Economic Operation and Control of Power System

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Week - 11

Lecture – 53

Hello and good morning everyone, welcome you all for the NPTEL online course on Economic Operations and Control of Power Systems. Today we will discuss about short term demand forecasting. Operational planning and inventory policies are dependent upon some forecast of demand as well as present and future prices of resources. The forecast is an essential component of production management when finding optimal manufacturing policies. So when you have to produce some commodity you need to forecast what is the demand. So based on the demand only you will manufacture otherwise you keep it in inventory and that may not give you any return.

So unnecessarily you are investing which is not of much return then it will be company under loss. So these policies are derived from production and demand models and are dependent upon the forecast of demands or consumption of the services. Forecasting is an essential process of any successful production oriented or trading oriented company. It is important to note that a forecast is not a final product it is often recursive in nature as the need for refined solutions is required.

So electricity is also a trading you need to also you are selling the product which is electricity you need to have a proper forecasting of demand based on the demand only you will be able to generate. So predictions of future events and conditions are called forecast and the act of making such predictions is called forecasting. So forecasting is a key element of decision making its purchase is to reduce the risk in decision making and reduce unexpected profit or cost. In broad terms power system demand forecasting can be categorized into long term, medium term and short term forecasting. So what is long term demand forecasting? It covers from 1 to 10 years see the time duration is very long, long term henceforth the name is long term.

1 to 10 years ahead in yearly values and is explicitly intended for long term capital investment studies when you are making some planning, augmenting the power system network for all these things you need to estimate after 10 years what could be the possible areas where demand may rise up. So for capital investment studies this is very much important and medium term demand forecasting, forecasting is also used for maintenance and fuel scheduling for several years on a monthly basis. And what is short term demand forecasting? It requires knowledge of the demand from 1 hour up to a few weeks it is for

dispatching the generators. So medium forecasting will help you to have an idea about what are the sort of generators that you need to go for maintenance and what is the fuel scheduling basically you need to also procure the fuel in a medium term so this is very important. Continuing so we will focus on short term demand forecasting in today's lecture.

Operations derived from the short term demand forecast are vital to the system as operations in terms of short term unit maintenance work, weekly, daily and hourly demand scheduling of generating units and economic and secure operation of power systems. So we have dealt in detail the entire course is about economic operation and also we discussed about security analysis. So for these things we need to have demand forecasting. So here we will focus on short term demand forecasting with mathematical methods. So production theory for electrical power system is found by economic dispatch and unit commitment.

So inventory theory for electrical power system is based on fuel and hydro scheduling. Fuel scheduling is achieved by an optimal search of the various raw resources available under existing contracts or open markets. So the fuel scheduling is depending upon what are the resources. So let us say thermal power plant who are the possible you know who are the possible persons who are able to deliver us this kind of thermal resources which is coal basically. So we can obtain from open markets.

So production of electric power inventory management and fuel scheduling policies are dependent on the forecast of the energy and ancillary services. So dependent upon some forecast of production the optimal operating schedules are found. The optimal fuel schedules are found based on the production schedules basically. So a competitive environment requires price forecasting as well as demand forecasting as the revenue received from sales has to exceed the cost of production. So any company wants to have profit nobody wants to run a company with loss.

So revenue received from the sales should be more than the cost involved in the overall production so that is objective. So for that you need to have proper inventory management you need to purchase fuel or coal at a lesser price and such that you know you will be able to have a more profit. Forecasting is an essential component of all operational functions including transmission, maintenance scheduling, unit outage scheduling for maintenance, nuclear fuel recycling etcetera. Other examples where forecasting is the key driver include marketing, financial planning and labour policies because it is a whole system which is running you have a lot of manpower requirement to run a generating station. So financial planning, purchasing, marketing, selling and managing the manpower and all these things require forecasting.

So forecasting are about or obtained using two types one is qualitative techniques and quantitative techniques. So what is qualitative technique? Qualitative techniques perform a forecast based on the result of an expression of one or more experts personal judgment or opinion. So here you do not have much historical data. So based on the experience of

experts you will be able to develop some forecasting techniques basically. So such methods are useful when historical data are not available or scarce.

