

Renewable Energy and Distributed Generations

Lecture 1

Power Systems Planning Basics

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Lecture learning outcomes:

At the end of this lecture you will be able to:

- i. Define power system planning
- ii. Explain the objective of power system planning
- iii. Define the load forecasting
- iv. Identify the types of load forecasting

Introduction

- Power system is one of the largest man-made network that comprises different equipment's starting from generation to consumers
- Running this very large system is a real difficult task.
- It has caused numerous problems that need engineering solutions from educational sectors and *Industries*
- For planning's, lessons should be taken from the past, present and future trends
- Accordingly, the term planning is defined as the actions required for the future based on the past and recent trends.

- Power system planning is a process in which the aim is to decide on new as well as upgrading existing system elements, to adequately satisfy the loads for predicted future.

The elements that needs planning are;

- Generation facilities
- Substations
- Transmission lines
- Capacitors/Reactors/Controllers

The main objectives of power system planning are:

1. Generating an adequate energy for satisfying the demands at *low price, efficient conversion system with low environmental and social impacts*
2. Transmitting the generated energy through long distances to the load centres at *low price, more efficient, stable and reliable* conditions.
3. Distributing the power or energy considering *quality service, low price and efficient utilization* of the energy.

Accordingly, power system planning is defined as;

- Power system Planning is optimization of facilities necessary to provide adequate electrical energy in a power system network at a least cost, low environmental and social impacts through which a sustainable energy supply to customers is attained.

1.1 Load Forecasting:

- It is defined as determining the future trend of energy consumption based on the the base year and past trends.
- It determines the total annual consumption as well as its discissions in to local and interconnection power pool loads.

It depends on:

- the historical and current data of the base year
- GDP
- Population growth
- customers' income growth
- government plan on rural electrification
- Government policies and climate issues etc.

- Power system planning starts with a forecast of projected future load requirements.

Why Load forecasting is needed?

- There is a **time lag between** awareness of a future need and serving that need.
- Having the forecasted load, the power utility company should think about an adequate power generation, transmission and distribution system facilities and other circuit protective devices.
- However, delivering requires long-time in terms of construction of generation and transmission facilities
- Thus, the time lag is the main reason for forecasting and planning.

Prior to load forecasting the knowledge on:

- Load Classification and Characteristics of Loads,
- Load Curves and Load duration curves
- Demographic data
- Forecast Methodologies are needed.

Classification and Characteristics s of Loads

Classification of loads

Classification of customers for forecasting purposes would be made by

- Types of Use,
- Level of Use,
- Rate of Schedule, or
- Geographic Area.

• Loads are classified into

- Residential,
- commercial,
- industrial,
- agricultural,
- public services

- The agricultural sector includes energy demand for low and medium scale agro-industries and farming.
- The public service sectors may include schools, medical centres, street lighting, public offices and entertainments.
- Other can include government offices, electric utility own consumption, power pool interconnections, electric railways, etc.
- Classification of loads is important to study the group behaviour as load behaviour for the different groups varies significantly.
- Within the broad class mentioned, further subdivisions or sub-sectors maybe defined as follows

Characteristics of Loads

- In most part of the world, the residential loads have the most seasonal fluctuations, responsible for the seasonal variations of the system peak.
- This is **mostly due to the climate sensitive devices that** used for space heaters and air conditions.
- In some countries, the climate condition does not significantly vary throughout the year. Therefore seasonality demand is minimal.

- Again in some parts of the world, commercial and public services loads are characterized by *seasonal fluctuations just* like that of the domestic category.
- In countries like east Africa, there is no significant demand seasonality.
- However, seasonality is common in Asian countries, Europe and USA
- On the other hands, the industrial loads are considered as a base load that contain little weather dependent.
- Therefore, the planning should consider seasonality

Load Curves and Its duration curves

Load curve is a graphical representation between load in kW/MW in proper **time sequence and times**. It shows the variation of load on the power station.

