VOL. 11, NO. 13, JULY 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

A STATISTICAL ANALYSIS ON PRICE ELASTICITY OF ELECTRICITY DEMAND USING RESPONSE SURFACE METHODOLOGY

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ABSTRACT

For strategic planning under restructured environments, it is essential to assess how consumers respond to the price changes in order to increase the profits of supliers and customers. In this study, a case study based on Iran power system was collected to explore the effect of different factors including proportion of income spent-level (A), consumer academic-level (B), demand-types (C), demand time (D), possibility of postponing demand-level (E), price-level (F), demand-level (G) and awareness of participation benefits-level (H) on price elasticity of electricity demand. To achieve this, an nonlinear-empirical model based on Response Surface Methodology (RSM) is created. The statistical analysis reveals that factor A which represents proportion of income spent-level has the most significant effect on determination of the price elasticity of electricity demand while consumer academic-level (B) factor has the least effect. The results can be utilized as a tool for policy makers in developing an effective electricity pricing schemes.

Keywords: statistical analysis, strategic planning, price elasticity of demand, response surface methodology, empirical model.

1. INTRODUCTION

Since 1982, more than half of the world countries have restructured their electricity market [1]. The basic concept of restructuring power markets were the introduction of competitive energy markets, unbundling electricity services and opening access to the network [2]. The price elasticity of demand analysis are the key factor for developing of the electricity markets [3].

According to the National Electricity Market (NEM) assessment, customers might be exposed to the volatile electricity prices as a result of restructuring of the power market [4]. This possibly leads the consumers to modify their demands profile in order to decrease their electricity costs [5]. Therefore, it is essential to estimate how consumers respond to the price changes and also to assess their effects on both annual energy volumes and peak demand. This assessment is vital for authorities in developing proper and effective electricity price schemes [6].

According to economic theory, with increase of energy prices, the electricity demand decrease [7]. The consumer's sensitivity to the price changes can be measured by the coefficient of price elasticity: the change of demand divided by the change in price ($\partial d/\partial \rho$) [7]. This ensued in determination of the price elasticity of demand (E_d) that represents the willingness and the ability of demand change to the price change [8].

Moreover two kinds of price elasticity coefficients are considered including own-price elasticity and substitution elasticity. Self-price elasticity is a useful measure of how customers adjust to the increases of the electricity price by adjusting their consumption of electricity.

This is particularly useful during evaluation of longer-term adjustments to the changes in electricity prices. Self-price elasticity is typically negative, indicating the reciprocal relationship between demand and price. Own-price elasticity is generally of two types, inelastic and elastic, and the range of each type differs by region and system. For a commodity, the range of inelasticity is usually between the absolute values of 0 and 1, and the elastic range begins with values greater than 1. In the elastic range, consumer demand responds with a greater than proportional change for a given price change. [7]

These are some factors in determination of E_d which represents the immediate postpone to the consumption from the customers or a decision for search of suitable substitutes [9] including: proportion of income spent-level, consumer academic-level, demand-types, demand time, possibility of postponing demand-level, price-level, demand-level and awareness of participation benefits -level.

Price elasticity of demand has been meticulously detailed by many researchers during the past three decades. Most of the early researches reported on the flat electricity rates in the context of vertically integrated mechanisms.

However, Arisoy *et al*. [10] estimated the price and income elasticity of industrial and residential electricity demand in Turkey between 1960 and 2008. In this research time dependent parameters were modeled based on Kalman filter.

Furthermore, the findings indicated that the electricity demand is inelastic with respect to its price in the short term, although this is different in residential compared with the industrial demand. In the case of residential demand, consumers react in a short time to the increases of electricity price, while the reaction of companies and large consumers is virtually non-existent.

Besides, there is a definite relationship between the level of per capita household income and the electricity elasticity demand [11]. Therefore Jamil and Ahmad *et al.* [12] conducted an analysis by collecting data from residential, commercial, industrial and agricultural sectors. Moreover, the price elasticity of demand has been estimated for south Australia which represented the sensitivity of customer demand to the price of electricity [13].

Likewise, He *et al.* [14] simulated the impact of electricity price adjustment on demand for electricity based on the Computable General Equilibrium (CGE) model, the findings revealed the range of price elasticity for different consumers.

