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Tariff-worthiness Model of Electric Power Systems Based on Technoeconomics and Hedonic Heuristics

Perambur S. Neelakanta[1], Dolores De Groff[2] and Roxana Meléndez[3]
[1,2,3](Department of Computer & Electrical Engineering & Computer Science/Florida Atlantic University, USA)
Corresponding Author: Dr. P.S. Neelakanta, email: neelakan@fau.edu

ABSTRACT : *Developing a business model on cost-reflective tariff (CRT) levied by electric-power utility services is the theme proposed in this study. Relevant tariff-worthiness is ascertained via synergistic aspects of technoeconomics and productivity considerations of utility operators; plus, hedonic preferences of customers on service products is judiciously included in the model. Hence, a new version of electricity-pricing approach expressed by a parameter named as, hedonic cost-reflective tariff index (H-CRT-I) is proposed to evaluate tariff worthiness of traditional power-distribution services (with possible adjunct support of smart-grid infrastructure). Hence, corresponding results on a set of incumbent utility are deduced, compared and discussed. Foreseeable limitations as well as, merits of using the proposed H-CRT-I are also identified.*

KEYWORDS *Electric-power utility, Hedonic cost-reflective tariff index, smart-grid planning, tariff-worthiness, technoeconomics*

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I. INTRODUCTION

Concomitant to traditional infrastructure, modern electric-power utility expansions could assume inevitable inclusions of smart-grids supporting renewable energy resources and related infrastructure. Relevant considerations on electricity tariff levied on users and pertinent tariff details should reflect the associated source of revenue accrued by utility services consistent with their *willingness-to-accept* (WTA) matching operating and capital cost/capital expenses (OPEX and CAPEX) and *willingness-to-pay* (WTP) considerations by the consumers.

Typically, models on tariff prescription rely on technology-implied economics and associated cross-subsidizations; however, such electricity pricing may not be totally cost-reflective of any underlying customer preferences and choices. Hence, the present study is objectively motivated to deduce a more comprehensive tariff-model. It is judiciously formulated *via* a prorated, synergistic combination of selective preferences (or hedonic perspectives) of consumers on services rendered and technoeconomics-specific details plus productivity-based considerations. Thus, the proposed model is intended to depict an integrated assessment of a tariff structure consistent with WTA considerations *vis-à-vis* the technoeconomics of the *return-of-investment* (ROI) and preferential hedonic choice (or selective preferences) of consumers towards the consumed product related to the WPI involved.

In all, a complete and comprehensive measure is proposed here on electricity-pricing with the inclusion of both marginal WTP and WPI details. It is termed as *hedonic cost-reflective tariff index* (H-CRT-I) and depicts a new version of electric tariff modeling. Further, it enables estimating a price function (and related tariff considerations) that could be different from traditional utility-function (*sans* choice-model details) while detailing the involvement of total cost-reflective revenues and tariff worthiness of electric utility.

II. TARIFF WORTHINESS OF ELECTRIC POWER SYSTEMS

Electricity pricing

Electricity pricing (also known as, *electric power distribution tariff*) refers to judiciously structuring the cost of electric utility services rendered to a set of customers in a service area. In general, it could vary extensively from locale-to-locale of service distribution sites. Further, for utilities rendered to diverse residential (domestic), commercial and industrial customers, there are alternative rate structures adopted in vogue. Well-known examples of electricity-pricing rate structures are as follows: Flat-rate payment based on per kWh usage, tiered payments matching stepped levels of power consumption, variable rates depending on *time-of-use* (TOU), demand-specific rate on the basis of peak-consumption, a sub-tiered rate (within the TOU) based on usage *versus* specific time-of-the-day, rates for seasonal usages of electricity, special rates for weekends/holidays and pricing schemes by utilities supported on a *distributed generation system* (DGS) and/or smart-grid. The defined and identified pricing avenues of electricity in vogue and associated tariff considerations are dependent on several factors [4]-[6] characterized by a set of random variables (RVs) that decide load-curves of the incumbent electric-power utilities; and, related stochastic profiles are described in [5][6]. Correspondingly, unique price-forecasting methods and cost-reflective tariff (CRT) models are indicated to predict the wholesale and/or retail prices of electricity in [7]. Relevant to cost-reflective electric tariff, the motivated theme of this study is thus an effort targeted to deduce an augmented version in terms of the proposed H-CRT-I modeling on estimating a price function. Explicitly, this modeling of total CRT on electric pricing involves cohesively, WTA considerations (on technoeconomics of service providers) and WTP aspects of consumer decisions on hedonic preferences towards electricity consumption.

