

Forecasting Load Curve Shape for Predicting the Possible Capacity of Pumped Storage Power Plant

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Abstract

Both electric power consumption and maximum demand in Sri Lanka have shown growth rates of 6~8% per year over the last 10 years. Therefore, the planning of power plants and the transmission network has been a main concern in Sri Lanka. In addition, daily electricity demand varies significantly with time. The daily maximum demand (1850MW in 2008) occurs between 0630pm to 0930pm. The maximum demand is more than twice the lowest demand (750MW in 2008) which occurs between 0030am to 0430am. According to the Ceylon Electricity Board (CEB) Generation Plan 2008-2021, more than 3500 MWs of coal fired power plants will be connected to the power system in the future. So there will be surplus of cheaper coal power in low demand period (midnight to 0930am). That means there is a possibility to install a pumped storage power plant (PSPP). The focus of this paper is on forecasting the load curve shape and thereby predicting the possibility of installing PSPPs in the Sri Lanka power system and the possible capacity of PSPPs.

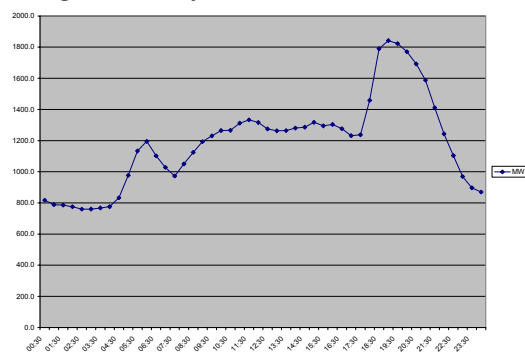
Keywords

Load curve shape, forecast, Pumped Storage Power Plant

Introduction

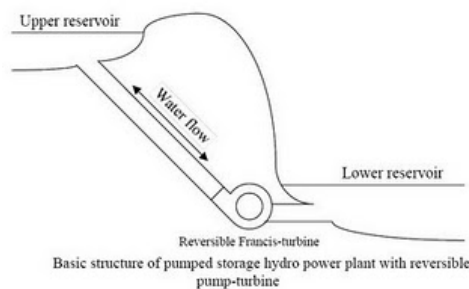
The daily load curve is the variation of electricity demand with the time of the day. The typical Sri Lanka daily load curve for year 2008 is shown below (Figure 1). The daily maximum demand occurs between 630pm to 930 pm. The maximum demand is more than double the lowest demand which occurs between 0030am to 430am.

Figure 1: Daily Load Curve in Year 2008



In a PSPP, electricity is generated with the water stored in the upper pond in response to the peak in the night time. During the day when the power demand drops, water is pumped up from the lower pond to the upper pond using the excess energy available in low cost coal power plants. Thus, the water is circulated to generate electric power.

Figure 2: Schematic Diagram of Pumped Storage Power Plant



Source:<http://cleanhydropower.blogspot.com>

According to the Long Term Generation Expansion Plan (LTGEP) 2008-2021, the first coal fired power plant will be connected to the power system by year 2012. By year 2015, the total coal power plant capacity connected to the system will be 2155 MW. The forecast

minimum demand (between 0030am and 430am) in that year will be about 1500 MW. There will be a surplus of cheaper coal power in the low demand period (0030am to 430am) by year 2015 and the amount such excess generating capacity available will be increase afterwards. Hence there is a possibility to install a PSPP owing to the availability of the excess capacity above the base load of the Sri Lanka power system in the near future, using surplus cheaper coal power.

PSPP can also take on the tasks of peak-shaving and valley-filling of a demand profile, emergency reserve, frequency modulation, phase modulation, etc. in power system. It is of significance for improving the stability and flexibility of electric system, amending supply quality, and raising network safety and economics. It is an economic and effective way to regulating a power system.

Forecasting the Shape of Daily Load Curve

A forecast is a quantitative estimate about the possibility of future events based on past and current information, and making statements about future events whose actual outcomes (typically) have not yet been observed. There are numerous methods for forecasting and modeling data for forecasting. In most cases, the choice of a method will depend more on the data and time available to conduct analyses and the results expected, than the technical merits of each method. In this study the load curve points were forecast based on an econometric method. The multiple linear regression model is the most commonly used in econometric analysis, thereby used in the study.