Furthermore, Nojavan *et al*. [15] offered a new stochastic framework for large consumers expected procurement cost reduction by considering the effect of price elasticity of demand and demand response program.

A review of the literature indicates that up to now, there has been no investigation on the effect of all parameters including A, B, C, D, E, F, G and H on the E_d. In addition also there is no proposition of a regression model based on the effective factors for E_d. It was reported that response surface methodology is a suitable statistical and mathematical technique to investigate the effect of factor at different levels on response especially when the response is affected with different factors.

This method is worthwhile for modelling of the factors and their interactions in accordance with a specific response [16, 17].

Therefore, in this study the effect of factors and their interactions on the E_d based on the collected results from real distribution network in Iran is investigated simultaneously. A precise model based on the effective factors and their interactions was created to be utilized as a tool for policy makers in developing an effective electricity pricing schemes.

2. PRICE ELASTICITY OF DEMAND

One of the significant aspect of supply-demand curve is to find the response of demand changes when the price of electricity changes [7]. The economy measure of this response is the price elasticity of demand [18]. The sensitivity to the price changes which is called price elasticity of demand presents the relationship between a change in quantity demand of electricity and a change in price. It is defined by the Equation 1 [7]:

$$E_d = \frac{\rho_0}{d_0} \cdot \frac{\partial d}{\partial \rho} \tag{1}$$

Where E_d is the price elasticity of demand, ρ_0 is the initial price of electricity price, d_0 is the initial demand for electricity, ∂d is the Changes in electricity demand due to changes in electricity prices $(\partial \rho)$.

In the present study, it is hypothesized that the number of factors namely: proportion of income spent-level (A), consumer academic-level (B), demand-types (C), demand time (D), Possibility of postponing demand-level (E), Price-level (F), demand-level (G) and awareness of participation benefits-level (H) have an effective influence on the price elasticity of demand. In order to investigate their impact on a standard response surface methodology design called Center Composite Design (CCD) with 1/2 factorial portion at two levels of high (1) and low (-1), α value of 1 and 10, center points (0) were employed. The definition of levels for each factor is presented in Table-1.

Table-1. Factors and their levels.

Factor	Low (-1)	Middle (0)	High (+1)
A	A > %5	2% ≤ A ≤ 5%	A < 2 %
B	High school	Undergraduate	Postgraduate
C	Agriculture- Other	Public- Residential	Industrial -Commercial
D	00:00 to 7:59	8:00 to 16:59 and 22:00 to 23:59	17:00 to 21:59
E	E < 5%	5% ≤ E ≤ 15%	E > 15%
F	F< 0.5 Initial Price	0.5 Initial Price ≤ F ≤ 1.5 Initial Price	F > 1.5 Initial Price
G	G < 200 Kwh	200Kwh ≤ G ≤ 300 Kwh	G > 300Kwh
H	Full information	A Litter information	No information

Eight factors including A, B, C, D, E, F, G and H were considered as the independent variables while dependent variable or response is the price elasticity of demand. Accordance to the DOE software (version 7) 154 runs was suggested for analysis of variance. The effect of each factor and their interactions on the price elasticity of demand was investigated through analysis of variance. Finally an empirical model based on the effective factors and their interactions were created to be used as an estimation tool.

3. RESULTS AND DISCUSSIONS

Analysis of variance (ANOVA) was performed for 154 runs based on the collected data from all different conditions. Table-2 presents the ANOVA Table for Price elasticity of demand. The results indicate that the model is significant based on the fact that the p-value for the model is less than 0.05. This means that the factors have substantial effect on the model which is desirable [17, 19]. However, some interactions and square of the factors in the quadratic model are not significant. Therefore, these non-significant factors and their interactions should be detached in reduction model to prevent inaccuracy in the

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model. The R-squard of the model is 0.9155 which is close to 1 and are in close agreement with the Adj R-squard which indicates good agreement between the observed and calculated results. The difference between the "Pred R-Squared" and "Adj R-Squared" was a reasonable agreement. "Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. In this model the ratio of 13.423 indicates an adequate signal.

