DC Microgrid and Control System
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Lecture - 01
Overview of Microgrids

Welcome to our NPTEL courses on DC microgrid system. DC microgrid are now one of the important research topic as well as it has a huge commercial potential. For this reason we are now taking these courses on DC microgrid. Our presentation layout will be based on this.

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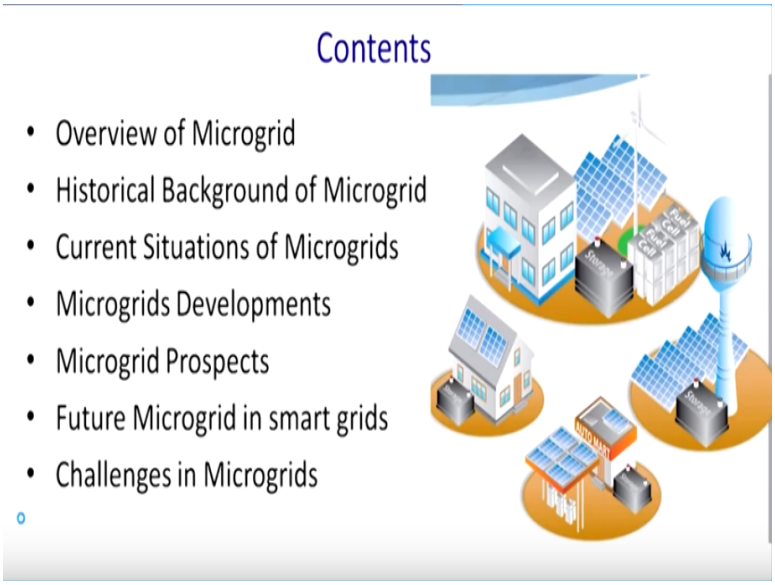

First we will give the overview of the microgrid with the advent of the distributed generation. The age of the microgrid has come. So we find lot of microgrid. We can have a AC microgrid. We can have a DC microgrid and we may have a hybrid microgrid. But our concentration will be on this course on DC microgrid. And we shall see the historical background of the DC microgrid.

We shall go back to the days of the Nikola Tesla so where actually he proposed the actually AC system. All those debate will be taken care of. But at that time with the bioelectronics was (()) (01:34) or was not available. For this reason DC microgrid actually put a back set but with the advent of the power electronics now again DC microgrid comes in a (()) (01:45).

Then we shall see the different current situation of the microgrids. So thereafter microgrid development, which places we can look for the microgrids kind of solutions,

what will be its commercial criteria, what should be its population or the different kind of necessity to make or establish a DC microgrid. Thereafter we shall see the prospects and the financials or the economics behind this microgrids.

Then we shall see that actually research-based microgrid, that is basically future microgrid acts as a smart grid and what are the challenge at present we have on the smart grid. So now why microgrid and why do microgrid matters. Of course the reason is that with the greater enhancement of the distributed generation.

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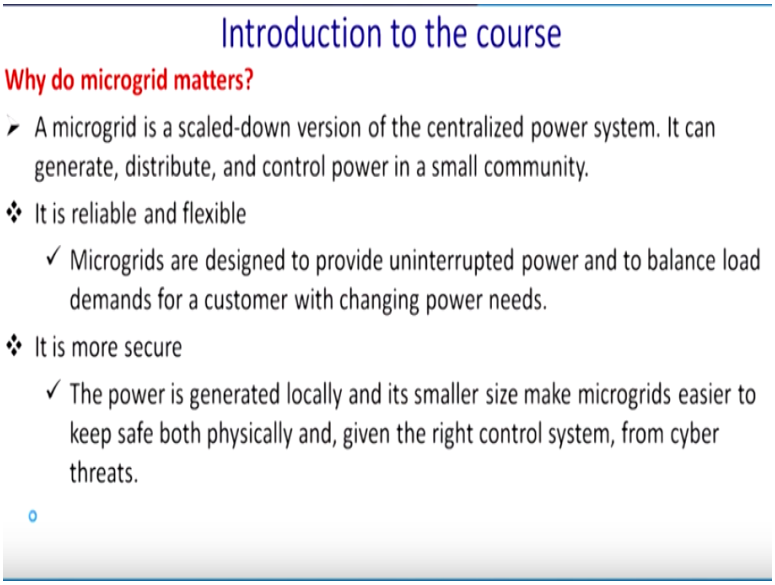

Now what we can say that microgrid is a scaled-down version of the centralized power system. It can generate, distribute and control power in a small community. It is reliable and flexible. Microgrids are designed to provide uninterrupted power to the balanced load demand for a customer with the changing power need. So these are the balanced load and all those things comes into the AC system.

So we are talking about DC microgrid. There we have only the voltage is an issue. Why it is more secure than the centralized grid? The power generated locally and in its smaller size make microgrid easier to keep safe both physically and given the right control system from the cyber threats. So one can actually introduce the corrupted data in a centralized distribution system or the transmission system and thus whole system can collapse. But in that aspect our microgrid are resilient from this point of view.

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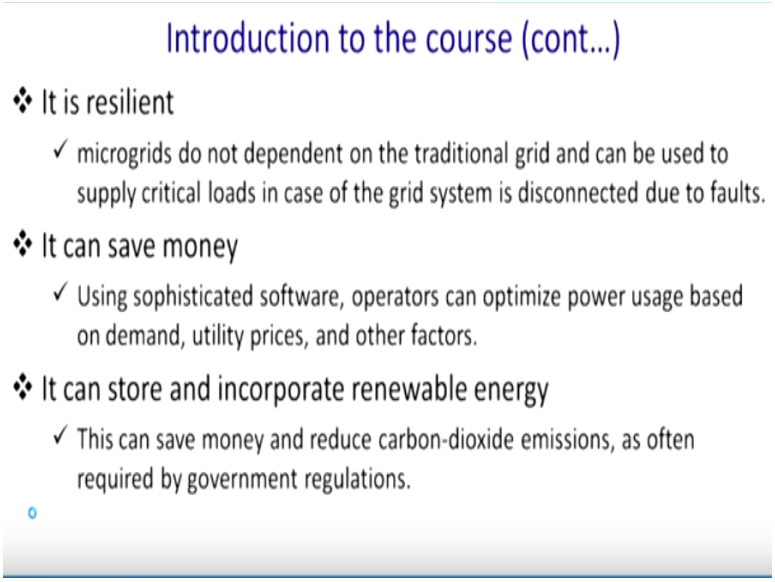

So why it is resilient? Microgrid do not depend on the traditional grid and can be used to supply critical load in case of the grid system is disconnected. Like please recall that in 2012 we in India it has a catastrophic failure because actually the UP took huge amount of power and whole India grid was collapsed.

