LONG TERM LOAD FORECASTING OF ADIGRAT TOWN FOR SUSTAINABLE ENERGY UTILIZATION

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***Abstract*:** Global electricity demand is projected to increase by 85% in 2040 as living standards rise, economies expand and the need for electrification of society continues. Electricity demand forecasting plays an important role in load allocation and planning for future generation facilities and transmission augmentation. In this paper among the different methods of load forecasting econometric method of load forecasting is implemented. For the work to be real and successful different historical load data were collected from the utility by customer categorical level such as Domestic, commercial and industrial customers, and also historical load driving factors like the number of population and the gross domestic products (GDP) were collected from the central statistical agency and from the Ethiopian Power System Expansion Master Plan Study Respectively. The total GDP of the adigrat town is derived from the total GDP of the country as the whole. Logarithmic (log-log) Regression model was used and Analytical results such as R^2 (coefficient of determination), Coefficient of elasticity, Probability value (P-Values) and the residual standard error were observed to determine the validity of any historical relationship. The Main objective of this study is to assess the future energy demand of customers and to ensure onward sustainable energy utilization.

Keywords: Long-term, Demand forecasting, econometric, trading, simulation, customers.

1. INTRODUCTION

Adigrat is located in Tigray region Eastern Zone in the Northern part of Ethiopia, approximately 900km from the capital city Addis Ababa, at longitude and latitude of 14°16’N 39°27’E with an elevation of 2457 meters above sea level. Its Distribution Substation is established in May 1990E.C, with a capacity of 16MVA. Before this year the town got electricity from diesel generators. Currently The Distribution substation is working totally with three independent transformers, two with three winding transformers with the rating of 40/20/20 MVA (HV, LV, and Tertiary) and 20/12/8 MVA capacity and one with two winding transformer with capacity of 12MVA on 33KV side. Thus the total Capacity of the substation is 40MVA. But for Adigrat, Zalambse, Edegahamus and Addis Pharmaceutical Factory, the total capacity is 28MVA since these loads are connected to the three winding transformer only. The substation has one in coming line feeder with 132KV from mekelle, and two outgoing feeders with 15KV (KO1-Feeder and KO6-Feeder) and four outgoing feeders with 33KV (P1, P2, P3, P4 Feeder). The 33KV side is almost not loaded. The meter reading for this side is negligible (below the meter reading). Almost all the loads are found in the 15KV side of both the higher and the lower transformers.

A long-term load forecast is required to be valid from 5 to 25 years. This type of forecast is used to deciding on the system generation and transmission expansion plans. A long term forecast is generally known as an annual peak load [1]. Methods used for long-term forecasting can be classified into two categories: Parametric methods and artificial intelligence based methods. Parametric load forecasting methods are based on statistical techniques and historical data of loads and factors affecting on loads. The parametric methods are described as: Trend analysis, end use modeling and economic modeling. The artificial intelligence methods are classified into neural networks, genetic algorithms, wavelet networks and fuzzy logics methods [2].

Trend analysis focuses on past changes or movements in electricity demand and uses them to predict future changes in electricity demand. Usually, there is not much explanation of why demand acts as it does, in the past or in the future. Trending is frequently modified by informed judgment, wherein utility forecasters modify their forecasts based on their knowledge of future developments which might make future electricity demand behave differently than it has in the past [3].

The basic idea of end-use analysis is that the demand for electricity depends on what it is used for (the end-use). For instance, by studying historical data to find out how much electricity is used for individual electrical appliances in homes, then multiplying that number by the projected number of appliances in each home and multiplying again by the projected number of homes, an estimate of how much electricity will be needed to run all household appliances in a geographical area during any particular year in the future can be determined. Using similar techniques for electricity used in business and industry, and then adding up the totals for residential, commercial, and industrial sectors, a total forecast of electricity demand can be derived [3].

Econometrics uses economics, mathematics, and statistics to forecast electricity demand. Econometrics is a combination of trend analysis and end-use analysis, but it does not make the trend-analyst’s assumption that future electricity demand can be projected based on past demand. Moreovr, unlike many end-use models, econometrics can allow for variations in the relationship between electricity input and end-use [3].