Table 1: Planned Coal Power Plants

Year	Coal Power Plant Additions
2012	285 MW Puttalam Coal (Stage 1)
2013	285 MW Puttalam Coal (Stage 2) 2x250 MW Trin. Coal (Stage 1)
2014	285 MW Puttalam Coal (Stage 3)
2015	2x250 MW Trin. Coal (Stage 2) 1x300MW Coal Steam (East coast 2)
2016	1x300MW Coal Steam (East coast 2)
2017	1x300MW Coal Steam (East coast 2)
2018	1x300MW Coal Steam (East coast 2)
2019	1x300MW Coal Steam (West coast)
2020	1x300MW Coal Steam (West coast)

Source: Long Term Generation Expansion Plan 2008-2021

Multiple Linear Regression

If more than one independent variable is considered, multiple linear regression is used. For K independent variables the model is;

$$y_i = \alpha + \beta_1 x_{i1} + \beta_2 x_{i2} + \dots + \beta_k x_{ik}$$

The assumptions listed in the above are correct for Y and each x_i variable in this model. The least-square estimates for the α and β parameters are called regression coefficients and are obtained by minimizing the error (residual) sum of squares.

Minimize $s = \sum \epsilon^2_i = \sum (y_i - \hat{y}_i)^2$

Where the model for \hat{y} is (subscript i omitted)

$$\hat{y} = a + b_1 x_1 + b_2 x_2 + b_3 x_3 + \dots + b_k x_k$$

Methodology for Forecasting the Shape of the Load Curve

Load curve shapes for 9 years (1998 to 2006) were obtained from System Control & Operations Annual Reports (1998 to 2006) of CEB. Each load curve is for the day on which records the maximum demand (which occurred in the night) for the particular year was recorded.

Figure 3: Daily Load Curve on 26th Nov 2002

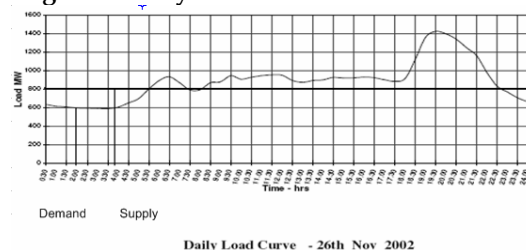
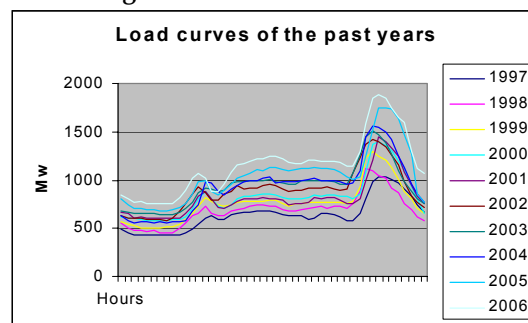


Figure 4: Actual Load Curves



The 48 load points (electricity demand) along the daily load curve obtained from daily load

curves of past years were used for estimation. Considering each point, the following different independent variables were used for the investigation.

- Gross Domestic Product
- Population
- Gross Domestic Product per capita
- Number of domestic consumer accounts
- Number of domestic consumer accounts in the previous year
- Average electricity price

The previous year electricity demand for a particular time interval of the daily load curve was considered as the dependent variable.

Gross Domestic Product (GDP) is the market value of all final goods and services produced in a country over a specific time period, normally for a year. The population of the country determines the amount of electricity demand. The GDP per capita (per person) can be obtained by dividing the total GDP by the country's population in a given year. GDP and GDP per capita are also used as an indicator of the living standard of the population. Hence GDP and GDP per capita variable are directly correlated with the electricity demand. Although GDP, population and GDP per capita were interdependent, in this study it was considered that these three variables were different inputs for the Statistical Package for the Social Sciences (SPSS) software. The SPSS helps to find the most correlated variable for given times which decide the electricity demand for that particular time in the load curve. The number of domestic consumer accounts also reflects the necessity of electricity. In this study the forecast values of GDP per capita, population and GDP were taken from Central Bank Reports and the forecast number of domestic consumer accounts, number of domestic consumer accounts in the previous year and average electricity price were calculated.