As it mentioned the P values less than 0.05 are significant terms. According to this AB, AH, CE, EG, DH, D^2, DE, E^2, CD, DG, BH, DF, CH, BE, EF, BF, G^2, BG, CF, AH, F^2, FG, CG, BD, EH, A^2 are not considered as significant factors or interactions in this model, therefore, should be omitted for the regression model. From the ANOVA results, the correlation equations and coefficients under actual factors can be determined and is shown in Equation 2:

$\mathbf{E_d}$ = 0.14830 - 0.074052**A** + 5.34800E-003**B** + 0.021966**C** + 6.41631E-003**D** + 0.017054E + 0.051556**F** +0.040482**G** - 0.026597**H** - 0.030593**AB** - 0.023790**AC** - 7.24766E-003**AD** - 9.29891E-003**AE** - 0.017945**AF** - 0.013777**AG** - 0.014560**BC** - 7.58609E-003**FH** - 7.42109E-003**GH** + 0.054453$\mathbf{B^2}$ + 0.056253$\mathbf{C^2}$ +0.059553$\mathbf{H^2}$

Table-2. ANOVA table for the response surface quadratic model.

Source	Sum of squares	df	Mean square	F Value	p-value Prob > F	
Model	2.36	44	0.054	26.84	< 0.0001	significant
A	0.71	1	0.71	356.7	< 0.0001	
B	3.72E-03	1	3.72E-03	1.86	0.1754	
C	0.063	1	0.063	31.38	< 0.0001	
D	5.35E-03	1	5.35E-03	2.68	0.1046	
E	0.038	1	0.038	18.92	< 0.0001	
F	0.35	1	0.35	172.9	< 0.0001	
G	0.21	1	0.21	106.59	< 0.0001	
H	0.092	1	0.092	46.01	< 0.0001	
AB	0.12	1	0.12	59.94	< 0.0001	
AC	0.072	1	0.072	36.25	< 0.0001	
AD	6.72E-03	1	6.72E-03	3.36	0.0694	
AE	0.011	1	0.011	5.54	0.0204	
AF	0.041	1	0.041	20.62	< 0.0001	
AG	0.024	1	0.024	12.16	0.0007	
AH	1.40E-03	1	1.40E-03	0.7	0.4051	
BC	0.027	1	0.027	13.58	0.0004	
BD	2.29E-03	1	2.29E-03	1.15	0.2867	
BE	4.57E-04	1	4.57E-04	0.23	0.6336	
BF	8.23E-04	1	8.23E-04	0.41	0.5223	
BG	1.03E-03	1	1.03E-03	0.52	0.4744	
BH	2.07E-04	1	2.07E-04	0.1	0.7484	
CD	6.35E-05	1	6.35E-05	0.032	0.8589	
CE	4.27E-06	1	4.27E-06	2.14E-03	0.9632	
CF	1.17E-03	1	1.17E-03	0.58	0.4464	
CG	2.19E-03	1	2.19E-03	1.09	0.298	
CH	2.91E-04	1	2.91E-04	0.15	0.7035	
DE	3.99E-05	1	3.99E-05	0.02	0.8878	
DF	2.33E-04	1	2.33E-04	0.12	0.7335	
DG	9.61E-05	1	9.61E-05	0.048	0.8269	
DH	1.86E-05	1	1.86E-05	9.32E-03	0.9233	

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EF	5.34E-04	1	5.34E-04	0.27	0.6062	
EG	6.58E-06	1	6.58E-06	3.29E-03	0.9544	
EH	2.54E-03	1	2.54E-03	1.27	0.262	
FG	1.82E-03	1	1.82E-03	0.91	0.3418	
FH	7.37E-03	1	7.37E-03	3.69	0.0575	
GH	7.05E-03	1	7.05E-03	3.53	0.063	
A^2	1.53E-03	1	1.53E-03	0.77	0.3836	
B^2	2.16E-03	1	2.16E-03	1.08	0.3005	
C^2	2.42E-03	1	2.42E-03	1.21	0.2732	
D^2	3.11E-05	1	3.11E-05	0.016	0.9009	
E^2	4.40E-05	1	4.40E-05	0.022	0.8823	
F^2	1.05E-03	1	1.05E-03	0.53	0.4693	
G^2	7.47E-04	1	7.47E-04	0.37	0.5423	
H^2	2.94E-03	1	2.94E-03	1.47	0.2279	
Residual	0.22	109	2.00E-03			
Lack of Fit	0.22	100	2.18E-03			
Pure Error	0	9	0			
Cor Total	2.58	153				
Std. Dev.	0.045	R-Squared	0.9155			
Mean	0.29	Adj R-Squared	0.8814			
C.V. %	15.31	Pred R-Squared	0.7821			
PRESS	0.56	Adeq Precision	24.41			