III. HEDONIC HEURISTICS: AN OVERVIEW

The scope of the study as above (in deciding the required H-CRT-I measure/pricing of electricity) basically refers to concepts that guide the selection of characteristics of goods and products by their economic meanings; and, meaningful or interpretable technoeconomic variables are chosen to prescribe a regression equation on the product characteristics “which not only absorb producers’ resource cost but also generate value to users” [8]-[10]; but also, it is modified to capture the features of goods and services that influence pricing that matches consumers' choice of the product expressed by the desired "pleasure and comfort." Thus, relevant hedonic-pricing of heterogeneous goods includes considerations on selected variables being a homogeneous set of economic building blocks valued by both buyer and seller; as well as, the associated price represents the valuation of all the variables combined [8]. Pertinent linear model estimates how the dependent variable is predicted by the independent variables; further, the so-called Box-Cox methodology [11] provides a means to relax the assumption of linearity by determining the adequate data transformation that gives rise to the best goodness-of-fit.

IV. HEDONIC PRICING STRUCTURE

The hedonic heuristics mentioned above relies on the assumption that the associated product or a service is perceived to bear a "bundle of characteristics"; and, the consumers would tend to buy such a bundle instead of the product itself. Relevant modeling implies a “characteristics-dependent” or “adjusted price index” for the services in question opted by a preferential inclination or choice as warranted in modern electric power distribution services (rendered to users, for example, *via* smart- and feature-systems). The underlying procedure of modeling the price-worthiness involves decomposing the technoeconomic product (namely, the electricity) into its constituent characteristics; and, it obtains the estimates of the contributory value of each characteristic. For the individualized valuation, an attribute vector (a dummy or panel variable) is then typically assigned to each characteristic or group of characteristics. Pertinent to the electricity market, the discretized value of a service product would depend on customer-based vagaries in demand and supply of the service rendered.

Hence, proposed here is a valuation (or prescribing a price-worthiness measure) of power distribution services implicitly depicting the required performance index (defined earlier as, H-CRT-I) for the tariff involved. In short, a customer’s preference towards a particular version of service (or operator) may involve paying an extra premium thereof. Introducing a tariff-structure then becomes H-CRT-I specific, if the service-related quality component of the value and the market price are separated. In other words, the market price can be regarded as a surrogate for the quality value of the service utilized beneficially.

A classical, hedonics-based pricing model is due to Rosen [12] who recognized that the market price of complex goods is jointly linked to consumer evaluations of each of the individual version of services facilitated and by the service provider's offering price for each such services. More such hedonic perspectives in businesses are described in [13].

Proposed model description

In view of the above, described below are vertical aspects of such a electricity pricing model (or tariff sought) via an implicit performance index (H-CRT-I) as described below:

Suppose WTP-attributes of consumers (namely, the maximum price that the subscriber is willing-to-pay) correspond to alternative (k) bundles of a set $\{Z_k\}_{j = 1, 2, \ldots, K}$ of service options available from $\{j = 1, 2, \ldots, j, \ldots, J\}$ operators in the i^{th} service area of interest. Further, for any j^{th} option (or operator), the offered service-bundle Z_k is assumed to contain varying extent of attributes, $\{X_S: x_1, x_2, \ldots, x_s, \ldots, x_S\}_{i,j,k}$ characterized by technoeconomics, productivity and hedonics specific details. Explicitly, they represent, (i) technology-specific, product-dictated index (PDI)*;* (ii) economics-related performance index, (EPI)*;* (iii) productivity-related performance index (PPI) and (iv) consumer-related (preferential or “crush”)-specific hedonic performance index (HPI).

Hence, the set $\{X_s\}_{i, j, k}$ depicts a statistical assortment of service features indexed and valued by: (PDI) $\leftrightarrow (M_i)_{j,k}$, (EPI) $\leftrightarrow (E_i)_{j,k}$, and (PPI) $\leftrightarrow (F_i)_{j,k}$ with corresponding quantifying or weighting coefficients (WC) given by: $\{(\beta_\ell)_{i,j,k}$, $(\gamma_m)_{i,j,k}$ and $(\eta_n)_{i,j,k}$. Relevant cardinality of the set $\{X_{s:\, \ell,\, m,\, n}\}_j$ namely, (s: ℓ, m, n) could vary from provider-to-provider and technoeconomics specified, option-to-option.

Denoting ψ as an offer-function on the unit-price that a utility is willing-to-accept (WTA) for the bundle of services it offers. Then, assuming that the utility operators in a service area are competitors who rationally attempt to maximize their profit (and hence, their RoI), then ψ can be formally written in terms of an implicit function $\Phi(.)$ of $\{Z_i\}_{j,k}$ made of supply capacity (C) of the network and associated technology-dependent CAPEX and OPEX details that specify the liability (L_{co}) on service provisioning. That is,

$$\Psi = \Phi(Z_1, Z_2, \ldots, Z_k \ldots, Z_K; C, L_{co}) \qquad (1)$$

Symmetrically, assuming consumer's choice of the price as H, it is consistent with levels-of-affordability (y) on the price; and, a formal expression for H can be written in terms of an implicit function, $\Theta(.)$ as follows:

