Power Quality
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Chapter - 15
Module - 02
Lecture - 42
Power Quality Improvement in Wind Energy Conversion System

Welcome to the course on Power Quality. [FL] today, we will discuss Power Quality Improvement in Wind Energy Conversion System.

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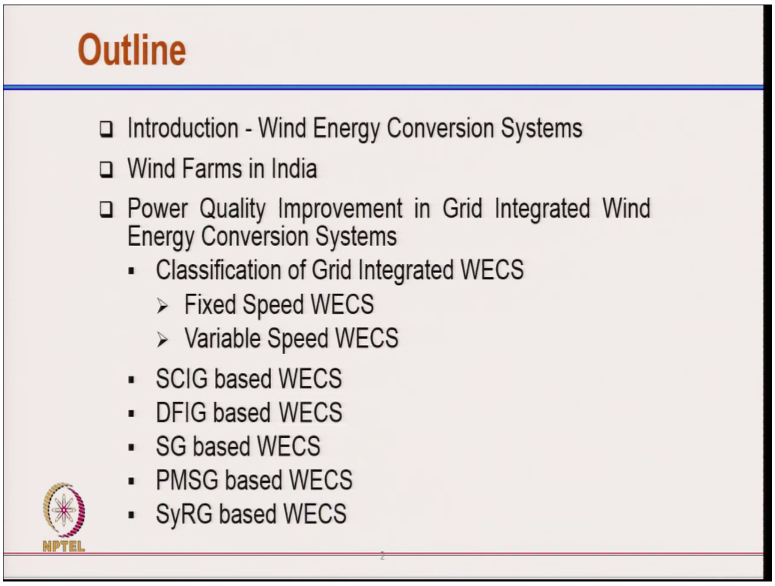

Well, we will discuss with the outline just introduction to wind energy conversion system and of course, Wind Farm in India and power quality improvement in grid connected wind energy conversion system, then we will talk about classification of grid integrated wind energy conversion system, I mean in which we will talk about fixed speed wind energy conversion system and variable speed wind energy conversion system.

Then, we will talk about squirrel cage induction generator based wind energy conversion system, then doubly fed induction generator based wind energy conversion system and synchronous generator based wind energy conversion system and then, permanent magnet synchronous generator based wind energy conversion system and then, synchronous reluctance machine based wind energy conversion system.

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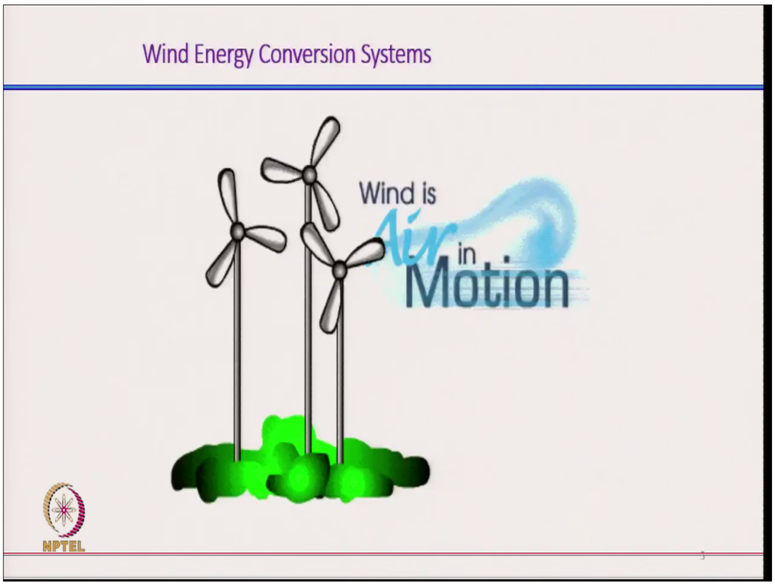

And of course, I mean like you can call it the wind is the now second largest sustainable energy source for generating the electricity throughout the world and of course, in India also it is coming up big way.

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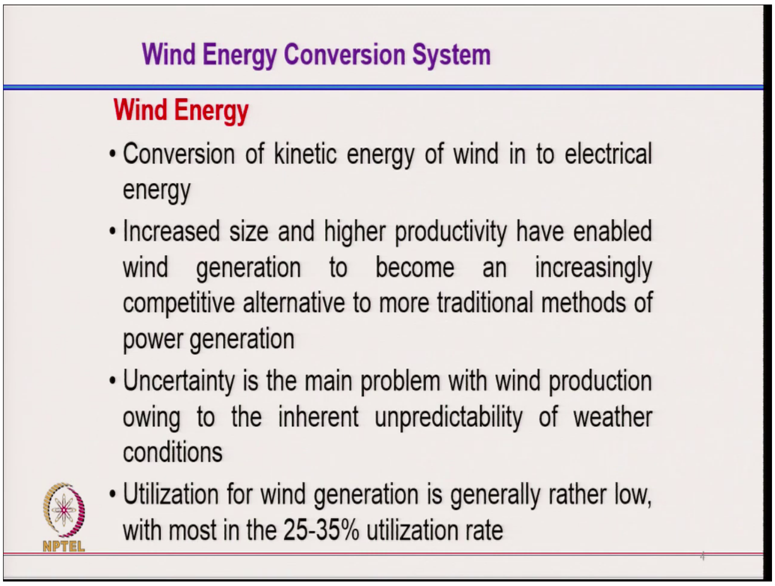

Well, [FL] this wind energy conversion system convert the wind energy of wind conversion of kinetic energy of wind to in to electrical energy and in it has increased size, higher productivity and enable the typically enable wind energy to become an increasing competitive alternative to more traditional methods of power generation. And uncertainty in the main problem with wind production owing to the inherent priority of weather conditions and utilization of wind generation is generally rather low with most in the 25 to 35 percent utilization area.

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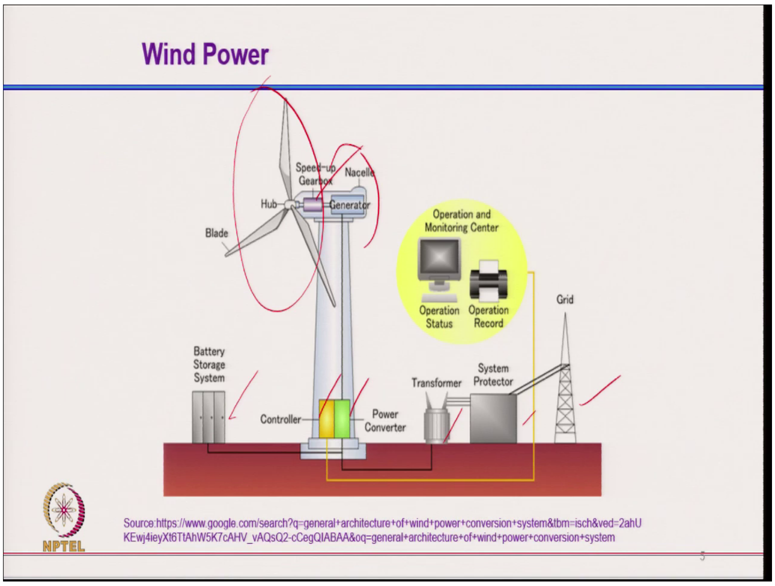

And this is the typical block diagram of wind energy conversion system, where we have a typically a wind turbine on the along with the generator on nacelle and with of course, we have a normally gear box because the wind turbine runs at very low speed and many many generator runs at quite high speed like a DFIG and induction is called induction. Normally, they run at 1500 rpm 15 to 800 rpm. [FL] it that is a 4 pole machine, we adopt it and wind turbine certainly runs typically around 50 to 150 rpm [FL] that is the reason.

And then, we have a controller and power converter which convert this variable, you can call it variable frequency, output to typically to constant frequency which can I mean feed to the transformer and then with the protection, it goes to the grid. And of course, we have a sometime, not all the time battery energy storage system for smoothing the fluctuations I mean typically the (Refer Time: 02:52) of wind energy conversion system.

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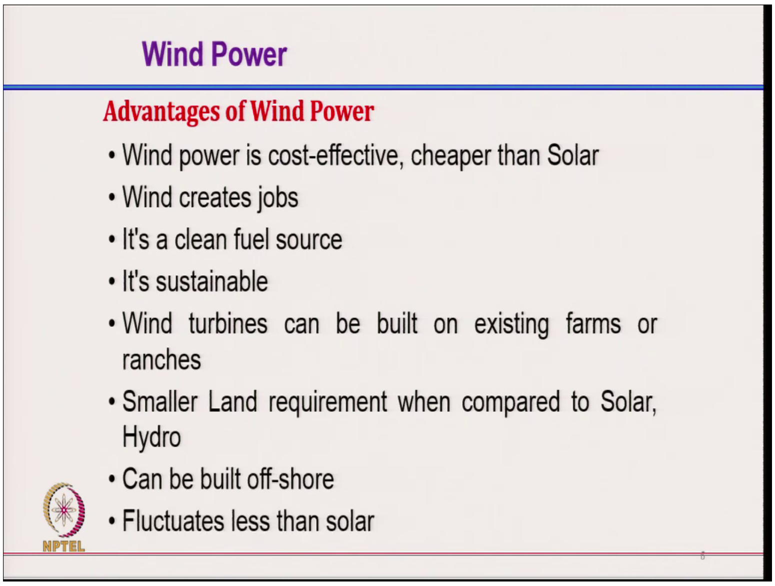

Well, the advantage of wind energy, you can call it wind power. It is a cost effective cheaper than solar and wind creates the job, it is clean fuel source. It is sustainable and wind turbines can be built on existing farms or ranches and a smaller land requirement when compared to the solar hydro and it can be built of course, offshore and fluctuates lesser than solar.