This developed regression model for the Price elasticity of demand which is based on the effective factors and interaction can be applied for estimation of price elasticity of demand. This assessment is vital in generation, transmission and distribution of electricity energy. The effect of each factor on the price elasticity of demand is presented in Figure-1. It is obvious that the proportion of income spent-level has significant effect on the price elasticity of demand due to the fact that this factor is determined by the ratio of bills to income. This finding is in close agreement with the reports of Pielow *et al*. [20]. This indicates that price-level also has the significant effect on the E_d. This indicates that ρ is in a direct relationship with the price elasticity of demand which is also shown clearly in the Equation 1. With the escalation in price level, E_d is also increased. The same results was also reported by Hernandez *et al.* [21]. This means that the price of electricity has significant effect on the E_d. In the other words, minor change in energy price has lower influence on customer's response. Based on factor effect plot and p-value of the factors, the significant of the factors in the model is in the following order:

$$A > F > G > H > C > E > D > B \quad (3)$$

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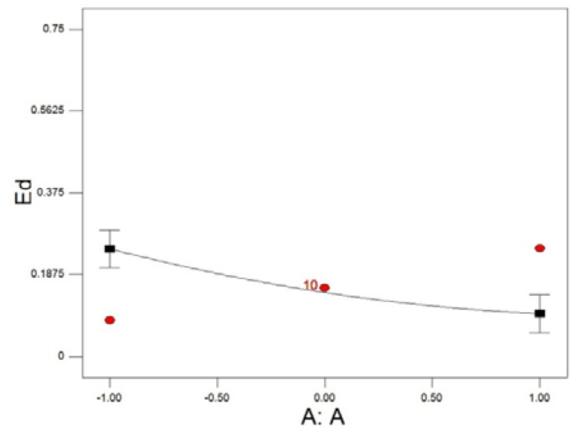

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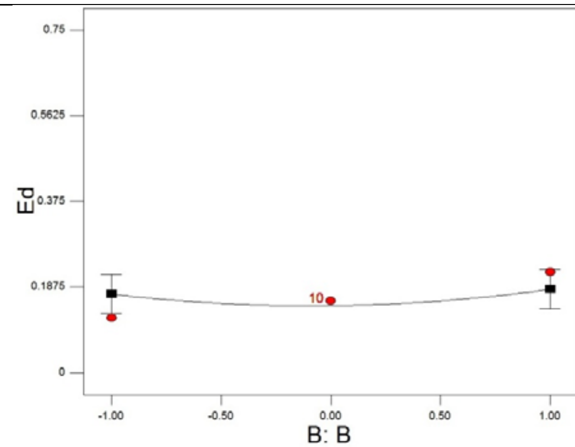

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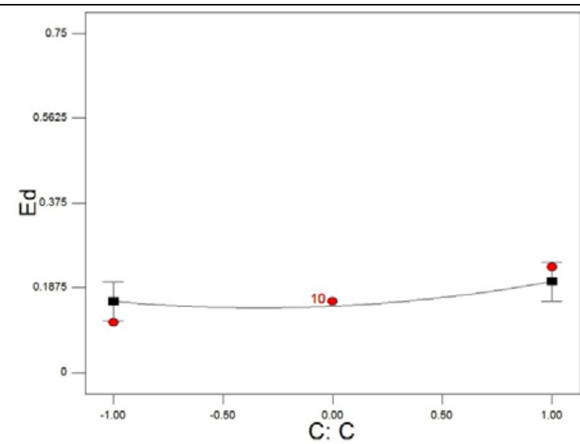

