Economic Operation and Control of Power System

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Week - 01

Lecture - 02

A very good morning. Welcome you all to this NPTEL course on Economic Operation and Control of Power System. And today we will be focusing on our lecture two on Evolution of Indian Power Systems. As you have gone through the lecture one where we talked about the introduction and complete background of the course, today we will be focusing on the evolution of Indian power industry. Now if you go back as 1882, the first commercial DC power system set up at Pearl Street Station in New York by Thomas Alva Edison to light 11,000 bulbs for 500 customers. And perhaps the operating voltage at that time was 110 volt DC and later on upgraded to 220 volt DC.

And because of this, because the initial, the first electrification of a particular street was at 110 volt or further it is 220 volt, but it was completely DC system. And hence the creator Thomas Alva Edison is known as father of DC distribution system. Now but there was one challenge. Because of the low voltage, the current become very high for a given volt ampere transmission. So that led to high copper loss in underground cables and that is limited DC power distribution to lower Manhattan area only. Means the project could not expand further because of its major losses. So Pearl Station also burned on January 2nd of 1890 and later decommissioned in 1895. Now in the meantime, the transformer which has been created by William Stanley in 1885 and also we came across induction machine which is a AC machine by Nikola Tesla in 1888. And those two devices is basically the turnaround of electricity system where completely we converted from DC system to AC system. And also the voltage can be either upgraded to any value and that may lead to reduction in current and hence losses. Nikola Tesla now named as the father of alternative current. So please remember Thomas Alva Edison who is father of direct current and also Nikola Tesla considered to be father of alternative current AC distribution system. Now in 1889, the first single phase AC system installed at Oregon City and the power generation was from two 300 HP hydro generators and transmitted to Portland via 4 kV 21 kilometer transmission line. And the project was successful and hence in 1891, first three phase AC system installed in Germany for a length of 179 kilometer at 12 kV voltage. Although initially there was no standard for frequency in three phase power generation. So I mean there is a lot of variation in frequency

depending upon the laboratories. So people experimented from 25 Hz to 133 Hz. But today as you all know only 50 and 60 Hz are considered to be prominent frequencies for operation. Now interconnection and parallel operation of different pass system was not possible.

So later on the frequency was standardized and as I told that there are two frequency range operators typically one is 60 Hz and the other one is 50 Hz. So for North America they operate with 60 Hz and the rest of world operate with 50 Hz. Now let us focus a little bit on Indian power system. Now July 24th, 1879 the first DC power system installed in Calcutta by PW Flueryand Co company that is British administered company. And in 1896 the first hydro installation of 130 kW in Darjeeling by Crompton & Co.

And 1899 first thermal power station 1 MW in Emambagh, Kolkata by Calcutta Electricity Supply Company (CESU). Now the 1948 after independence we have introduced Electricity Supply Act led to modernization in Indian power system. We have established both state electricity boards as well as central electricity authorities to regulate power generation, transmission and distribution in each state as well as a different I mean at national level. So that means we have many state governed bodies as well as one national governed body. Now 1975 is one of the remarkable year because Electricity Supply Act has been amended where National Thermal Power Corporation NTPC, National Hydro Electric Power Corporation NSPC, Nuclear Power Corporation of India Limited NPCIL were established for the first time.

In 1989 the NTPC which has been divided into multi fold, first of all NTPC, operation of controlled own thermal plants. So NTPC has been made the owner of all the thermal power plants and however the second part led to power grid corporation of India limited so called PGCIL which is responsible for planning operation and maintenance of grid between the states. So if you see very closely the generation and the transmission were you know divided into two different verticals. In 2003 Electricity Act superseded all previous acts that means 2003 become a remarkable year which had nothing doing whatever the final version of the 2003 need to be acted upon by every individual of this nation. Now there we formed a new body known as Central Electricity Regulatory Commission CERC which has been formed for the first time and then the PGCIL divided into PGCIL for planning and power system operation corporation limited POSOCO for operation of grid. So PGCIL further divided into two component one is POSOCO and PGCIL for planning activity only. Now POSOCO started looking into the operation of the grid in real time. So if you see that way, I mean 1991 we had an interesting scenario where we had five zones northern, southern, eastern, western and north eastern. So those zones started integrating you know or interconnecting each other for a better operational activities. So 1991 northern eastern and eastern grid were interconnected.