2. REVIEW OF RELATED LITERATURE

Svetlana.C, Paulo. S and Mário.V [2]: The importance of forecasting has become more evident with the appearance of the open electricity market and the restructuring of the national energy sector. This paper presents a new approach to load forecasting in the medium voltage distribution network in Portugal. The forecast horizon is short term, from 24 hours up to a week. The forecast method is based on the combined use of a regression model and artificial neural networks (ANN). The study was done with the time series of telemetry data of the DSO (EDP Distribution) and climatic records from IPMA (Portuguese Institute of Sea and Atmosphere), applied for the urban area of Évora - one of the first Smart Cities in Portugal. The performance of the proposed methodology is illustrated by graphical results and evaluated with statistical indicators. The error (MAPE) was lower than 5%, meaning that chosen methodology clearly validate the feasibility of the test.

Emiyamrew.M and Melaku.M [3]: have studied a realistic methodology that can be used as a guide to construct Jimma town Electric Power Load Forecasting models. Trending methodology statistical analyses are involved to study the load features and forecasting precision, such as linear regression, compound growth model and quadratic regression. Real monthly and yearly load data from Jimma distribution system substation is used as a case study. By using the best optimal value of the rank correlation coefficient and mean absolute percentage error, the compound growth model is used in the coming five years load forecasting. By forecasting of Jimma town load demand will result in proper utilization of energy and for planning of any electricity related projects it will use as a baseline to be applied cost wise. The main objective of this study is to assess the future energy demand of customers so that supplying of power and using that without shortage will be optimized.

N. Phuangpornpitak and W. Prommee [4]: Load demand forecasting is an essential process in electric power system operation and planning. It involves the accurate prediction of both magnitudes and geographical locations of electric load over the different periods of the planning horizon. Many economic implications of power utility such as economic scheduling of generating capacity, scheduling of fuel purchases, security analysis, planning of power development, maintenance scheduling and dispatching of generation units are mainly operated based on accurate load forecasting. This paper presents the survey of electricity demand forecasting for power system management. The introductory section provides the importance of electricity demand forecasting. Subsequent sections cover recent trends of demand forecasting techniques development in energy power systems. Several models have been surveyed to identify the demand pattern and predict the future demand. These techniques would be useful to determine the powerful energy management strategy so as to meet the required load demand at minimum operating cost.

3. METHODOLOGIES AND REQUIRED DATA

Based on the available actual historical data from Adigrat substation, utility, Central Statistical Agency and ministry of finance and economic development, a new methodology to forecast long-term random demand up to six years (2011 to 2016) ahead is proposed. The forecasting methodology that is employed in the study is based on a technique that is statistically based and written by econometric theory.

Statistically based methods of forecasting rely on good quality historical data to establish relationships and trends to produce the future projections. Although not sufficient data are available for long term forecast, more of the historical data obtained from the Adigrat substation and utility are of good quality and thus reliable for use in regression analysis. Regression Analysis is a very important statistical tool which is very useful in determining the statistical relationship or dependence between a change in one variable and the change in another when compared to it. To carry out a long term load forecast of the electrical energy consumption by the study area, the following procedural steps have been taken.

3.1. COLLECTION OF DATA

In long-term energy demand forecasting, the role of historical information is very important. Success of a demand forecasting method largely depends on the availability of data. All the historical data are collected on annual basis, energy consumption by consumer category, the demand requirements of new infrastructural projects and the key driving parameters of considerable significance in the forecast such as the population number of Adigrat area, number of consumers connected, and the gross domestic product (GDP). Thus all the data collected are preprocessed for the model.

3.2. PRE-PROCESSING OF THE DATA COLLECTED

It may be inevitable to have improperly recorded data and observation error. Therefore, bad and abnormal data are identified such as the recorded energy consumption data in 2005 and 2009 from the utility are discarded to avoid contamination of the model. Then the normal collected data are analyzed, arranged in type and projected enough to appropriate long term forecast for six years using the estimated annual growth rate.

