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REGRESSION-BASED PREDICTIVE MODELS FOR ESTIMATION OF ELECTRICITY CONSUMPTION

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Abstract

The estimation of electric power consumption is an integral part of power generation economics and is critical to optimization of cost of production of electricity, since it allows demand matching for optimized generation of electricity. The present paper augments a simple regression-based scheme with a predictive machine-learning based piecewise linear slope-estimation technique for more accurate estimates, which is further modified to compensate for initialization error.

Keywords: electric power consumption, demand matching, regression, machine learning, piecewise linear, slope estimation

1. Introduction

Economical generation of electric power is one of the most relevant research problems of the present era. Depletion of natural reserves of conventional fuels as well as growing environmental pollution concerns has focused many researchers to shift their attention to the domain of demand matched power generation. It is thus extremely important to be able to arrive at a good estimate of power requirements for any given geography, be it a city, a state or even a country. Therefore current research in this area has focused on design of estimation techniques and algorithms, inclusive of techniques employing artificial intelligence and machine learning approaches. The techniques seek to determine a correct estimate of electrical power consumption at a future period of time based on historical data. The estimates can then be used in multiple ways to economically generate electric power, ranging from the design of load-balancing schemes and equipment to policy-level decisions to determine the quanta of generation of electric power from different sources. Accurate estimation algorithms for forecasting electric power demands are therefore studied in this paper, and novel techniques are proposed.

2. Literature Survey

Estimation of electrical energy and power requirements have been investigated by researchers extensively in recent times. Popular techniques explored have included grey forecasting techniques based on neural networks to achieve accurate forecasts from a limited dataset [1], energy requirement estimation for bioclimatic buildings using neural networks [2] and grey prediction based forecasting of electricity consumption [3]. Multiple techniques such as Kalman Filter based estimation, regression and Artificial Neural Network based forecasting have been studied together to determine the best-in-class technique among them [4]. Prediction models involving deep recurrent neural networks have also been used for estimating energy requirements in buildings [5]. For estimation of electricity consumption in large regions, data mining techniques have been used by researchers to forecast power requirements with a low percentage of relative error [6]. Radial basis function neural networks are used along with Genetic Algorithm based techniques to mitigate the errors in estimation using back propagation based neural networks for estimation of electricity demand [7][8]. Soft computing based approaches have also become popular in recent years in case of industrial data where the datasets as well as variations are large [9]. Other interesting approaches involve local polynomial regression based machine learning algorithms [10].

The current paper compares and contrasts a linear regression based estimation technique with a piecewise linear machine learning based regression model, and refines the piecewise linear model with power series based estimation to further reduce the error in estimation.

3. Regression Models

A dataset for power consumption in India is studied from 1994 to 2004, with respect to GDP per unit of energy use, and a corresponding linear regression model is proposed for 2004 to 2014 [10]. The regression equation 1 with *g(t)* representing the GDP for a year *t* versus the electric power consumption *e(t)* is shown below. *C(t)* represents the value of the constant for the year *t* and *m(t)* is the slope. For standard linear regression, all *C(t)* values are equal.

$$e(t) = m(t) * g(t) + C(t) \quad (1)$$

The actual regression equation for the dataset is shown in equation 2 below where *el(t)* is the linear regression based estimate of the actual consumption *e(t)* for any year *t*.

$$e(t) = 122.3 * g(t) - 293.2 \quad (2)$$

The dataset for 2004 to 2014 is compared with the forecast values obtained from the linear regression model. The variation of GDP per unit of energy used with electric power consumption is shown in figure 1.

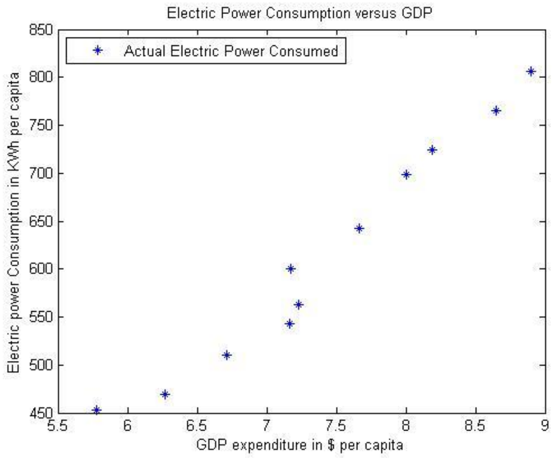

Fig. 1. Variation of GDP with Electric Power Consumed

The dataset and its forecast values for 2004 to 2014 are represented in Table 1.