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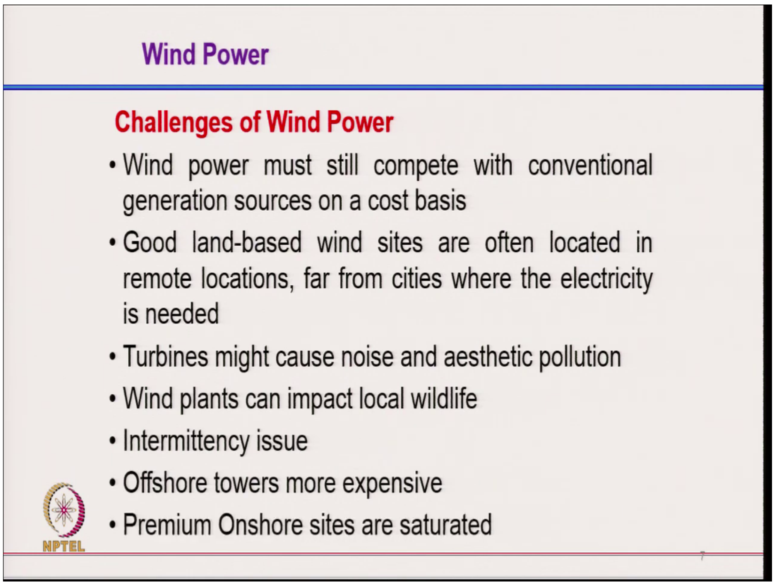

[FL] challenges of wind power is wind power must still compete with the conventional generation sources on a cost basis and good land based wind sites are often located in remote locations far from city, where the electricity is needed and turbines might cause noise and aesthetic pollution. And wind plants can impact local wildlife and of course, it has intermittency issue and of course, offshore towers are more expensive and premium of onshore sites are saturated.

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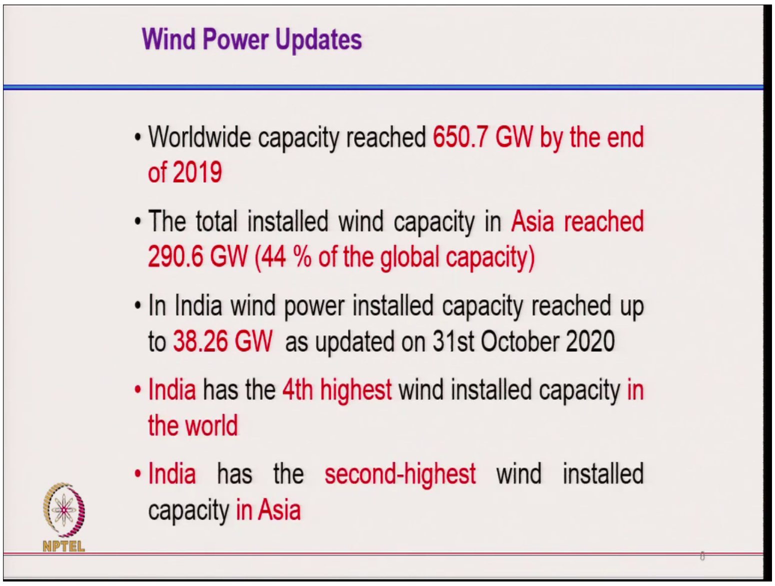

And worldwide capacity reached 650.7 gigawatt by the end of 2019 and total installed wind capacity in Asia reached 290.6 gigawatt, 44 percent of the global capacity. And in India, the wind power installed capacity reached 38.26 gigawatt up to 31st October 2020 and India has the 4th largest wind installed capacity in the world. India has the second-highest wind installed capacity in Asia.

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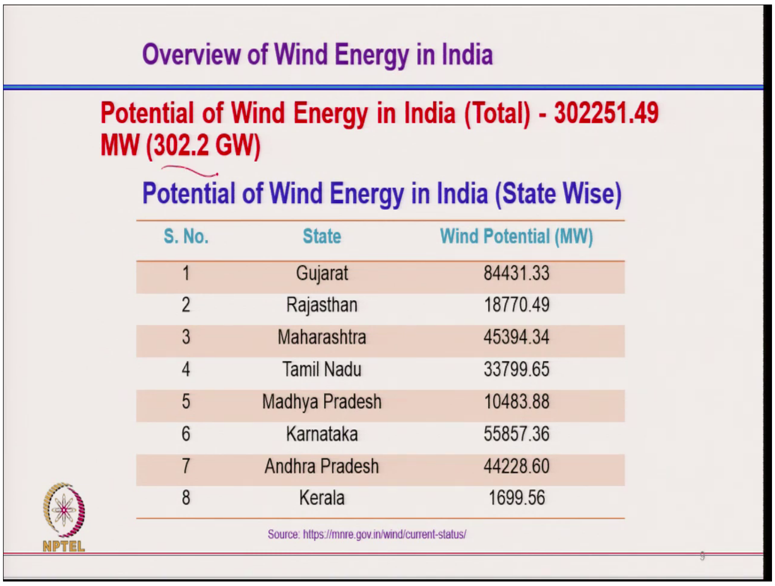

And these are the typically you can call it potential of wind energy, typically in India total of I mean you can call it the potentially 302.2 gigawatt with the different potential different state, I mean typically of the India.

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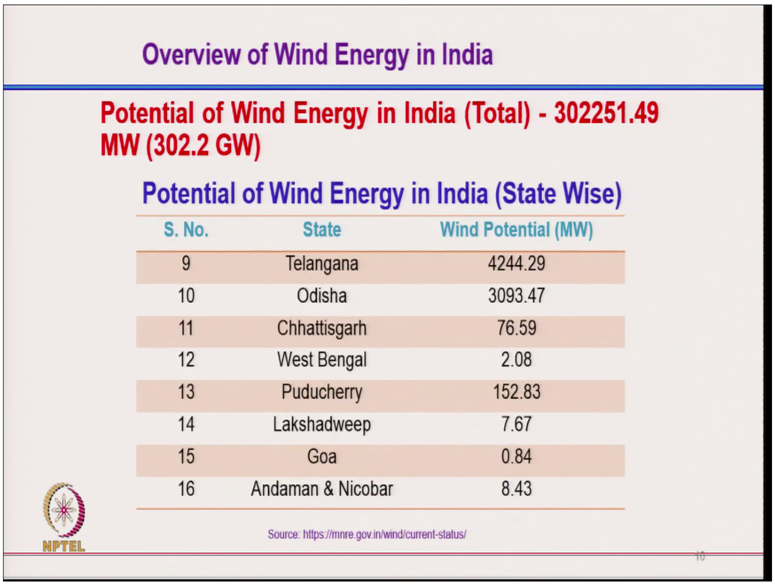

S. No.	State	Wind Potential (MW)
9	Telangana	4244.29
10	Odisha	3093.47
11	Chhattisgarh	76.59
12	West Bengal	2.08
13	Puducherry	152.83
14	Lakshadweep	7.67
15	Goa	0.84
16	Andaman & Nicobar	8.43

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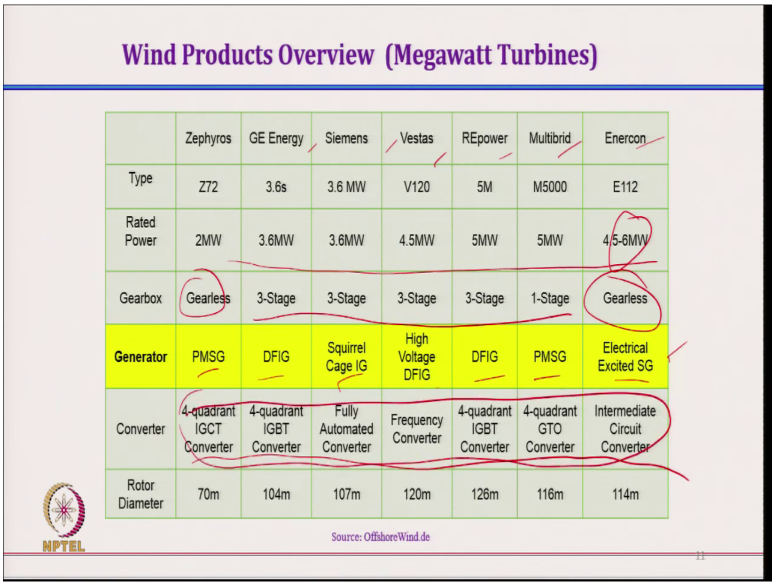

	Zephyros	GE Energy	Siemens	Vestas	REpower	Multibrid	Enercon
Type	Z72	3.6s	3.6 MW	V120	5M	M5000	E112
Rated Power	2MW	3.6MW	3.6MW	4.5MW	5MW	5MW	4,5-6MW
Gearbox	Gearless	3-Stage	3-Stage	3-Stage	3-Stage	1-Stage	Gearless
Generator	PMSG	DFIG	Squirrel Cage IG	High Voltage DFIG	DFIG	PMSG	Electrical Excited SG
Converter	4-quadrant IGCT Converter	4-quadrant IGBT Converter	Fully Automated Converter	Frequency Converter	4-quadrant IGBT Converter	4-quadrant GTO Converter	Intermediate Circuit Converter
Rotor Diameter	70m	104m	107m	120m	126m	116m	114m

And these are the typically you can call it wind products overview in megawatt turbines; I mean from Zephyros, then GE energy, Seimens, Vestas, Repower, Multibrid and Enercon and they have a different, they are using different generators like permanent synchronous generator, doubly fed index generator, squirrel cage index generator, then high voltage doubly fed index generator, doubly fed induction permanent generator and electrical excited synchronous generator.

[FL] you can see that they are using both kind of induction machine and you are they are using permanent synchronous generator as well as the conventional salient pole synchronous generator by enercon and the unit size of course, varies from 2 megawatt; it goes to it has gone even typically of 6 megawatt by enercon and well you use of course, the I mean only in

PMSG, we use the gearless as well as conventional synchronous gearless. But otherwise, they use the different stages gears to match the speed.

