RESEARCH ARTICLE                                          OPEN ACCESS

# Lamp-Ballast Compatibility Index for Efficient Ceramic Metal Halide Lamp Operation

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**ABSTRACT**
Development of energy efficient products and exploration of energy saving potential are major challenges for present day's technology. Ceramic Metal Halide lamp is the latest improved version of metal halide lamp that finds its wide applications in indoor commercial lighting especially in retail shop lighting. This lamp shows better performance in terms of higher lumen per watt and colour constancy in comparison to conventional metal halide lamp. The inherent negative incremental impedance of CMH lamp demands the use of current control device in the lamp circuit and perfect matching of lamp ballast combination is required for efficient lamp operation. The electrical and photometric performance of two sets of commercial 70 watt CMH lamp and intregated ballast units were measured to investigate their compatibility for optimum lamp operation. The measured data were utilized to develop an electrical model for lamp ballast combination. Using this model a compatibility index is proposed which can be used for assessment of lamp performance.
*Index Terms-* CMH Lamp, compatibility index, ballast

## I. INTRODUCTION

Ceramic Discharge Metal Halide (CMH) lamps are unique among the presently used light sources in providing high-efficiency lighting and controlled color with compact size. These lamps require high voltage to initiate a discharge and a ballast to limit the current after the lamp starts. The low wattage version of Ceramic Discharge Metal Halide lamps are very useful to replace low efficacy and high CRI spot halogen and PAR lamps due to their higher luminous efficacy, almost 100 lumen/watt and high CRI, about 90. At present low version CMH lamp are used for retail shop lighting & commercial lighting. Like other discharge lamp, metal halide lamps exhibit negative incremental impedance and thus need a current limiting circuitry called ballast to ensure a stable operation. However compared with the ballasting of fluorescent lamps the metal halide lamps need more sophisticated ballasting circuitry with starting high voltage short duration pulse generating igniter. Now a day's several manufacturers develop an Integrated Ballast Unit (IBU) which is nothing but a combination of ballast and igniter. In order to obtain satisfactory performance of CMH lamp it is necessary to drive those lamps at recommended wattage and current as given by IEC 1167. Therefore it is crucial that a specification for them is written in terms of measurement made against some common baseline of reference. The criterion can be put in effect by selecting a special inductive type ballast as a reference called "Reference ballast"[1]. In this paper electrical and photometric performance of CMH lamps and Integrated Ballast Units were studied according to IEC guidelines. Based on the experimental result a "Compatibility Index" is introduced which can be employed as a touchstone of compatibility between a CMH lamp and IBU.

## II. METAL HALIDE & CERAMIC METAL HALIDE LAMPS

### A. MH as a Discharge Lamp

The high pressure mercury lamp is an efficient high pressure discharge lamp with the main disadvantage of unevenly distributed spectral lines. This leads to medium luminous efficacy and poor color rendering with CCT. The transformation of UV radiation from the resonance lines of mercury may improve this situation but sacrificing energy losses. A solution to this problem would be the addition of metals in form of halide salts to the discharge, because they have in general a lot of atomic lines in the visible part of the electromagnetic spectrum. A blend of sodium and scandium iodides is widely used in the USA and JAPAN, while mixtures of indium (blue), thallium (green) & sodium iodides are popular in Europe. Mixtures including rare earth iodides are also used. [2,3]

The additional metal atoms in the discharge lamp have several advantages [3]. The visible lines emitted by the metals are often resonance lines. Since resonance lines require the least energy to become excited, the luminous efficacy increases. Moreover resonance lines are usually very strong lines, thus vapour pressure may not require to be too high. Again

by adding suitable combination of metal halides the CRI can be increased. Another advantage is the high voltage gradient due to the high pressure mercury gas