Table 1. Electricity consumption dataset (2004-2014) comparison with linear regression estimate

Year	GDP per unit of energy use ($)	Electric Power Consumption (kWh)	Estimated Consumption from linear regression(kWh)	Estimation Error (%)
2004	5.78	453.01	413.694	8.679
2005	6.274	469.454	474.11	-0.992
2006	6.713	510.752	527.8	-3.338
2007	7.162	543.359	582.713	-7.243
2008	7.231	562.899	591.151	-5.019
2009	7.177	600.202	584.547	2.608
2010	7.663	642.112	643.985	-0.292
2011	8.001	698.548	685.322	1.893
2012	8.188	724.791	708.192	2.29
2013	8.652	765.564	764.94	0.082
2014	8.9	805.599	795.27	1.282

The authors have proposed a piecewise linear regression model to reduce the estimation error. The model uses a simple machine-learning based regression algorithm for slope estimation based on the previously encountered error in estimation [4]. The primary regression relation corresponding to this model is shown in equation 3. Here, (*t-1*) represents the year previous to *t* and *ep(t)* is the piecewise linear estimate of *e(t)*.

$$ep(t) = \frac{el(t)-el(t-1)}{g(t)-g(t-1)} * g(t) - C(t) \quad (3)$$

Using the above equation, a software program computes the estimate of electric power consumption using the previous and current linear estimates, the previous and current GDP and the constant. The variation in the estimated slope is used to generate the regression estimate for each year by the method illustrated above. The corresponding data obtained for piecewise linear regression based estimates generated in this manner are displayed in the following table 2.

Table 2. Electricity consumption dataset (2004-2014) comparison with piecewise linear regression estimate

Year	GDP per unit of energy use ($)	Electric Power Consumption (kWh)	Estimated Consumption from piecewise linear regression(kWh)	Estimation Error (%)
2004	5.78	453.01	413.694	8.679
2005	6.274	469.454	474.108	-0.991
2006	6.713	510.752	527.804	-3.339
2007	7.162	543.359	582.717	-7.243
2008	7.231	562.899	591.078	-5.006
2009	7.177	600.202	584.521	2.613
2010	7.663	642.112	643.988	-0.292
2011	8.001	698.548	685.313	1.895
2012	8.188	724.791	708.188	2.291
2013	8.652	765.564	764.955	0.08
2014	8.9	805.599	795.256	1.284

It can be seen from the preceding table that he piecewise linear model varies very slightly from the standard linear regression model for the given dataset. Thus a better technique needs to be proposed for more accurate estimation. The authors have therefore proposed a model involving accurate estimation of the change in the quasi-constant *Cv(t)*. The regression equation used in this machine learning based estimation model is a modification of the piecewise linear estimation model. The estimated electricity consumption obtained by this model is represented as *epc(t)* and the previous error in estimation from linear regression model as *err(t-1)* in percentage. The corresponding equation 4 represents the model mathematically.

$$epc(t) = \frac{el(t)-el(t-1)}{g(t)-g(t-1)} * g(t) - Cv(t) \quad (4)$$

$$Cv(t) = C(t) * \left\{\frac{100-err(t-1)}{100}\right\}^n \quad (5)$$

C(t)=293.2 is the value assumed for the current estimation. *n* is a positive number in this model. The machine learning model therefore tries to iteratively find the best-fit *n* to minimize subsequent error in estimation from previous historical data. It is also to be kept in mind that for *n*=0, the model converges to the previous piecewise linear estimation model. The corresponding simulation data are represented in table 3 that follows.

Table 3. Electricity consumption dataset (2004-2014) with piecewise linear regression estimate with initialization error compensation

Year	GDP per unit of energy use ($)	Electric Power Consumption (kWh)	Estimated Consumption from piecewise linear regression with initialization error compensation(kWh)	Estimation Error (%)
2004	5.78	453.01	413.694	8.679
2005	6.274	469.454	481.986	-2.669
2006	6.713	510.752	526.935	-3.168
2007	7.162	543.359	579.815	-6.709
2008	7.231	562.899	584.862	-3.902
2009	7.177	600.202	580.181	3.336

2010	7.663	642.112	646.303	-0.653
2011	8.001	698.548	685.056	1.931
2012	8.188	724.791	709.864	2.059
2013	8.652	765.564	766.985	-0.186
2014	8.9	805.599	795.328	1.275

The comparative analysis of the data obtained is carried out in the succeeding section.

4. Results

The results from simulations run using both types of machine learning based regression techniques are better than the standard linear regression based forecasting popularly used to estimate yearly power consumption of countries. The comparison of actual and estimated power consumption from linear regression is shown in the following figure 2.