And you will find all are using power electronics converters; I mean for different purpose. The reason of power electronics converter is that you will be able to have the generation with the maximum power tracking at variable speed and you are able to generate around 50 percent more energy using the variable speed wind generation system and that is the reason that lot of power converters, I mean either even in case of DFIG or other machines are there like I mean also.

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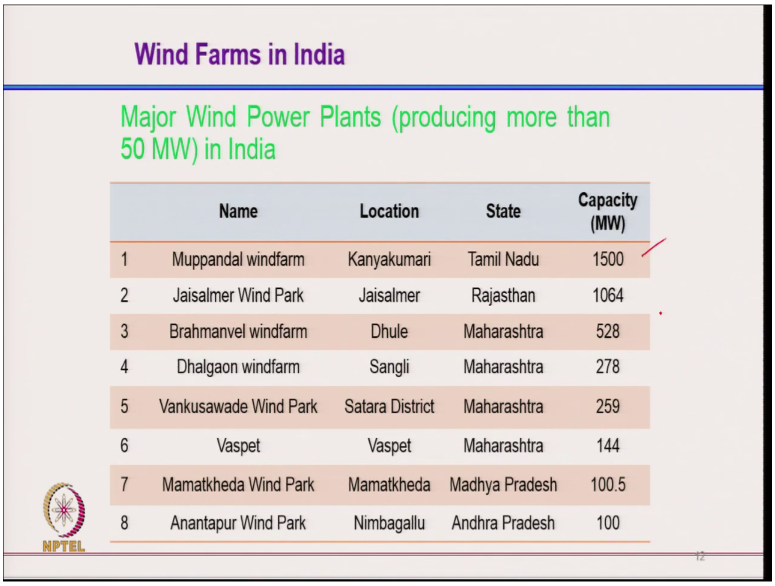

	Name	Location	State	Capacity (MW)
1	Muppandal windfarm	Kanyakumari	Tamil Nadu	1500
2	Jaisalmer Wind Park	Jaisalmer	Rajasthan	1064
3	Brahmanvel windfarm	Dhule	Maharashtra	528
4	Dhalgaon windfarm	Sangli	Maharashtra	278
5	Vankusawade Wind Park	Satara District	Maharashtra	259
6	Vaspet	Vaspet	Maharashtra	144
7	Mamatkheda Wind Park	Mamatkheda	Madhya Pradesh	100.5
8	Anantapur Wind Park	Nimbagallu	Andhra Pradesh	100

[FL] there are in India like there are 4 this major power plants are located in all these typically 8. So, many plant is starting from 1500 megawatt, then 1064.

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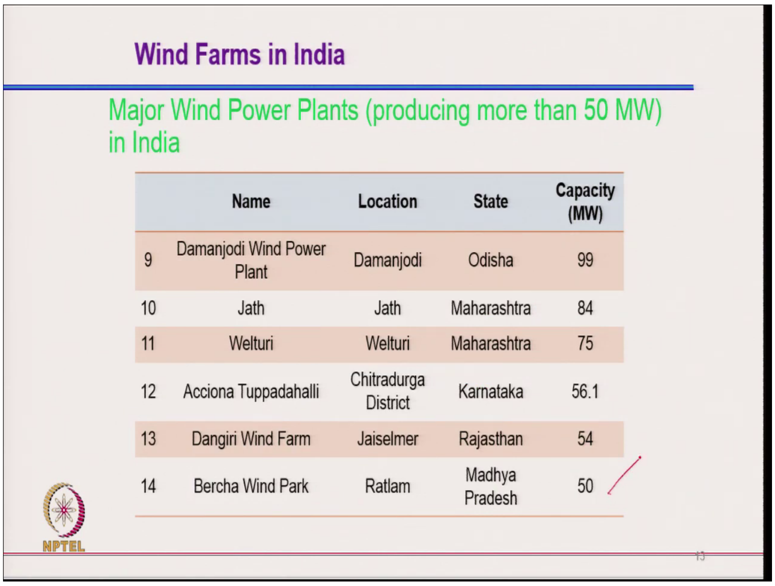

[FL] it goes to typically even like a the plant of typically of 4 14 major plant up to 50 megawatt capacity are already installed in India.

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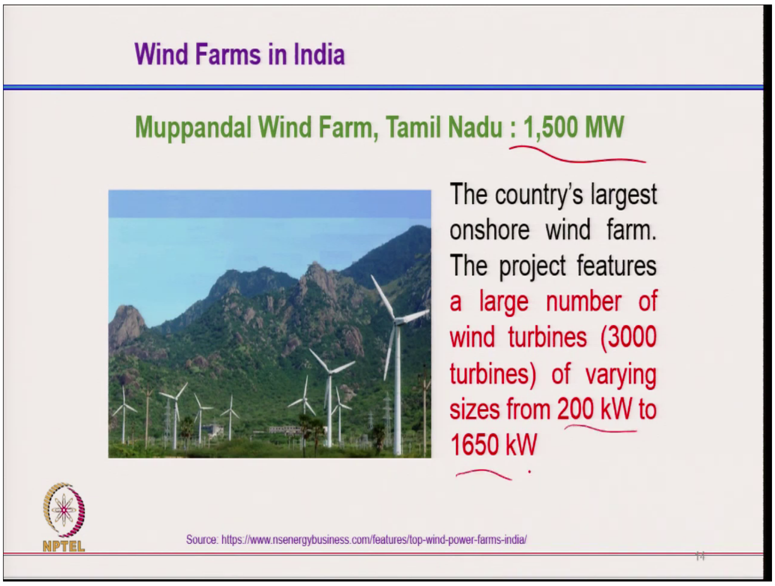

And these are the typical some photographs of typically varying of 1500 megawatt plant with the capacity of you can call it sizes varying from 200 kilowatt to 1650 kilowatt.

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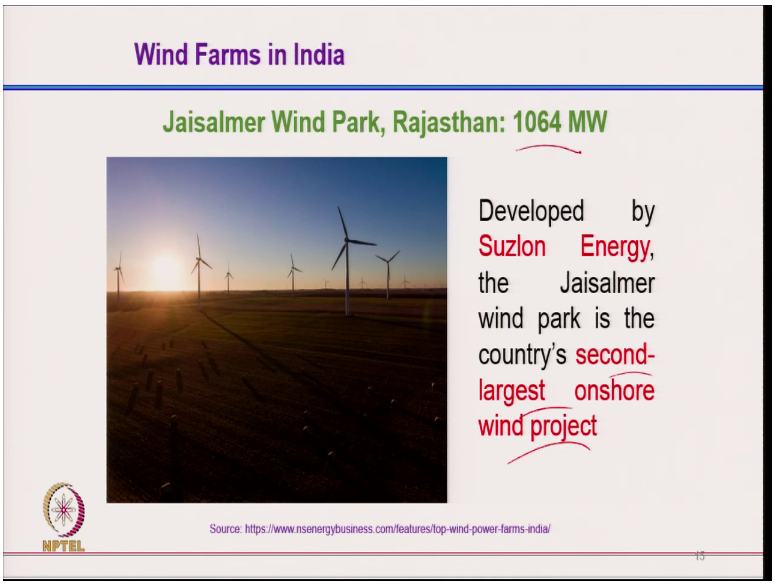

And then, you have a of course, develop the Suzlon Energy developed by the Jaisalmer wind park, the second largest on onshore wind project of 1064 megawatt.

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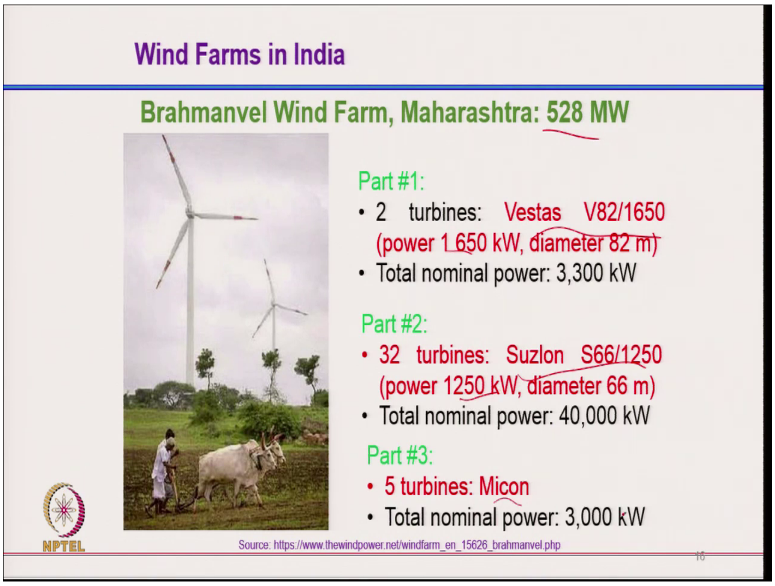

And then, we have a Brahmanvel Wind, Maharashtra 528 megawatt. Of course, in two stages I mean like installed by Vestas turbine of 1650 kilowatt and then, Suzlon model of 1250 kilowatt. And then of course, Micon put another total power of 5 turbine in typically of 3 megawatt like.