- The highest point on the load curve represents the maximum demand (peak demand) on the station on that day.
- The area under the load curve gives the total energy supplied on that day.
- If this area is divided with the number of hours gives the average load (power) on the station.
- Load curves can be daily, weekly, monthly and yearly depending on the period of observation.
- For daily load curve, the period of time is taken as 24 hours and for annual load curve the time is considered as $(24*365)=8760$ hours.

Load duration curve:

- **Defined as** representing the loads in descending magnitude, that is, with the greatest load at the left, lesser loads towards the right and the lowest load at the extreme right.
- It is derived from the load curve, represents the same data as load curve.
- Load duration curve determines the % of system peak load.
- Load duration curve helps in deterring the average load or average demand as given by:

$$\text{Average Load} = \text{Total Energy} / \text{Total Hours}$$

- It is the ratio of energy consumed in a given period of the time in hours.

Load Factor:

Load factor of a system is the ratio of the average load over a given period of time to the maximum demand (peak load) occurring in that period.

Load Factor = Average Load / Peak Load

- It would be ideal to have a flat load curve. *In practice*, load curves are far from flat. For a flat load curve, the load factor will be higher.
- Higher load factor means more uniform load pattern with less variations in load.
- This is desirable from the point view of maximum utilization of associated equipment which is selected on the basis of maximum demand.
- Ethiopia's power system has a load factor of around **0.57** (in 2006) and 0.7(2014). The industrialized countries have a load factor higher than this.
- This means, the power system operates at an average **57%** of the peak system load in the year 2006 and 70% in year 2014.

Other Important Terms and Factors for load forecasting are

- **Connected load.** It is the sum of continuous ratings of all the equipment's connected to supply system.
- The sum of continuous ratings of all the equipment's in the consumer's premises is the “connected load” of the consumer.
- For instance, if a consumer has connections of five 1000-watt lamps and a power point of 500 watts, then connected load of the consumer is $5 \times 1000 + 500 = 5500$ watts.

Maximum demand : The largest of all the demands that have occurred at a given period (*say* a day) is known as maximum demand.

- Maximum demand is generally less than the connected load because all the consumers do not switch on their connected load to the system at a time.
- The knowledge of maximum demand is very important as it helps in determining the installed capacity of the station.
- The station must be capable of meeting the maximum demand.

Demand factor. *It is the ratio of maximum demand on the power station to its connected load i.e.,*

$$\text{Demand factor} = \frac{\text{Maximum demand}}{\text{Connected load}}$$

- The value of demand factor is usually less than 1.
- Example: If the maximum demand on the power station is 80 MW and the connected load is 100 MW, then demand factor = $80/100 = 0.8$.
- The knowledge of demand factor is vital in determining the capacity of the plant equipment.

$$\text{Daily average load} = \frac{\text{No. of units (kWh) generated in a day}}{24 \text{ hours}}$$

$$\text{Monthly average load} = \frac{\text{No. of units (kWh) generated in a month}}{\text{Number of hours in a month}}$$

$$\text{Yearly average load} = \frac{\text{No. of units (kWh) generated in a year}}{8760 \text{ hours}}$$

Load factor. *The ratio of average load to the maximum demand during a given period is known as load factor i.e.*

$$\text{Load factor} = \frac{\text{Average load}}{\text{Max. demand}}$$

If the plant is in operation for T hours,

$$\begin{aligned} \text{Load factor} &= \frac{\text{Average load} \times T}{\text{Max. demand} \times T} \\ &= \frac{\text{Units generated in T hours}}{\text{Max. demand} \times T \text{ hours}} \end{aligned}$$

Diversity factor. The ratio of the sum of individual maximum demands to the maximum demand on power station is known as diversity factor i.e.,

- A power station supplies load to various types of consumers whose maximum demands generally do not occur at the same time.
- Therefore, the maximum demand on the power station is always less than the sum of individual maximum demands of the consumers.
- Obviously, diversity factor will always be greater than 1.

$$\text{Diversity factor} = \frac{\text{Sum of individual max. demands}}{\text{Max. demand on power station}}$$

- The greater the diversity factor, the lesser is the cost of generation of power.