3.3. DEVELOPING THE FORECASTING MODEL

Logarithmic model (log-log): This is the simplest model of regression analysis. It comprises of an independent and dependent variable. The general form of the analysis uses the following econometric equation:

$$\mathbf{Y = AX_1^B X_2^C \ldots etc, \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots 1}$$

$$\mathbf{\log Y = \log A + B \log X_1 + C \log X_2 \ldots etc, \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots 2}$$

Where:
Y = Sector sales
A = Constant
B, C = Elasticity's of demand (coefficients)

X_1, X_2 = Independent driving parameters.

3.4. SIMULATING THE MODEL

The dependent and the independent variables that have been processed are now substituted into the regression model that has been built. the date are imported in to R- programming as individual column vector and then using model described above the simulation will be made for each category.

3.5. Evaluation of the Model

A strong historical relationship can normally be determined by analyzing the statistical output that the model produces for any combination of consumer category and economic drivers. There are four main statistical results that can be used to determine the validity of any historical relationship, as described below:

R^2 ("R squared")/coefficient of determination: - The R^2 statistic describes the correlation between historical sales (the dependent variable) and the economic drivers (the independent variables) selected in the regression. An R^2 value of 1 would indicate 'perfect correlation', whilst a value of zero would indicate 'no correlation'.

Beta Coefficients/coefficient of elasticity: - The coefficients determine the impact of the economic drivers on historical sales. Regressions should only be accepted if the coefficients appear to be of the correct sign (positive or negative). For example, if price were included in a regression for domestic sales, the analyst should expect the price coefficient to be negative. A negative price coefficient indicates that a fall in price would result in an increase in sales (and vice-versa). The analyst should also expect the coefficients to be of the correct size. For example, the coefficient of any economic driver should not be too large, such that they indicate that a small change in the economic driver would result in a large change in the level of sales.

P-Values (Probability Value): - The P-values identify whether the economic drivers are adding anything to the regression. A P-value for any specific economic driver that is close to zero indicates that it is very likely that the particular economic driver in question plays a significant role in the determination of sales.

The residual standard error: - is a measure of accuracy in a fitted time series value in statistical trending. It usually expresses accuracy as a percentage.

3.6. FORECASTING

After investigating the different outputs of the model mentioned above, projection for the future demand forecasting will takes place.

3.7. REQUIRED DATA

The necessary data for the research work are collected from different governmental sectors. These data include, Historical Energy Sales Data of the Utility, yearly substations energy report, the historical and forecasted data of the Population number of Adigrat, the number of available costumers and the GDP per Capita. There for these data are arranged and tabulated as shown below.

3.8. DATA OF THE ENERGY SALES AND NEW DEMAND REQUESTS

The historical energy sales data of the Domestic, Commercial and Industrial sectors until the year 2018 were collected from the Ethiopian electric utility north region (EEU) as given in Table below:

Table 1: historical energy sales data of the utility obtained from energy sales and billing records.

Year (G.C)	ANNUAL ENERGY SALES DATA(MWH)				Transmission & Distribution Loss (%)	Total Generated Energy (MWh)	Load factor
	Domestic	Commercial, street light and own	Industrial (LV)	Sum of Energy Sales			
2008	7,351.82	3,240.66	2,002.6	12,595.1	12.92%	14,463.018	---
2009	8,248.97	4,216.07	2,007.77	14,472.81	13.7%	16,770.027	---
2010	9,000.49	6,015.84	2,083.87	17,100.2	10.14%	19,030.27	---
2011	11,342.74	7,891.56	3,071.21	22,305.51	13.1%	25,667.82	---
2012	12,561.24	9,706.71	3,270.72	25,538.67	11.14%	28,739.1625	0.54
2013	13,910.49	11,939.37	3,483.20	29,333.06	15.2%	34,576.041	0.58
2014	15,774.28	13,196.82	4,834.88	30,805.98	11.3%	38,115.94	0.61
2015	17,638.07	15,454.27	4,186.56	37,278.9	17.5%	45,189.7	0.6
2016	19,324.45	18,665.54	5,141.19	43,131.18	21.65%	55,048.13	0.6
2017	23,101.31	22,972.53	5,393.8	51,467.64	21.3%	65,388.21	0.55
2018	25,051.14	26,994.39	5,661.82	57,707.35	24.98%	76,737.97	---

