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Calculation of Colouration Voltage for a Multifunctional Glazing Powered by Photovoltaic

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CALCULATION OF COLOURATION VOLTAGE FOR A MULTIFUNCTIONAL GLAZING POWERED BY PHOTOVOLTAIC

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ABSTRACT: Multifunctional glazing is a combination of various glazing systems and can comprise permutations of vacuum glazing, aerogel glazing, PV double glazing and Electrochromic (EC) glazing. It controls solar heat gain, improves thermal conductivity and can generate small scale electricity, in a variety of climates. The objective of this research is to investigate the switching voltage of multifunctional glazing, with respect to orientation, time of day and temperature of the system. We report a relation between temperature and voltage required for the switching condition.
Keywords: Modelling, Solar Radiation, System, PV System, Photovoltaic

1 INTRODUCTION

Windows of a building offers privacy, visual amenity, comfort and control of light and air. Window which has dynamic relation with outside atmosphere, heat gain and heat loss both ensue through window. Present available windows are vacuum glazing, aerogel glazing, Building Integrated Photovoltaic (BIPV) glazing and electrochromic (EC) glazing. Vacuum glazing consist vacuum between two glass panes separated by small pillars to withstand the atmospheric pressure and insulated hermetic edge sealing around the periphery of the two glass sheets. This glazing shows total heat transfer coefficient (*U* value) values between 0.5-0.9 W/m^{2}K [1, 2, 3]. In an aerogel glazing consists aerogel which is a translucent solid gel that exhibits high thermal insulation and suitable candidate for low heat loss windows [4]. In addition it has low refractive index, and very low density. This glazing can achieve a heat loss coefficient less than 0.7W/m^{2}K for 15 mm thick aerogel between two glass panes [5]. In BIPV glazing transparent or semitransparent solar cells are placed between two glass panes [6, 7] which can be used as small scale electricity generation, control solar heat gain and transparency of visible light. In case of electrochromic glazing electrochromic material are placed between two glass panes. Electrochromic material is an electro chromic cell which changes its state from transparent to opaque state by redox reaction in the presence of applied D.C. voltage typically 0 to 5 V [8]. Change of optical properties of EC can be reversed by simple inversion of electrical polarity [9, 10]. The switching speed of this colour change process decrease with increase of ambient temperature and bleaching to colour process take more time than colour to bleach process EC material has potential to control transmissivity, absorptivity, reflectivity and emissivity of a glazing[11,12]. Main purpose of EC glazing is to control solar heat gain and daylight through the window by blocking the transmission of near infrared (NIR) and visible light through [13, 14]. All these available glazing's are, only applicable for specific application. Vacuum and aerogel glazing can only control the heat loss through it. After manufacturing and installation of BIPV transparency and solar heat gain factor cannot be changed based on occupant's' desire. EC glazings have potential to change solar heat gain but can't control the heat loss and need external supply. An initiative was taken to add vacuum and EC device to get both effects together [15, 16].EC device needs external supply to change colour which can be reduce if PV can be added together with EC [17]. Multifunctional glazing offers the system integration of all these different existing system (EC, Vacuum/Aerogel, and PV). Multifunctional Glazing can be solution for new fenestration devices.

To achieve a multifunctional glazing optimization of different components are necessary. In this paper colouration voltage calculation of EC material in a multifunctional glazing was reported. Colouration voltage calculation is essential to determine accurate switching condition. Temperature effect on colouration voltage was also investigated.

2. MODEL

To determine the colouration (switching) voltage of an EC device needs a detailed modeling. As EC needs external supply, here the necessary DC supply was given by PV device. Solar radiation model, PV model and EC model is reported in this section.