(vii) Plant capacity factor. *It is the ratio of actual energy produced to the maximum possible energy that could have been produced during a given period i.e.,*

- The plant capacity factor is an indication of the reserve capacity of the plant.
- A power station is so designed that it has some reserve capacity for meeting the increased load demand in future. Therefore, the installed capacity of the plant is always somewhat greater than the maximum demand on the plant.
- Reserve capacity = Plant capacity – Max. demand

Standards needed while forecasting loads are:

❖ Five broad categories:

– Domestic

- Demand factor: *70-100%*
- Diversity factor: *1.2-1.3*
- Load factor: *10-15%*

– Commercial

- Demand factor: *90-100%*
- Diversity factor: *1.1-1.2*
- Load factor: *25-30%*

– Industrial

- Small-scale: *0-20 kW*
- Medium-scale: *20-100 kW*
- Large-scale: *100 kW and above*
 - Demand factor: *70-80%*
 - Load factor: *60-65%*

Standards needed

cont.....

– Agricultural

- Demand factor: *90-100%*
- Diversity factor: *1-1.5*
- Load factor: *15-25%*

– Other loads

- Street lights, bulk supplies, traction etc.

- Commercial and agricultural loads are characterized by seasonal variations.
- Industrial loads are base loads and are little weather dependent.

1.1.1 Load Forecast Methods

- Load forecasting is vitally important for the electric industry especially in the *deregulated economy*.
- Accurate models for electric power load forecasting are essential to the operation and planning of a utility company.

Load forecasts can be divided into three Types:

- Short-term forecasts, which are usually from one hour to one weeks or a year
- Medium forecasts which are usually from a week to one or two years, and
- Long-term forecasts which are longer than one or two year.

a. Factors Affecting load forecasting

- Time factors such as:
 - Hours of the day (day/night)
 - Day of the week (week day/weekend)
 - Time of the year (season)
- Weather conditions (temperature and humidity)
- Class of customers (residential, commercial, industrial, agricultural, public, etc.)
- Special events (TV programmes, public holidays, etc.)
- Population
- Economic indicators (per capita income, Gross National Product (GNP), Gross Domestic Product (GDP), etc.)
- Trends in using new technologies
- Electricity price

B. Driving parameters for load forecasting's

Short Term Load forecasting (STLF)

- Time of the day, week
- Price , special events, weather conditions
- class of customer

Medium Term Load forecasting (MTLF)

- Time of the day, week
- Price , special events, weather conditions
- class of customer

Long Term Load forecasting (LTLF)

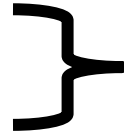
- *GDP, per capita income , Trends of technology, population*

C. Forecasting Approaches

1. Naive
2. Moving averages
3. Exponential smoothing
4. Trend projection
5. Linear regression



time-series models



**Associative model(end-user and
econometric approach's**

Forecasting Approaches

Cont.....

- Determining the systematic relationships between *loads at various points in time is the essence of time series* modelling[1].
- Needs only the past values, no other variables are important
- Since time is the only explanatory variable, the data collection requirements of this technique are the least of any forecasting technique

However, not all time series models are easy to implement.

- The predictive accuracy of time series analysis varies tremendously from application to application.
- For short-term forecasts of relatively large and stable systems, it can be as accurate as more elaborate models.
- It is subject to extreme errors in the 10—20 year horizon required for capacity expansion planning.