which acts as a buffer. This allows high electrical power densities and small lamp current.
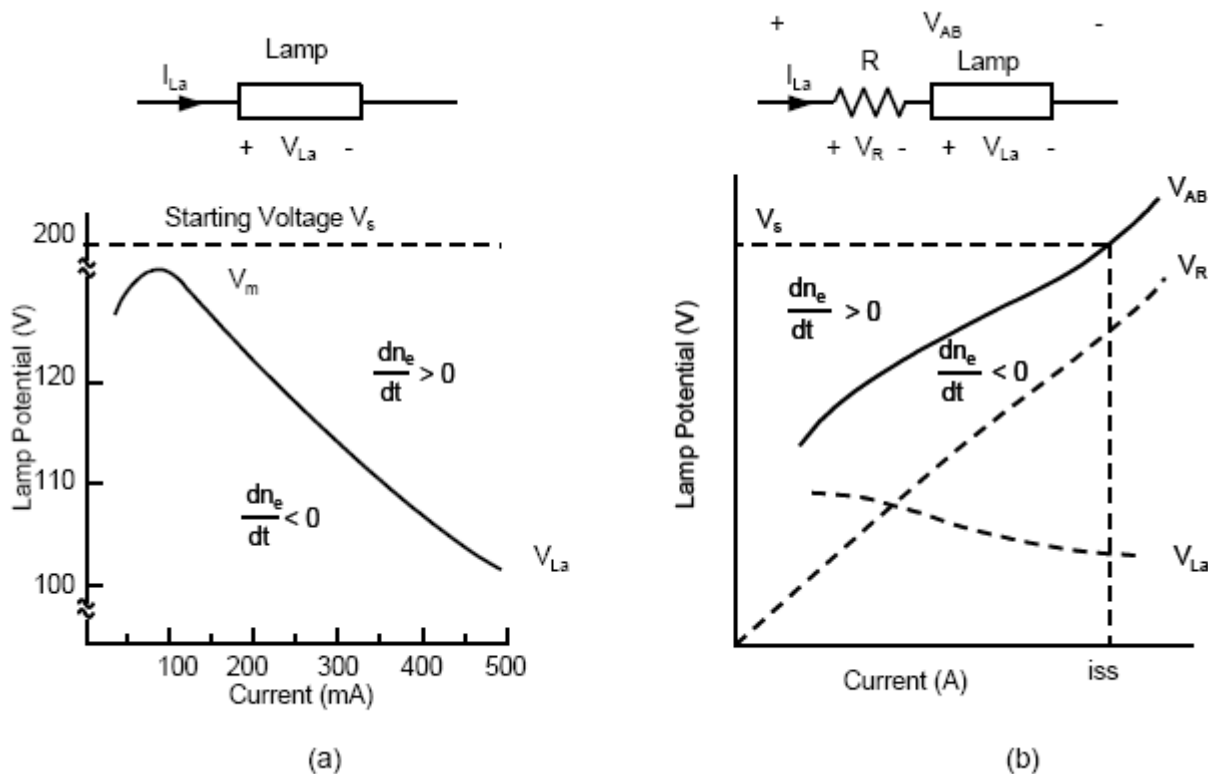


Fig 1. (a) Discharge potential drop versus current    (b) The effect of series resistance to stabilize current

B. Advancement of MH using PCA material

A new trend for metal halide lamps is the usage of polycrystalline alumina (PCA) for the burner instead of quartz. This ceramic material, which bought the major breakthrough for high pressure discharge lamps allows for higher wall temperature as compared to quartz (about 1500 K compared to 1300 K for quartz). This implies the opportunity to operate with higher metal halide vapour pressure, resulting improved efficacies and better colour rendering. Moreover PCA has a high chemical resistance. In difference with quartz PCA is not transparent but only translucent. Translucent material allow light to pass through them only diffusely. The reason for this is this is the microstructure of PCA, which consist of many randomly distributed grains. As light passes through the PCA it scattered at the many grain boundaries along the optical path due to different effective refractive indices techniques allow the production of transparent ceramic burners either by using single crystal PCA or submicron-grained structures ( grain size less than 1 μm) [4].