Table 2: new industrial demand requirements from 2018 – 2024

NO	Name of the sector	Expected demand in MW
1	Adigrat pharmaceutical factory(APF)	1.2
2	Adigrat university(ADU)	1.898

Table 3: the historical and forecasted data of the population number of Adigrat from the central statistical agency (CSA) and the number of available costumers from the utility

Historical Population Data					Forecasted Population Data				
Year G.C	Population No	No of house holds	No of connection	Electrification ratio	year	Population No	No of house hold	No of connection	Electrification ratio
2008	404,591	80,918	7509	9.3%	2019	508,922	101,784	23133	22.7%
2009	413,185	82,637	8219	9.9%	2020	519,508	103,902	25627	24.7%
2010	421,962	84,392	9026	10.7%	2021	530,314	106,063	28390	26.8%
2011	430,925	86,185	9946	11.5%	2022	541,345	108,269	31450	29.0%
2012	440,079	88,016	10998	12.5%	2023	552,605	110,521	34840	31.5%
2013	449,427	89,885	12204	13.6%	2024	564,099	112,820	38596	34.21%
2014	458,974	91,795	13523	14.7%	2025	575,832	115,166	42757	37.13%
2015	468,751	93,750	14933	15.9%					
2016	478,591	95,718	16774	17.5%					
2017	488,393	97,679	18176	18.6%					
2018	498,552	99,710	20882	20.9%					

3.9. GDP DATA

The historical and forecasted Gross Domestic Product per capita (GDP/capita) data of the country were collected from Ethiopian Power System Expansion Master Plan Study. From 2002 to 2011 the average annual real GDP growth rate was 9.8%, and the annual average GDP forecast up to 2015 was 11.2% and also average growth per annum forecast from 2016 to 2020, is 9.6%. And for the industrial sector the average annual real GDP growth rate from 2012 to 2015 is 20%, from 2016 to 2020 is 15.6% and from 2021 to 2025 is from 13.9% at constant price.

The total GDP is the aggregate of the GDPs obtained from Agriculture, industry, service or commercial GDPs. Real Gross Domestic Product (GDP) per capita is obtained by dividing annual or period GDP at constant prices by population. It is a basic economic growth indicator measuring the level and extent of total economic output as well as reflecting changes in total production of goods and services in real terms excluding inflationary effects.

Table 4: historical and forecasted gross domestic product data

Historical GDP(Millions Birr)			Forecasted GDP(Millions Birr)		
Year (G.C)	GDP/Capita	Total GDP of Adigrat	Year(G.C)	GDP/Capita	Total GDP of Adigrat
2008	1562	632.0	2019	4330	2,203.63
2009	1676	692.5	2020	4746	2,465.58
2010	1806	762.1	2021	5173	2,743.31
2011	1961	845.0	2022	5639	3,052.64
2012	2181	960.0	2023	6146	3,396.31
2013	2425	1,090.0	2024	6699	3,778.90
2014	2697	1,237.9	2025	7302	4,204.73
2015	2999	1,405.78	2026		
2016	3289	1,574.1	2027		
2017	3605	1,760.66	2028		
2018	3951	1,969.78	2029		

Table 5: historical and forecasted industrial gross domestic product data

Historical GDP(Millions Birr)			Forecasted GDP(Millions Birr)		
Year (G.C)	Industrial GDP per capita	Industrial GDP of Adigrat	Year (G.C)	Industrial GDP per capita	Industrial GDP of Adigrat
2008	212.2	85.85	2019	1,013.55	515.82
2009	226.38	93.54	2020	1,171.66	608.69
2010	244.87	103.33	2021	1,334.52	707.71
2011	274.33	118.22	2022	1,520.02	822.86
2012	329.2	144.87	2023	1,731.30	956.73
2013	395.03	177.54	2024	1,971.95	1,112.38
2014	474.04	217.57	2025	2,246.05	1,293.35
2015	568.85	266.65			
2016	657.6	314.72			
2017	760.18	371.27			
2018	876.77	437.12			

4. SIMULATION STUDIES AND ANALYSIS OF THE RESULTS

4.1. DOMESTIC ENERGY SALES

The correlation between the historical Domestic Energy Sales and the historical GDP and Population number/number of connection using **Logarithmic model (log-log)** is obtained as follows:

$$\log Y = A_0 + A_1 \log X_1 + A_2 \log X_2 \dots\dots\dots\dots\dots\dots\dots\dots\dots.. 3$$

Where,
Y = energy sale (MWH)
X_1 = population number/ number of connection
X_2 = GDP (millions Birr)
A_0, A_1, A_2 = elasticity constants.