Advantages of extrapolation time series method[2]:

- It is the simplest type of forecast
- It requires only access to basic electricity sales and peak statistics
- It can be developed by the use of simple statistical models

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Time series forecasting approaches

i. Naive Approach

- Assumes demand in next period is the same as demand in most recent period
 - ◆ e.g., If the February energy demand at industry K is 1000 MW, then March energy demand will be 1000MW, too
- ◆ Sometimes cost effective and efficient

ii. Moving Average Method(MA)

- MA is a series of arithmetic means
- Demands for next period is given by;

$$\text{Moving average} = \frac{\sum \text{demand in previous } n \text{ periods}}{n}$$

Example

Month	Actual demand	3-Month Moving Average
January	10	
February	12	
March	13	
April	16	$(10 + 12 + 13)/3 = 11 \frac{2}{3}$
May	19	$(12 + 13 + 16)/3 = 13 \frac{2}{3}$
June	23	$(13 + 16 + 19)/3 = 16$
July	26	$(16 + 19 + 23)/3 = 19 \frac{1}{3}$

Time series approach

Cont....

iii. Weighted Moving Average

- Used when some trend might be present

Older data is less important

- Weights based on experience and intuition

$$\text{WMA} = \frac{\sum W * D}{\sum W}$$

EXAMPLE

		Weights Applied	Period
		3	Last month
		2	Two months ago
		1	Three months ago
		6	Sum of weights

Month	Actual energy	3-Month Weighted Moving Average
January	10	
February	12	
March	13	
April	16	$[(3 \times 13) + (2 \times 12) + (10)]/6 = 12\frac{1}{6}$
May	19	$[(3 \times 16) + (2 \times 13) + (12)]/6 = 14\frac{1}{3}$
June	23	$[(3 \times 19) + (2 \times 16) + (13)]/6 = 17$
July	26	$[(3 \times 23) + (2 \times 19) + (16)]/6 = 20\frac{1}{2}$

Weighted Moving Average cont..

- The weighted moving average (WMA) makes forecasts more responsive to the most recent actual occurrences (e.g., demand).
- The most recent n periods are used in forecasting.
- Each period is assigned a weight between 0 and 1.
- The total of all weights adds up to one (1).

Weighted Moving Average (using monthly demands)

Example: Another good example

$$\text{Forecast (4)} = 0.2 * (\text{Demand 1}) + 0.3 * (\text{Demand 2}) + 0.5 * (\text{Demand 3})$$

Weighted Moving Average Method $n=3$				Weights
				0.2
				0.3
Month	Sales	Forecast	Calculation	0.5
1	100			
2	80			
3	90			
4	110	89.00	$= 0.2 * 100 + 0.3 * 80 + 0.5 * 90$	
5	100	98.00	$= 0.2 * 80 + 0.3 * 90 + 0.5 * 110$	
6	110	101.00	$= 0.2 * 90 + 0.3 * 110 + 0.5 * 100$	
7	95	107.00	$= 0.2 * 110 + 0.3 * 100 + 0.5 * 110$	
8	115	100.50	$= 0.2 * 100 + 0.3 * 110 + 0.5 * 95$	
9	120	108.00	$= 0.2 * 110 + 0.3 * 95 + 0.5 * 115$	
10	90	113.50	$= 0.2 * 95 + 0.3 * 115 + 0.5 * 120$	
11	105	104.00	$= 0.2 * 115 + 0.3 * 120 + 0.5 * 90$	
12	110	103.50	$= 0.2 * 120 + 0.3 * 90 + 0.5 * 105$	

Potential problem of moving average:

- Increasing n smooths the forecast but makes it less sensitive to changes
- Do not forecast trends well
- Require extensive historical data

iv. Exponential Smoothing

- Form of weighted moving average[3].
 - Weights decline exponentially
 - Most recent data weighted most
- Requires smoothing constant (α)
 - Ranges from 0 to 1
 - Subjectively chosen
- Involves little record keeping of past data

New forecast = $\text{Last forecast} + \alpha (\text{Last actual demand} - \text{Last forecast})$

$$F_t = F_{t-1} + \alpha (A_{t-1} - F_{t-1})$$

Where, F_t is the new forecast
 F_{t-1} is the previous forecast
 α is smoothing (or weighting) constant ($0 \leq \alpha \leq 1$)

Exponential Smoothing Example

Assume: If the Predicted demand(t-1) of customer A in February was 142MW. However, the actual demand (t-1) was 153MW. Determine the new forecast (Ft) of customer A using the smoothing constant of $\alpha = 0.20$.