## III.    NECESSITY OF PROPER CONTROL GEAR

Although CMH lamps have tremendous advantages over Metal Halide lamps, they also require an auxiliary apparatus called a ballast to run

with them because gas discharge lamps have negative incremental impedance. Figure 1(a) shows a typical curve of discharge potential drop versus current when a lamp is operated from a DC power source. The curve can also be regarded as the locus of points $(i,v)$ for which the time rate of change of electron density, $dn_e/dt$, is zero. For points above and to the right, $dn_e/dt$ is greater than zero (production exceeds loss), and electron density would increase with time. For points below and to the left, $dn_e/dt$ is less than zero, and electron density would decrease with time. Obviously, the slope of the curve, defined as incremental impedance (r = $dv/di$ ) is negative. The negative increase impedance characteristic poses a circuit problem for operating lamps. In general, a starting voltage Vs that is higher than the steady-state operation voltage is needed to establish ionization in the gas. After the discharge begins, the operating point $(i,v)$ of the discharge would lie somewhere on the line of the constant V = Vs, which is in the domain for which the ionization rate exceeds the loss rate, and thus electron density $n_e$ increases continuously with time. Consequently, the discharge current increases without any regulation, and eventually causes system failure.

As a result, gas discharge lamps cannot be directly connected to a voltage source. Certain impedance must be placed between the discharge

lamp and the voltage source as a means to limit lamp current. For example, Figure 1(b) shows the effect of series resistance in stabilizing lamp current. The dotted lines $V_{La}$ and $V_R$ show the voltage

potential across the discharge and resistor, respectively, and the solid line $V_{AB}$ shows the potential across the pair in series. Upon application of a starting voltage to the lamp-
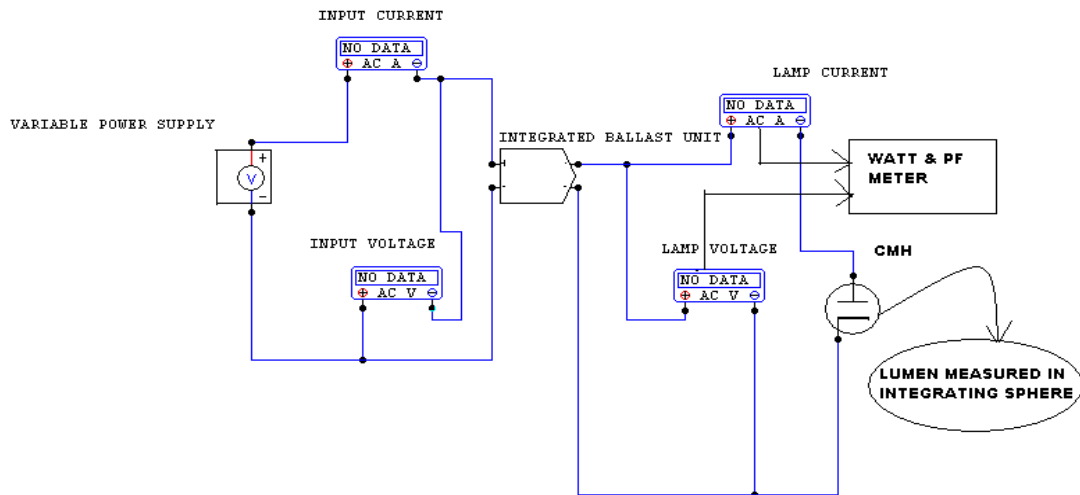


*Fig 2.   Experimental Set Up*

resistor system and establishment of ionization, the operating point $(i,v)$ is in the domain of positive $dn_e/dt$, increasing the lamp current until it reaches the point $(i_{ss}, Vs)$. A further increase in current would move the operating point into the region of negative $dn_e/dt$, forcing the current back to $i_{ss}$ The resistor $R$ helps to establish the stable operating point of the discharge lamp and acts as the ballast.

Obviously, the resistive ballast incurs large power loss and significantly reduces the system efficiency. Fortunately, most discharge lamps are operated in alternating-current (AC) circuits so that inductive or capacitive impedance can be used to provide current limitation. AC operation also balances the wearing of two electrodes and maintains a longer lamp life.