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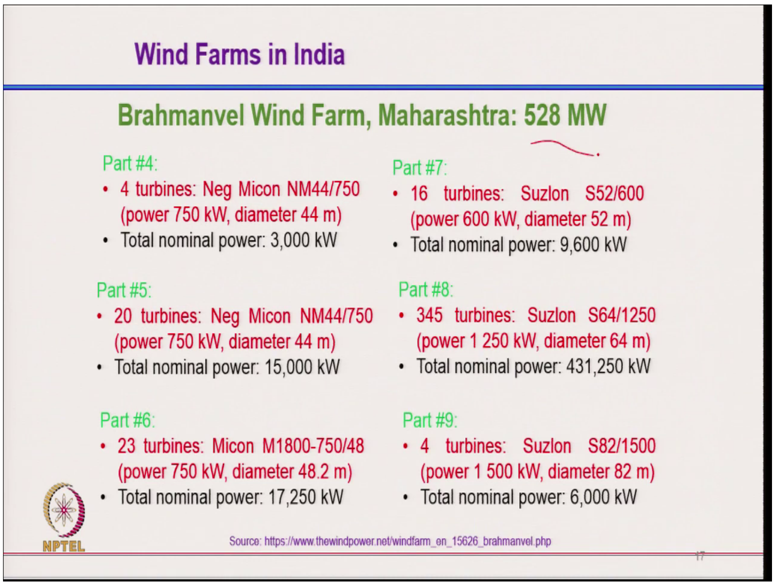

And these are the different parts of this plant of 528 megawatt, they have a different; I mean, you can call it different stages or so.

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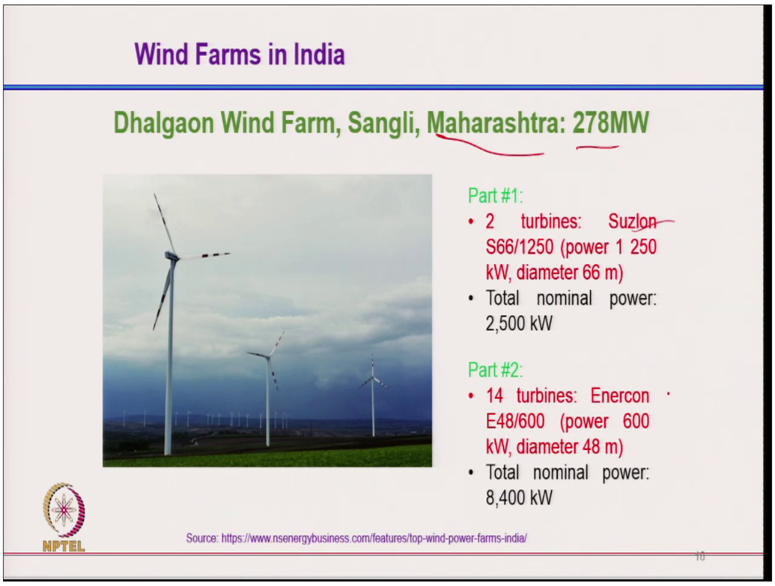

And another is 278 in Maharashtra, the plant with the typical capacity of Suzlon and enercon; enercon of course, use the conventional synchronous generator.

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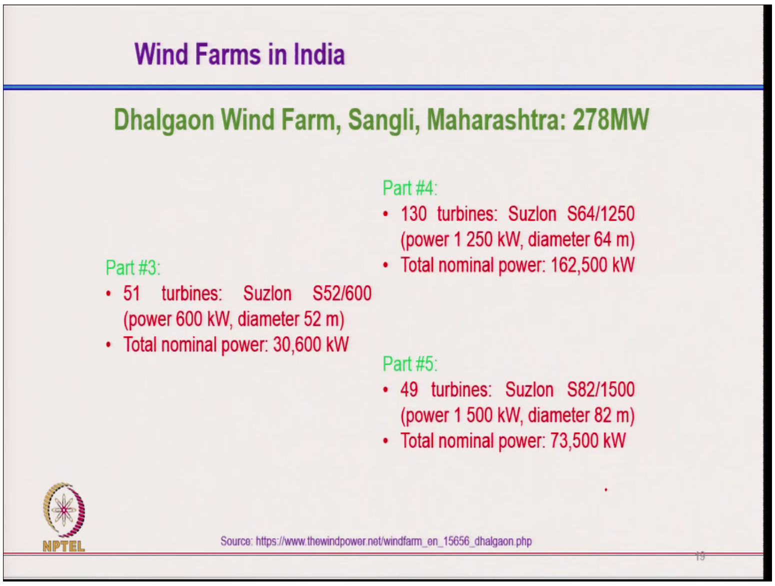

And then, typically the they have been in different part with different typically generators of different rating.

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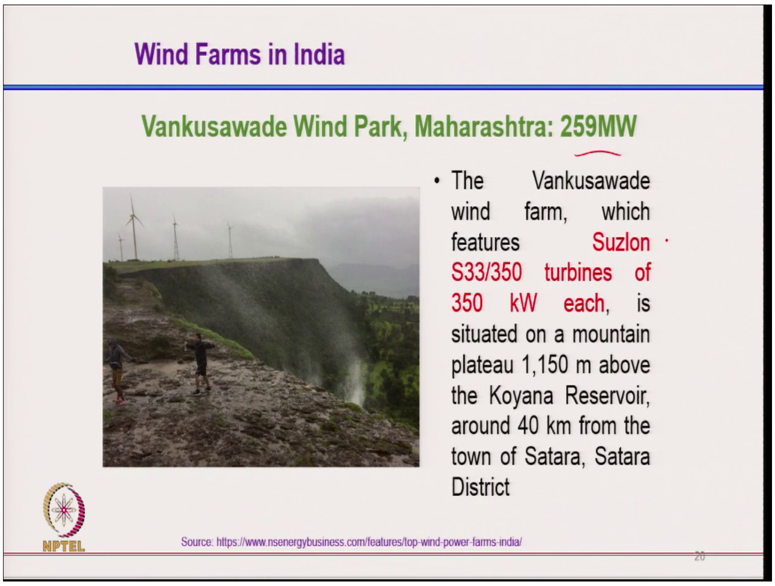

And then, this is another plant of 259 megawatt with the Suzlon, I mean like typically in different areas.

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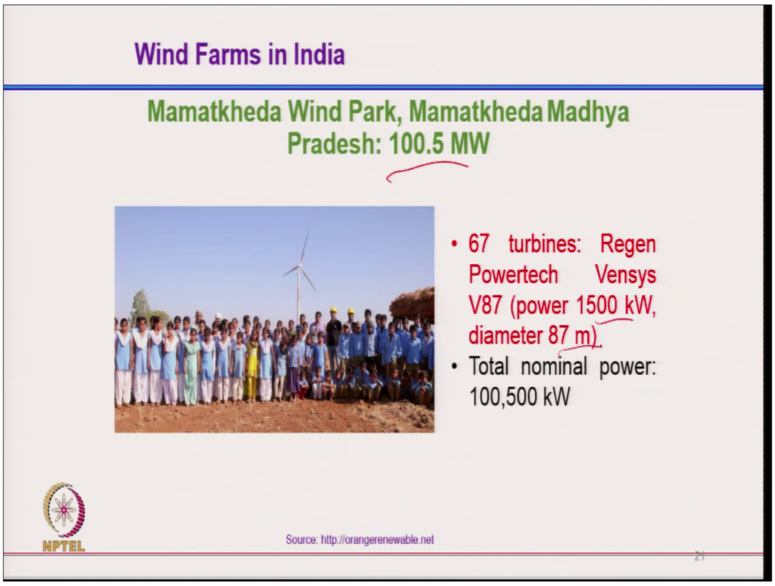

And they are again 100.5 megawatt in Madhya Pradesh like, where you have a typically by vesta turbine of 1500 kilowatt I mean diameter of 87 or so with the capacity of your 100.5 megawatt.

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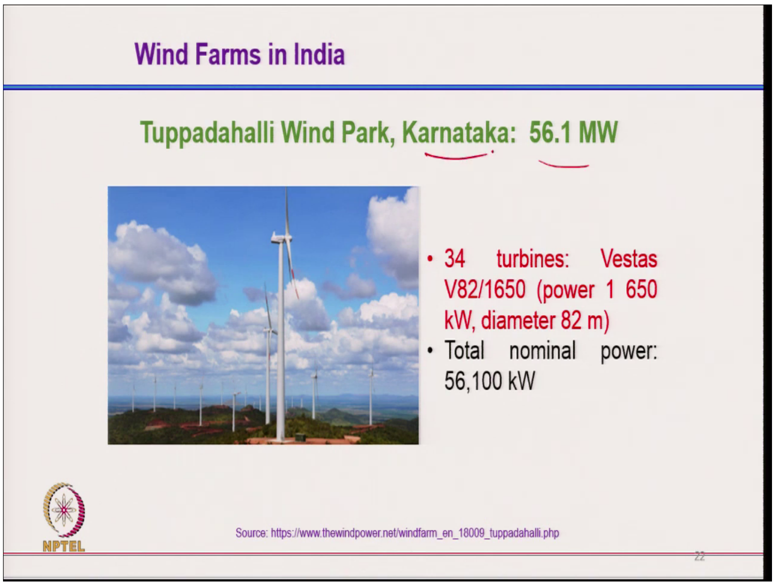

And then, you have another in 56 megawatt; 56.1 megawatt in Karnataka, I mean this is we are talking about different states.

