HID Lamp Electrical Properties - for Homebrew Ballast Builders, Experimenters and Hackers and Basement Bombers!

Introduction and General Requirements

Beware that this is a very technical document intended only for people with electrical and electronic project skills and the knowledge of the involved hazards to property and to life forms including people, and the necessary safety procedures. Use the info here only at your own risk.

First - note that HID lamps in general and all HID lamps described below have an electric arc in them in normal operation and during nearly all of the warmup. The arc does not operate in a stable manner if a fixed voltage, regulated voltage, or other usual voltage source is applied directly to the lamp. For a further explanation, look in my Discharge Lamp Mechanics File.

These lamps require current limiting or a current source to work properly. In some cases, a constant wattage supply will also work and in some other cases constant wattage will destructively overheat the electrodes of the lamp early in warmup. The ballast must have significant output impedance that outweighs the "negative resistance" that the arc usually has for stable operation. The open circuit output voltage of the ballast, not including any starting pulses, needs to be well above the normal voltage across a warmed-up lamp for stable operation - at least 1.4 times as high for even somewhat reliable operation and preferably at least 1.6 times the normal arc voltage.

Metal halide lamps should have power delivered to them within 10 percent of rated wattage after warming up. Note that the "35" watt general purpose metal halide lamps are actually 39 watt lamps but 35 watt high pressure sodium lamps and 35 watt automotive xenon metal halides are actually 35 watt lamps. Mercury and high pressure sodium lamps are more tolerant - they need rated power +/- 15 percent after warming up.
High pressure sodium lamps can take an amazing amount of overwattage (like 3 times rated wattage) and survive at least short term (usually hours if the ballast provides enough voltage), but exceeding rated wattage by more than 15 percent is not recommended.
I have seen a Philips 50 watt metal halide lamp suffer very severe arc tube discoloration from running at 37 watts for half an hour. And I consider this a more abusable than average metal halide lamp. Thankfully this one has a halogen cycle and it recovered by being operated at 55 watts for 2 hours.

Using the figures below for voltage across a warmed up lamp and the lamp's wattage, determine the normal lamp current. For AC of 50-60 Hz, you need a few percent more since the lamp voltage has a distorted waveform and therefore power factor slightly below 1.

During warmup, the lamp current can be anywhere from normal to twice normal for most lamps.

Metal halides are the fussiest - do not exceed twice the normal current and maybe even not exceed 1.5 times the normal current in metal halide lamps. (Note - the Philips 50 watt can take twice normal current during warmup.) Exception - 35 watt automotive headlight xenon metal halide lamps can easily take full wattage during warmup up to a maximum current of 1.75 or 2 amps for accelerated warmup. Automotive ballasts even have circuitry to model the thermal characteristics and even provide over 35 watts during some part of the warmup to minimize warmup time and to give light output as close to normal as possible during the warmup.

Mercury and high pressure sodium lamps can easily take twice the normal current during warmup, although most ballasts do not provide this much. In my experience, mercury lamps can take 2.5 to probably 3 times the normal operating current during warmup. High pressure sodium lamps can take even more, at least 3 and usually 4 times the ratio of nominal wattage to nominal arc voltage during warmup (in my experience) as long as rated wattage is not exceeded by more than 15 percent. Most high pressure sodium lamps 100 watts or less can probably do OK with a constant power accelerated warmup.

Most metal halide lamps and high pressure sodium lamps only work properly with AC. DC in a high pressure sodium lamp will make the mercury and sodium separate - the mercury will have a higher arc temperature than usual in these lamps and the sodium will have higher heat conductivity than normal in these lamps so the arc tube can overheat. Light output will be reduced. DC can cause destructive electrolysis effects in most metal halide lamps not made specially for DC.
Mercury lamps work OK on AC or DC, but life may be reduced with DC. Some mercury lamps only reliably work with DC after being broken in if the shell of the base is positive and the tip of the base is negative.

High intensity discharge lamps also have current waveform requirements. Most want a crest factor (ratio of peak to RMS current) no higher than 1.7. Metal halide lamps are fussiest and may want crest factor to not exceed 1.6. Automotive headlight xenon metal halide lamps may have a really severe crest factor requirement in order to withstand the higher currents involved in constant wattage or accelerated warmup - these traditionally get a squarewave current waveform with a crest factor not much above 1! Higher crest factor in any HID lamp is harder on the electrodes and in addition crest factor above 1.45 limits the ability of the lamp to withstand unusually high current during warmup.
High pressure sodium lamps can mostly tolerate higher crest factors - I have seen some last a long time on unusual ballasts that produce a crest factor that had to exceed 3! They may not like high warmup currents with high crest factors however.