Although there are several independent variables, only the significantly correlated variables were considered for forecasting the electricity demand of the coming year for the particular time Table 4.

Past Data for Forecasting

Gross Domestic Product per capita (GDP per capita) and Population

The past data of above variables can be obtained from Central Bank Reports.

Gross Domestic Product (GDP)

Forecast GDP = GDP per capita × Population

Domestic consumer account and previous year domestic consumer account

The past data of above variables can be obtained from Sales and Generation data book published by Statistical Unit, CEB.

Table 2: Past Data

Year	Domes. Sales (GWh)	Domes. Revenue (mill Rs)	Price Index-CCPI	Year End Popula. (mill)	GDP (mill Rs)
1997	1,528	3,356	2,089.1	18.66	73,9763
1998	1,697	4,201	2,284.9	18.91	77,4796
1999	1,886	4,659	2,392.1	19.20	80,8340
2000	2,093	5,433	2,539.8	19.05	85,7035
2001	2,272	6,971	2,899.4	18.87	84,3794
2002	2,389	9,278	3,176.4	19.13	87,7248
2003	2,414	11,044	3,377.0	19.36	93,0057
2004	2,626	11,988	3,632.8	19.62	98,0720
2005	2,884	13,558	4,055.8	19.87	103,9763
2006	3,086	18,364	4,610.8	19.89	111,6215

Previous year electricity demand for a particular time in daily load curve

Previous year electricity demand for a particular point can be obtained from the load curves published by System Control & Operations-Annual Reports (1998 to 2006).

Average domestic electricity price

Table 3: Average Domestic Electricity Price

Year	Average Domestic Electricity Price (Rs/kWh normalized to CPI)
1998	0.001083
1999	0.001033
2000	0.001022
2001	0.001058
2002	0.001022
2003	0.001350
2004	0.001260
2005	0.001159
2006	0.001290

CPI = Consumer Price Index

Average price of electricity households

$$= \frac{\text{Income from sales to households}}{\text{Sales to households}}$$

The best fit equations were obtained for each and every 48 load points (electricity demand) of future load curves using the past data independent variables described above and the load points of the daily load curves of past years. The forecasting was done using the SPSS software. These forecast 48 load points for each coming year were used to obtain the future load curve for that particular year.

SPSS is a computer program used for statistical analysis. SPSS is among the most widely used programs for statistical analysis in social science. It is used by researchers, survey companies, government, marketing organizations and others. The SPSS software helps organizations to predict future events and proactively act upon that insight to drive better business outcomes.

Results of the multiple linear regression analysis for 48 points obtained using SPSS are given in Table 4. When selecting the best fit equations for the points, they have to satisfy the requirement of R², F value and significant level as follows.

R Square: R Square is the goodness of fit measure of a linear model, sometimes called the coefficient of determination. It is the proportion of variation in the dependent variable explained by the regression model. It ranges in value from 0 to 1. Small values indicate that the model does not fit the data well.

F Value: F Value is the ratio of two mean squares. When the F value is large and the significance level is small (typically smaller than 0.05 or 0.01) the null hypothesis can be rejected. In other words, a small significance level indicates that the results probably are not due to random chance.

Significant Level: The conditional probability that a relationship as strong as the one observed in the data would be present, if the null hypothesis were true. It is often called the p-value. Typically a value of less than 0.05 is considered significant.

Future Data for Forecasting

Gross Domestic Product per capita (GDP per capita) and Population

These future data was obtained from previous Central Bank Reports. This information is summarised in Table 5.

Table 5: Population and GDP Per Capita from Central Bank Data

Year	Population (million)	GDP/Per capita (Rs in 1996 FCP)
2007	20.24	58,178
2008	20.42	60,363
2009	20.60	64,442
2010	20.78	68,862
2011	20.96	73,761
2012	21.11	78,980
2013	21.28	84,490
2014	21.44	90,300
2015	21.61	96,420
2016	21.77	102,958
2017	21.88	109,941
2018	22.00	117,399
2019	22.13	125,362
2020	22.26	133,865
2021	22.39	143,059
2022	22.46	153,005
2023	22.56	163,644
2024	22.65	175,022
2025	22.75	187,191
2026	22.84	200,332
2027	22.89	214,530