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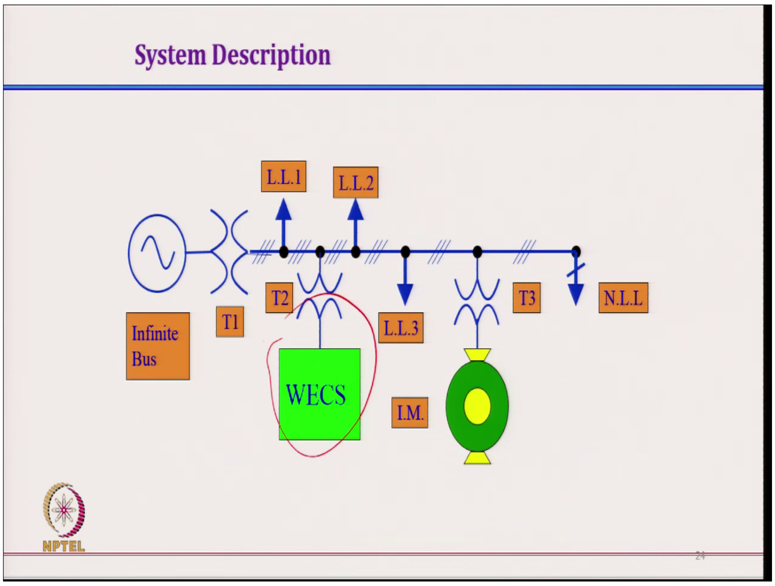

Now, coming to typically now power quality improvement in grid connect; grid integrated wind energy conversion system, I mean typically, they have to be indicated to the grid like I mean like wind energy conversion system connected to the grid normally with the transformers, where the other loads and other generation and typical loads are there.

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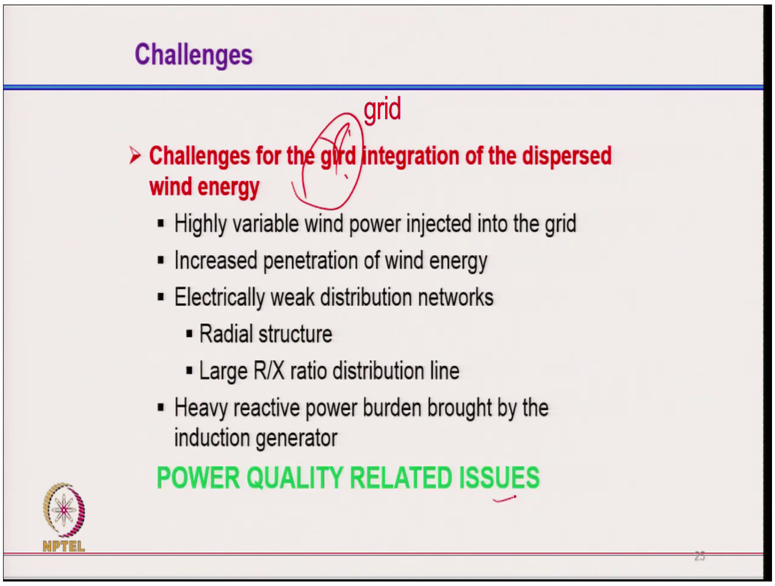

[FL] That there are challenges like typically in the for the grid integration of dispersed wind generation and that is highly variable and wind powering typically injected into the grid and increased penetration of the wind energy and electrically weak distribution network like radial structure and large R by X ratio distribution line and heavy electrical heavy reactive power burden brought by the induction generator and we have a other power quality related issues in this.

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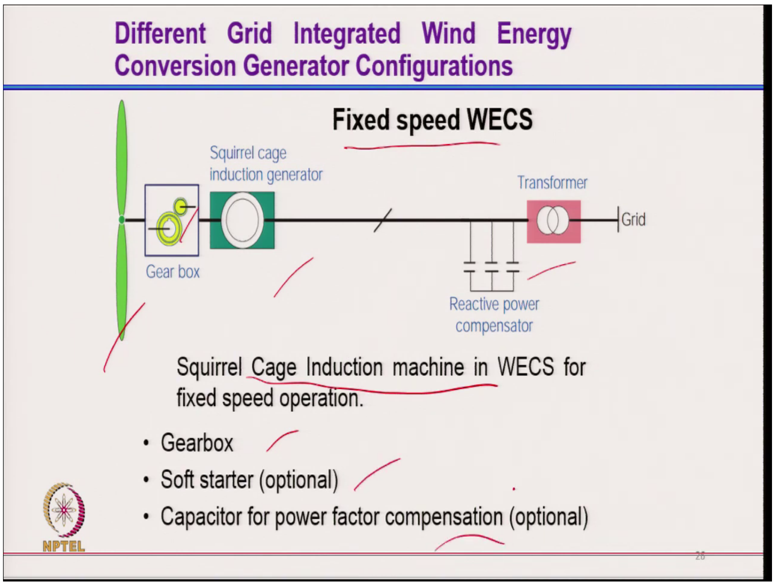

And typically is like a this is the first fixed speed wind generation; I mean like still seimen's is manufacturing that [FL] you have with the gearbox a machine; normally two machine of squirrel cage 4 pole or 6 pole are there and for reactive power, use the capacitor and put the power to this. Of course, in spite of typically with the gear two machines of 4 pole and 6 pole, [FL] some concept of you can call it maximum power is used 4.2 speed; but of course, it is limited, [FL] we still call the fixed speed configuration.

But other [FL] this has a like a typically gearbox normally because squirrel cage machine is used of 4 pole and 6 pole which runs at around little bit more than 1000 rpm and 1500 rpm. [FL] to bring the wind turbine speed of very low 150 to 150 rpm to order of that about more than around 1000 rpm to more than 1550 rpm you have to use the gearbox and then, they have a soft starter also and capacitor 4 power factor compensation.

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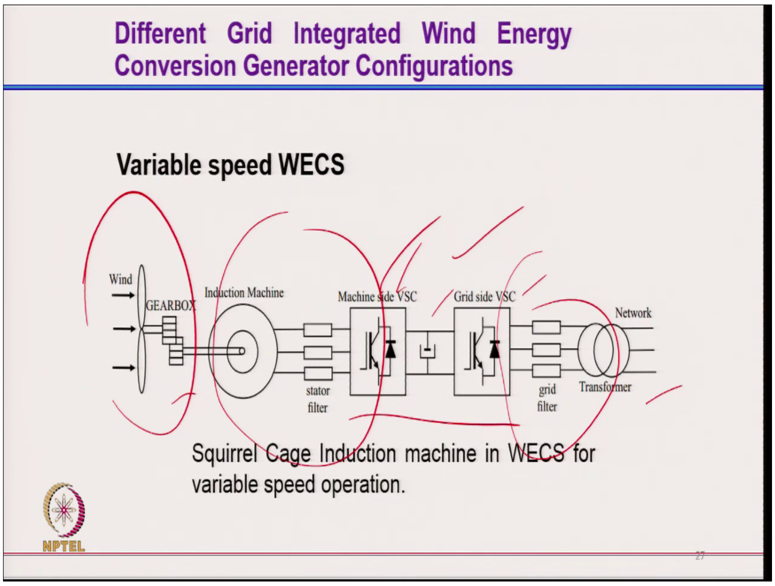

This is of course, the induction machine used for variable speed generation. Again, we use the kind of gearbox, but we use of course, double converter. [FL] its run with the you can call it like a normally variable frequency induction generator by controlled by this machine kind converter and it puts the generated power to the DC link and from DC link, this grid side converter put to the grid. [FL] here it is more important that we worry about the typically that this power is fed without power quality problem, even there may be a power quality problem in the grid like I mean.

[FL] why we are using in? In spite you are using this converter more than twice, the rating of the power which you are generating because process twice; but since wind power generation is I mean like able to generate around 50 percent energy from very wind blowing by putting a maximum power tracking algorithm and that is the reason, we are able to even process the with the couple of power converters whole power is.

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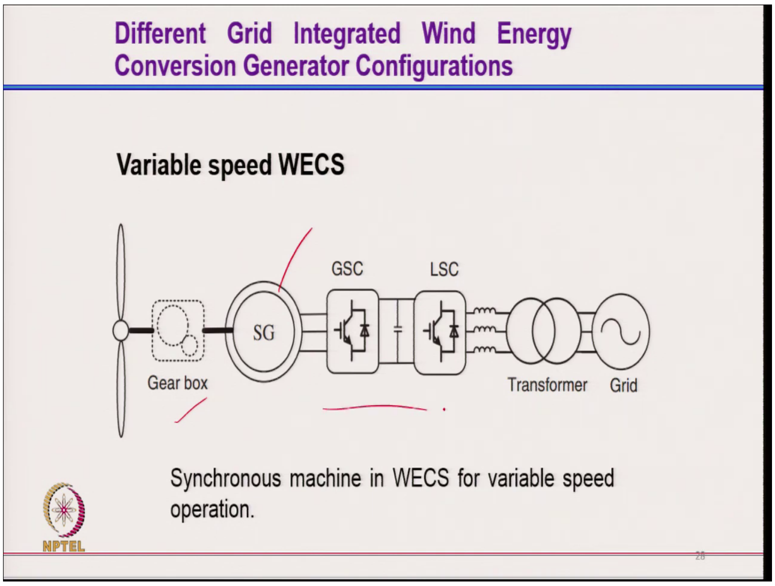

Similarly, synchronous generator. I mean we have a like a again the gearbox. Of course, I mean in salient pole machine; enercon is not using the gear box otherwise all cases there are again double the converter input to the grid.

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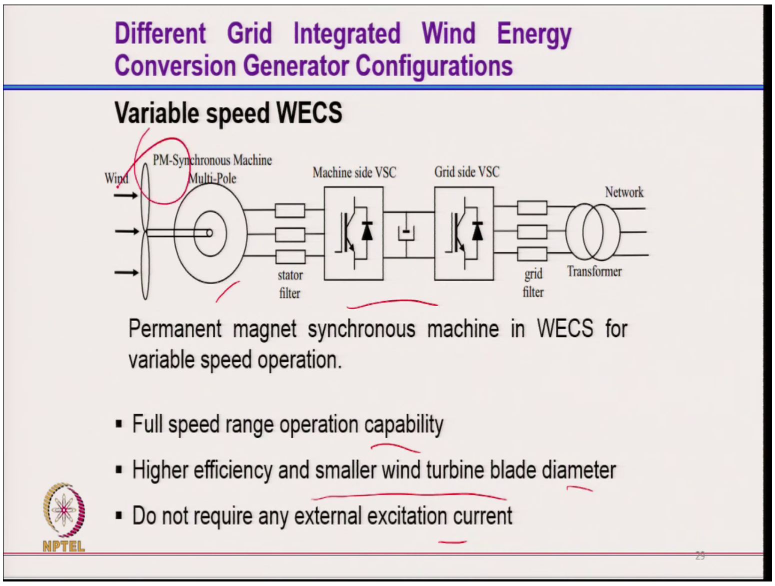

Then, you people have a permanent typically you can call it permanent synchronous machine, again double converter input to the power to the grid and of course, with the because you are having a converter, you can have a very wide speed range, a high efficiency with the smaller typically you can call it wind turbine blade diameter and do not require any external excitation typically because it is a permanent excitation here.