Table 5: regression statistics

Regression Statistics	Connected population and GDP
Multiple R-squared	0.991
Adjusted R-squared	0.988

Table 6: elasticity factors

	Total customer and GDP		
	Coefficients	Estimated Std. error	P- values
intercept	3.426	4.292	0.45
Customer	0.55	0.942	0.58
GDP	0.58	0.82	0.5
The entire equation P-value			$7.47*10^{-7}$
Residual standard error		0.0193	

High value of Adjusted R-squared, low value of Residual standard error, low P-value and appropriate elasticity's constants in terms of both the sign and magnitude are best for load forecasting. So from table 5-6 **Logarithmic model (log-log)** forecasting is best suited. Based on this the next six years domestic load demand of Adigrat town can be forecasted as follows,

$$\log Y = 3.43 + 0.55 \log X_1 + 0.58 \log X_2 \dots\dots\dots\dots\dots\dots 4$$

Table 7: forecasted energy sales of the domestic customers

Year	Projected population in millions	Projected GDP in millions	Forecasted energy in MWH
2019	0.0231	2,203.63	29,444.22
2020	0.02563	2,465.58	33,265.96
2021	0.02839	2,743.31	37,411.06
2022	0.03145	3,052.64	42,169.65
2023	0.03484	3,396.31	47,424.2
2024	0.038596	3,778.90	53,456.44

4.2. COMMERCIAL SALES FORECAST

The growth in consumption (sales) of the commercial customer category is driven by a combination of total GDP and electricity price. But on the basis of our country and from the experience the electricity price is set by the government and is not changed for long time, thus it is assumed that the commercial customer category is mainly driven by total GDP.

The correlation between the historical commercial Energy Sales and the historical GDP and using **Logarithmic model (log-log)** is obtained as follows:

$$\log Y = A_0 + \log X_2 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 5$$

Table 8: regression statistics

Regression statistics	GDP
Multiple R-squared	0.968
Adjusted R-squared	0.965

Table 9: elasticity factors

	GDP		
	Coefficients	Estimated Std. error	P- values
intercept	-1.24	0.319	0.0037
GDP	1.73	0.105	$4.8*10^{-8}$
The entire equation P-value			$4.84*10^{-8}$
Residual standard error		0.0558	

Based on the above results the next six years commercial load demand of Adigrat town can be forecasted as follows,

$$\mathbf{\log Y = -1.24 + 1.73 \log X_2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..\mathbf{6}$$

Table 10: forecasted energy sales of the commercial customers

Year	Projected GDP in millions	Forecasted energy in MWH
2019	2,203.63	29,241.524
2020	2,465.58	42,657.95
2021	2,743.31	51,404.37
2022	3,052.64	61,944.11
2023	3,396.31	74,131.02
2024	3,778.90	89,125.094

4.3. INDUSTRIALS SALES FORCAST

Similarly the growth in consumption (sales) of the industrial customer category is driven by a combination of industrial GDP and electricity price. But it is assumed that the industrial customer category is mainly driven by industrial GDP.