Metal halide lamps are sometimes fussy in one additional way - the arc is prone to extinguishing easily in the middle stages of warmup. There are two reasons:
1. Higher mercury pressure than in a mercury lamp makes the arc slightly narrower. In addition, some other ingredients such as scandium make the arc narrower and sometimes snakelike. When the lamp is fully warmed up, sodium (or other metals that absorb some of their spectral output) fattens the arc. But when the arc is narrower, it can be snakelike and unstable. Higher current fattens the arc and makes it more stable, and this is another reason to not underpower a metal halide lamp.
2. The presence of mercury halides or halogens makes the arc de-ionize more easily than a mercury arc does between half-cycles. This is one of the reasons why metal halide lamps need more ballast output voltage than mercury lamps of the same arc voltage drop do. And the shorter the duration of voltage less than the normal arc voltage between the voltage peaks of

each half cycle, the better. This effect is worse before warmup is complete - sodium helps the arc stay ionized and higher thermal mass of higher pressure mercury vapor keeps the arc hot throughout the AC cycle. This is also not as bad in larger lamps where the higher thermal mass of the larger quantity of high pressure mercury vapor keeps it white-hot throughout the AC cycle.

Normal Arc Voltages and Other Figures for Specific Lamps

Now for these figures - arc voltage in normal operation, arc voltage minimum during warmup, and starting voltage. Note that with the exception of d2 type automotive headlight lamps, the only lamps covered below are the usual general lighting purpose HID lamps.

ARC VOLTAGE IN NORMAL OPERATION:

Mercury and metal halide, 50 watt: 95 volts.
Mercury and metal halide, 100 watt: 115 volts.
Mercury and metal halide, 175-400 watt: 135-140 volts.
Mercury 1000 watt H34: 135-140 volts.
1000W mercury H36 and 1000W metal halide: around 220 volts.

Note that 175 to 400 watt mercury lamps will work in metal halide ballasts, but the reverse is often not true. Metal halide ballasts under 175 watts will operate mercury lamps OK except the high starting voltage might be hard on mercury lamps if attempting to restart them hot less than 2 minutes after a shutdown.

35 watt automotive headlight xenon metal halide: approx. 80-90 volts.

High pressure sodium, most models 35 to 100 watts: Nominally 55 volts but varies with age and condition from 45 to 85 volts.
High pressure sodium, most models 150, 200, 250, and 400 watts other than mercury retrofit: Nominally 100 volts but varies with age and condition from 80 to 170, sometimes 180 volts.
High pressure sodium, mercury retrofit 150-360 watts: Nominally 130 volts but varies with age and condition from 100 to 175, sometimes 180 volts.

Note that mercury retrofit sodium lamps will be overpowered when their voltage is high if the ballast is a CW or CWA type or other type with a capacitor in series with the lamp, or with almost any metal halide ballast.

MINIMUM VOLTAGE ACROSS THE LAMP IN EARLY WARMUP:

Mercury and metal halide 70 watts or less: 11 volts.
Mercury and metal halide 100-125 watts: 12 volts.
Mercury and metal halide 175-400 watts: 13 volts.
Mercury and metal halide over 400 watts: 14 volts, maybe 16 for the higher voltage (not H34) mercury lamp.
High pressure sodium 100 watts or less: 11-13 volts.
High pressure sodium 150-400 watts, most models: 12-15 volts.
High pressure sodium 1000 watts: 15-18 volts.

35 watt automotive headlight xenon-metal halide: Typically in the 20's of volts, but I heard

allow for 16 volts.

PEAK VOLTAGE NECESSARY FOR STARTING:

Mercury 400 watts or less and the H34 1000 watt mercury: 250 volts, and 220 usually works.
Metal halide 175-400 watts: 500 volts, 450 usually works.
Metal halide 1000 watts or more: 600 volts?
Metal halide under 175 watts and other pulse start models: At least 1500, possibly as much as 2500 volts.
High pressure sodium 35-100 watts: 2500 volts!
High pressure sodium 150-1000 watts: 4000 volts!
High pressure sodium mercury retrofit 150-360 watts: 300 volts.
Automotive 35W xenon metal halide: 7-10 kilovolts, 12-15 kilovolts for hot restrike, 18 to maybe even 20 kilovolts for truly reliable in all cases hot restrike.

OPEN CIRCUIT OUTPUT VOLTAGE of ballast, besides peak of starting pulses:

Mercury 400 watts or less as well as H34 1000W mercury: 180, preferably 200 volts RMS, maybe 220 sustained at least a couple milliseconds with substantial current.
Metal halide 35/39 to 400 watts: May need to be as high as 280 volts RMS with peaks possibly 450-500 volts sustained at least a millisecond or two with substantial current. Maybe a little less for lamps 100 watts or less.
1000W or higher metal halide: probably about 400 volts RMS AC with 525 volts sustained a couple milliseconds with substantial current.
High pressure sodium 35-100 watts, most models: 110 volts RMS AC.
High pressure sodium 150-400 watts, most models: 220 volts RMS AC.
High pressure sodium 1000 watts: 400 volts AC.
35 watt automotive xenon metal halide: over 300 volts with substantial current for cold start, 400 maybe 450 volts with substantial current for hot restart.

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