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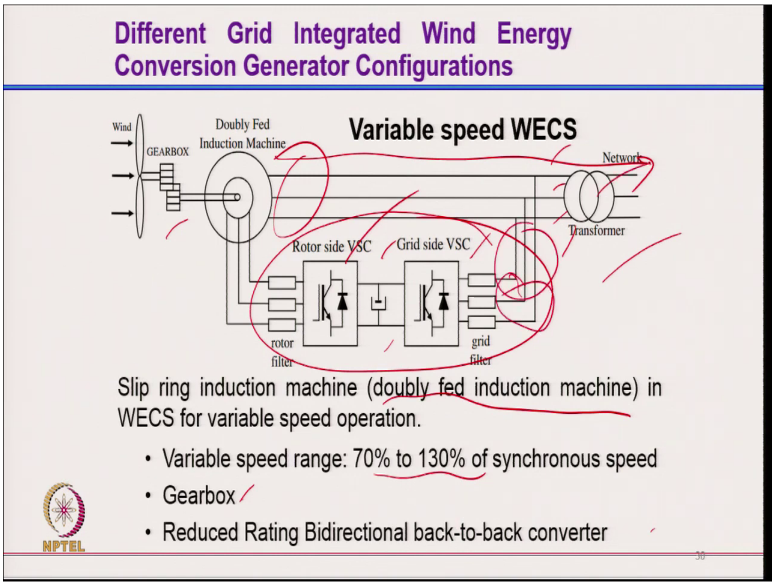

And then, DFIG this is considered one of the best machine for wind power generation and the reason being that the major amount of the power is directly process stator to grid without only to facilitate I mean the variable speed, I mean we have a this rotor side converter and stator side converter. Rotor side converter is responsible for maximum power tracking to by controlling the torque in vector control. And by generating the reactive power, we generate the we have a unity power factor on stator so that there is no reactive power burden on the supply system.

And the DC link is maintained by the grid side converter. However, the grid side if anything else you need the grid reactive power, the grid side converter can provide that also. [FL] this and moreover, it shows of course, you the gearbox because machines with the four pulse runs around typically 1000 rpm to 2000 rpm. So, that you can have MPPT for that. [FL] around 75 percent manufacturer are manufacturing this, you can call it the your one this is a doubly fed induction adder; I mean like because the speed range is enough from 1000 to 2000 rpm for this wind power energy conversion system.

And moreover, the here the process power is hardly typically if you are going to let us say 1000 to 2000 rpm with the synchronous speed of your 1500, you only process around 30 or 30 to 35 percent power. [FL] power converter rating is hardly 40 percent of each. [FL] it is less than even both the converter rating is not even 100 percent, where the other cases you have a 200 percent rate of power converter. Here, more 0 amount of power is going to be through directly connected to stator line like.

And of course, you can [FL] variable speed from 70 to 130 percent of synchronous speed and of course, you need the gear and reduced rating of bidirectional back to back converter or typically sometime, we have even a transformer here also; but otherwise, this transformer also serve the purpose like.

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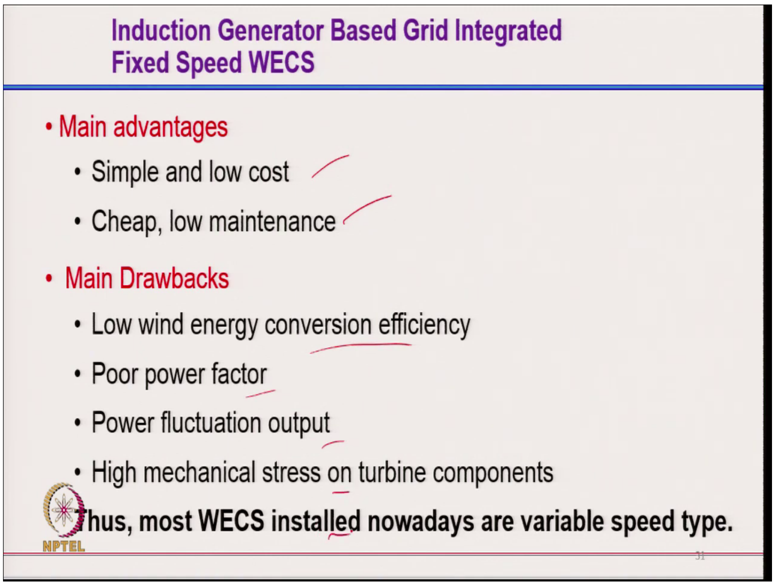

[FL] main advantage are simple and low cost, cheap and low maintenance and major drawback is low wind is energy conversion efficiency. Of course, sometime and power fluctuation and high mechanical stress on turbine, [FL] most installed nowadays are variable speed type.

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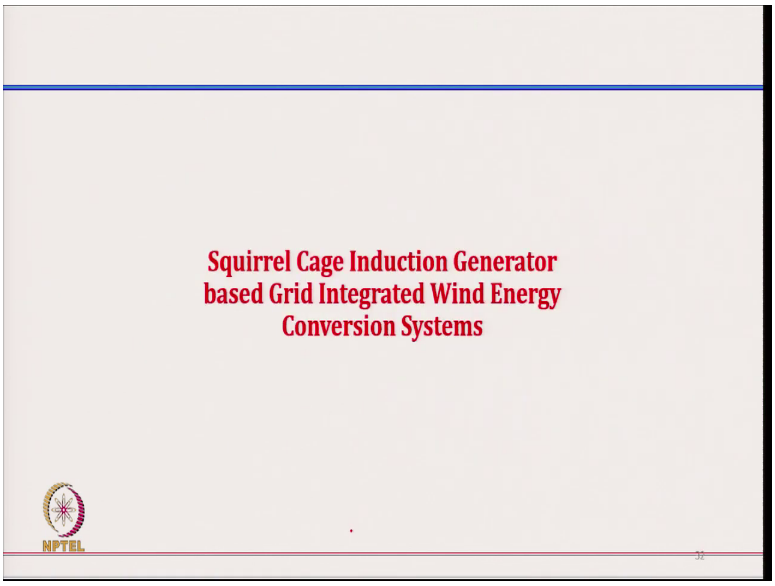

[FL] coming to squirrel cage induction generator based typically grid integrated energy conversion system.

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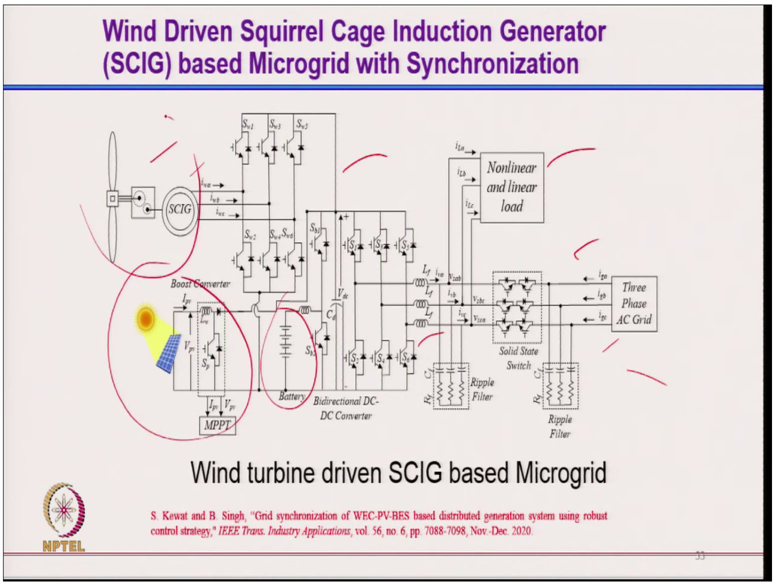

This is typically that we have with the gear there and we have a one converter, you have can have another converter and connected to the grid and of course, for a small unit, you can have connected battery and you can have a local load also here. [FL] you can improve the power quality on the grid side and moreover, you can have a feature with islanding mode also to feed this local load with the because the battery can take care even the power variation from the solar as well as from the wind I mean like or so.

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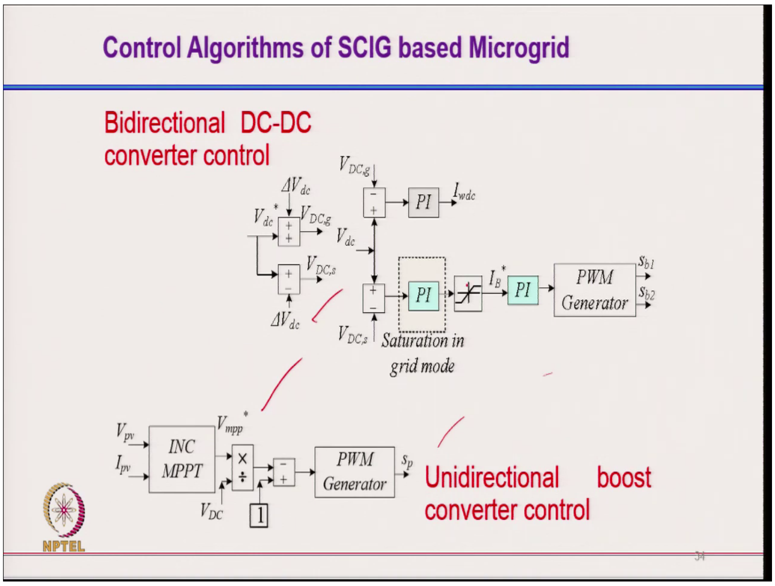

And they typically that how you are regulating the you how you are doing MPPT of the wind generation and how you are typically having the DC link voltage control; I mean like from there, how you are having a control of the DC link typically from the battery, you are regulating the DC link control from that.