These methods include subjective curve fitting. The Delphi method and technological comparisons this technique is often used for long term forecast it is especially appropriate for events that are not periodic in nature. So the periodic in nature includes the short term load loads which depends upon the weather changes and let us say there is a specific festive seasons where the load would change. So this qualitative technique does not involved in such kind of regular periodic load changes. It depends upon such kind of long term futuristic planning approaches which may be helpful for us to augment the power system network.

Two distinct quantitative techniques are used in forecasting they are both conventional statistical techniques one is time series analysis and econometric analysis. What is time series analysis? So time series analysis is simply the reduction of a series of numerical values that a random variable takes on over a period of time. A random variable example is to consider demand for energy each hour of every day. So clearing price for the exchange of electricity energy for each hour of every day and daily market closing prices of a particular fuel commodity over the period of a year. So these are all time based events.

So analysis is carried out for time based events basically. It is noted that many time series are discrete in nature. So AGC algorithms require knowledge of the inertia, governor and frequency response for the next period of operation. So we discussed about AGC in detail. So you need to have this information for the next period of operation.

The response capabilities of each unit have to be known to provide sufficient response capability as demand changes. So if there is a sudden change in the demand you should have that proper we have discussed about ramp up and ramp down, sudden change in the demand. So your generator should be capable enough to meet out that ramp up rate. So the unit participation factor should be based on the economic dispatch to optimally follow demand changes. And some recent AGC packages do directly use demand forecast as that knowledge of demand trends in the next few minutes can provide more optimal AGC control strategies.

Basically this generation control will be more optimistic, more accurate if you have proper forecasting. So this is especially true when renewable energy, wind and solar are included as such generation does not provide inertia, governor or frequency response. So in future as we are looking more into renewable energy sources the demand forecasting will become more and more challenging. So that is where we are looking into because of lack of inertia from renewable energy sources. So when demand changes then what happens there is a sudden change in frequency, rate of change of frequency is very clearly visible.

So your AGC will be put into more trouble as renewables energy penetration increases in the system. So this is a very interesting research topic altogether. So AGC algorithms when augmented with knowledge of demand trends in the next few minutes permits the use of feed forward or tracking controls that take into account the rate of generation increases,

increase limits, wall point loading, prohibited zone operation, loss of renewable generation etc. all these factors are considered. So ED presently does utilize forecasted demand to minimize crossing of prohibited zones.

Optimal power flow, so we discussed about OPF which requires bus demand forecast for power for the next 10 to 16 minutes for short term planning. So optimal power flow also has load flow, so where you need to have PQ bus means you need to have what is the generation load demand, active and reactive power demand. So proper OPF can be run only if you have a forecasting of load demands. So we are just listing out what are the areas where the load demanding is very critical. One is economic dispatch for accurate generation you need to have accurate load forecasting and optimal power flow to understand whether system constraints are not violated or not you need to have proper load forecasting.

So bus demand forecast has a future expected demands at each demand load in the power system to be studied. Operational planning can extend up to next 1 to 6 months for maintaining scheduling of transmission equipment. So and next security analysis, security analysis requires bus demand forecast for the next hour up to 24 hours to facilitate in predicting trouble periods. The security analysis requires up to 6 months of bus load forecast to include planned outages for maintaining schedule. So there will be planned outages that means scheduled sort of power outages and unscheduled.

So unscheduled power outages is not usually recommended, but scheduled power outages due to maintenance may be recommended for that to happen you need to have proper load forecasting, you cannot have scheduled outages, planned outages during a critical event of a day. So that means if there is a peak hour or if there is you know emergency loads wherever they are connected that part of load need not be isolated during scheduled outages. So there should be proper planning altogether. So unit commitment traditionally required hourly system demands for the next 168 to 336 hours. So some unit commitment programs even require knowledge of future demands for the next month that is 744 hours that means for 1 month.

Unit commitment should include all of the ancillary services when searching for the optimal planned schedule. So extensions to unit commitment for transaction evaluation management require a 24 hour to 168 hour forecast coupled with a good demand spec model will help in controlling demand peaks and valleys in spot pricing strategies. So I mean even I have come across practical challenges where I have heard people will pay lot of price for energy purchase during spot pricing mechanisms. If you do not have proper load forecasting what will happen is at hourly requirement you will go and purchase in energy market, so the spot pricing market then you will have to pay a very high price for any small change in load. So that cause a very the whole system becomes uneconomical because of that.