Given:

Predicted demand (t-1) = 142 MW

Actual demand = (t-1) 153

Smoothing constant $\alpha = .20$

Solution:

$$\text{New forecast (t)} = 142 + .2(153 - 142)$$

$$\text{New forecast} = 142 + .2(153 - 142)$$

$$= 142 + 2.2$$

$$= 144.2 \approx 144 \text{ MW}$$

Choosing α

Cont....

- The objective is to obtain the most accurate forecast no matter the technique
- We generally do this by selecting the model that gives us the lowest forecast error

$$\begin{aligned}\text{Forecast error} &= \text{Actual demand} - \text{Forecast value} \\ &= A_t - F_t\end{aligned}$$

❖ Common Measures of Error are[4];

a. Mean Absolute Deviation (MAD)

$$\text{MAD} = \frac{\sum |\text{Actual} - \text{Forecast}|}{n}$$

b. Mean Squared Error (MSE)

$$\text{MSE} = \frac{\sum (\text{Forecast Errors})^2}{n}$$

c. Mean Absolute Percent Error (MAPE)

$$\text{MAPE} = \frac{\sum_{i=1}^n 100|\text{Actual}_i - \text{Forecast}_i|/\text{Actual}_i}{n}$$

Example:

- Assume, During the last 8 months, substation D has supplied large number of customers based on the early forecasted demands. The substations Manager wants to test the forecasting method using *exponential smoothing* to see how well this method works in predicting the area. He has guessed that the forecast of substation unloaded in the first quarter was 175 MW.

Comparison of Forecast Error

Quarter	Actual substation load	Rounded Forecast with $\alpha = .10$	Absolute Deviation for $\alpha = .10$	Rounded Forecast with $\alpha = .50$	Absolute Deviation for $\alpha = .50$
1	180	175	5.00	175	5.00
2	168	175.5	7.50	177.50	9.50
3	159	174.75	15.75	172.75	13.75
4	175	173.18	1.82	165.88	9.12
5	190	173.36	16.64	170.44	19.56
6	205	175.02	29.98	180.22	24.78
7	180	178.02	1.98	192.61	12.61
8	182	178.22	3.78	186.30	4.30
			<u>82.45</u>		<u>98.62</u>

Comparison of Forecast Error

$$\text{MAD} = \frac{\sum |\text{deviations}|}{n}$$

For $\alpha = .10$
 $= 82.45/8 = 10.31$

For $\alpha = .50$
 $= 98.62/8 = 12.33$

8	182		178.22	<u>3.78</u>
				82.45

Rounded Forecast with $\alpha = .50$	Absolute Deviation for $\alpha = .50$
175	5.00
177.50	9.50
172.75	13.75
165.88	9.12
170.44	19.56
180.22	24.78
192.61	12.61
186.30	<u>4.30</u>
	98.62

Comparison of Forecast Error

$$\text{MSE} = \frac{\sum (\text{forecast errors})^2}{n}$$

For $\alpha = .10$

$$= 1,526.54/8 = 190.82$$

For $\alpha = .50$

$$= 1,561.91/8 = 195.24$$

Rounded Forecast with $\alpha = .50$	Absolute Deviation for $\alpha = .50$
175	5.00
177.50	9.50
172.75	13.75
165.88	9.12
170.44	19.56
180.22	24.78
192.61	12.61
186.30	4.30
	<u>98.62</u>
	12.33

8

182

178.22

3.78

82.45

MAD

10.31

Comparison of Forecast Error

$$\text{MAPE} = \frac{\sum_{i=1}^n 100|\text{deviation}_i|/\text{actual}_i}{n}$$

For $\alpha = .10$

$$= 44.75/8 = 5.59\%$$

For $\alpha = .50$

$$= 54.05/8 = 6.76\%$$

ed st	Absolute Deviation for $\alpha = .50$
0	5.00
0	9.50
5	13.75
8	9.12
4	19.56
2	24.78
1	12.61
8	4.30
	98.62
	12.33
	195.24