# IV.   TESTING METHOD
## A.  Design of the Experiment
The performance of a lamp means photometric performance such as lumen output, luminous efficacy, CCT, CRI and electrical performance such as lamp voltage, wattage, current, power factor. The above mentioned performance depends on the ballast used, more specifically lamp-ballast combination.

To study the lamp ballast performance I have chosen 70 W CMH lamp and collected two different lamps of same watt of different brands. To drive those lamps a couple of IBU of separate manufactures are procured. For the purpose to study the lamp ballast compatibility at rated voltage as well as for dimming operation of four sets of lamp ballast combinations (as per Table 1) input and lamp terminal parameter is measured. Input parameter is measured in terms of input voltage and wattage. The

schematic of experimental set up is as shown in fig 2. By setting up the arrangement lamp terminal data is collected in terms of lamp voltage, current & wattage for different input voltages. Corresponding light output is also measured accordingly using integrating sphere.

## B.  Experimental Procedure
1) The input voltage is fixed at 240 volts and wait for 20 to 25 minutes to stable the lamp. After that the input current, input wattage and input power factor value is taken. At the same time the lamp wattage, lamp voltage, lamp current and lamp pf is observed.
2) Then the input voltage is decreased by 10 volts, i.e, 230 volt and give 20 to 25 minutes to stabilize the lamp. Then again the previously mentioned parameters are observed. In this manner the data are taken up to input voltage 200 volts.
3) Before the start of the experiment each lamp is burnt for 100 hours to get stable photometric result.

TABLE  I
Lamp Ballast Combination Code

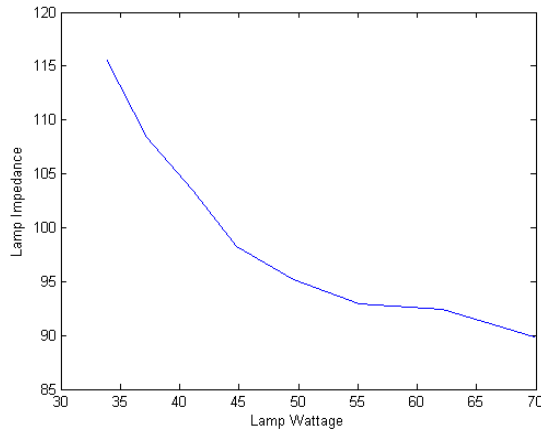| Code | Combinations |
|------|-------------|
| C1 | Sample Ballast 1+ Sample Lamp 1 |
| C2 | Sample Ballast 1 + Sample Lamp 2 |
| C3 | Sample Ballast 2 + Sample Lamp 2 |
| C4 | Sample Ballast 2 + Sample Lamp 1 |

*Fig 3  Tipical Variation of Lamp Impedance with Lamp Wattage*

## V.  PROPOSED THEORETICAL MODEL OF CMH LAMP BALLAST SYSTEM

Previously it was shown that at steady state condition V-I curve of fluorescent lamp depends on the power of the lamp. For a low power ($P_1$) the lamp impedance ($R_{eq1}$) is relatively high, where as the impedance ($R_{eq2}$) is much smaller in a high power ($P_2$) level [5]. This phenomenon is also true for CMH lamp. Fig 3  shows that the impedance and power of lamp is in inverse-proportional relationship, with the power increasing, the impedance of lamp is decreasing. This is possible only when the relationship between voltage and current of the lamp is non-linear. Again the impedance of the lamp is also inversely proportional to lamp current. As the input voltage the power fed to the lamp also increases as a consequence of increment in lamp voltage and current. But the increment in lamp current is much more than the increment in lamp voltage. From the result obtained from four sets of lamp ballast combination it is clear that lamp power or lamp light output is totally dependent on ballast performance strictly speaking on lamp current fed by the current limiter. Depending upon the ballast that connected with same lamp exhibit different lamp current and power for same input voltage. So, to model this CMH lamp a dependent current source is placed in parallel with a resistor as shown in  fig 4
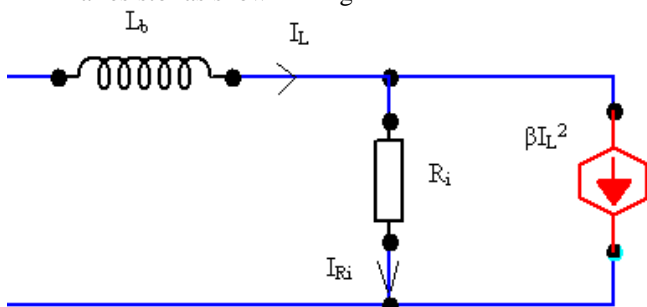