2003 western grid interconnected with those northern eastern grid as well as eastern grid. Now in 2006 northern grid integrated with western, north eastern and eastern and 2013 southern grid joined the northern, western, north eastern and eastern grid. So that day in 2013 we started naming India as a one nation and one synchronous grid. That means everyone operates with the same frequency all those five grids. Now if you look very much closely to the voltage levels the generations as I mentioned in my introduction section it is 11.6 kV and 21 kV. Transmission they are 1100, 765, 400, 220, 132 as well as HVDC with the plus or minus 500 as well as 800 kV. Sub transmission distribution they are at 33 kV, 11 kV and single phase consumption with 415 in three phase and 240 single phase for the residential customers. Now because of lot of renewable energy available in this nation and they started generating so we need to create a proper transmission of those power to the major grid. So green energy corridor which has been established. So the main objective of green energy corridor project aim at synchronizing electricity produced from renewable sources such as solar and wind with conventional power station in the grid. Especially for evacuation of large scale renewable energy interstate transmission system so called InSTS project was sanctioned by ministry during the year 2015 and 2016. Now exactly the government cleared a budget of close to 12,000 crores planned to set up infrastructure to transmit electricity from renewable energy projects as it seeks to boost the output from green sources and meet half of the nation's energy requirement from them by 2030 as a ambitious plan until unless you have proper grid integrated system which can evacuate all those energy available through renewable sources it may not be possible to achieve your target in 2030. The investment approval by cabinet committee on economic affairs for the second phase of the green energy corridor which will help supply of 20 gigawatt of renewable energy to the national grid from Gujarat, Himachal Pradesh, Karnataka, Kerala, Tamil Nadu and Uttar Pradesh for the second phase. Now it will also involve approximately 10,750 circuit kilometer of transmission lines, 27,500 megawatt-ampere transformation capacity. This will help to ensure huge injection of electricity into national grid from intermittent energy sources such as solar and wind does not threaten the grid anymore. The corridor also forms important components to keep frequency within the limit 49.9 to 50.05 hertz band. So that means the frequency cannot drop I mean less than one that is 49.9 less than 0.1 and also it cannot go beyond 0.05 that is 50.05. So there is a very strict boundary for frequency operation which is 49.9 to 50.05. Now for that an AGC, automatic generation control, recently made operational. We send signal to power plants every four seconds to maintain frequency ensuring power grid reliability. The transmission system will be created over a period of five years and through 31 March 2026 as expected completion date. Now the first phase of green corridor is under various stage of implementation in Andhra Pradesh, Gujarat, Himachal Pradesh, Karnataka, Madhya Pradesh, Maharashtra, Rajasthan and Tamil Nadu. It will supply around 24 gigawatt of renewable energy.

The first phase will add 9,700 circuit kilometer transmission lines and 22,600 MVA capacity of substation at an estimated cost of 10,000 crores approximately. Now where we are leading to in November Summit 2021 the Prime Minister pledged to increase the country on fossil fuel power generation capacity to 500 gigawatt and which can meet close to 50% of its energy requirement from renewable sources by end of the decade. The CEA, Central Electric Authority estimate India's power requirement will rise to 817 gigawatt by 2030, almost too much. So further the interest in India's green energy economy continue to grow with the sector receiving foreign direct investment of 7.25 billion dollar from 2014 to 15 up to June 2021 and 797 million dollar was received during only one year, 2020-21. Hence the future is green energy for sure that none of us can deny anymore. Now how do we regulate? What are the administrative blocks that control the whole Indian power sector? Dear friends, I am very much keen to emphasize here because all the textbooks that we study most of the time they are either focusing on North American power systems or European power system. It is good to know that but in the meantime it is also important to understand how a large power sector like India operates today. The architecture through which we function must be known to every power engineer of this country. Now we do have a mechanism called or a body which is Ministry of Power that deals with planning, policy formation, processing and implementation of projects as well as it looks into the legislation in regards to power generation, transmission and distributions. Then we have one more body which is PGCIL, Power Grid Corporation of India Limited responsible for national and regional power transmission planning. Then we have one more important body which is CEA, Central Electricity Authority, advises on matters related to national electricity policy and formation of short term and prospective plan for development of power systems. Then we move to CERC Central Electricity Regulatory Commission and State Electricity Regulatory Commission. This commission of those regulates the tariff, formulates policies regarding subsidies and promotion of efficient and environmental policies at central and state levels respectively. Then we move to transmission: state transmission as well as central transmission units where development of efficient, coordinate and economical system of interstate and interstate transmission line is possible through CTO and STUs. Now this is one diagram though the letters are not very big actually so you can zoom perhaps when you study your room and you can see the whole architecture of Indian power system the central part which is talks about central government that is the Ministry of Power all the components that I talked are being presented here and then that interlink to my state level. So the state and centers are integrated and you can also see different state sectors their generation, transmission, distribution and different distribution companies like BSES Rajdhani or Tata Power there are many distribution companies too and then you have actually a trading companies they are also available and you can see there is one corner which is POSOCO which is also there and then you have