Gross Domestic Product (GDP)

Forecast GDP = GDP per capita × Population

Domestic Consumer Accounts

Assume that 4 people live in 1 house. Hence, the number of domestic consumer accounts =

$$\frac{\text{Population}}{4} \times \frac{85}{100}$$

Average Domestic Electricity price

Figure 5: Average Electricity Price

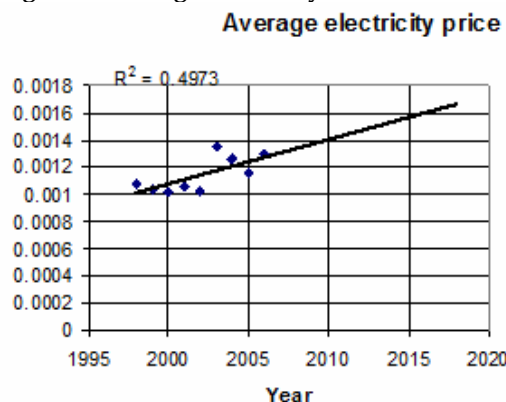


Table 4: Multiple Linear Regression Equations for 48 Points by using SPSS

Time	Regression equation	R square	F value	Signifi. Level
0.00	Load=-217.125258026402+1.865E-02(GDPpercapita)	0.86	36.9	0.001
0.30	Load=-168.44+0.01693453(GDPperca)	0.87	23.5	0.002
0.10	Load=-139.09+0.01584271358134(GDPperca)	0.77	22.8	0.002
1.30	Load=193.4597572815+0.01697949894153(GDPperca)	0.80	28.6	0.001
2.00	Load=-171.02+0.01637045282383(GDPperca)	0.81	30.7	0.001
2.30	Load=-141.59+1.574E-02	0.79	26.3	0.001
3.00	Load=-204.15+1.693E-02(Gdpperca)	0.82	32.8	0.001
3.30	Load=-189.86+1.661E-02(GDPperca)	0.81	29.1	0.001
4.00	Load=-147.94+1.586E-02(GDPperca)	0.87	32.6	0.001
4.30	Load=-187.20+1.732E-02(GDPperca)	0.75	20.5	0.003
5.00	Load=-187.11+0.0181(GDPperca)	0.70	16.6	0.005
5.30	Load=-218.20+2.082E-02(GDPperca)	0.67	14.5	0.007
6.00	Load=-229.086+0.0227(GDPperca)	0.69	15.5	0.006
6.30	Load=428.736+0.0018(Consacc)	0.93	88.1	0.000
7.00	Load=248.51+2.483E-02(Consacc)	0.95	133.6	0.000
7.30	Load=375.81+0.00177(Preconsacc)	0.83	33.4	0.001
8.00	Load=295.01+2.178E-03(Preconsacc)	0.86	44.4	0.000
8.30	Load=232.19+2.690E-03(Preconsacc)	0.89	54.4	0.000
9.00	Load=153.03+2.990E-03(Consacc)	0.92	81.0	0.000
9.30	Load=-492.34+0.0297(GDPperca)	0.97	221.2	0.000
10.00	Load=-312.84+0.00135(GDP)	0.97	240.4	0.000
10.30	Load=-362.17+1.417E-03(GDP)	0.98	308.7	0.000
11.00	Load=-348.93+0.00141(GDP)	0.97	266.8	0.000
11.30	Load=-420.15+0.00149(GDP)	0.97	251.8	0.000
12.00	Load=-408.92+0.00147(GDP)	0.96	156.8	5E-06
12.30	Load=-462.75+1.506E-03(GDP)	0.98	389.0	2E-07
13.00	Load=-497.33+1.523E-0(GDP)	0.98	315.3	4E-07
13.30	Load=-443.68+1.468E-03	0.97	202.1	2E-06
14.00	Load=-455.05+0.00149(GDP)	0.96	158.6	5E-06
14.30	Load=-449.34+1.501E-03(GDP)	0.96	179.2	3E-06
15.00	Load=-396.44+1.456E-03(GDP)	0.98	293.1	6E-07
15.30	Load=-373.26+1.426E-0(GDP)	0.97	252.6	9E-07
16.00	Load=-399.78+1.455E-03(GDP)	0.97	214.5	2E-06
16.30	Load=-344.91+0.00139(GDP)	0.99	633.9	4E-08
17.00	Load=-330.55+0.00135(GDP)	0.99	661.3	3E-08
17.30	Load=-263.21+0.001264(GDP)	0.95	133.4	8E-06
18.00	Load=274.66+2.815E-03(Preconacc)	0.72	18.1	4E-03
18.30	Load=394.40+2.802E-02(Preconacc)	0.87	30.6	4E-02
19.00	Load=-31.12+1150635(Elecprice),Load=-5838.26+3.685E-04 (Population)	0.57	9.3	2E-02
19.30	Load=-577.76+4.242E-02(GDPperca)	0.88	49.4	2E-04
20.00	Load=-899.89+4.999E-02(GDPperca)	0.95	133.1	8E-06
20.30	Load=-774.46+5.967E-02(GDPperca)-542386.25(Elecprice)	0.96	81.8	4E-05
21.00	Load=-824.63+6.465E-02(GDPperca)-770244.63(Elecprice)	0.95	51.1	0,0.032
21.30	Load=-743.34+6.584E-02(GDPperca)-989303.08(Elecprice)	0.93	52.0	0,0.01
22.00	Load=-1320.98+5.145E-02(GDPperca)	0.94	49.7	3E-04
22.30	Load=-845.79+3.808E-02(GDPperca)	0.93	54.4	6E-04
23.00	Load=-698.63+3.274E-02(GDPperca)	0.86	43.5	3E-04
23.30	Load=-687.61+3.087E-02(GDPperca)	0.92	60.3	1E-04