But anyway if you have a smart isolated microgrid these can survive and catering the all the critical load. So this is its religion and it can save money because you need not have to put long transmission line and its maintenance cost you can get rid of. So using sophisticated software to monitor, operate and optimize the power usage based on the demand utility price and other factors, will power.

These are many entities you may not require if you concentrate more on the microgrids. And another major aspect or major feature of the microgrid is that it can store because of the small size it is possible to have a proper energy management and incorporate renewable energy. Most of the cases it will have a solar system or a micro hydel or micro wind turbine in a seashore places or the hilly places.

So it can save money and reduce carbon emission as often required by the government regulations. So this is quite actually quite fit for our today's requirement. Now the question becomes definitely how do microgrid work? Because there are different entities and ultimately they are but surely you will find little later every household can be a source as well as load.

Because you know if you have put solar installations and maybe that consumption of the particular house is low so they will inject power to the grid and same house after hour or two can become a consumer. So for this reason we require an advanced control system enables microgrid component to operate, coordinate, and optimize. Otherwise you will

have a, size of the microgrid will be larger if you do not properly optimize the system.

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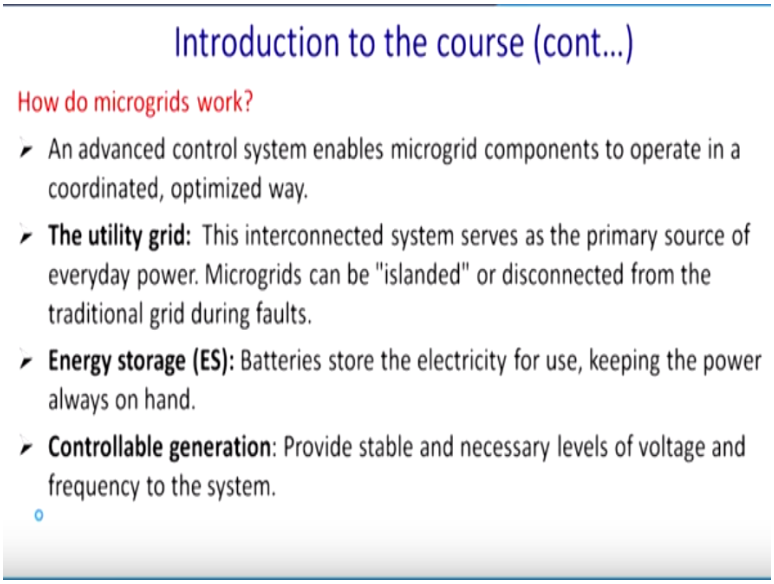

The utility grid, the interconnected system serves as a primary source of everyday power. Microgrid can be islanded or disconnected from the traditional grid during the fault. So that is what I was saying that if you have a fault so you can cut your system from the traditional grids and you can operate with the critical load depending on the availability of your power on that local grid.

Energy storage element, so you shall use this abbreviation quite frequent which is ES that is most of the cases we will have a batteries stored electricity for use for keeping the power in hand that will give autonomy. It means that let us say if you have a solar power plant based system so you may have two or three rainy days then you require to supply power from the storage battery that is called the autonomy.

So storage power will come will serve to meet the contingencies of those conditions. Now next important aspect of the DC microgrid is or the microgrid is that controllable generations provide stable and necessary levels of the voltage and the frequency of the system if it is a AC system or high pressure system in every point you have to maintain the frequency. And if it is a DC system so you have a DC bus and you require to maintain its voltage every point as prescribed within a limit of tolerance.

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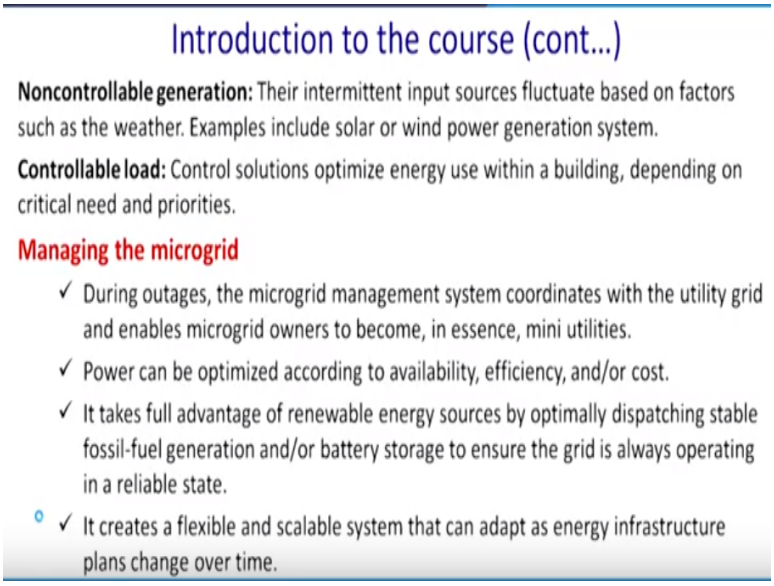

And in AC of course you require to maintain both voltage as well as frequency. Now there are a few entities that we will find that quite critical while discussing on the microgrid. One is non controllable generations. In a solar because you do not have a control because you can control, please recall your thermal power generations or the or your hydel power generation where you can open the throttle of the valve and you can control.

Then you have a governor to actually control the flow of the stream. But here solar radiation is not controllable. So it is not that you can change your control input from the solar and you can have the power output as required. So for this reason we require to meet the reverse. You know one of the basic problem of the electrical engineer is that we consider that load is something is not controllable.