*Fig 4  Model of CMH Lamp Ballast System*

Where,   $I_L$ = Lamp Current which also control the dependent current source.

$R_i$ = Internal Equivalent Resistance &
$\beta$ = Coefficient of Dependent Source

From the fig 4 it is clear,

$$I_L = I_{Ri} + \beta I_L^2 \quad \text{................ . (Eq-1)}$$

$$I_{Ri} = I_L - \beta I_L^2$$
$$V_L = I_{Ri} \times R_i \quad \text{................. (Eq-2)}$$

Where $V_L$ = Lamp Voltage

$$V_L = (I_L - \beta I_L^2) R_i$$

$$\frac{V_L}{I_L} = (1 - \beta I_L) R_i$$

$$Z_L = (1 - \beta I_L) R_i \quad \text{...............(Eq-3)}$$

Where $Z_L$= Equivalent Impedance of the Lamp

The expression shows as $I_L$ increases $Z_L$ decreases which are similar to the result obtained.

## VI.  CHARACTERIZATION PROCEDURE

In order to investigate the lamp ballast compatibility it is important to find out the $\beta$ and $R_i$ from the result obtained from the experiment for four sets of lamp ballast combinations. It has done using following steps.

Step 1

The dynamic impedance of lamp is calculated for different input voltages at different power level for a particular lamp ballast combination.[6]

Step 2

The relationship between lamp impedance ($Z_L$ ) and lamp current ($I_L$) is observed using MATLAB [7]

Step 3

By suitable linear curve fitting method the expression $Z_L = f (I_L)$ is found out by taking 60% of output power (Lamp Power) variation in consideration.

Step 4

The expression is re-oriented in such a manner so that we can readily compare with Equation 3 and find out the value of $\beta$ and $R_i$.

Step 5

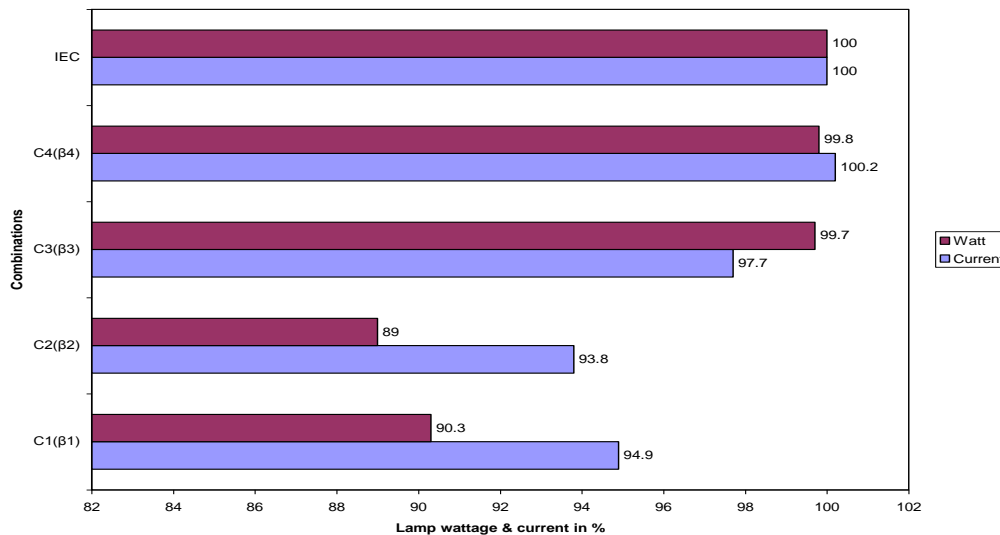Step 1 to Step 4 is followed up for different combinations (C1, C2, C3 and C4)