state independent power producers small small power producers and the right side you can see there is a SERC regulator power exchanges there are two power exchanges in this country today those who carry out the tradings that is one is known as IEX the other one is known as actually PXIL there are two different power exchanges those who do business on power you know similar to your money exchange they talk about power exchange and we have a CERC Central Electric Regulatory Commission and also we do take care of actually applied Tribunals if there are some complication cases that need to be resolved and moving slowly you can see there is a center called CPRI Central Power Research Institution and they basically do R&D as well as bit of training for power engineers and then you have different authorities like your CEA Central Electricity Authorities which really directly in contact with your central governments. Now you can also see different type of organizations where you have NTPC, NHPC, NEEPCO transmission like Power Grid and then you have actually POSOCO and then finance power corporations rural electrification so these are the bodies so this is the only diagram which will make you clear how Indian power system operate today. Unfortunately all the power segments or power sector management of the world is not saying different country operate with their own strategic planning and strategies so this is the Indian power sector management we must know it. Here I do wish to acknowledge Professor S.C. Srivastava retired from IIT Kanpur who has helped me to create this slide. Now moving to short term transition of electricity so short term transition of electricity depends you know how we create an agreement and how those energy can be procured through a market mechanism so electricity transacted interstate through interstate trading mechanism and that is directly by the distribution licenses so different distribution company present in your state can procure power from a generation company through a trading mechanism and then supply to your local consumers. So power exchanges that is Indian Energy Exchanges Limited which is named as IEX and Power Exchange India Limited PXIL and Deviation Settlement Mechanism DSM. So these are the three bodies who always settle down your market in a very short term. Now why do we go for short term reports? Short term reports are important because settling the market is very important the consumers we have differently the suppliers we have differently the market we have differently so we have to be very careful under no circumstances the customers are not being you know kind of given electricity or energy 24 hours a day so that is the main objective and hence to analyze the volume and price of the short term transition of electricity.

Now what happens? Now let's say if you there is some commodity which is very important like for example gold price you know so the trading happens and the cost may go from 50,000 to 60,000 70,000 doesn't matter all right so if you are comfortable you can buy it if you are not comfortable you will not buy it but electricity if that happens from 100 rupees to 500 rupees okay for a particular hour then it is very because this is a must commodity for us to leave okay so we cannot you know though we can encourage