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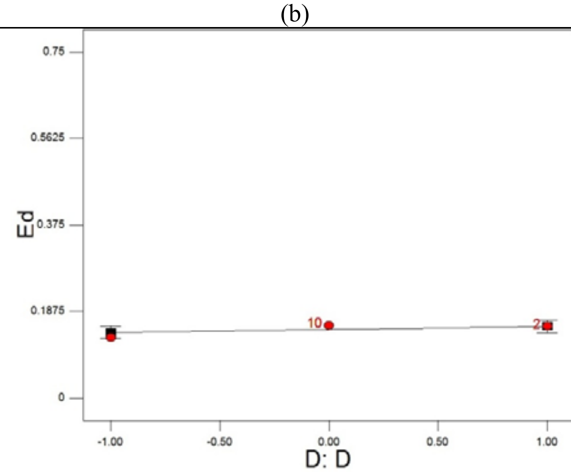

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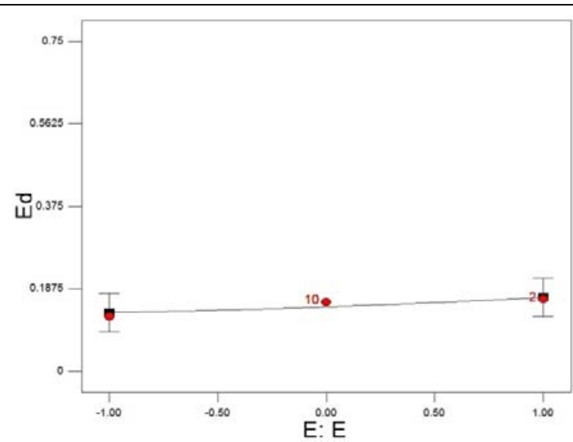

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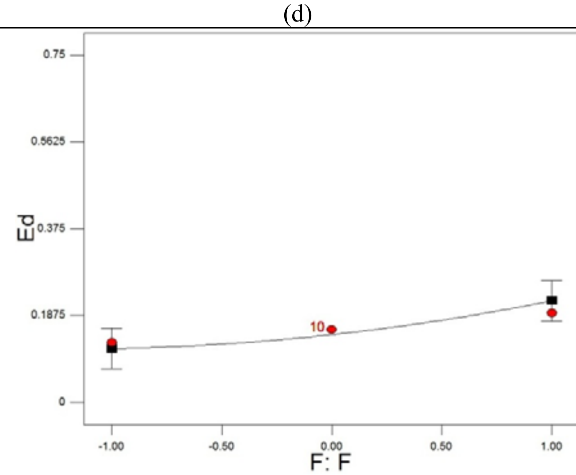

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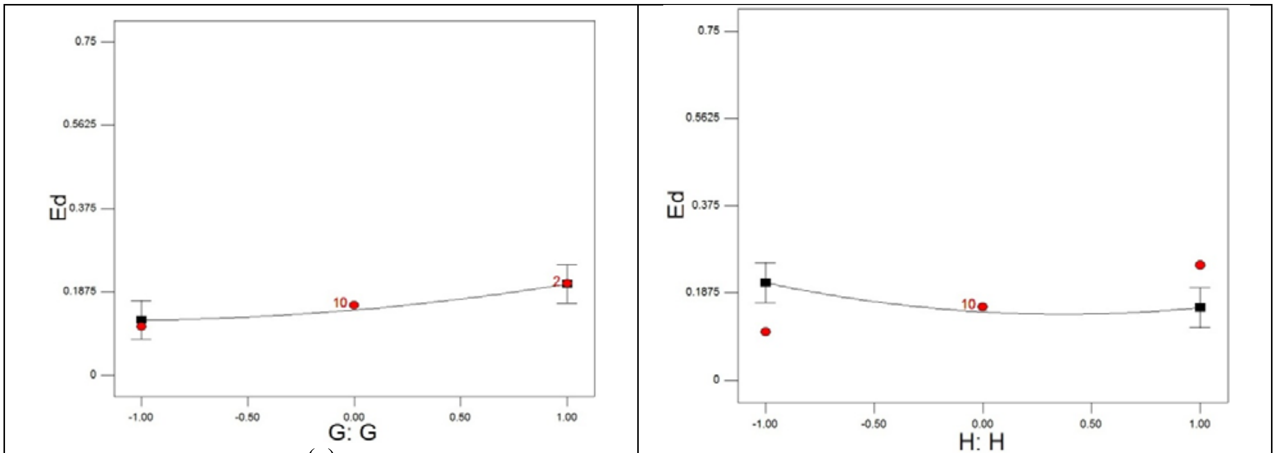