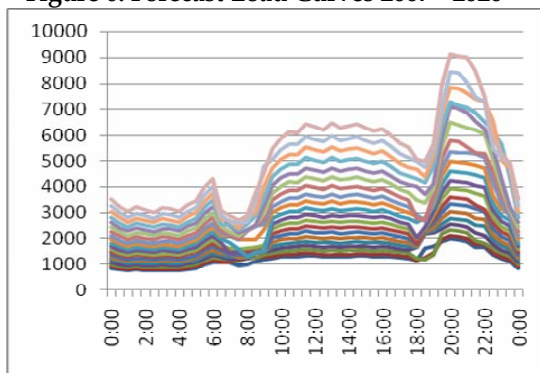
Using the trend lines, forecast the Average electricity demand for next 20 years. The Following Load Curves were forecasted by using SPSS Software up to year 2026.

Table 6: Domestic Consumer Accounts

Year	Population	Domestic consumer Account	Previous year Domestic consumer accounts
2008	20,420,000	4,339,250	3,409,440
2009	20,600,000	4,377,500	4,339,250
2010	20,780,000	4,415,750	4,377,500
2011	20,960,000	4,454,000	4,415,750
2012	21,110,000	4,485,875	4,454,000
2013	21,280,000	4,522,000	4,485,875
2014	21,440,000	4,556,000	4,522,000
2015	21,610,000	4,592,125	4,556,000
2016	21,770,000	4,626,125	4,592,125
2017	21,880,000	4,649,500	4,626,125
2018	22,000,000	4,675,000	4,649,500
2019	22,130,000	4,702,625	4,675,000
2020	22,260,000	4,730,250	4,702,625
2021	22,390,000	4,757,875	4,730,250
2022	22,460,000	4,772,750	4,757,875
2023	22,560,000	4,794,000	4,772,750
2024	22,650,000	4,813,125	4,794,000
2025	22,750,000	4,834,375	4,813,125
2026	22,840,000	4,853,500	4,834,375

Forecast Load Curves for 2007~2016

Figure 6: Forecast Load Curves 2007 ~2026



According to the Long Term Generation Expansion Plan (LTGEP) 2008-2021, additions by plant type are summarized in five year periods in Table 7.