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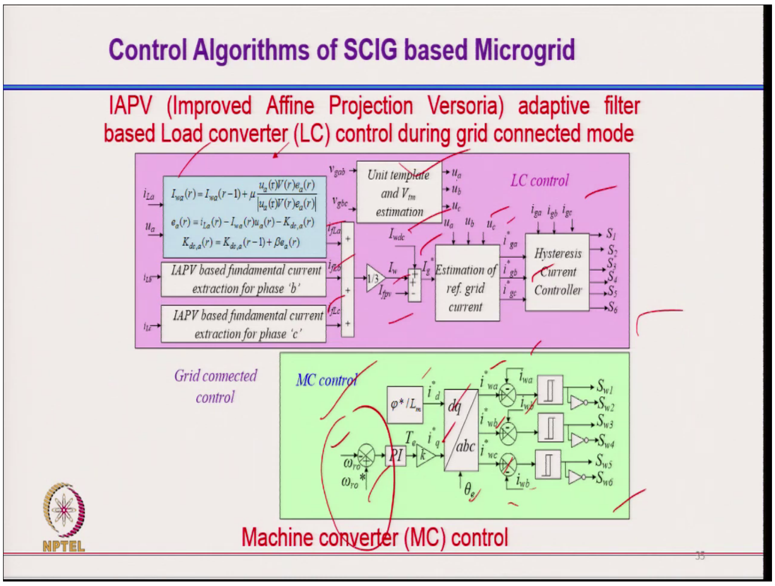

And these are typically the load compensation that you are as we discussed already in many times that we are able to extract the fundamental form here, from the load and then we are able to have averaging. We have a wind power feed power term, we have a solar feed power button and then, we are able to get the grid current, we have a template of the grid from voltage template and then, we have a reference grid current, we have a sense grid current and we are able to control the grid side converter like or so.

And these of course, machine side converter control for maximum power tracking; typically, normally I mean even we are able to use sensor less control most of the time in motor control like. [FL] that maintain the typically with the vector control of the machine speed for corresponding to because you have a reference speed corresponding to MPPT and you have a feedback speed either by estimation or by your sensing.

And then, you get the torque from which torque regime component and from flux, you get the flux producing component and you are able to convert three phase currents from this angle which call flux angle and able to have a reference current, then with the feedback and you control it. [FL] machine currents are also close to sinusoidal as well as the grid current also control close to sinusoidal. [FL] power quality improved are is improved on both the side like.

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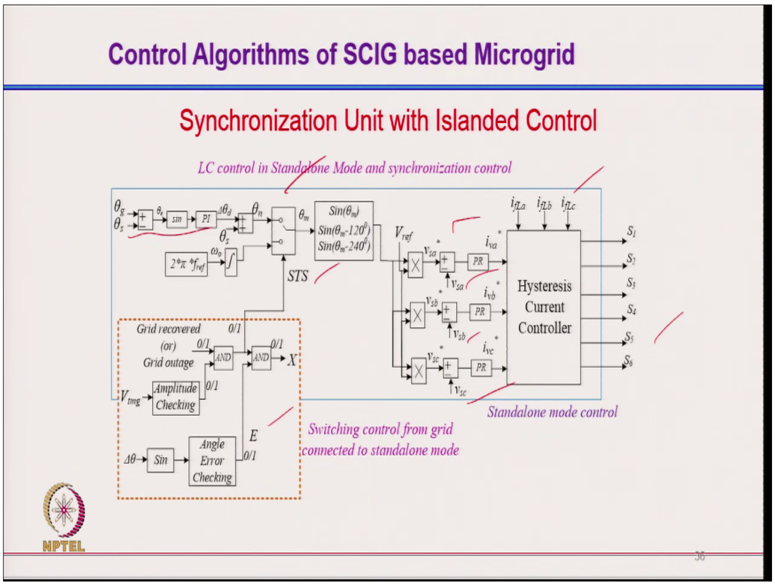

And this is typically the kind of you can call it the in your typically when grid is covered, how it is synchronization take place by floating the angle of the your grid side converter towards the grid and then, once its closes, I mean comes to close, you can close the switch; otherwise, its operate in islanding mode, I mean like with the power resonant controller which have a steady stator zero with the even sinusoidal varying current and then, you have a typically the local load current and you are able to have a switching of this converter like and is still maintaining the what is in frequency across the load line.

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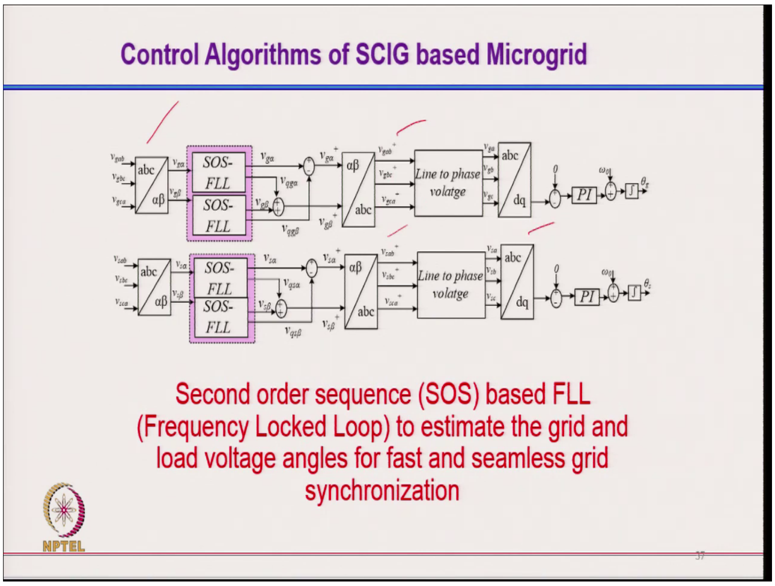

And this is typically even though your voltage are typically are on the grid side, typically on the distorted still you are able to get the filtered voltage and then, using the typically in the control for controlling purpose like I mean or so.

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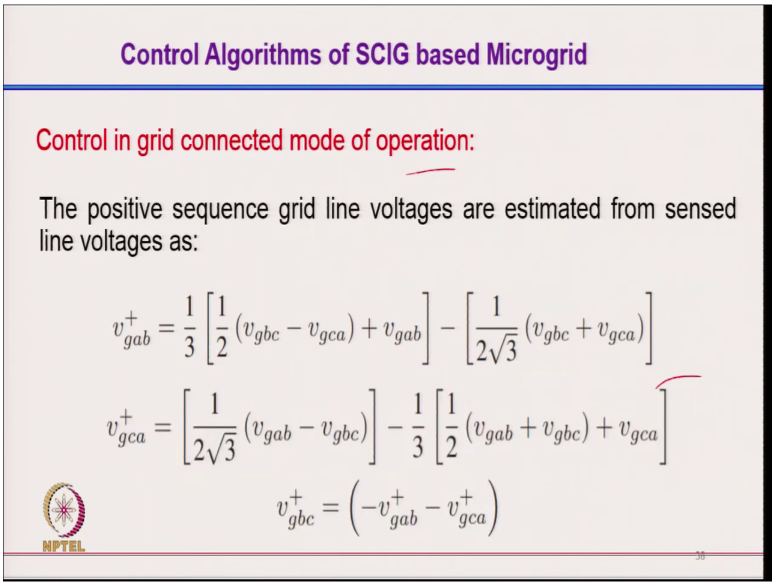

[FL] we can call it like control of grid mode operation, the positive sequence grid line voltage are estimated from the sensed voltage. [FL] from the sensed line voltage, we are able to estimate positive sequence.

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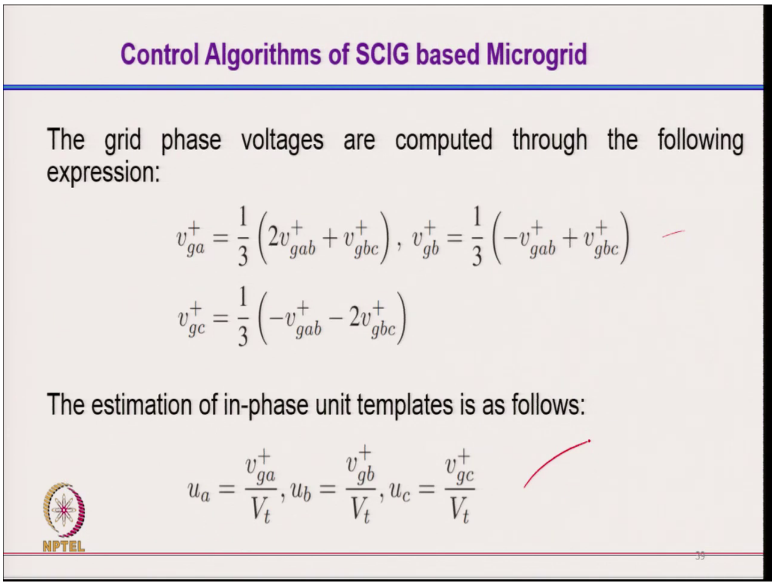

A voltage and then, we are able to get a typically from these voltage, we are able to get phase voltage from line voltage from positive sequence which are balanced and sinusoidal and then, we are able to estimate the template in phase with the these phase voltage.