marketing or trading but nevertheless we cannot allow to grow to an extent so that it is not affordable and you cannot really have electricity because of money matters so that is where actually the government comes to action and see to that everything is properly being managed to assist the competition among the market players we encourage competition but also we make sure they do not exploit the whole market business because it is a must commodity to analyze the effect of congestion on volume of electricity transacted through power exchanges now what happens we have transmission system and they do have actually limited capabilities to carry the power now if a particular customer like to extract all the powers through the client because you know because of some business model and the transmission line is not able to carry so that lead to congestion which is not acceptable so business come the technology they have to go together to provide information on volume and price of renewable energy certificate are is transacted through power exchanges for an example let's say there is a wind power park which is keep on generating electricity at a particular hour but somehow actually there is no business model helping that power plant so you are not ready to buy that power just for an example so then what will happen those renewable energy being produced because this fellow poor chap cannot store it okay so it is keep on generating and if you do not get into the greed and being purchased or being acquired by someone then the energy will be wasted the gentleman has to deal it its power plants to lower rating which is not advisable okay so we need to help those intermittent nature of renewable energy producers also to survive in this competition now to disseminate all of the relevant market information which is very very important now this very clearly shows the different volumes of actually sort of transitions of electricity in that in India in the month of January 2022 you can see the magnitude the volume power being actually transacted and it's a very interesting though the percentage is not very high but we are happy that India to experience the wonderful market requirements and it could see that the power being exchanged to the graph below which talks about the bilateral transactions bilateral transition means two parties agree to have a fixed exchange of power for a given duration so you can see the bilateral transition is the green one and this blue one and then the green one is power exchange and then you have the settlement DSM which in the red lines okay but one thing is very clear the component of trading today in India is not very significant most of them are fixed transactions because they are fixed consumers and you can also see the percentage share of electricity transacted by trading licensing different companies and you could see that the percentage of trading that has been taken place in Indian market now the price of electricity which is a very important as you could see the price is one rupee per kilowatt hour which is minimum and the maximum is rupees as high as eight so that source in a given day the price can go eight to ten times higher so that is sometimes risky so you do very careful in encouraging market environment to electricity this is one important thing where you can see the short-term transactions how it has taken place and then you can also see the volume and price of electricity in green a

term ahead market actually or different exchanges in the month of January so that will also give an idea that the cost which is you know in the order of between three to four rupees this gives an idea how the market takes place in this country now what is the impact now the issue here is the global demand of energy is expected to climb about 25 percent by 2040 okay so energies keep on increasing requirement of energy no one can stop. Now India contributes about 45 percent of world energy demand growth in 2040 means there is an increase no doubt about it so whatever being increased in 2040 India will contribute 50 percent close to 50 percent of the global demand so we are the kind of you know huge energy demand in this country so you should be well prepared and India and China so the largest increase with each listing more than 1 billion middle class citizens so because of aspiring middle class wanted to have electric vehicles, air conditions very comfortable lighting systems and everything okay so to make a good life we need electricity that we cannot deny India will grow strongly with its share of global GDP doubling in recent time. Now what are those factors affect the performance of your electricity grid. Now first of all increasing demand of electricity supply shortfall of electricity and we need to reduce the losses and we have to also reduce the peak demand requirements and then integration of renewable energy to the main grid, so these are the factors we are taking care to make sure the performance of the existing grid improves a lot. Also we need to have solution for global warming, effective use of electric vehicles, customer satisfaction that is one important that means we cannot afford to provide I mean we need to provide reliable electricity to all the customers okay and overcoming difficulties in meter reading you know first of all millions of electric meters sometime they are functional non-functional taking those readings so we need to replace all those conventional meters by smart meters in recent time to come support efficiency of conventional power system because they have been established almost more than 50 years back and their life is not in good condition so probably the efficiency is going down so that is also another challenge Indian moment has to implement.

Now also one more important part is aging asset and lack of circuit capacities so if you see the transformers they're also equally I mean decade old devices and the power network design life need to need for placements the capacity cost of life for replacement will be very very high so if you because you know nobody really knows how expensive it is to replace your transmission colliders or the substations they are very very costly and that is an asset for us so it is always better to delay your investment but nevertheless we need to plan strategically to make sure all the age devices are being replaced at a given point of time now the security of the supply which is certainly an issue in India need of reliable electricity supply as more and more critical loads are connected we cannot afford to have even five to ten minutes energy delay supply systems or non availability of electricity for hospitals and for data centers so we have to make sure that 24 hours the electricity is available to us. One more interesting challenge is about thermal constraints