$$H = \Theta(Z_1, Z_2, \ldots, Z_k \ldots, Z_K; y, \{\Omega\}_r) \qquad (2)$$

where, $\{\Omega\}_r$ denotes a preferential set of choices or consumer-related (preferential) hedonic features. It refers to the *vector-of-taste* with each choice identified by a subscript index, r and (HPI) $\leftrightarrow (Y_i)_{j,k}$ with corresponding WC given by: $(\zeta_r)_{i,j,k}$. Hence, $\{\Omega\}_r$ represents a set of choosy (preferred) domain characteristics of different service options available to consumers via different operations. In applying the aforesaid functional considerations (of H and ψ) in deducing the proposed H-CRT-I, an assumption is that the value of a service is affected by a particular combination of characteristics that it possesses; as such, better characteristics are graded with higher prices as compared to those with subdued characteristics implied by notions of hedonic heuristics. The vector set of weighting coefficients, (WC): $\{(\beta_\ell)_{i,j,k}, (\gamma_m)_{i,j,k}, (\eta_n)_{i,j,k}, (\zeta_r)_{i,j,k}\}$ are explicitly described in Table I.

TABLE I:
DESCRIPTION OF THE CONSTITUENTS OF THE VECTOR SET {PDI, EDI, PPI, EPI} AND THEIR WEIGHTING COEFFICIETS (WCs)

Vector set	WC	Descriptions of the constituents (Examples)
PDI-specific parameters		β_1: Power-generation type and technology β_2: Distribution infrastructure β_3: TOU and load-curve β_4: Renewable energy used β_5: OGI/smart-grid deployment etc.
$(M_i)_{j,k}$	$(\beta_\ell)_{ij,k}$	
EDI-specific parameters		γ_1: CAPEX/OPEX (WTP) γ_2: Consumer willingness (WPI) γ_3: *per capita income*(PCI) γ_4: Taxes and regulatory fees, overheads and subsidies γ_5: Competitive market and incentives to customers etc.
$(E_i)_{j,k}$	$(\gamma_m)_{ij,k}$	

TABLE I (CONTINUED)

PPI-specific parameters			
$(X_i)_{j,k}$	$(\eta_n)_{ij,k}$	η_1: Availability of skilled labor η_2: Availability of expertise: Engineers, technician and corporate staff η_3: Corporate planning and policies η_4: Customer power usage Patterns (domestic, business and industrial outlays) η_5: Proactive forecasts etc.	
HPI-specific parameters			Type
$(Y_i)_{j,k}$	$(\zeta_r)_{ij,k}$	ζ_1: Green energy	GE
		ζ_2: WTP for clean - environment preference factor	PA
		ζ_3: Intensity of green-Energy usage "crush"	UA
		ζ_4: Demand-category based preference factor	CA
		ζ_5: Age-based preference factor	AA
		ζ_6: Preference for basic essential domestic power	ES
		ζ_7: Social awareness towards green energy	SN
		ζ_8: Preference on service reliability	SR
		ζ_9: Service-call availability etc.	SC
Each coefficient of the vector set identified/defined above is multiplied further by a binary-index: $\sigma_{1,o}$ in order to specify, either the presence (Yes: Y; σ_1 = 1) or absence (No: N; σ_o= 0) of that coefficient			

The turf details and pertinent exo- and/or endogenous input variables of {PDI, EPI, PPI, HPI} (and related coefficients) can be availed from various databases of World Bank, International Energy Agency (IEA) and Energy Sector Management Assistance Program (MSMAP); as well as, companion information can be gathered at relevant citations of [14]-24] listed in Table II.

TABLE II
ELECTRIC ENEGY CONSUMPTION WORLDWIDE DATA: SOME SALIENT REFERENCES

Data on	Ref	Type
Sustainable energy for All (SE4ALL)	[14]	SS
IEA statistics © OECD/IEA 2014 – Coal-related sources	[15]	CS
Usage of electricity from renewable sources, excluding hydroelectric (% of total)	[16]	TS, POS
Electric energy sources of traditional types: From oil, gas and coal sources	[17]	TS, ES
Energy use (kg of oil equivalent per capita)	[18]	PS. HS
Alternative resources - nuclear energy (% of total energy use)	[19]	TS, POS, HS
Electricity production from renewable sources, excluding hydroelectric (kWh).	[20]	TS, HS
Fossil fuel energy consumption (% of total).	[21]	TS, PS
Combustible renewables and waste (% of total energy)	[22]	POS, HS
Statistics on access to electricity (% of population)	[23	TS, ES
Statistics on access to electricity in urban areas (% of population)	[24]	TS, ES

Explicit details and compiled data on spatiotemporal random variables (RVs) of the set {PDI, EPI, PPI HPI} and relevant expected means, *E[.]* adopted in evaluating the proposed pricing coefficient (H-CRT-I) are furnished in Tables III(A) and III(B).

In all, the exercise towards assessing relative "price-worthiness" of electricity provisioned by a set of incumbent service providers (*via* different service options) forms the thematic effort of this study; and, deciding pertinent tariff worthiness (indicated as, H-CRT-I) is elaborated in the following pseudocode.