2.1 Solar radiation model

Solar radiation model was adopted from Perez sky model [18]. Total solar radiation on a vertical surface can be expressed by below equation 1

$$I_T = I_b R_b + I_d \left(1 - F_1\right)\left(\frac{1+\cos\beta}{2}\right) + I_d F_1 \frac{a}{b} + I_d F_2 \sin\beta + I\rho_g \left(\frac{1-\cos\beta}{2}\right) \quad \text{..................(1)}$$

Where a_1 and b_1 are the solid angle occupied by the circumsolar region and their values are given in equation 2 & 3, I_d is the diffuse radiation on the horizontal plane F_1 and F_2 are the coefficients of the circumsolar and horizontal brightness (dimensionless) and given in equation 4 & 5

$$a_1 = \max\left[0, \cos\theta\right] \quad (2)$$

$$b_1 = \max\left[\cos 85^0, \cos Z_s\right] \quad (3)$$

$$F_1 = \max\left[0, \left(f_{11} + f_{12}\Delta + f_{13}Z_s\right)\right] \quad (4)$$

$$F_2 = \left(f_{21} + f_{22}\Delta + f_{23}Z_s\right) \quad (5)$$

$f_{11}, f_{12}, f_{13}, f_{21}, f_{22}, f_{23}$ Have different values depend on the sky clearness

Sky clearness can be calculated from equation 6

$$\varepsilon = [(I_d + I_{exth}) / I_d + KZ_S^3] / [1 + K Z_S^3] \quad (6)$$

K is empirical constant 1.041 [18] when Z_s is radian and 5.535×10^{-6} [19] when Z_s is degree

And sky brightness

$$\Delta = \frac{mI_d}{I_{exth}} \quad (7)$$

$$m = \frac{1}{\sin\alpha_s + 0.15\left(\alpha_s + 3.885\right)^{-1.2583}} \quad (8)$$

2.2 PV model

There are one-diode [20, 21] and two-diode models [22, 23] to evaluate the maximum power output from a PV cell. In case of two-diode model the extra diode represents recombination carriers. A three diode model also used to add more information not present in two diode model. Here a simplified one diode model [24] is used to reduce the need for unknown parameters and number of iterations.

An equivalent circuit of a practical PV device is shown in figure 1. Here I_{pv} and I_0 are the photovoltaic and saturation current while equation 7 represents the thermal voltage.

$$V_T = \frac{N_s KT}{q} \quad (9)$$

When cells are connected is parallel then total output current will increase and if cells are connected in series provide greater output voltage. Equation 8 represents the current output from a solar cell

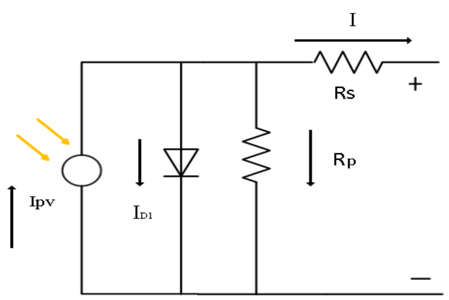

Figure 1: Equivalent circuit of a practical PV device

$$I = I_{pv} - I_0 \exp\left[\left(\frac{qv}{akT}\right) - 1\right] - \left[\frac{V + IR_S}{R_p}\right] \quad (10)$$

$$I_{pv} = \left(I_{scn} + K_i\right)\frac{G}{G_n} \quad (11)$$

$$I_0 = \frac{\left(I_{scn} + K_i\right)\Delta T}{\exp\left[\dfrac{Vocn + Kv\Delta T}{aV_T}\right] - 1} \quad (12)$$

2.3 Electrochromic model

Colouration process of EC material is a double injection process. The current can be limited by series resistance of the cell, a barrier at the ion injecting interface, diffusion of ions within the electrochromic films

Applied voltage V (t) to change the colour of the electrochromic is [25]

$$V(t) = emf + V_c \quad (13)$$

Here emf is the electromotive force of the electrochromic and V_c is the voltage association with ion insertion

$$emf = a + bV_m c(0,t) - \frac{vRT}{F}\ln\left(\frac{V_m c\left(0,t\right)}{1 - V_m c\left(0,t\right)}\right) \quad (14)$$

and

$$V_c = iR - \left(\frac{dE}{dy}\right)V_m c\left(0,t\right) \quad (15)$$

$$V(t) = iR + a + (b - \frac{dE}{dy})V_M \frac{2j}{nF\sqrt{D}}\Gamma - \frac{vRT}{F}\ln\left[\frac{V_M c\left(0,t\right)}{1 - V_M c\left(0,t\right)}\right] \quad (16)$$