So henceforth long term forecasting and short term forecasting, medium forecasting everything is very much important. So summary of existing and potential uses of short term demand forecasting you can see here these are different functions AGC, economic dispatch,

power flow, optimal power flow, voltage stability, situational awareness, contingency analysis, unit commitment, transaction evaluation management, wind forecasting, hydro fuel scheduling, there are so many functions that are involved in a power system operation and control. So they have different time zones of operation, forecast horizon, some of them are 50 minutes hourly, daily based and minute based and all. So quantitative technique continuing, so time series analysis exploits techniques that identify the pattern in the data for forecasting the future values that the variable of interest will attain. So time series analysis is often broken into two components, one is deterministic and stochastic.

So the time series analysis approach is to analyse the data using some type of analysis such as regression analysis that is curve fitting optimization, we have discussed about curve fitting optimization problem or a time series which is frequency fitting optimization problem, there are two types of it. So the model form used as the basis for forecasting demand is based on system identification. System identification determines if the form is additive, multiplicative or both. The first step is to remove the demand trends, then slow frequency oscillations and then faster frequency oscillations until all demand components outside the time origin of interest are eliminated or modeled.

Ultimately you need to exactly model. So the load is further dependent upon so many other factors. As I already told, for example in a very long term if you can think of a global warming is an issue. So because of global warming there will be as temperature across the globe increases there will be load pattern also keeps changing because if global temperature increases then AC may be required more and then there are certain faster frequency oscillations. For example, in a year there are so many seasonal changes, winter comes and summer comes and during seasonal changes also there will be change in load pattern. So these are faster frequency oscillations as compared to the global warming scenarios.

So load depends upon so many factors and all those may be included in the overall system modeling but that may be little challenging also. So sometimes you may have to ignore some of the components, sometimes you may have to include it for accurate forecasting. So short term demand forecasting requires that all components outside the next week have been explained and eliminated. So during short term demand forecasting you will not be bothering about global warming scenario because on hourly basis you are working upon to forecast and there will not be any change in global warming temperature. So they are added after the resulting time series has been identified and parameters estimated.

And next apart from time series analysis which is based on time based events, now we will discuss about econometric analysis, this is another approach. So it identifies the economic drivers that lead to demand. The electric demand is often a function of the business index, the weather index that is temperature and other sociological indices. Econometric analysis requires that all demand is based on a cause to effect explanation. Econometric analysis is often based on least square fitting techniques classified as regression analysis.

So econometric analysis expresses the variable to be forecast, the dependent variable as a mathematical function of independent variable. There are some dependent variables and

independent variables. So dependent variables are expressed in terms of its dependency on independent variables. So data on demand for example in retail stores and over the internet mail order sales as a function of total sales over previous periods may be used to forecast total sales in a future period given the internet order sales for that period. So total purchase include somebody will come to retail shop and purchase physically and most of them also purchase through Amazon and Flipkart and other online platforms.

So if you have now the total model is there which includes the sales through physical purchase, retail purchase and online purchase. Once you have the complete modeling of how the purchase is happening then you can forecast what would be the retail purchase if the data of internet order purchase for that period is given. So the variables to be forecast is expressed as a mathematical function of other variables in regression analysis. For example, forecasting the total sales of burgers in a given period may be functionally related to the adjacent factory production during the same period. And econometric techniques are usually additive in nature.

So each customer type is identified, this is how it works. Then the appliances or energy needs of each customer are identified. Once all or at least the major energy needs are modeled, the total demand is simply the sum of various components for each customer. Suppose in the network first you will do the analysis or survey to identify what sort of customers are there in this particular area. There could be some very posh customers who are very rich and they have a different load pattern.