Pseudocode

%% *Problem Statement*: To formulate an algorithm and computational steps towards evaluating the proposed pricing index, H-CRT-I

Initialize

Input

→ (i) Service period from (i = 1)→ 2010 to (i = 4) →2013; (ii) Service area (A) with service providers: (SP-a, j = 1), (SP-b, j = 2), (SP-c, j = 3) and (SP-d, j = 4); (iii) Type of services (k): (k = 1 ↔ k_1:Traditional technology), (k = 2 ↔k_2: Modified infrastructure with smart-grid), (k = 3 ↔ k_3: New resources with wind-mill, solar-cell etc. and (k = 4 ↔ k_4: Total clean-energy preference in terms of green environmental reasons *etc.)*

Define

← *Algorithmic parameters of PDI, EPI, PPI and HPI*

→Explicit details of the constitutive entities of: $(M_i)_{j,k}$, $(E_i)_{j,k}$, $(X_i)_{j,k}$, and $(Y_i)_{j,k}$ and quantify them using the data availed (from the literature)

← Express the quantified values in normalized forms with each vector of the set $\{(M_i)_{j,k}, (E_i)_{j,k}, (X_i)_{j,k}, (Y_i)_{j,k}\}$ specified in the range 0 to 1(or in relative percentages)

→ Assign thereof to each constitutive vectors of the set $\{(M_i)_{j,k}, (E_i)_{j,k}, (X_i)_{j,k}, (Y_i)_{j,k}\}$, the coefficient (or weighting factor) in the range 0 to 1) as shown in Table IIIA: (The numerical values indicated for the coefficients can be prescribed by an analyst on the basis of perceptive experience gained in the turf

Construction of the Model

Description

→ Proposed (real) pricing model for the i[th] year offered by the j[th] service provider for the k[th] service type: H-CRT-I: $(P_{i,j,k}) = f(M_i, E_i, X_i, Y_i)_{j,k}$

← $P_{i,j,k}$ represents the real price of the service; constrained by: Expected *return-on-investment* (RoI); also, it denotes the *producer price index* (PPI) valued by WTA; and, consumers' willingness for the tariff expressed by WTP

Modeling objective and constraints

→ The objective in hand, is to estimate H-CRT-I, $(P_{i,j,k}) = f(M_i, E_i, X_i, Y_i)_{j,k}$ denoting the real-price index of the service under technoeconomic plus hedonic perspectives. It is constrained by: $[P_{i,j,k}] \geq$ WTA as decided by budget-line restrictions/RoI and $[P_{i,j,k}] \leq$ WTP decided by consumers' choice

Analysis

→ The model (algorithm) specified above determines $(P_{i,j,k})$: H-CRT-I with its Wiener upper- and lower-bounds (UB and LB) using relevant parameters of: (i) Technology coefficients, β_ℓ of PDI↔ $(M_i)_{j,k}$; (ii) economics-related performance details, γ_m of EPI↔ $(E_i)_{j,k}$; (iii) productivity-specific set of coefficients, η_n of PPI↔ $(E_i)_{j,k}$ and (iv) hedonic or preference parameters of the consumers, ξ_r of HPI↔ $(Y_i)_{j,k}$ listed in Table I.

Procedural steps

→ $(P_{i,j,k})$ is set by the functional relation: $f(M_i, E_i, X_i, Y_i)_{j,k}$ with the constraints namely, {WTA and WTP} and it accommodates the said constraints towards the optimization in question using a penalizing *Lagrangian* coefficient, λ. Hence, a solution towards maximizing *f(.)* can be found in terms of the Lagrangian, L(.) given by:

$$L(M_i, E_i, X_i, Y_i; \lambda_i)_{j,k} = f(M_i, E_i, X_i, Y_i)_{j,k} + \sum_c [(\lambda_i)_c \times [\Phi \text{ or } \Theta(M_i, E_i, X_i, Y_i)_{i,j,k}]_{(WTA,WTP)_c}$$

where c refers to the constraint applied to the set associated with each $(\lambda_i)_c$ in deciding the price.

→ A suboptimal solution for the maximized functional relation: $f(M_i, E_i, X_i, Y_i)_{j,k} \leftrightarrow [f_c(z)]_{i,j,k}$ corresponds to a logistic function, P(z), which can be written in a general form such that, it conforms to an explanatory variable z of the set $\{M_i, E_i, X_i, Y_i\}_{j,k}$. It is equal to: $[a_0 + a_1 z_1 + \ldots + a_u z_u]$, where, the entities $\{z_1, z_2$, etc.$\}$ denote contributory variables denoting predictive regressors of the set $\{M_i, E_i, X_i, Y_i\}_{j,k}$; and, $\{a_1, a_2$, etc.$\}$ are regression coefficients properly assigned to 'weigh' such predictive regressors. Further, the logistic regression function, P(z) satisfies the following limiting cases: As $z \to \infty$, $P \to 1$ and as $z \to 0$, $P \to 0$. That is, the outcome of computing the logit-function, $P(z = a_0 + a_1 z_1 + \ldots + a_u z_u)$ specified between, 0 to 1.