Table 7: Capacity Additions by Plant Type

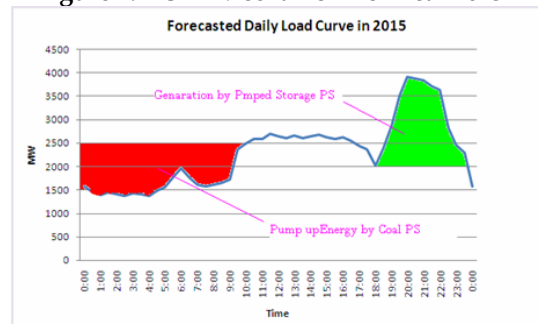
Type of Plant	2007-2011 MW	2012-2016 MW	2017-2021 MW	Total Capacity Addition	
				MW	%
Hydro	150	-	-	150	3.1%
CC	315	-	-	315	6.6%
Coal	-	2,455	1,200	3,655	76%

GT	185	-	-	185	3.9%
HVDC	-	-	500	500	10.4%
Total	650	2,455	1,700	4,805	100%

Note: Summarized from Long-term Generation Expansion Plan 2008-2021, CEB.

The major share of the total new power generation capacity (i.e. 76%) will be from coal-based power plants by year 2021. Hence coal-fired thermal power plants will play an important role in serving the future electricity demand of Sri Lanka. Since Sri Lanka load curve is not a flat curve, there would be surplus capacity in coal-fired power plants in off-peak periods. Furthermore, operating coal power plants below the rated capacity results in lower efficiencies. So there will be a possibility to install a pumped storage power plant due to the availability of the excess cheaper power within the period of midnight to 0930am after year 2015. Figure 7 illustrates the forecast daily load curve for 2015 and how to use excess energy to pump up water during off-peak hours and releasing during peak hours.

Figure 7: PSPP Mechanism for Year 2015



Summary of Evaluation of possible total capacity of Pump Storage Power Plants

If we consider 6 hour operation of PSPP including maximum peak time duration (0630am to 0930pm), we can introduce 500MW PSPP by year 2015, another 500 MW PSPP by year 2021 and another 500 MW PSPP by year 2026.

Thermal Maximum Day Peak (TMDP) demand, Hydro Maximum Day Peak (HMDP) demand, Pump Up Energy (PUE) by Coal Power plant (CPP) in TMDP, PUE by CPP in HMDP and Power Generation by PSPP in the future years starting from 2015. The day time operation of Sri Lankan power system can be categorized by its main power supply. If the higher percentage

of day peak demand is supplied by thermal sources, it's called TMDP. If the higher

percentage of day peak demand is supplied by Hydropower sources, it's called HMDP.

Table 8: Possible Energy from PSPP

Year	Day Time Peak at around 11.30 am MW	TMDP Demand MW	HMDP Demand MW	PUE by CPP in TM DP MWh	PUE by CPP in HM DP MWh	Gene. by PSPP MWh
2015	2,703	2,782	2,887	11,858	13,065	4,071
2016	2,939	3,077	3,003	14,386	13,635	5,368
2017	3,185	3,168	3,164	13,927	13,881	5,396
2018	3,451	3,517	3,463	15,194	14,573	7,347
2019	3,738	3,842	3,763	16,861	15,953	9,524
2020	4,046	4,142	4,063	18,568	17,660	10,285
2021	4,380	4,432	4,443	19,920	20,046	10,047
2022	4,730	4,732	4,743	21,019	21,145	9,933
2023	5,113	5,032	5,043	22,153	22,279	10,304
2024	5,521	5,332	5,343	22,928	23,054	11,233
2025	5,962	5,632	5,643	23,410	23,536	10,026
2026	6,438	5,932	5,943	24,057	24,183	11,481

Conclusion

According to the forecasted values of the load curve points, it shows there won't much difference between today's load curve shape and the future load curve shapes. That means there won't much industrial and commercial development according to the available data which obtained from the Central Bank reports. So this study shows the load curve shape can improved by introducing Pumped Storage Power Plants in to the Sri Lanka power system. Further this study shows the 500MW Pumped Storage Power Plants can be introduced to Sri Lanka power system by year 2015, another 500MW Pumped Storage Power Plants by year 2021 and another 500MW PSPP by year 2026.

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Ms EMTG Jayathilaka

was born in Sri Lanka, on March 09, 1982. She is graduated from The Open University of Sri Lanka in 2010, specializing in Electrical Engineering. Her research

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