a controlled current source whereas for a voltage-fed design, the transformer is driven by a voltage source, in the case of the SCR controlled EM ballasts, the mains. While this may be a subtle point, if for some reason there is a slight offset in volts-seconds between switching operations of a voltage-fed transformer, the transformer core quickly saturates causing the switching devices to draw excessive currents. To prevent this condition a special circuitry is required [1]. This situation cannot exist in current-fed designs.

Conventional and SCR controlled electro-magnetic ballasts with high-voltage capacitor banks, series or power factor capacitors, and mercury filled relays are known for reliability issues. In the switching capacitor arrangement, the extremely high currents in the capacitors and switches have an effect on reliability [1]. The SCR controlled EM ballasts do not have power factor correction capacitors, however, in most applications the around 0.7 power factor requires power factor correction. Adding power factor capacitors in these types of applications are common source to reliability problems since they can sink unknown system harmonics.

### *Efficiency*

EM ballasts are an efficient solution in applications where power regulation is not important. This is not the case when power regulation is required. With 92% and higher efficiency, the LW Series electronic ballast and the SCR controlled ballasts are a significant improvement over inefficient ferroresonant ballasts. Either choice will result in significant lifetime operating cost savings.

### *Diagnostics*

Historically, adding diagnostics to conventional ballasts has been a part of the system design. For mainly cost reasons, this has been limited to basic status indicators: lamp-out, warm-up, etc. The LW Series with its optional IEEE-488/RS 232 interface raises the ballasts performance and diagnostics level to one today found in modern manufacturing process environment. This opens the door to real-time on-line access to all lamp parameters of interest and ballast condition, features necessary to achieve improved process control and, if leveraged appropriately, reduce maintenance costs [3].

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