← Hence, a suboptimal solution for the maximized $[f_c(z)]_{i,j,k}$ as above would correspond to a logistic function, which (in normalized form) is specified between, 0 to 1. Explicitly, the logit-function is given by the relation: $P(z) = 1/[1 + \exp(-z)] \equiv [(1/2) + (1/2)\times \tanh(z/2)]$; and, in an alternative form, P(z) can also be written as follows: $[1/2) + (1/2)\times L_Q(z/2)]$, where $L_Q(.)$ is known as Langevin-Bernoulli function given by [25] [26]:

$$L_Q(\mu) = (1 + 1/2Q) \times \coth[(1 + 1/2Q) \times \mu] - (1/2Q) \times \coth[(1/2Q) \times \mu] \qquad (3)$$

with Q depicting a stochastic order-parameter that duly accounts for the underlying random features of regressor variables involved in the model. Further, as $Q \to ½$, the function $L_Q(\mu) \to \tanh(\mu)$ depicting the Wiener upper-bound (UB) meaning, a totally-disordered state of the system; and, when $Q \to \infty$, the function $L_Q(\mu) \to [\cot(\mu) - 1/\mu]$,which depicts the Wiener lower-bound (LB) of the regressed function, $P(.)$ as detailed in [25] [26].

Computation

← With reference to the intended objective of sub-optimally establishing the real-price of the service as decided by pertinent coefficients of the set, $\{M_i, E_i, X_i, Y_i\}_{j,k}$, the underlying computational steps explicitly refer to deducing the following: $P(z_{i,j,k}) = (1/2) + (1/2)\times \tanh(z_{i,j,k}/2)$where:

$$z_{i,j,k} = \begin{bmatrix} \sum_{\ell} \beta_\ell \times (S_{1,0})_\ell + \sum_m \gamma_m \times (S_{1,0})_m + \sum_n \eta_n \times (S_{1,0})_n \\ + \sum_r \zeta_r \times (S_{1,0})_r \end{bmatrix} \qquad (4a)$$

And, the corresponding UB and LB are as follows:

$$[P(z_{i,j,k})]_{LB,UB} = [(1/2) + (1/2) \times L_Q(z_{i,j,k}/2)]_{Q = 1/2:\ UB}$$
$$= [(1/2) + (1/2) \times L_Q(z_{i,j,k}/2)]_{Q = \infty:\ LB} \qquad (4b)$$

Compilation

Results

→ The evaluated detail on H-CRT-I conform to the proposed price (or tariff structure) of the electric utility service as decided by the set, $\{M_i, E_i, X_i, Y_i\}_{j,k}$.

→ Parameters (coefficients) identified and used thereof in the computations of H-CRT-I are detailed in Table I; and pertinent literature details vis-à-vis electric energy consumption worldwide are availed from various citations summarized in [14] – [24] (as listed in Table II). Further, necessary information as needed refer to those that are presented in tabular forms as follows:

→ Table III(A): Compiled performance indices on PDI, EPI and PPI across service years, (i) 2010-2013 in the service area, A and service provider, (SP)-(j)

→ Table III(B): Furnished here are availed and compiled performance indices across service years, (i): 2010-2013 in the service area, A and four service providers: (SP)-(j = 1 to 4) pertinent to the expected values of PDI, EPI and PPI

→ Table IV: Indicated in Table IV are corresponding (expected values) of performance indices compiled on HPI across service years, (i) 2010-2013, in the service area A and four service provider, (SP)-(j = 1 to 4).

Plot

← Compiled data on the expected values of the parametric set, {PDI, EPI, PPI, HPI} in Tables III and IV (that decide the eventual pricing index, H-CRT-I sought) are plotted in Figs. 1 through 4 over the service period for each service provider. Further, these expected values of the set {PDI, EPI, PPI, HPI} are pseudo-replicated *via* statistical bootstrapping [27]. Hence, an ensemble stretch of details for each data-point is generated depicting a vertical an error-bar in each case with limiting upper- and lower-bounds as shown in Figs 1 to 4.

Summary

← Thus, the assorted details and parameters listed in Tables II through IV lead to required computed results on H-CRT-I as furnished in Table V where, a summary of computed results on tariff and pricing structure as well as, actual prices enforced by service providers in the service area are presented

End

V. RESULTS: SUMMARY

As mentioned earlier, details on expected values of the RVs, PDI, EPI and PPI expressed in terms of their normalized coefficients (in the range 0 to 1) are presented in Table III(A). Further in Table III(B), the set $\{(Y_i)_{j,k}\}_r$ constituted by:$\{\zeta_r\}_{r = 1, 2, ..., 9}$ (each denoting the type of the HPI parameter in the set {GE, ..., SC} described Table I) are identified; and; these parameters are denote spatiotemporal RVs each having an expected-mean, E[.] as shown; further, Table III(B) contains the estimated H-CRT-I (in the normalized range of 0 to 1).