We shall try to meet the load by the generation. But here the philosophy is different. Whatever you earned you are going to spend. That means whatever generation you do you will spend that amount of it. And for this reason you have a uncontrollable generations. The intermittent input of the source fluctuates based on the factors such as weather.

Like you know if it is solar it is the iterations and temperature. If it is a wind the wind speed. Example solars and wind power generation system and thus you have a controllable load. You have to segregate your critical and the non-critical load. So critical load has to run always if there is a non-critical load. For example I require to wash my clothing it can be done anytime.

And you have plenty of time in a day where plenty of the power is available from that moment it can start and do it. So for the reason we have controllable load. So control

solutions for this (()) (11:15) we have different kind of energy availability in different point of time accordingly you will actually schedule your loading. So control solution optimize energy uses within a building or the community depending on the needs and the priorities.

Of course if you require to run this washing machine we have actually got to pay the higher tariff, if solar is less. So managing the microgrid, so this is something we require to understand. So who are the stakeholder of the microgrid. So during outages that the main grid if it is off, microgrid management systems coordinates with the utility grids and enables microgrid owner. Enables the microgrid owner to become in essence the mini utilities. So it will act itself as a utility.

Power can be optimized according to the availability, efficiency and the costs. So you may have a right of option then you have to pay the higher tariff like if (()) (12:30) power is available then power become cheap you are supposed to do most of the task then. When the power is costly you will just run your critical loads.

It takes full advantage of the renewable energy sources for optimally dispatching the stable fossil-fuel generations or the battery storage to ensure the grid is always operating at a reliable state. So this is one of the priority area of the microgrid operation. It creates a flexible and the scalable system that can adapt as energy infrastructure plan change over time.

So you know actually there is a issue right you know you take a dinner at night thereafter you have a dishwasher and you want the dishwasher to be done at 9:00 p.m. but there is a pick load. But you do not bother because (()) (13:28) throughout the day. Or in a microgrid system so you have a timers and all or you can put it to the this because your dishes will be used in the morning.

So at the time at night maybe when the grid power becomes cheap you can do that. So accordingly it has to be scheduled and thus proper energy management system is required to be placed in case of the microgrids.

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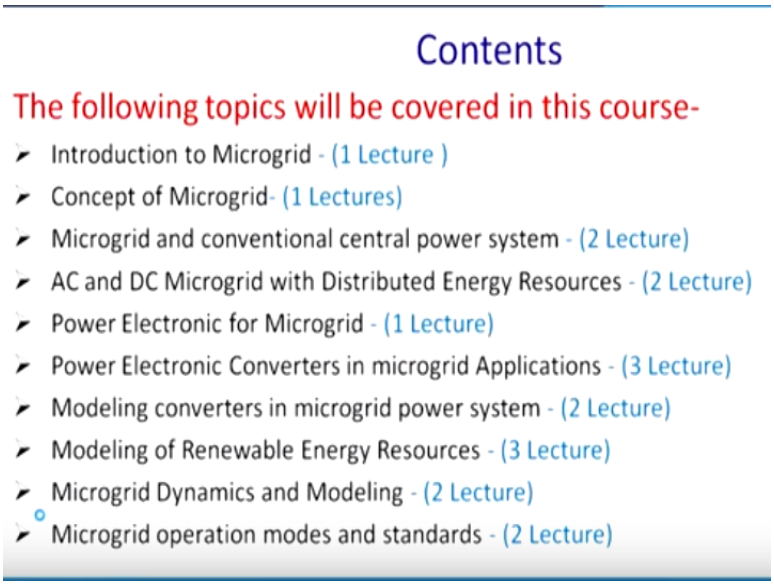

So now these are our actually content or overview of our course structure that will be on the eight weeks. So first what we are continuing today that will be actually the introduction to the microgrid. Thereafter we shall discuss concept of the microgrid. Each lecture will have a half an hour durations. Thereafter microgrid and the conventional central power system we will take two lectures that in one hour.

AC DC microgrid with distributed energy sources we will have two lectures. Thereafter power electronics for AC microgrid. One lecture where power electronic converter in AC microgrid application. That will be three lectures. We shall discussed different kind of DC to DC converters here. Modeling of the converter in the microgrid power system we will take two lectures.

That are modeling of the renewable energy resources, quite interesting topic. That we will try to cover in three lectures quite challenging though this task. Thereafter microgrid dynamics and modeling, thereafter, and its stability. Then microgrid operation modes and standard. So these are the presentation layout of your microgrid topic, DC microgrid topic.

And followed by you know we will have a microgrid control architectures. Then we shall have a intelligent microgrid operation and control and operating power network energy management for the microgrid.

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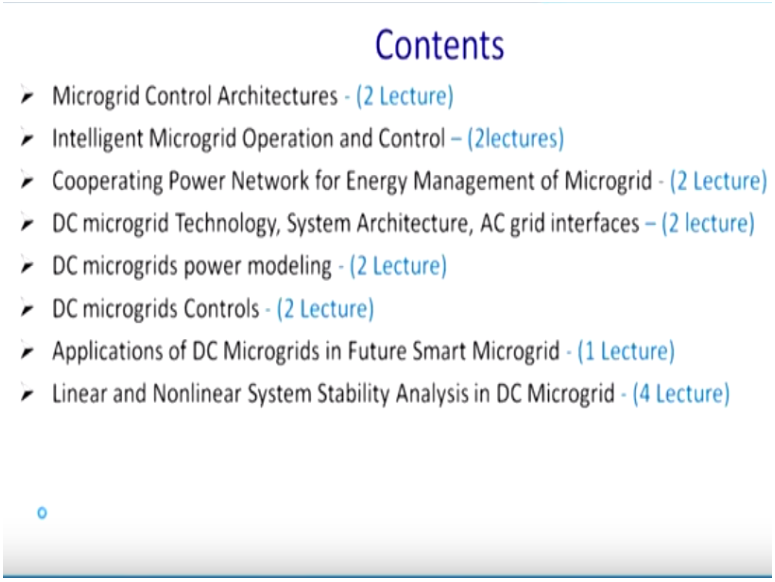

This is the important topic in terms of the energy efficient system. Then we shall see the different type of architecture that is DC microgrid technology, system architecture, AC grid interface that we will try to cover in two lectures. Microgrids, DC microgrid power modeling, two lectures. And DC microgrid control two lectures. Thereafter you know application of the DC microgrid and the future smart grids.