8	182	178.22	<u>3.78</u>	186.30
			82.45	
		MAD	10.31	
		MSE	190.82	

Trend Projections

- Fitting a trend line to historical data points to project into the medium to long-range[4]
- Linear trends can be found using the least squares technique

$$\hat{y} = a + bx$$

where \hat{y} = computed value of the variable to be predicted
(dependent variable)

a = y-axis intercept

b = slope of the regression line

x = the independent variable

Trend Projections cont....

Least Squares Method:

- Equations to calculate the regression variables

$$\hat{y} = a + bx$$

$$b = \frac{\Sigma xy - n\bar{x}\bar{y}}{\Sigma x^2 - n\bar{x}^2}$$

$$a = \bar{y} - b\bar{x}$$

Least Squares Example

Year	Time Period (x)	Electrical Power Demand (megawatt)	x^2	xy
2006	1	74	1	74
2007	2	79	4	158
2008	3	80	9	240
2009	4	90	16	360
2010	5	105	25	525
2011	6	142	36	852
2012	7	122	49	854
	<u>28</u>	<u>692</u>	<u>140</u>	<u>3,063</u>
	$\sum x = 28$ $\bar{x} = 4$	$\sum y = 692$ $\bar{y} = 98.86$	$\sum x^2 = 140$	$\sum xy = 3,063$

Assume x is number of population

$$b = \frac{\sum xy - n\bar{x}\bar{y}}{\sum x^2 - n\bar{x}^2} = \frac{3,063 - (7)(4)(98.86)}{140 - (7)(4^2)} = 10.54$$

$$a = \bar{y} - b\bar{x} = 98.86 - 10.54(4) = 56.70$$

Least Squares Example

Year	Time Period (x)	Electrical Power Demand	x^2	xy
2003	1	74	1	74
			4	158
			9	240
			16	360
			25	525
			36	852
			49	854
	$\sum x = 28$ $\bar{x} = 4$	$\sum y = 692$ $\bar{y} = 98.86$	$\sum x^2 = 140$	$\sum xy = 3,063$