(g) (h)

Figure-1. Effect of factors (a) A, (b) B, (c) C, (d) D, (e) E, (f) F, (g) G, (h) H on price elasticity of demand (Note: the all value of E_d is absolute value.

The normal probability plot is a graphical technique to evaluate whether the data is distributed normally or not. The normal probability plot of residual in comparison with the function of predicted response (E_d) is presented in Figure-2. As it is obvious in the plot, the gradual fall of the residual on the straight line indicated that the distributions of the error are normal in the model. This implies that the proposed models are sufficient and there is no reason to suspect any violation of the independence or constant variance assumption [19].

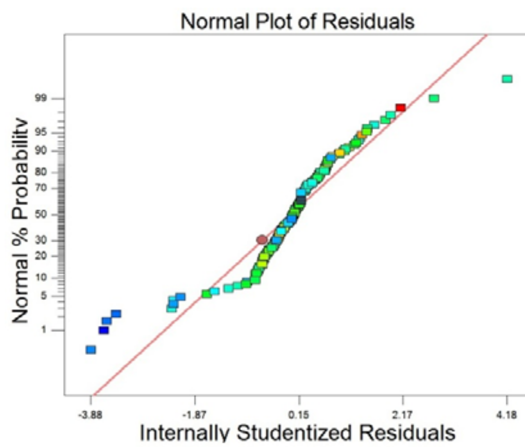

Figure-2. Normal probability plot of residuals for E_d.

Figure-3 illustrates the 3D plots of the E_d. The plots show that AB, AC, BC, FH and HG have curvilinear profile in accordance with the fitted quadratic model. However, AD, AF, AG, and AH displayed linear profile.

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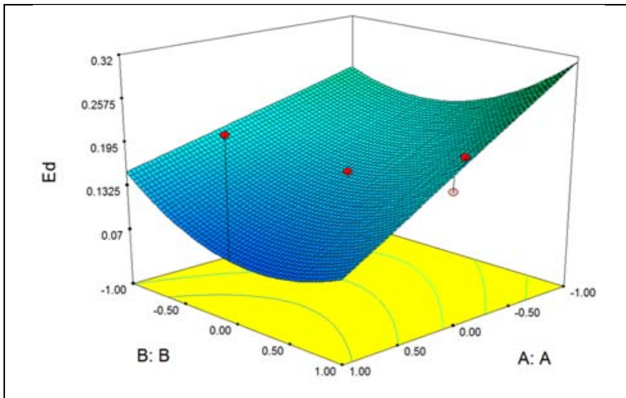

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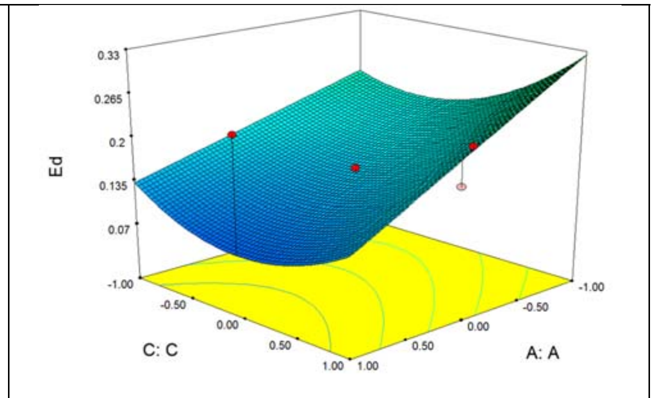