They have very sophisticated energy equipments, refrigerators, ACs, every room may be having one AC and they will be having ovens and all these things and they may be having big electric cars also. So and there will be mediocre sort of houses where you the sort of equipments you have is very less and poor families may have simply LED lights and some TV, so minimum loadings. So identify these customers and then how many such customers are there in this area and this just multiply by them and then add them put together. Then you will get a complete picture of what could be the load of this particular area. Like that you do it for all area, then you will get for the entire network.

So this is the way it works. That is what I told. An example is to identify the appliances in high income bulbs such as the refrigerator of freezers, central air conditioning, central heating by heat pumps, energy storage, home theatre, heated swimming pool, electric vehicle etc. These are some of the equipments that are seen in high income house. Then the number of high income households is counted normally through public records and pass electric invoices. So you also take previous electric invoices, electric bills. This procedure is then repeated for each type of household, commercial enterprise or each type of industrial enterprise also.

You do it for industrial loads as well. There is housing and industrial loads. Note that each type of customers including government, enterprise, policy, hospital, fire etc. has to be identified and inventorized. Now the state estimation chapter provides the general background for computing the statistics of state and parameter estimates for certain cases

where the weighted least square estimation approach is used. We discussed about weighted least square approach to have a better prediction.

In the case of the state space mode, alternative techniques are available such as Kalman filtering. This is also very recent technique, Kalman filtering based estimation. So how it works is let us say you need to identify the aircraft location where it is exactly. Then the Kalman filtering will also predict by its own and also take the information from the signal. Then it will try to improvise its own prediction and finally arrive at a point where the accuracy of prediction is very close to the actual position.

So Kalman filtering is also used for recently the forecasting of demand and generation as well. Further moving, an alternative technique is to use artificial live techniques such as ANN, Artificial Neural Networks. ANN is an approximation to the neurons of the brain, just exactly mimicking the brain structure. ANN is an alternative technique to the Box-Jenkins approach and is well suited to replace curve fitting techniques. Whatever regression techniques we have, conventional techniques that may be replaced by this ANN based techniques.

So unfortunately all forecasting situations involve some degree of uncertainty which makes the errors unavoidable. So the forecast error for a particular forecast Xt cap with respect to the actual value Xt is the error, Et is equal to actual minus the estimated. To avoid the offset of positive with negative errors we need to use the absolute deviations. Hence we define a measure known as the mean absolute deviation MAD as follows. MAD is equal to Et square, that is why if there is a negative or positive errors we square it, divide by M. So it is average estimation basically of errors. Another method is to use the mean squared error, MSE or MAD, these two things are used. So system identification, system identification determines the formula of form for all components to minimize the forecast error. The major dimensions to be identified is the number of components. There are two basic model forms, one is additive and multiplicative. So one normally removes the longer term trends in demand growth that occurs over weeks, months and years into the future.

In general short term demand behavior is influenced by typical factors such as what is the hour of the day, day of the week, weather conditions, strikes or other political events. So like election is coming up, so you will have a different load pattern altogether. People will be watching more into news channels because they want to see what is the exit poll prediction and entry poll predictions. So distributed generation, demand response strategies and pricing strategies, other economic conditions. The inputs are applied to the neuron and are scaled and summed, this is how ANN works.

A bias term is added to the sum which is then passed through the transfer function of the neuron to yield the output. The transfer function may include a threshold trigger to give an output only if that threshold is reached. So there is input, neurons, neuron layers and then there is a threshold after which there is output. The standard symbol for a neuron is simply a circle with interconnection shown going into and out of the neuron.

Every neuron has an input and there is an output as well. For example, you see here typical neuron structure in neural networks. There are so many inputs to this weighted activation function and there is an output. For example, in load we will see input could be previous day, yesterday, yesterday's load data. For example, second input could be last week, same day, historical data, load data, last week data, this could be last week data.

And we may also have a yearly data, last year data. So you give different weightage for individual data and then there is average weightage that you come out and then based on that you will predict the future, what is the exact load for the next day. This is to decide what is the weightage that you need to give, you may use ANN. How to exactly decide the weightage for individual data? You can use our previous learnings and put accurate weightages such that you will be able to obtain the data and you can have the curve fitting. So exactly tomorrow the load could be of this pattern.