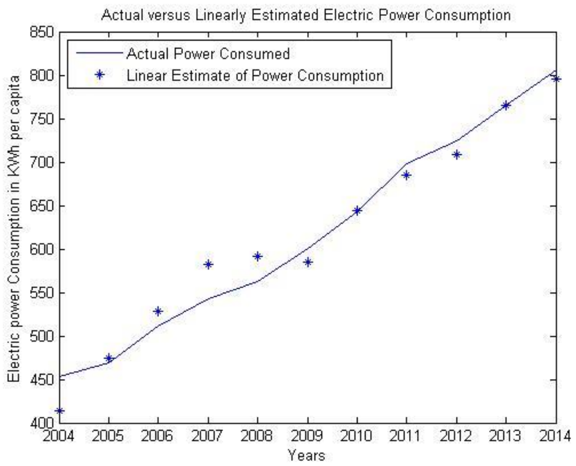

Fig. 2. Actual versus linear regression based estimate of electric power consumption (2004-2014)

The corresponding graphs for piecewise linear regression model and modified piecewise linear regression model with initialization error compensation are shown in figures 3 and 4 respectively.

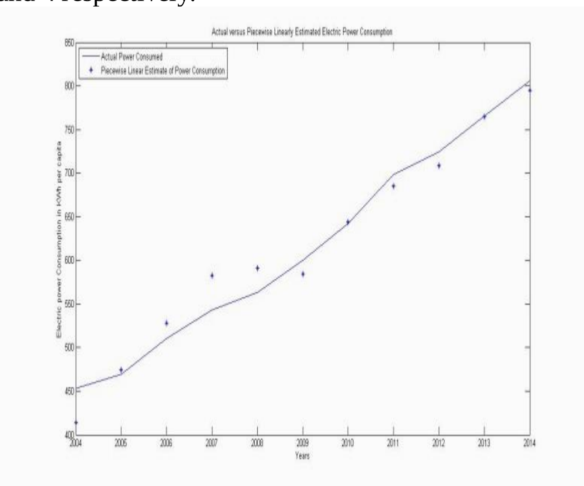

Fig. 3. Actual versus piecewise linear regression based estimate of electric power consumption (2004-2014)

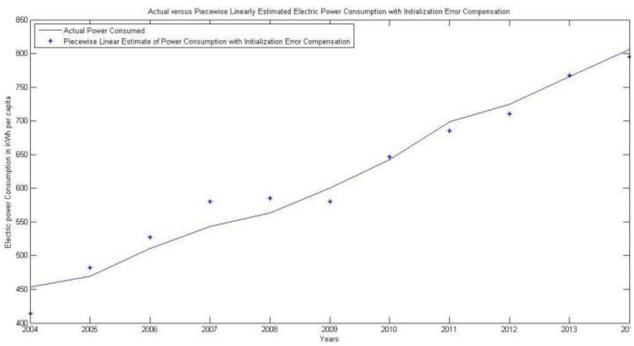

Fig. 4. Actual versus piecewise linear regression based estimate with initialization error compensation of electric power consumption (2004-2014)

The error percentage in forecasting is also compared for the three techniques and the results are illustrated in figure 5.

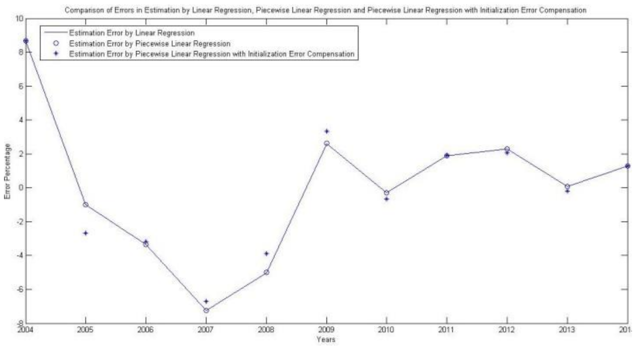

Fig. 5. Comparison of errors in estimation or linear regression, piecewise linear regression and piecewise linear regression with initialization error compensation (2004-2014)

From figure 5 it is clearly seen that the modified piecewise linear technique with initialization error compensation has the best performance among the three techniques.

5. Conclusion

The piecewise linear regression based machine learning technique proposed in this paper can be further modified through further optimization of slope estimation, for example, the radius of curvature based adaptive regression analysis techniques can be explored in the machine learning paradigm to better the results obtained here. The results obtained here also show that the models discussed here are effective in predicting electricity consumption provided the variation is of a comparatively smooth polynomial nature. The model needs to be adjusted for predicting electricity consumption more accurately in economies having oscillatory growth patterns. Additional techniques such as Artificial Neural Networks and Deep Learning algorithms can also be implemented in this regard, in future.

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