TABLE III(A)

PERFORMANCE INDICES: SUMMARY OF COMPILED ON EXPECTED MEANS OF {PDI, EPI, PPI} VALUES ACROSS THE SERVICE PERIOD 2010 TO 2013

Service area: A; service provider (SP)-(j) and service period: (i) – 2010-2013			
i = 1: 2010			
Service provider SP-j and (relative) power (in %) supplied *vis-à-vis* their demand-profile	Performance indices		
	E[PDI]	*E[EPI]*	*E[PPI]*
SP-a -- 50%	0.76	0.68	0.89
SP-b -- 100%	0.69	0.66	0.99
SP-c -- 100%	0.69	0.72	0.89
SP-d -- 100%	0.96	0.65	0.89
i = 2: 2011			
	Performance indices		
	E[PDI]	*E[EPI]*	*E[PPI]*
SP-a -- 50%	0.56	0.55	0.90
SP-b -- 100%	0.99	0.73	0.91
SP-c -- 100%	0.63	0.62	0.91
SP-d -- 100%	0.56	0.51	0.91
i = 3: 2012			
	Performance indices		
	E[PDI]	E[EPI]	E[PPI]
SP-a -- 50%	0.92	0.71	0.92
SP-b -- 100%	0.72	0.69	0.93
SP-c -- 100%	0.53	0.59	0.93
SP-d -- 100%	0.45	0.47	0.93
i = 4: 2013			
	Performance indices		
	E[PDI]	E[EPI]	E[PPI]
SP-a -- 50%	0.95	0.76	0.92
SP-b -- 100%	0.87	0.74	0.92
SP-c -- 100%	0.54	0.53	0.92
SP-d -- 100%	0.67	0.53	0.92

Note:
1. Data furnished above refers to a set of four (4) service providers operating in a service area in the United States. (The service providers are not explicitly identified due to proprietary reasons); however, relevant analyses and computational studies can be made for any such service areas without any loss of generality
2. Average performance indices indicated correspond to spatiotemporal variables that could change randomly across the service areas in the nation over a given study period.
3. Indicated also is an exemplar set of values of relative power supplied by four incumbent service providers *vis-à-vis* demand-profile faced in the service area.

Actual prices of monthly service-charges enforced by incumbent service operators during the year 2013 as availed are listed below. Corresponding normalized values denoted as a set of values P_A (in US \$); and, the values of P_A normalized with respect to the national mean value are also listed as, P_N. For utilities facilitated with smart-grid, the service providers may also decide more monthly prices on *ad hoc* basis consistent with service level agreement (SLA).

TABLE III(A) (CONTINUED)

Utility service provider (j)		Year 2013 (j = 4) Monthly price (P_A: Average values in US $) imposed by service providers	
		Nationwide	Local: Service area: A
SP-a		85	Not available
SP-b		90	120
SP-c		60	100
SP-d		70	100

TABLE III(B)
PERFORMANCE INDICES: SUMMARY OF COMPILED HPI VALUES ACROSS 2010 TO 2013

Service area: A; service providers (*j*) and differentiated (four) service types (*k*) improvised across the years (*i*): 2011-2013
Expected-mean performance, *E[.]* of constitutive variables of the vector sets of (HPI): $\{(Y_i)_{j,k}\}_r$ constituted by: $\{\zeta_r\}_{r = 1, 2, ..., 9}$
Availability status coefficient: σ_1: Y (Yes) = 1 and σ_o: N (No) = 0.

$\{\zeta_r\}_{r = 1, 2, ..., 9}$	r	Service-types k_1	k_2	k_3	k_4	σ_1	σ_o
		Expected mean coefficients, *E[.]*					
		$E[\alpha_1]$	$E[\alpha_2]$	$E[\alpha_3]$	$E[\alpha]$		
GE	1	0.09	0.15	0.27	0.49	1	
PA	2	0.11	0.16	0.28	0.45	1	
UA	3	3.16	4.86	6.96	9.25	1	
CA	4	0.11	0.20	0.30	0.39	1	
AA	5	1.91	2.59	2.94	2.98	1	
ES	6	0.52	0.70	0.80	0.81	1	
SN	7	0.40	0.55	0.62	0.81	1	
SR	8	0.53	0.71	0.81	0.81	1	
SC	9	0.24	0.33	0.38	0.81	1	
Year		2010	2011	2012	2013	Service period	
Estimated H-CRT-I		0.89	0.90	0.92	0.92	Normalized values	

Computed results using the parameters listed above (and as described in the pseudocode) on tariff performance profiles of service providers (in the service area) in terms of normalized values of H-CRT-I:p_{Comp} are summarized in Table IV along with their lower- and upper-bounds (LB and UB).