So this is one such application. So artificial neural networks have a wide range of applications. One of the first applications of the network was the pattern recognition problem. In this type of problem, items are taken from a set and classified into distinct groups based on their characteristics. So in a box if there are mangoes, apples and oranges, so it is a pattern recognition. What are the different types of, they have different color and size altogether.

So you will decide different patterns and classify them into different groups. So neural networks can also serve as a model for human memory. The half filled neural networks is one such model that is capable of recalling specific binary or bipolar patterns with which it has been trained. One of the most common applications for ANNs is forecasting future trends in many industries. The best types of problems to apply ANNs is to R1s where the variables that affect the output are known or can be determined while the exact functional relationships between these variables cannot be determined.

Let us say the load, as we have already discussed, the load depends upon hour of the day, weather forecasting and events like political events, cricket and all these things, so many factors. These are the factors which may be influencing the change in load pattern. You know these data's. But how exactly each of these data are interrelated to the output? That you do not know. How much weightage should be given for event? How much weightage should be given for weather forecasting? And all these things that you do not know.

That ANN as a learning technique it will decide and it will develop the learning relationship such that you will be able to predict the future load. There we get the advantage of learning techniques. Our example of this condition is the power system short term demand forecasting problem. The inability to determine these functional relationships makes the use of traditional techniques such as regression analysis impractical for these forecasts. ANNs are particularly valuable for problems that are extremely nonlinear and you do not know what is the degree of nonlinearity.

Specifically neural network training involves the determination of weights for interconnections between neurons. The goal of the training is usually to minimize the sum of a function of output error for a given set of inputs or to ensure that the stable points of a neural corresponds to a set of training patterns. For example training data there are two types of data training data and testing data. So we used to also do take we also have predicted IIT Kanpur load using ANN techniques.

So we took one year data using six months of data we did testing sorry training. You first train the neural networks and remaining six months data you use it for testing. That means you already have a model just give the input variables and obtain a data and verify that output with the data that you already have. So we also got very good accuracy actually so ANN really is beneficial. The goal of the training is to have the actual output of the network be as close in some performance measure to the associated output pattern when a given input pattern is applied. The back propagation algorithm and the interior point linear propagating algorithms are two such approaches used.

Then we will discuss about feed forward networks. The inputs are applied to the first layer of neurons which usually have a linear transfer function between input and first layer the relationship is linear and then this input layer is connected to the hidden layer via weighted interconnections. Each hidden layer neuron has an associated transfer function and the output of the hidden layer neurons serves as input to the next layer of neurons. Usually only one hidden layer is present. So this layer is directly connected to the output layer by weighted interconnections. Feed forward ANNs may have more than one hidden layer but this topology is rarely used.

The output layer neurons may have either a linear or non-linear transfer function depending on the design of the network. There are no limits to the number of neurons in a given layer. This is how possibly this looks like.

So a simple feed forward network, there are so many inputs. These are the input layer. This is input layer. We will see input and then this is the hidden layer and there is a output layer. See this is neuron 1. There are so many such neurons N1, N2 and there is no limitation.

You can have so many neurons. Each neuron is interconnected. You see here there is interconnection between the inputs and the output with each neuron. So ultimately output depends upon input that is coming from each individual neurons. So their weightage is decided actually. So there is a transfer function for each neuron.

Transfer output by input is transfer function. Output by input is transfer function. So that means output depends upon the transfer function of the neuron into the input it has. So there is an influence of each neuron to decide what is output. So you can have more hidden layers also and then we call it as deep neural networks. If you have more hidden layers, then you will have, it is termed as deep neural networks and its accuracy is further increases.

But on the other end complexity also increases. The most common non-linear activation

function for a neuron is sigmoid. This is a sigmoid function. The sigmoid typically starts at 0 and increases to 1 according to the function soft t is equal to 1 by 1 plus e to the power of minus t. So, artificial neural networks and its usage for load forecasting, renewable forecasting is a very upcoming trend. So most of the electrical utilities are also using it and the consumers are also using it because they want to have better forecasting.

They do not want to involve in spot pricing and henceforth pay high penalty. So this is a very important field and lot of research focus is also there in this area. So with this we will conclude short term load forecasting. Thank you very much. Thank you.