And linear and the non linear stability analysis of the DC microgrid and conclusions. So this will be our presentations layout as well as the topic we are going to cover in this course. Now let us go back to the introductions that is the background of the DC microgrid. So we shall cover this at the following topic.

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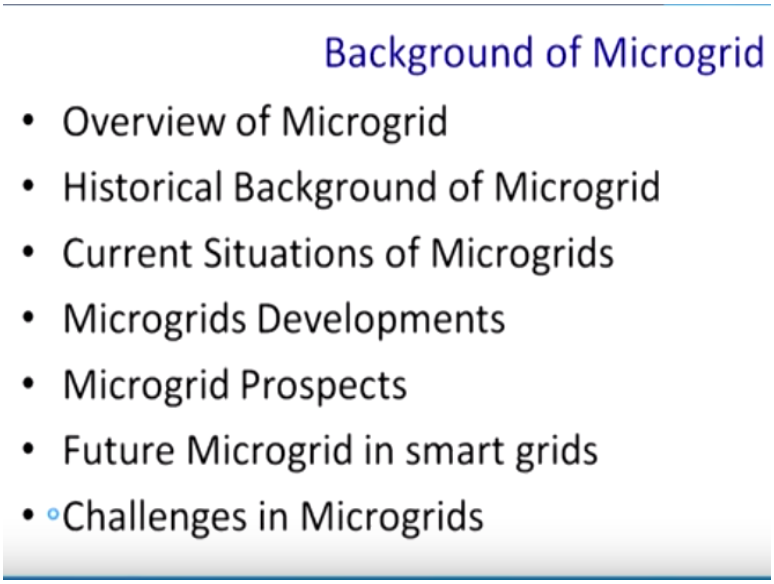

That is overview of the microgrid, historical background of the microgrid, current situations of the microgrids. Then microgrid development, microgrids prospects, future

microgrids in smart grids and challenges in microgrids. Now let us see that overview of it. Microgrid can be achieved power balance and the optimal energy allocations over a given area or as a virtual power source or load in the distribution network.

So it will acts as a virtual power source or virtual power plant. It can consist of one or more virtual power plant. That abbreviation we shall use frequently. Please remember it. It is VPPs. To meet the demand of the load center and which can be important office building or the factories, remote residence where the traditional way of electricity supply is expensive.

Like you can recall that you know first DC microgrid was actually microgrid was established in West Bengal in (()) (18:09) that was quite long ago in 80s. So that was basically the remote residence where traditional electric supply is expensive.

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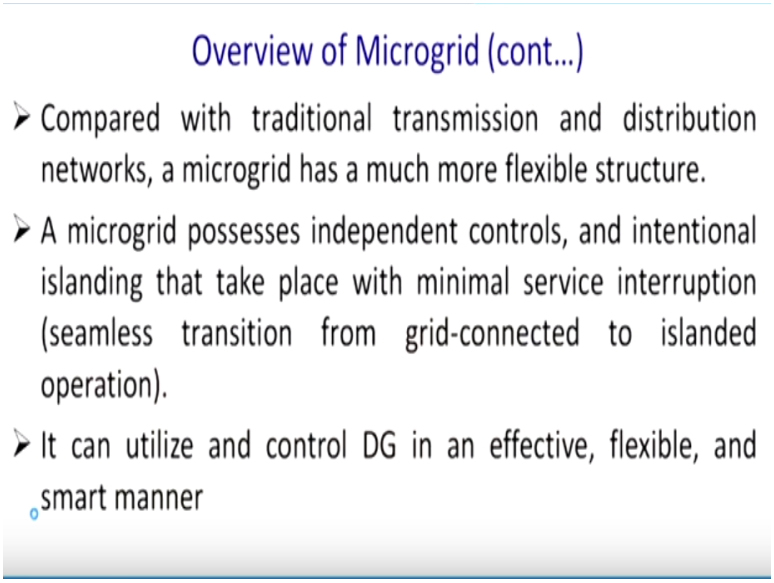

Compared with the traditional transmission and the distribution networks, a microgrid has a much more flexible structure. And you know it is not only that because you can consider a ship itself a microgrid. So there are many way you can look at it, a microgrid problem. Microgrid possess independent control and intentional islanding that takes place with the minimal service interruptions.

That mean seamless transition from the grid connected to the islanding operation. If any moment of microgrid decided to go into the islanding mode, it can go to islanding mode. So it may disconnect from the utility and is done independently. So this kind of system is quite advantageous to self maintenance or self sustainability of the microgrid. And it can utilize and control DG here transferred distributed generation not diesel generation mostly.

Please remember that is an effective, flexible and the smart manner. So we shall control the distributed generation in effective, flexible and smart manner.

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History of Microgrids

Year	Description
2001	R.H. Lasseter of the University of Wisconsin-Madison proposed the concept of "microgrid" and later Consortium for Electric Reliability Technology Solutions (CERTS) and European Commission Project Micro-Grid also gave their definitions of a microgrid.
2002	The National Technical University of Athens (NTUA) built a small laboratory microgrid project known as the NTUA Power System Laboratory Facility for tests on the control of DER and load with Multiagent technology.
2003	The University of Wisconsin established a small laboratory microgrid (NREL Laboratory Microgrid) with a capacity of 80 kVA, for tests on the control of various types of DRs in different operation modes.

So few histories of the microgrid, we have put into the perspectives. R. H. Lasseter of University of Wisconsin-Madison proposed the concept of the microgrid as long as in 2001 and later Consortium for the Electric Reliability Technology Solutions, CERTs and European Commission Project Microgrid also gave their definitions of the microgrid. So it has started its inceptions from 2001.

In 2002 in USA, National Technical University in Athens built a small laboratory of microgrid project known as NTUA power system laboratory facility for test and control of DER that is distributed electric resources load with the multiagent technology. Then again in 2003, same Wisconsin-Madison established the small laboratory of microgrid that is called NREL Laboratory of microgrid with the capacity of just 80 KVA for test and control of various type of distributed loads and its different modes of operation.