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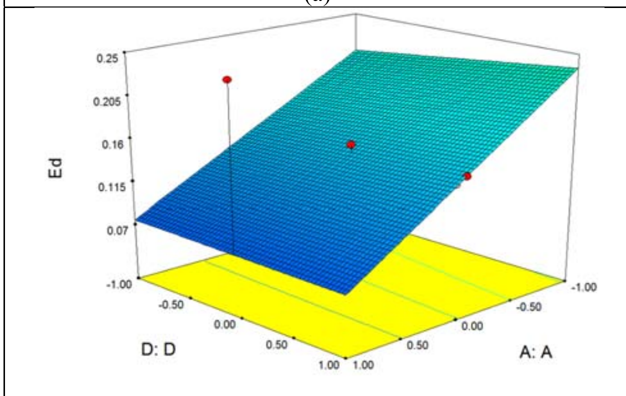

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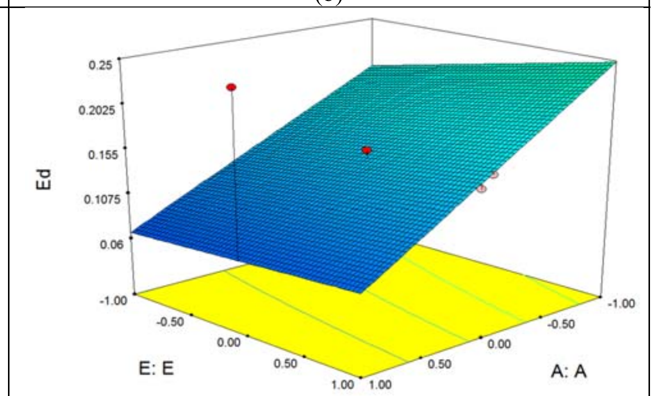

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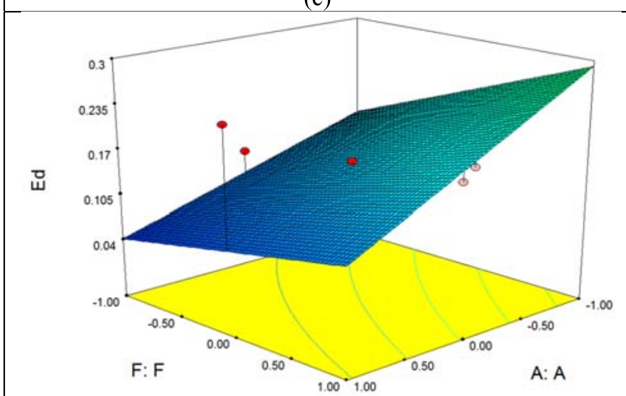

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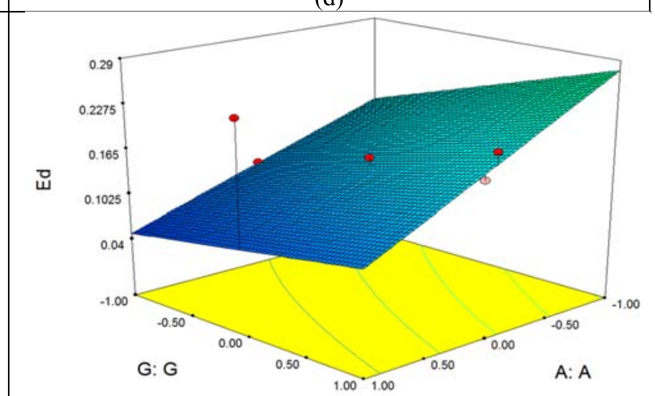

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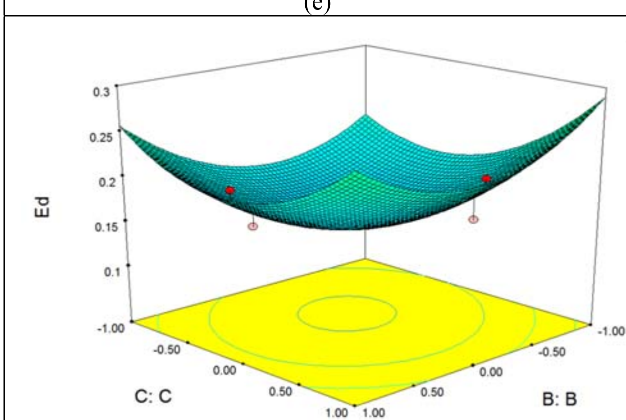