The correlation between the historical industrial Energy Sales and the historical industrial GDP using **Logarithmic model (log-log) Regression** is obtained as follows,

Table 11: regression statistics

Regression Statistics	GDP
Multiple R-squared	0.921
Adjusted R-squared	0.921

Table 12: elasticity factors

	GDP		
	Coefficients	Estimated Std. error	P- values
intercept	2.03	0.1485	$2.5*10^{-7}$
GDP	0.67	0.0653	$2.9*10^{-6}$
The entire equation P-value			$2.93*10^{-6}$
Residual standard error		0.0517	

Based on the above results the next six years industrial load demand of Adigrat town can be forecasted as follows,

$$\mathbf{\log Y = 2.03 + 0.67 \log X_1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..\mathbf{7}$$

Table 13: forecasted energy sales of industrial customers

year	Projected GDP in millions	Forcated energy in MWH
2019	515.82	7079.46
2020	608.69	7870.46
2021	707.71	8689.6
2022	822.86	9549.93
2023	956.73	10,641.43
2024	1,112.38	11,776.06

By inserting the GDP and the Population number into the equations 4 to 7 above, it is determined how much energy Sales of the Domestic, Commercial and Industrial customers there will be for the years 2019 to 2024. The result obtained is given in Table 14 below.

Table 14: total energy forecast of the years 2019 to 2024(G.C)

year	Domestic energy sales forecast(MWH)	Commercial energy sales forecast(MWH)	Industrial energy sales forecast(MWH)	Total energy sales forecast(MWH)	Total energy sales forecast including transmission loss (25%)
2019	29,444.22	29,241.524	7079.46	65,765.20	82,206.50
2020	33,265.96	42,657.95	7870.46	83,794.37	104,742.96
2021	37,411.06	51,404.37	8689.6	97,505.03	121,881.29
2022	42,169.65	61,944.11	9549.93	113,663.69	142,079.61
2023	47,424.2	74,131.02	10,641.43	132,196.65	165,245.81
2024	53,456.44	89,125.094	11,776.06	154,357.594	192,946.99

From table 14 above it is estimated that a Peak Demand of **16.14MW** is required by the year 2019, this estimated demand will increase by an annual average rate of **18.68%** and will reach **37.87MW** by the year 2024.

Considering the New Demand Request, the summation of the new energy request of the Adiss pharmaceutical factory(APF) and the adigrat university(ADU) given in table 2 to that of the total Energy Forecast of the existing demand categories given in Table 14 above is done as given in Table 15 below.

Table 15: total energy forecast of the years in 2024

NO.	Total Energy Forecast of the Existing Demand Categories (MWh)	Expected demand in MWh	Total Energy forecast(MWh)
1.	192,946.993	16,303.1	209,250.097

5. CONCLUSION

In this research among the different methods of load forecasting econometric method of load forecasting is implemented. For the work to be real and successful different historical load data were collected from the utility by customer categorical level such as Domestic, commercial and industrial customers, and also historical load driving factors like the number of population and the gross domestic products were collected from the central statistical agency and from the Ethiopian Power System Expansion Master Plan Study. The total GTP of the adigrat town is derived from the total GTP of the country as the whole.

Logarithmic model (log-log) Regression model was used and Analytical results such as **R^2 ("R squared")/coefficient of determination, Beta Coefficients/ coefficient of elasticity, P-Values and the residual standard error** were observed to determine the validity of any historical relationship. As the result the model is found to be with R^2= 0.988, A_0 = 3.43, A_1 = 0.55, A_2 = 0.58, P-Value = $7.4*10^{-7}$ and residual standard error 0.0193 for Domestic customers, and R^2= 0.965, A_0 = -1.24, A_2 = 1.73, P-Value = $4.84*10^{-8}$ and residual standard error 0.0558 for commercial customers and also R^2= 0.921, A_0 = 2.03, A_2 = 0.67, P-Value = $2.93*10^{-6}$ and residual standard error 0.0517 for industrial customers.

The Peak demand of the town was 2.84MW in 2008 and grew by an average rate of 18.33% per year and reached 15.06MW by the year 2018. Factors contributing to this high demand growth rate include:-

- The Town High GDP growth rate.
- Expansion of the national grid to rural towns and villages, raising the electricity access of the town or the electrification ratio which was 9.3% in 2008 to 20.9% in 2018.
- Industrial consumption enhancement due to the high industrial development of the town.
- Household energy consumption in the town shifted from wood-fuel and kerosene to electricity.

In the next years up to 2024, due to the factors given above and due to new demand requests from APF and ADU, the demand growth is expected to grow to 41.07MW. Since the maximum capacity of the present distribution system substation is 28MW, additional 13.07MW is looked-for to customers after six years.

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