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History of Microgrids (cont...)

Year	Description
2003	Multiple microgrid demonstration projects were built across the world, including the 7.2 kV microgrids in Mad River Park, Vermont, USA; the 400 V microgrids in Kythnos Islands, Greece; as well as the Aichi, Kyotango, and Hachinohe projects in Japan.
2004	The CESI RICERCA test facility was built in Milan, Italy, which can be restructured into different topologies for steady-state and transient operation tests and power quality analysis.
2005	The Imperial College London control and power research center was set up in London, UK, for distribution network prototype tests and load tests.

Now in 2003, multiple microgrid distribution systems were built across the world including 7.2 kV microgrid in Mad River Park, Vermont in USA and the 400 volt microgrid in Kythnos Island in Greece as well as in the Aichi and Kyotango and Hachinohe project in Japan. So in 2004 the CESI, this RICERCA test facility was built in Milan in Italy which can be restructured into the different topologies for the steady state and the transient operation state and power quality analysis.

So this was started in Italy. Thereafter in England in 2005 the Imperial College London control and the power research centre was set up in the London, UK for distribution network prototype tests and the load tests.

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History of Microgrids (cont...)

- Multiple demonstration projects were successively built all over the world, including:
  - Japan's Sendai system (2004), Shimizu Microgrid (2005), and Tokyo Gas Microgrid (2006)
  - Spain's Labein Microgrid (2005)
  - USA's Sandia National Laboratories (2005) and Palmdale's Clearwell Pumping Station (2006); and
  - Germany's Manheim Microgrid (2006)

Now history of microgrid, multiple distribution demonstration projects were successfully built around the world including Japan's Sendai system in 2004. Shimizu microgrid in

2005 and Tokyo Gas Microgrid in 2006. Spain Labein microgrid in 2005. USA's Sandia National Laboratories in 2005 and Palmdale's Clearwell Plumping stations in 2006 and Germany's Manheim microgrids in 2006.

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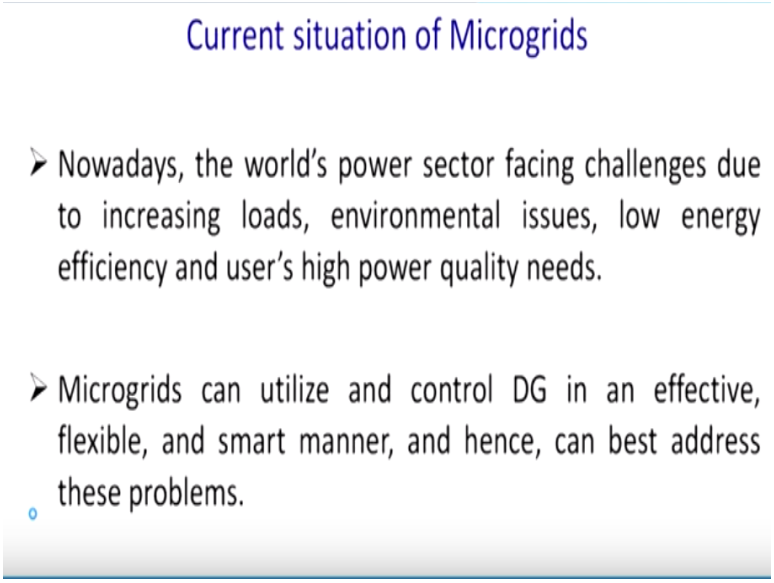

So what are the current situation of the microgrid? Nowadays the world's power sector is facing challenge due to increasing load and the environmental issues. So we require to reduce the carbon footprint and we want that same lifestyle required to be continued or lifestyle they got to be enhanced in case of the countries like India where still power consumption per capita is quite low.

Low energy and for this reason what happen, there are environmental issues, low energy efficiency and the user's power quality needs. So that all require to be addressed through the microgrids. Microgrid can utilize and control distributed generation in an effective, flexible, and smart manner. That we will see how it can be done and hence can best address these above-mentioned problems.

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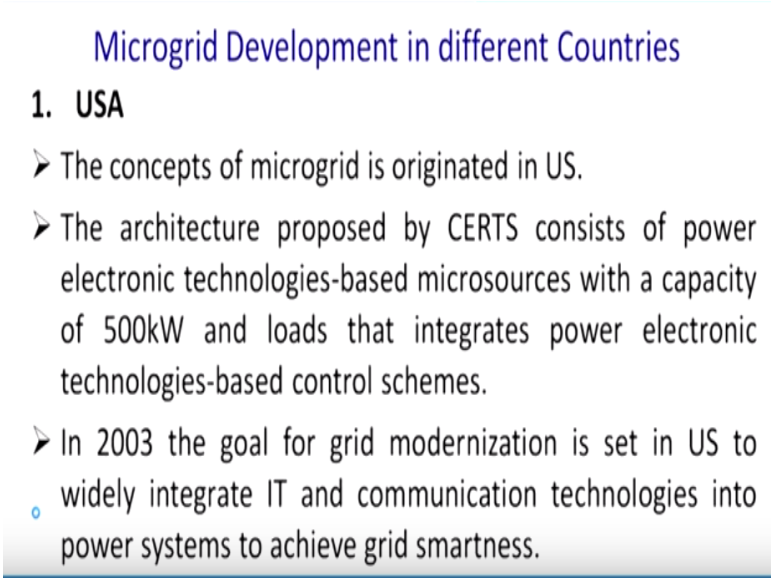

Now microgrid developed in different countries, of course USA was first started, the concept of the microgrid was originated in US. The architecture proposed by the, that is what I have shown few slide ago, CERTS consist of power electronics technologies based on power technology based micro sources with capacity of 500 kilowatts and loads that integrate power electronics technologies based control scheme.

In 2003 the goal of the microgrids modernization is set up in USA to widely integrate that IT that is information technology and the communication technology into a power system to get the smart grid or achieve grid smartness.