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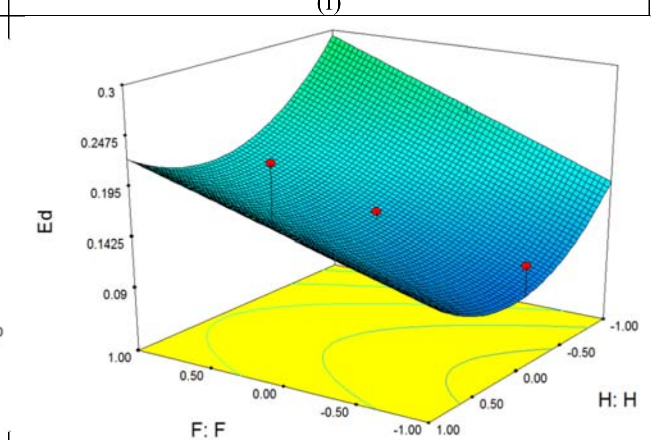

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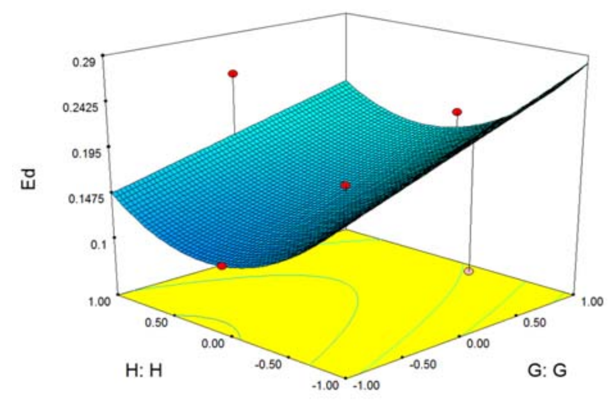

(i)

Figure-3. 3D surface graph for E_d and (a) A, B (b) A, C (c) A, D (d) A, E (e) A, F (f) A, G (g) B, C (h) F, H (i) G, H (Note: all values of E_d are absolute value.)

It is obvious from the 3D plots that with the increase in the electricity price and consumption, the price of elasticity of demand increased due to the fact that greater proportion of customers' income was spent on electricity supply which was also reported Gyamfi *et al* [22]. Consequently, in high electricity consumption hours, the tendency of consumption decreased due to the higher price. This finding is in close agreement with the reports of Thimmapuram *et al.* [2].With the increase of customer academic-level as well as the awareness of participation benefits, the price elasticity of demand increased. With the increased possibility of postponing demand-level as well as demand time, the price elasticity of demand increased which is also mentioned by Nugroho [23]. Resultantly, most of price elasticity of demand belongs to the industrial customers since the possibilities of reducing demand in the peak hours and/or creation of shifting in order to increase the efficiency.

4. CONCLUSIONS

This study was an investigation on the factors including the effect proportion of income spent-level (A), consumer academic-level (B), demand-types (C), demand time (D), possibility of postponing demand-level (E), Price-level (F), demand-level (G) and awareness of participation benefits -level (H) on the price elasticity of demand. Based on the collected data from statistical analysis and surface response methodology, the effect of each factor on the price elasticity of demand was investigated. Results revealed that with increase in the level of all factors from (-1) to (1), the price elasticity of demand was increased. Factor A which represents the proportion of income spent-level has the most significant effect in the determination of the price elasticity of demand while consumer academic-level (B) factor has the least effect on it. Industrial-commercial group type shows the strong influence on increasing E_d however agriculture-other group shows the least influence. Finally, according to the analysis of variance an empirical model which presents the relationship between the effective factors and their interactions on the E_d was created. This model is a productive tool for policy makers aimed at assessment and evolving effective electricity pricing schemes along with strategic planning.

ACKNOWLEDGMENT

The authors would like to thank Universiti Teknologi Malaysia for providing afforded platform; effective support and management under vote 03H45. Moreover we would also like to thank Malaysian Ministry of Education (MOE) for cooperation and financial support for performing this work.

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