TABLE IV
COMPUTED RESULTS ON H-CRT-I IN THE SERVICE AREA

Year (*i*), service provider-(j) and service type-(*k*)			Computed lower- and upper-bounds (LB and UB) of: H-CRT-I: p_{Comp}		
	k = 1		LB	UB	(LB + UB)/2
i = 1 2010	j = 1	SP-a	0.890	1.000	0.945
	j = 2	SP-b	0.890	1.000	0.945
	j = 3	SP-c	0.890	1.000	0.945
	j = 4	SP-d	0.890	1.000	0.945
i = 2 2011	j = 1	SP-a	0.900	1.000	0.950
	j = 2	SP-b	0.900	1.000	0.959
	j = 3	SP-c	0.900	1.000	0.950
	j = 4	SP-d	0.900	1.000	0.959
i = 3 2012	*k* = 2		LB	UB	(LB + UB)/2
	j = 1	SP-a	0.930	1.000	0.960
	j = 2	SP-b	0.930	1.000	0.960
	j = 3	SP-c	0.930	1.000	0.960
	j = 4	SP-d	0.930	1.000	0.960
i = 4 2013	*k* = 2		LB	UB	(LB + UB)/2
	j = 1	SP-a	0.920	1.000	0.960
	j = 2	SP-b	0.920	1.000	0.960
	j = 3	SP-c	0.920	1.000	0.960
	j = 4	SP-d	0.920	1.000	0.960

TABLE IV (CONTINUED)

Prices listed denote normalized values with respect to the average pricing enforced in the service area

Posted below are the set of P_A values (in US $) depicting actual prices of monthly service-charges enforced by service operator for the year 2013; and, their corresponding normalized values (normalized with respect to the national mean value) are indicated by: P_N

			Service area A		Nationwide		
i = 4 (2013) k = 2	*j*	SP	P_A in US $	P_N	P_A in US$	P_N	Mean P_A in US $
	j = 1	SP-a	-	-	85	1.11	76.25
	j = 2	SP-b	120	1.62	90	1.18	
	j = 3	SP-c	100	1.35	60	0.79	
	j = 4	SP-d	100	1.35	70	0.92	

Lastly, a summary of details on computed results as regard to H-CRT-I and actual tariff/pricing structure adopted are presented in Table V.

TABLE V
Summary of results: Tariff details and estimated pricing structure

Service Area: Nationwide Year 2013				
Service provider - (*j*)		Average of expected values of performance indices: (PDI, EPI, PPI and HPI		
		Upper and lower bound values		Mean performance index (MI)
		LB	UB	MI = (LB + UB)/2
SP-a	j = 1	0.880	1.000	0.940
SP-b	j = 2	0.840	1.000	0.920
SP-c	j = 3	0.660	1.000	0.830
SP-d	j = 4	0.710	1.000	0.850

Tariff details: Estimated and actual values of *per mensum* charges (in US $)				
Average nation-wide price (in US $) $[P_{av}]_{USA}$	(*j*)/SP	Estimated (computed) price (in US $) by the proposed method: $[P_{ES}]_{USA} = (MI \times [P_{av}]_{USA})$	Actual nationwide price (in US $) $[P_{AC}]_{USA}$	Percentage difference of: $\{[P_{AC}]_{USA}$ and $[P_{ES}]_{USA}\}$ with respect to: $[P_{av}]_{USA}$
	1/SP-a	72	85	17 %
	2/SP-b	70	90	26 %
	3/SP-c	63	60	4 %
	4/SP-d	65	70	7%
MI: Mean performance index = (LB + UB)/2				

VI. RESULTS: DISCUSSIONS

Commensurate with the objective of this study and analyses pursued, the results sought can be viewed in two perspectives: (1) How do electric-power utility service operators perform relatively when compared in terms of technoeconomics and productivity-based parameters? (2) How do such performance characteristics are further influenced by customer-liking (that is, hedonic trend of the customers) *vis-à-vis* their preferential choice of services offered?

Hence, pertinent analyses yield details and results as presented in Tables I through V; and, associated graphical illustrations on performance indices adopted in deducing the H-CRT-I are furnished in Figs. 1 to 4. Included in the illustrations are also statistical error-bars at the data-point of the indices. As mentioned earlier, each vertical stretch (marked as an error-bar) corresponds to a statistical ensemble of outcomes of simulations depicting the pseudo-replicates [27] (namely, the bootstrapped surrogates) of the expected mean values. Such ensemble values implicitly depict the statistical variations of input variables possessing a central tendency towards the expected value.

The practical issues that could place constraints on H-CRT-I estimations are as follows: (i) The associated variables of the estimation should remain homogeneous across the economics of the building-blocks of heterogeneous goods being priced; (ii) such variables could be valued both by the consumers and the sellers; (iii) the proposed pricing should be directly indicative of valuation of all the variables combined; and, (iv) a limitation of the proposed H-CRT-I model refers to the omission of rational and irrational preferences based on local affluence etc. that may skew the results obtained to some plausible extent. Thus, the H-CRT-I model of the price structure needs awareness/transparency on the acceptability of the product price *versus* the factors such as, the local income structure etc. Such sensitive factors could implicate rationally-objective preferences versus irrational influences.

VII. CONCLUDING REMARKS

In closure, the present paper offers an approach to view the tariff-related performance of electric-power distribution operations in a system with a framework of multiple resources and variety of diverse users (domestic, commercial, and industrial). Also addressed cohesively here are related technoeconomic, productivity and hedonic considerations, focused on such services, (as well as in any similar service industry operations like global telecommunication [28]). The results reveal that the relative performance of operators in a service area is dictated largely by the underlying and competitively-close, tariff structure imposed on the customers meeting the supply-and-demand *versus* technoeconomics, productivity and hedonic preferences of services rendered.