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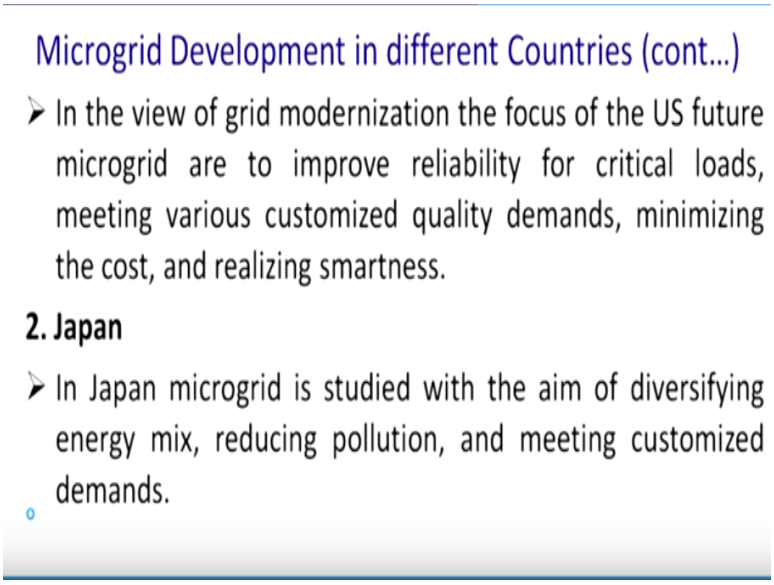

Microgrid developed in different countries, so in USA also. In the view of the grid modernization the focus of the US future microgrids are to improve the reliability for critical load, meeting various customized quality demand minimizing the cost and

realizing smartness. Thereafter it comes to the Japan. Japan also has contributed in the microgrid in a larger way.

In Japan microgrid is studied with the aim of diversifying energy mix reducing pollutions and meeting customized demand.

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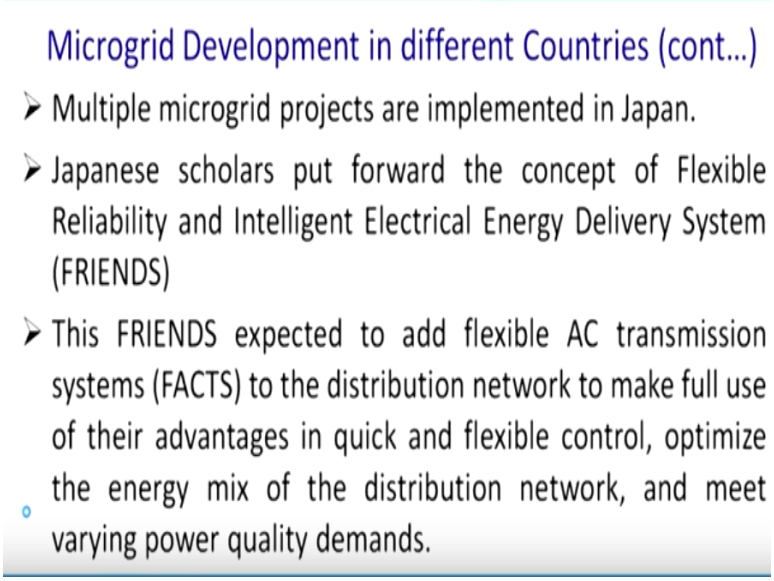

The multiple microgrid projects are implemented in Japan. Japanese scholar put forward the concept of flexible reliability and the intelligent electrical energy delivery system. It is called FRIENDS. The FRIENDS expected to flexible AC transmission system that is FACTS to distributed distribution network to make full use of their advantage in quick and flexible optimized energy control that mix with the energy operation and thus gives you a very good power quality demand.

Now FRIENDS have become the important form of deployment of the microgrid in Japan.

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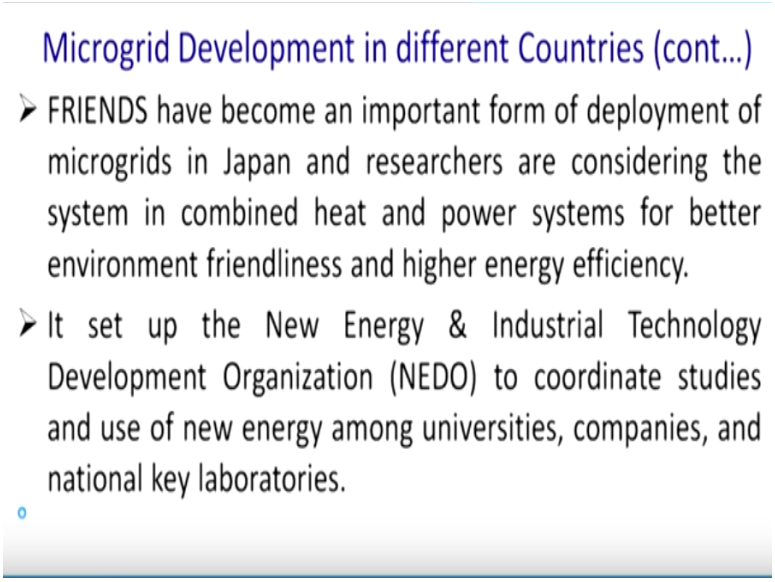

And researchers are considering the system combined with that heat and the power system for the better environmental friendliness and high energy efficiency. For example there are few reporting that you know charging and discharging of ultra capacitor that is a part of the storage element or the stability. So it is huge amount heat will be dissipated. So why cannot this heat can be used for the water heating purpose.

It set up the New Energy and Industrial Technology Development organization NEDO to coordinate studies and use the new energy among the universities, companies, and national key laboratories. So thereafter European Union considering the market demand and the power supply and the security and the environment and protection,