*Fig 5   Comparative Chart of Lamp Terminal Parameter with IEC*

## VII.    EXPERIMENTAL RESULT

### A.  Result & Analysis

Using the characterization procedure stated above expression for $Z_L$ and corresponding $\beta$ & $R_i$ value of all lamp ballast combinations have been found out which are tabulated in Table II

TABLE II
Result of Lamp Ballast Characterization

| Code | Expression | $\beta$ | $R_i$ |
|------|-----------|------|-------|
| C1 | $Z_L = -64.182\ I_L + 151.33$ | 0.42 | 151.33 |
| C2 | $Z_L = -69.574\ I_L + 158.60$ | 0.44 | 158.60 |
| C3 | $Z_L = -46.217\ I_L + 139.46$ | 0.33 | 139.46 |
| C4 | $Z_L = -31.731\ I_L + 120.70$ | 0.26 | 120.70 |

It is to be noted that as the $\beta$ value increases from 0.26 the corresponding lamp current for the lamp-ballast combination decreases. For example combination C4 has lowest $\beta$ value (0.26) with highest lamp current (.983 A), where as combination C2 has highest $\beta$ value (0.44) but lowest lamp current (0.92 A) at rated operating voltage. All the values of terminal parameters for each combination at operating input voltage (240 V) are shown in Table III and compared with IEC 1167 [8]. As per the reference [8] lamp current is recommended for 70 W MH lamp is 0.98 A. So it is obvious that C4 is the best possible choice in terms of lamp current. As per the lamp voltage is concern it should be between 85 to 105 Volt according to the reference. All the tested combinations meet up with that criterion, but in case of lamp power C4 again exhibit the best result and C2 is the worst among the bunch. Here also as $\beta$ value increases

TABLE III
Comparative Results of Lamp Parameter With $\beta$

| Code | C1 | C2 | C3 | C4 | IEC 1167 |
|------|-----|-----|-----|------|----------|
| $I_L$ (A) | .93 | .92 | .96 | .983 | .98 |
| $V_L$ (V) | 86.8 | 89.2 | 91.9 | 88.24 | 85-105 |
| $W_L$(W) | 63.2 | 62.3 | 69.8 | 69.9 | 70 |
| $\beta$ Value | 0.42 | 0.44 | 0.33 | 0.26 | ----- |

lamp performance in terms of lamp wattage decrease with respect to the IEC 1167 [8]. The comparison between lamp terminal parameters of four combinations (C1, C2, C3, C4) with reference is graphically shown in fig 5. Not only the lamp electrical performance but also the photometric performance is gradually decreases with increase in $\beta$. Fig 6 shows the variation of lumen output with change in $\beta$ for all the combinations. In case of deeming operation C2 provide best lumen output than other combination for a particular input voltage which is shown in fig 7.

So we can conclude that $\beta$ can be taken as a parameter which can take care of total system performance of lamp ballast combination.

### B.  Proposed Compatibility Index

From the previous analysis it is clear $\beta$ is a determining factor for overall system performance. To introduce Compatibility Index a reference $\beta$ value is required. In absence of reference ballast lamp terminal parameters of combination C4 shows very close matching with IEC 1167. [8] For this reason $\beta$ value of this combination can be taken as reference. To determine the compatibility between a lamp-ballast combination following formula is proposed.
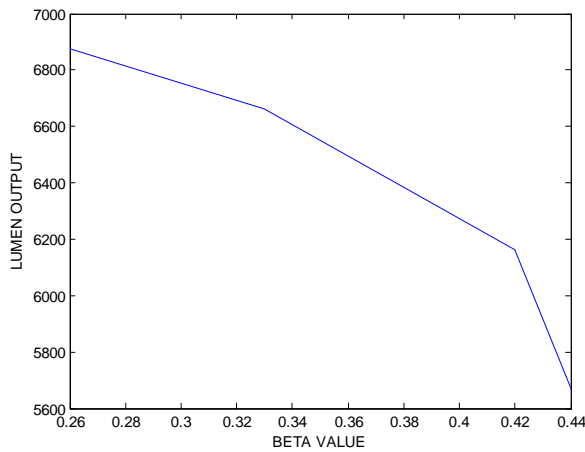
*Fig 6   Variation of Light Output With Beta*