you know the transmission lines they have some capacity if you allow it to be overloaded then probably they produce heat and then those lines will melt and fall on the ground so the transmission and distribution lines are almost at its limit in this country because of huge requirements of energy so probably that is another area we need to focus to avoid you know line to ground fault or maybe melting of different lines or maybe failure of different transmission distribution systems and also reduction in life of equipments I've already mentioned most of the devices in this country are not very new so I think they need replacement and replacement cost is really huge so you have to do in a phasor manner for proper replacement of those devices and also increasing incident of all very frequently we see the different transmission corridors are facing faulty challenges I think transmission systems are to my understanding it is as per the global standards in this country no one can challenge but about the distribution system we have to focus more now. Some of the recent concerns that we have realized that limited expansion of transmission network is compared to the generation expansion the way generation is increasing probably the transmission system has to increase in the same pace, most of the existing conventional generation transmission as well as distribution systems are quite old so we need to emphasize on combined expansion planning and also we need to have enough reactive power that is ancillary services because bringing too much of renewable energy to the system we are losing reactive power okay so reactive power planning is another important area that we focused on and also we need to see to that how distribution losses need to be reduced majorly and lack of dynamic data for health monitoring and control we need to monitor properly what are those areas actually we frequently face failures or faults now increase concern towards vulnerability and resilience of the system under natural and man-made disasters this country to face almost every year one disaster especially in the coastal areas so that spoils all our transmission distribution systems so we have to be careful and then growing environmental concern that is also a very big challenge to new integrations and poor customer participation in energy management system unfortunately we need to educate our people not to use electricity if it is not needed number one number two if for an example a very basic example I keep on telling I'm retreating today if you have to charge your electric vehicle then we need to see though anytime you can charge in a day but the full rise the cost is saying and but preferably it is always advisable to charge your electric vehicles or on your washing machines depending you know if you can delay the peak points to a optic hour probably were contributing to the nation's development and also there's a huge challenge for electricity demand so we need to be more conservative not consuming more electricity if it is not needed now moving to power system operation electric power system is a complex man-made system with several interconnected elements and spread over large geographical area as you know the generation transformers transmission distribution and loads classically vertical integrated power system has moved towards deregulation today in the past we have generation transmission distribution systems and

the energy is to flow from generation to the consumers but today it is not true today the energy is flowing from generation to consumers as well as from the consumer to the transmission systems similarly previously the money is to flow from the consumer to the companies okay reverse but today the money is flowing from all the directions okay from the consumer to generation system on generation system to consumers also now several utilities own control and operate different elements except transmission system which is still owned by the regulated by the possible and PGC I have so rest of the systems are actually completely utility owned okay transmission system has not been controlled by anybody excluding government of India that is also called and PGC because we cannot afford to give the whose current transmission corridors control to any individual as of now whereas the distribution companies and the generation companies they are being owned by many people for management of the energy segments now today we talked about the improved version of distribution system so we all realize that the distribution system need to be made smarter the main reason being availability of energy sources which was not there in the past within the distribution system and then you have a electric vehicle the company was not there earlier but it is available so if you see that way so we do have a lot of route of solar study and that creates a microgrid within a distribution system and and that system where we communicate to the different components of renewable energy sources from time to time loads as well as to the distribution companies and if you communicate along with accommodating generations with loads then your network is slightly different than a conventional distribution system and the hat new distribution system is named as smart grid as today's terms so smart grid networks is basically utilities are forced to move from the traditional power system to a highly flexible secured and green power system by using integrated communication and advanced control technology so we want imagine you have a huge Academy campus for an example in Manhattan-Jeopardy where we have actually load requirement of actually 3 megawatt and you have let's say 500 kilowatt of actually solar and rest of the energy is coming from a main grid so we need to understand how to utilize those renewable energy efficiently before bringing power from the main grid okay so the difference between the energy available and energy requirement need to be purchased from the external grid and if you have a battery then probably you need to optimize what time the battery need to be charged and what time it need to be discharged so you need to have an advanced control technology as well as you to speak to the grid frequently there is a communication system between both the sides. In the past, the system was not like this is a very steady conventional system so your conventional distribution system having advanced control technologies and having the capacity of communicating to different components then probably that type of distribution system can be named as smart grid networks. So there are four R's people talk about in case of smart grid it is it has to be a distribution system which is resilient, reliable, robust and reconfigurable so if you can achieve those four targets so probably your distribution system become smarter so smart grid is an advanced