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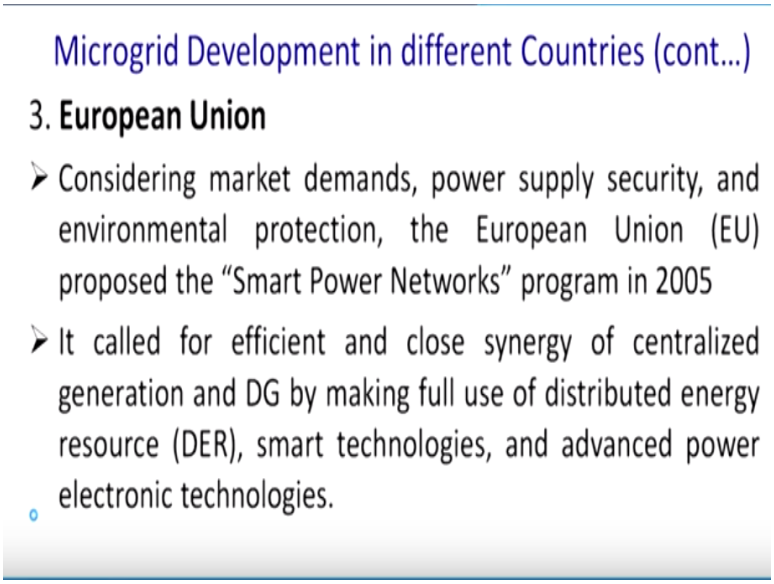

European Union proposed smart power network program in 2005. It called for the efficient and the close energy centralized generations and distributed generation by

making use of the distributed energy sources that DER smart technologies and advanced power technologies so put together and they came out the concept of smart power network program.

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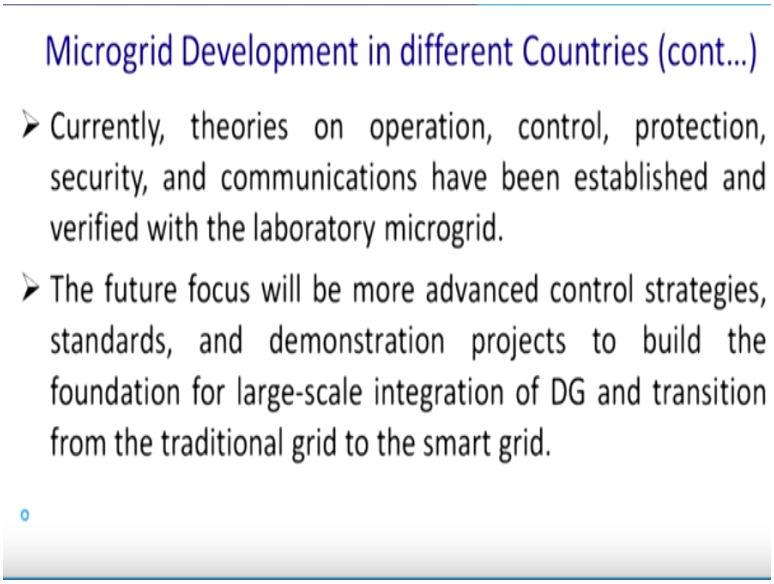

Currently these theories of operations, control, protection, security and communication has been established and verified in the laboratory for the microgrids. The future focus will be more advanced control strategies standard demonstrations projects to be built in the foundation of the large-scale integration of the distributed generations and transition from the traditional grid to the smart grid.

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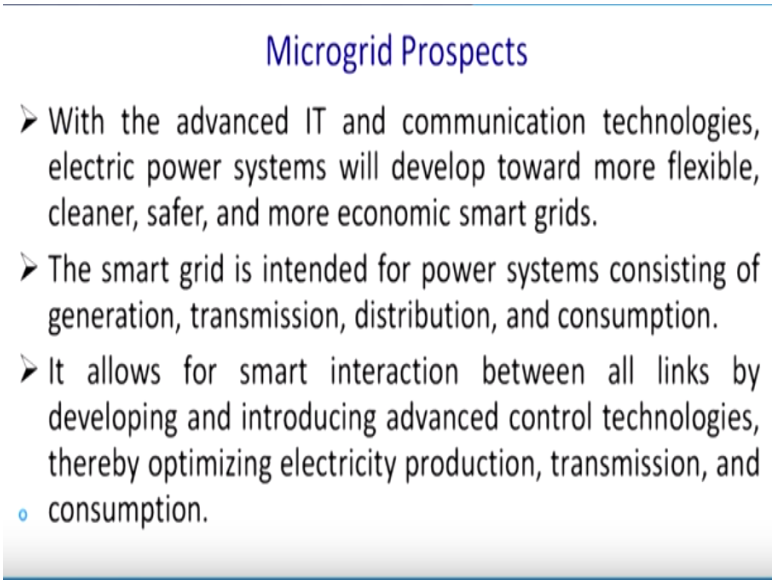

Now prospect of the smart grid with the advanced IT and the communication technologies, electric power system will develop towards more flexible, cleaner, safer and more economic for the smart grids. The smart grid is intended for power system

consisting of generation, transmission, distribution and consumption. It allows for smart interaction between all kind of developing and introducing advanced control technologies thereby optimizing electricity production, transmission, and consumption.

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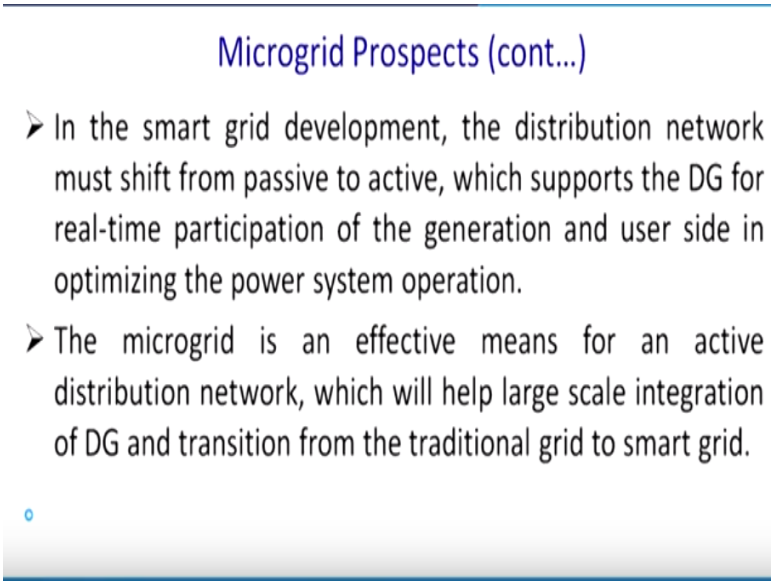

And in the smart grid development the distribution network must shift from the passive to active which support the DG for the real-time participation of the generation and user side in optimization the power system operation. Microgrid is an effective means for an active distribution system which will help large-scale integrations of the DG and transmission from the traditional grid to the smart grid.