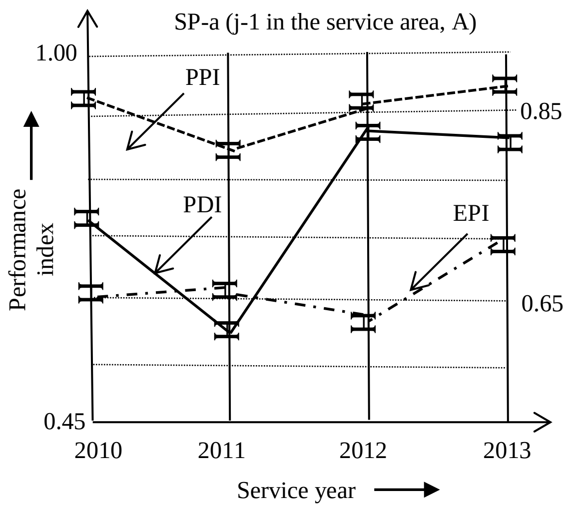

Fig. 1. Performance indices versus service period (2010-2013) for SP-a (j-1 in the service area, A)

Results presented in Figs. 1 to 4 show the implied limits of upper- and lower-bounds caused by statistical variations of input variables that decide the parameters PDI, EPI, PPI and HPI; and, correspondingly, the associated H-CRT-I values are decided each with a central tendency of expected value. Modeling tariff-structure using H-CRT-I heuristics (vis-à-vis results as in Table IV) becomes viably feasible considering utilities that may differ significantly in their infrastructure (with retrofits and/or implementing smart-grids [29]-[35]) across a diverse set of customer ambient and spatiotemporal statistics of operational and performance details; as such, the proposed approach can be pursued, if sufficient and statistically-large extent of information and data on incumbent services are robustly availed. In short, the proposed H-CRT-I modeling is a *de nova* approach on tariff worthiness of electric utility. Such pricing methods are not hitherto addressed in detail in literature (to the best of authors' knowledge).

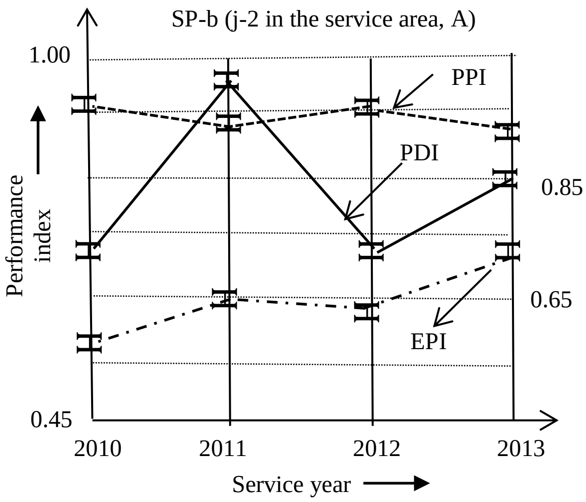

Fig. 2. Performance indices versus service period (2010-2013) for SP-b (j-2 in the service area, A)

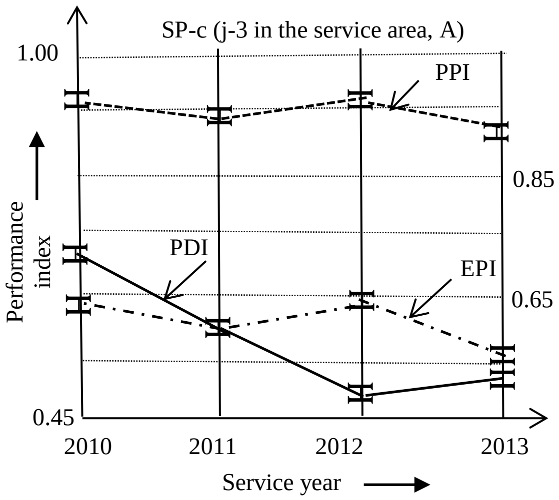

Fig. 3. Performance indices versus service period (2010-2013) for SP-c (j-3 in the service area, A)

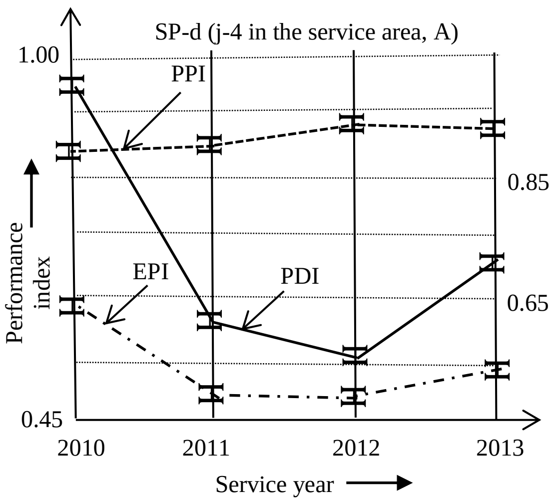

Fig. 4. Performance indices versus service period (2010-2013) for SP-d (j-4 in the service area, A)

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