power system network having two-way digital as well as electrical power flows capable of self healing and adaptive resilient and sustainable with foresight of prediction under different uncertainties. It is equipped for interoperability with present and future standard of components devices and systems that are cyber secure against malicious attack and that is how it prepare ourselves to have our distribution system in future in such a manner that we can make our system more resilient compared to previous conventional static systems. So what makes your distribution grid smarter so it is basically the digital technology that allows for two-way communication between the utility and its customers so in the past a customers cannot speak to utility utility never speak to customers but today it is expected that you know both talk each other in a very frequent way and the sensing along the transmission line is what makes the grid smarter. So do you mean that in the past we had the systems which are not smart I think they were equally smart but today the technology embedded distribution systems a automated functionalities that makes your distribution system more smarter compared to the previous practices. Now as for the customers perspective if you already manage activities such as personal banking from your home computer we say my mechanism of finance is becoming all smart but if you can do the same thing you can buy electricity I mean to be very honest today we can buy energy blocks to your apartment through a company by paying some money to your internet or online computers so probably to me this is a very smart way of managing your energy systems or energy systems and that makes my system smarter. Customers will no longer have to wait for monthly statements to know how much electricity he or she uses with a smarter grid he can have a clear and timely picture of it they are smart meters and able to see how much electricity you use, when you have to use, what is the cost of energy.

For Example, if you have a smart meter and also it talks about the time of use prices means sometime it is cheaper and sometime it is costlier if my electric meter which is available to me in my residence also displays the cost of energy that I am consuming at that point of time so probably I may not be using costly electricity for a non warranted devices okay or not which is not very important or emergent to be probably I'll avoid using those machines if the energy cost is very high so probably that is how customers believe the life has to be. For an example also the equipments like washing machine is expected to have smart sensors which can sense from the smart meter the cost of electricity and operate naturally similarly the electric vehicles will sense the smart meters costing the price of electricity at a given time and allow your electric vehicle to charge so these are the dream objectives that all the customers of this country expected to see through this modern distribution systems. So this is a kind of a representative diagram of smart grid as you could see a generation, transmission, distribution customer participation, operation, market and service providers and there are different definition but one definition that really I love it actually for example a smart grid is an electricity

network that can intelligently integrate the actions of all the users connected to its generators, consumers and those that do both in order to efficiently deliver sustainable economic and secure electricity supplies a smart grid employs innovative products and service together with intelligent monitoring control communication and self-healing technologies too that means when there is a failure we must come back to the original system very quickly and if you have technology for that to me that is smart there are many definitions so I expect everyone to read many more literatures to understand more about smart grid approaches and there is one more definition by US Department of Energy it says that Grid 2030 envisions it's a fully automatic power delivery network that monitors and control every customer and node ensuring two-way flow of information and electricity between the power plant and the appliances and all points in between so that means as I told you my electric vehicle to the distribution company they are connected through a you know a specific approach so if they are connected they talk to each other and they share their technology and they share their information get the energy charge at a cheaper cost so to me that is smarter now more efficient transmission of electricity could get restoration of electricity after power disturbances and also it reduces operation and management cost of utilities. Now very importantly it is expected to a modern distribution grid we can reduce peak demand which will also help the lower electricity rates probably I just like to explain you I mean by reducing the peak load what happens you know if for example this is my peak and if I because the energy the area of cross-section that you cannot reduce because either you use it at 6 p.

m. or at 8 p.m. because your pattern of consumption is same so if I if I do another characteristic for an example if I do this way all right so both the areas are same because this characteristic area and the characteristic of that area is same all right so the question is those areas being shifted to this new areas okay by doing so I have reduced my peak from x1 to this point which is x2 so when you reduce your peak that means the installation capacity of this country need not be increased in next four to five years even though there is energy growth but if you are not able to reduce your peak then what will happen every time you have to put lot of generations into a system and the cost of installation will increase so it is basically by reducing peak demand you are delaying the investment in other sense you are saving lot of money for the nation now there's one comparison you can see the conventional power grids and the smart grids. So probably this is about the architecture and then the consumer participations and then generation and storage options, power quality, new product and services asset optimization, self-healing so probably you can see the conventional systems do everything however the smart grid does much better compared to the conventional grid so it has couple of other options that you can do a better market for an example how our conventional power grid to limited customer focus and similarly no self-healing in case of conventional. However, self-healing is there for smart grids. So these are the advantages you can see in case of

smart grids. So coming to attributes of good power system to be is quality, reliability, stability, economy and security so with this note let me stop here. Thank you very much for your kind attention.