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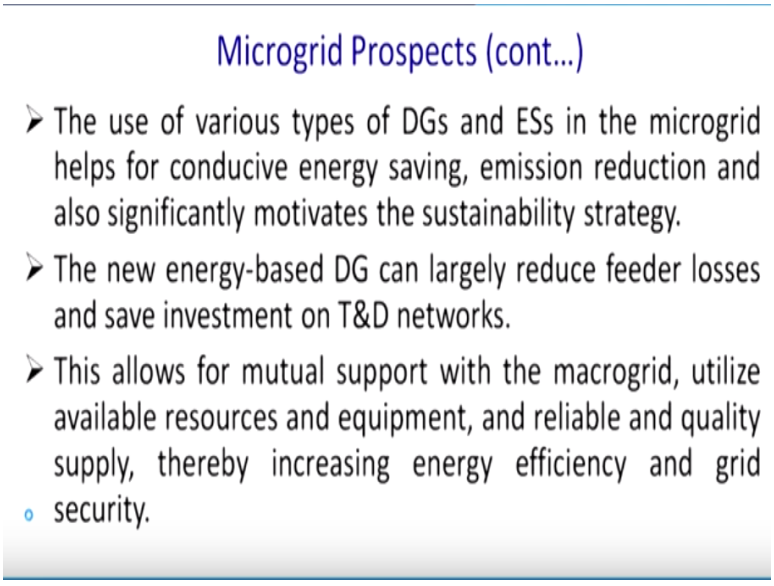

And last but not least the use of various type of DGs and storage element that is ES in the microgrid helps to conducive energy saving, emission reduction, and also we shall discuss all this thing in details. Also significantly motivates towards the sustainable

energy strategies. The new energy base DG that is can largely reduce the feeder losses and save investment and transmission distribution losses of the network.

It allows for mutual support with the microgrid utilized available resources and equipment and reliable and utility supply thereby increasing the energy efficiency and the security of the system. And what are the future?

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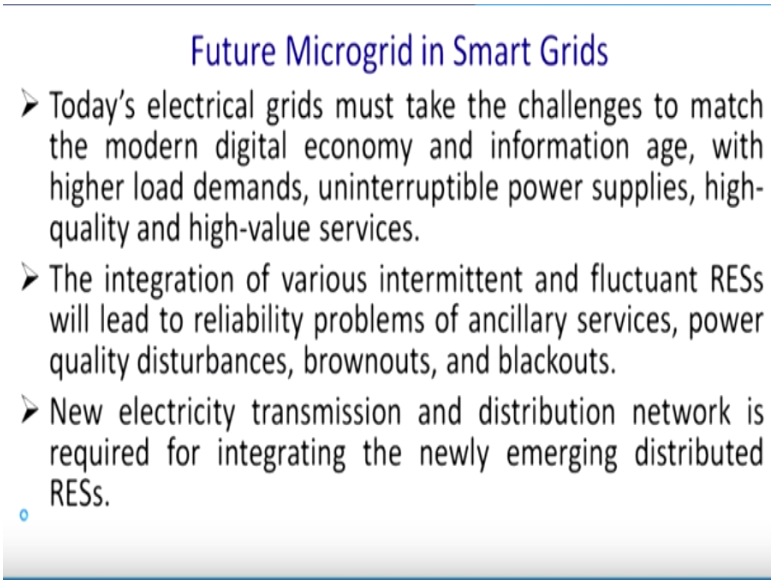

Today's electrical grid must take the challenge to match the modern digital economy and the information age with higher load demand, uninterrupted power supplies, high power quality and high value services. The integration of the various intermittent and fluctuating RES will lead to the reliability problem of the ancillary services, power quality disturbance and brownout and blackouts.

New electricity transmission and distribution network is required for integrating newly emerging distributed RES. So this is the challenge and we require to meet that. So for this reason we have a future microgrid and this smart grid.

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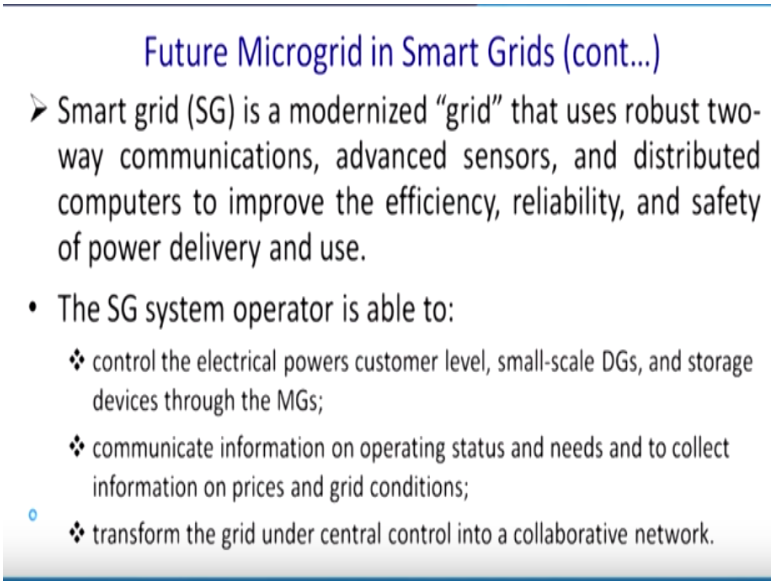

It is a modernized grid that uses a robust two-way communications, advanced sensors, distributed computers to improve the efficiency, reliability, safety of the power delivery use. And thereafter we have the system operator, the control of the electric power, customer level, small scale distributions as well as the storage devices. Communicate informations on operating status and need to collect the information on price and the grid conditions.

And last but not least, transformation of the grid and the central control into a collaborative network. So and the SGs incorporate the distributed intelligence and the interactive communication at all levels of the power of the network in order to coordinate power generation in an optimal way to improve the system.

And thus in future SG the interest for the microgrids are exposed specifically for integrating renewable energy and non-conventional energy resources. Thank you. This was your introduction to the microgrid. Mostly we discussed about the microgrids and its philosophy. We shall continue to the next class. Thank you for your attention.