$$c(0,t) = \frac{2j}{nF\sqrt{D}}\Gamma \quad (17)$$

$$\Gamma = \sum_{k=0}^{\infty}\left(\frac{2kl}{\sqrt{D}}\right) erfc\frac{2kl}{\sqrt{Dt}} - 2\sqrt{\frac{t}{\Pi}}\sum_{k=1}^{\infty}\exp\left(-\frac{k^2 l^2}{Dt}\right) - \sqrt{\frac{t}{\Pi}} \quad (18)$$

Here t is the time , D is the diffusion coefficient, c(0,t) is the concentration of injected charge, F is faradays constant, R is the series resistance, I is the switching current, V_m is the molar volume of the film, j is the current density is the film thickness and n is the number of electron in the process .

3. RESULT AND DISCUSSION

Here colouration voltage of a 220 nm thick electrochromic material was simulated. Necessary supply was provided by a PV device.Figure2 represents the solar radiation data for Dublin on 29^{th} January 2011 for south facing surface. Figure 3 represents the I_V curve for a PV device kept on latitude angle (53.3428^0N) of Dublin.

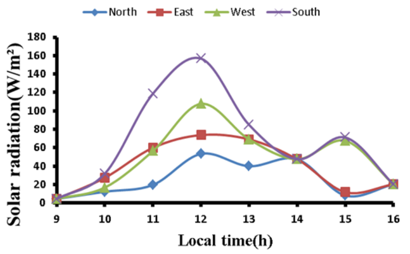

Figure 2: Solar radiation data for 29th January 2011 in Dublin for different orientation

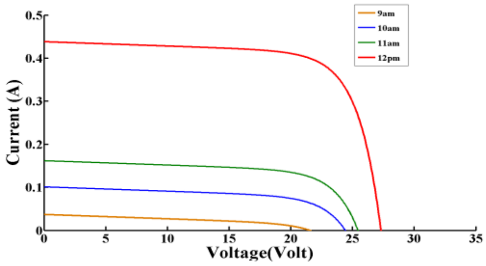

Figure 3: I-V for a south facing PV module.

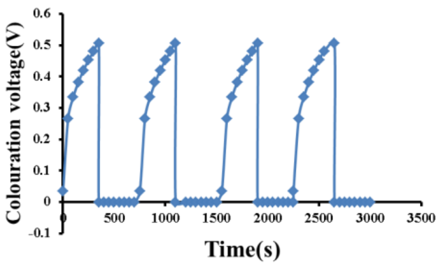

Figure 4: Colouration voltage for every 200S of an EC device

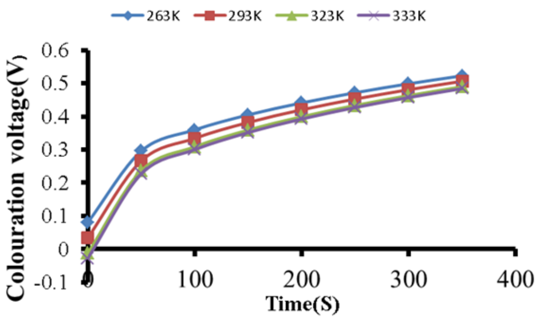

Figure 5: Temperature effect on colouration voltage of Multifunctional glazing.

To simulate the EC material, the data was collected from Wang et .al. [25]. Figure 3 represents the colouration voltage required for EC device. This particular EC material took 200s to colour fully and voltage requirement was 0.5V. Then supply was stopped for another 200s to achieve bleach state from coloured. Colouration model was simulated for 3000s.Fig 5 indicates the reduction of triggering voltage of EC material. It was found that when temperature increment was large voltage requirement was less. Fig 4 no reduction was noticed as the operation was performed for short period of time.

4. CONCLUSIONS

Here this EC material took 200s to changes its colour and 200 s to return its initial state. During short time operation process voltage requirement was same for every switching interval. At high temperature operation the switching voltage requirement actually reduced and for low temperature it increased.

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