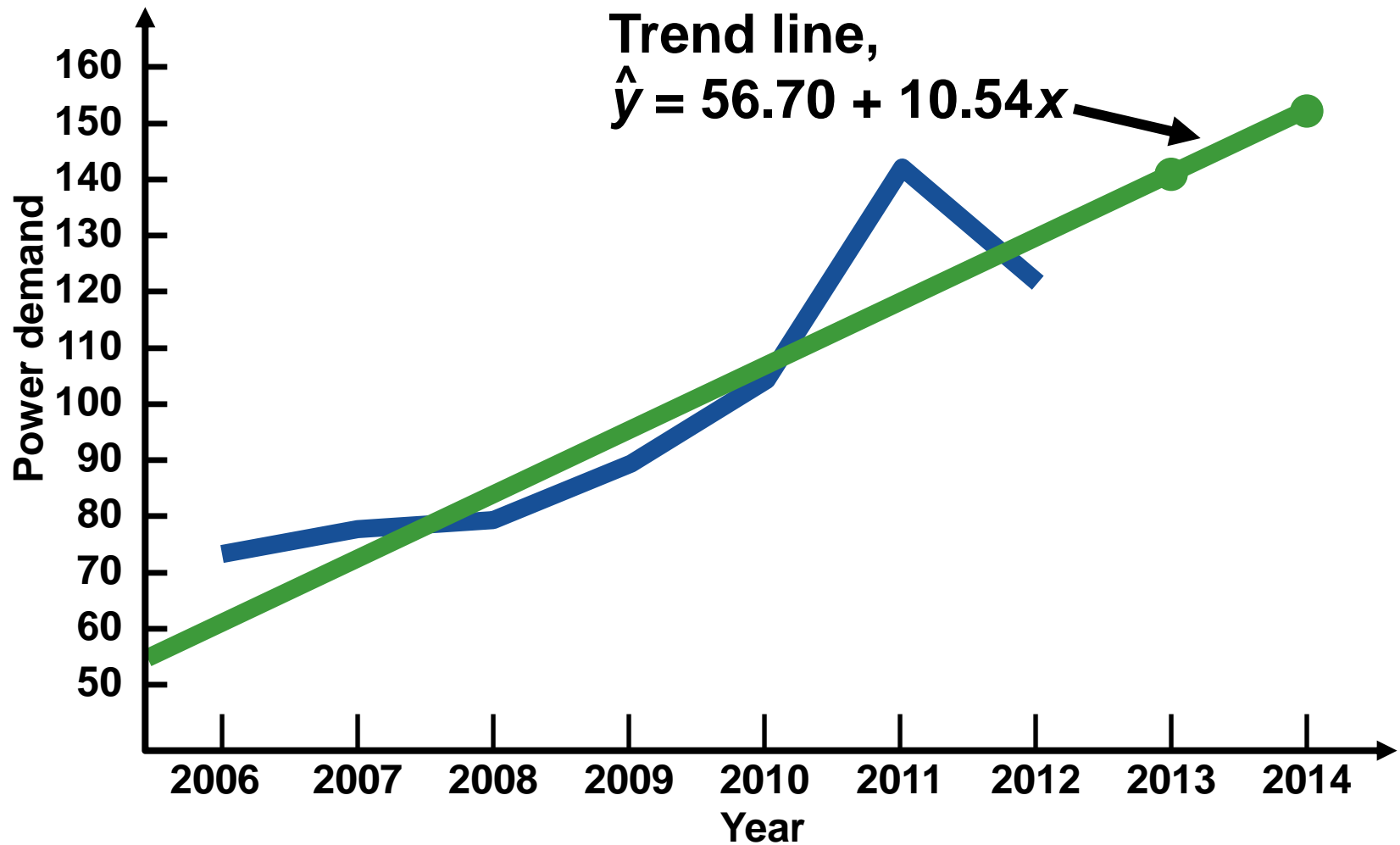
The trend line is

$$\hat{y} = 56.70 + 10.54x$$

$$b = \frac{\sum xy - n\bar{x}\bar{y}}{\sum x^2 - n\bar{x}^2} = \frac{3,063 - (7)(4)(98.86)}{140 - (7)(4^2)} = 10.54$$

$$a = \bar{y} - b\bar{x} = 98.86 - 10.54(4) = 56.70$$

Least Squares Example



Multiple Regression Analysis

- If Demand Y is depends on two or more parameters[5]

$$\hat{y} = a + b_1x_1 + b_2x_2 \dots$$

- It is very complex and needs soft computing techniques

Econometric forecasting

- In this approach, *initially the relationship between the load and the driving parameters is estimated.*
- The relationship may be nonlinear, linear; additive or in the form of multiplication.
- This relationship is established based on available historical data.
- Various driving parameters may be checked to find the ones that have the dominant effects.
- Once this relationship is established, the future values of the driving variables (i.e. per capita income, population, electricity price, etc.) should be projected.

Mostly used independent variables include:

• *GDP, Population, Electrified Population, Price and GDP/Cap*

The dependent variables

• Energy demand or Peak demand

Multiple Regression Equation

$Y=f(x_1, x_2, x_3, x_4, x_5)$

$=a+b*GDP+C*pop+d*electrified\ Population+e*GDP/Cap+f$

Examples of economic and other variables often used to develop econometric relationships are:

- Household income
- Electricity prices (by customer group)
- Labour productivity
- Commercial sector output (by sub sector)
- Price of other fuels
- Use of other fuels (gas,oil,coal,..etc)
- Employment (by sector and subsector)
- Industrial or agricultural productivity

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Thank you !