$$CI = 100 - \frac{|\beta_R - \beta_C|}{\beta_C} \times 100$$

……….(Eq 4)

Where,

CI = Compatibility Index
$\beta_R$ = Reference Value Of $\beta$
$\beta_C$ = $\beta$ of Combination to be Tested

Using the Equation- 4 compatibility of all the measured combinations can be found out which is shown in Table IV

TABLE IV
Compatibility Index of Different Combination

| Combination Code | Compatibility Index |
| --- | --- |
| C1 | 61.90 |
| C2 | 59.09 |
| C3 | 78.79 |
| C4 | 100.00 |

## VIII.    CONCLUSION

Ballasts and lamps are designed to meet standards for interchangeability between lamps and ballasts of the same type and wattage. A lamp must be operated by the ballast designed for that lamp, as improper matching of lamp and ballast may cause damage to the lamp or ballast or both. [9] The model presented in this paper can help to design compatible ballast for the CMH lamp. Moreover Compatibility Index proposed in this paper can ensure the
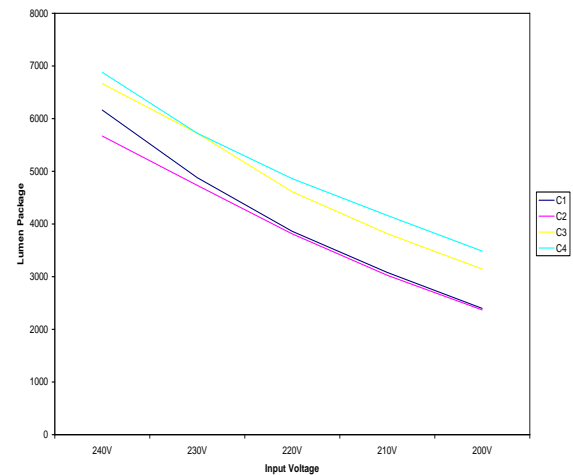


*Fig 7   Deeming Characteristics*

degree to which the control-gear controls the lamp performance. It is represented taking 100 as full scale. The lower value of compatibility index results either diminution of lamp life or decrease in photometric performance of lamp. The impact of the CI on other photometric parameter like CCT and CRI will be reported in future papers.

## IX.    ACKNOWLEDGMENT

## REFERENCES

[1]    IEC International Standard 60923 , Edition − 3.1 , 2006-09

[2]    G.G.Lister, J.E. Lawler, W.P. Laptovich, V.A. Godyak, Rev. Mod.Phys 76, (541-598) (2004)

[3]    C. Meyer, H.Nienhuis, Discharge Lamps (Philips Technical Library, Kluwer Deventer, 1988) ISBN 90-201-2147-2

[4]    T.Kappen, Ceramic Metal Halide Lamps ; A World Of Lighting, Light Sources 2004.

[5]    Ben-Yaakov et al  Statics and Dynamics Of Fluorescent Lamps Operating At High Frequency

[6]    X.Cao, WeiYan, S.Y. R.Hui, et al. High-Frequency Modeling of Low-Wattage High-Intensity-Discharge (HID) Lamps. IEEE PESC'01:62~66.

[7]    MATLAB Version 7.7.0.147

[8]    IEC International Standard 1167, Amendment 1, 1995-03

[9]    **A.** Franke, W. C. Gungle, J**.** F. Ring, and J**.** F. Waymouth, "Reignition characteristics of metal halide lamps and their effect on ballast design," *Illumination.* ***Eng.*** (New York), vol. 62, 1967, pp.  204-213.