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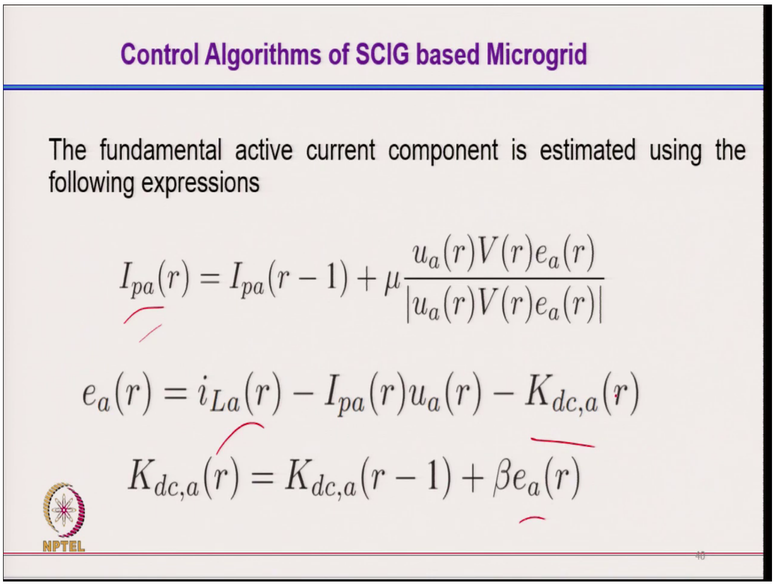

We are able to get like a typically the fundamental current of the corresponding the load to extract from this and typically from the load current and this is the typically the load current, this is a fundamental extracted current and of course, the constant which you use in this algorithm, I mean this is the typically coming from this algorithm.

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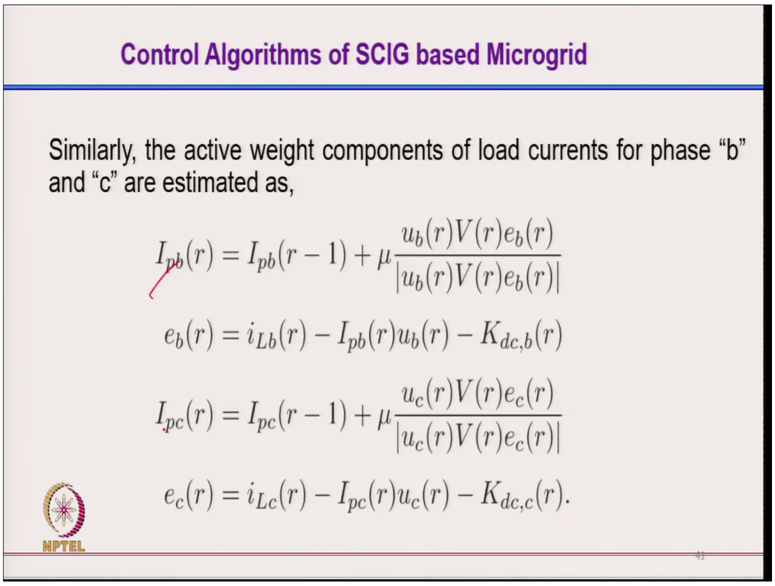

And these are the four typically "b" and "c" phases.

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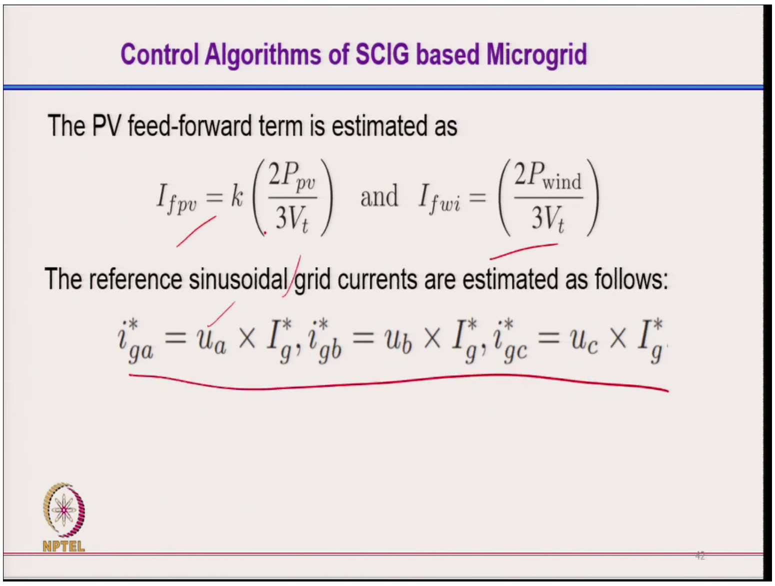

And you are able to take then feed forward term for solar and feed forward term form the wind. And you are able to get a reference grid current like; I mean from this relation from template and the amplitude of the grid current like.

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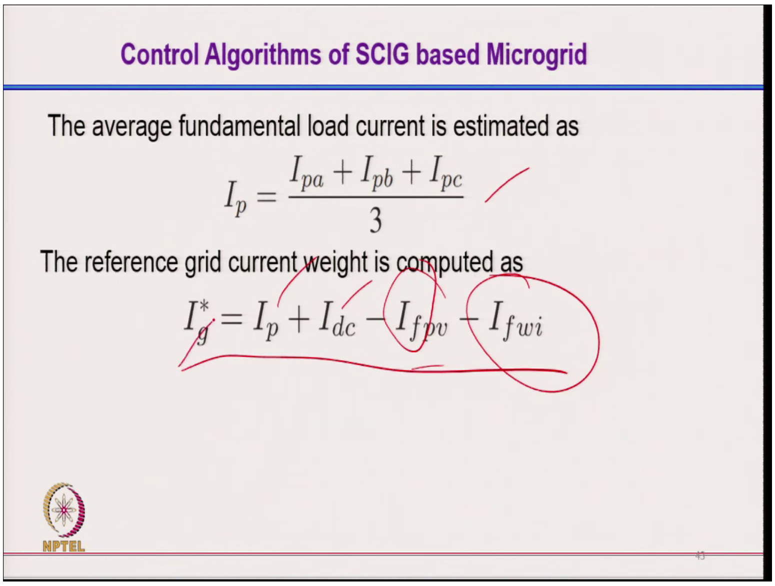

[FL] that controls typically and where you have a load current average and then, you have a reference grid current, where you have a positive sequence of load current. Then, you have a DC link voltage control output that also the kind of loss is there and then, you have a pv feed power term and you have a feed power term of the wind generation. [FL] you get the amplitude of grid current from which you have calculated the reference current.

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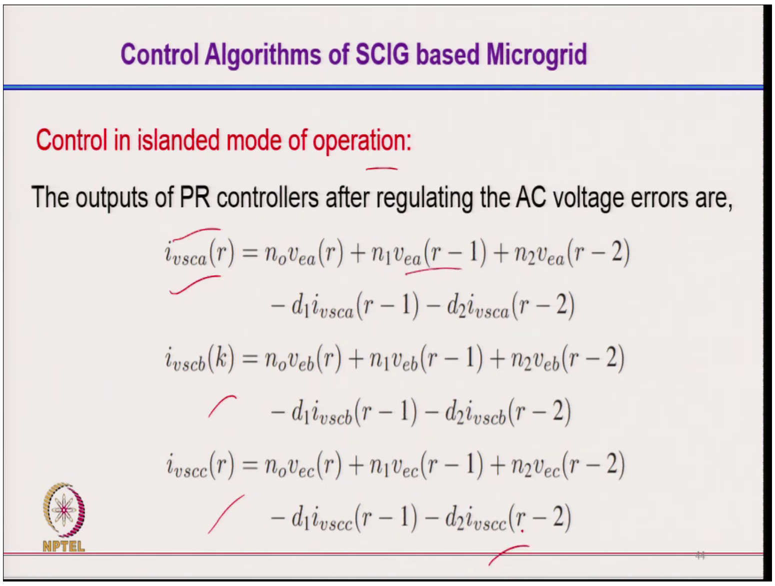

Coming to islanding control, you use the normally proportional resonant controller because that can have a steady state zero even with the sign varying voltages like. [FL] you have here the typically inverter current from the voltage typically from the voltage error.

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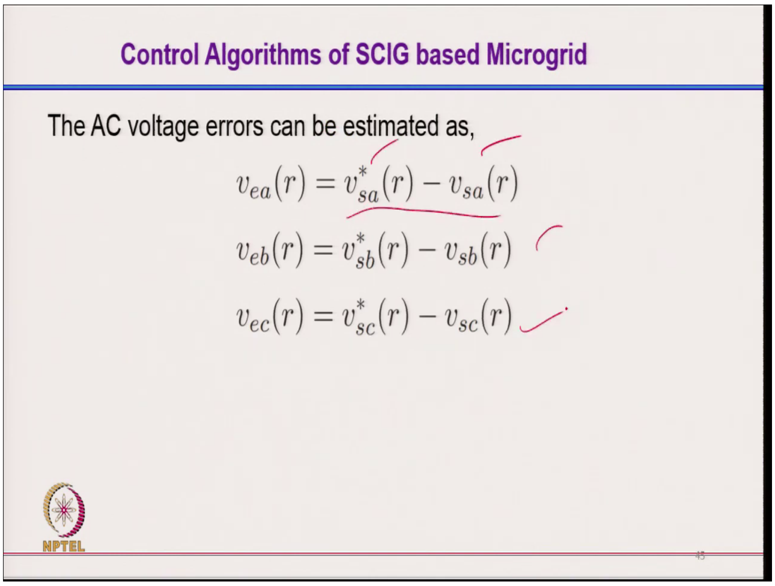

And you are having a voltage error with the reference voltage and typically, the sense voltage for all three phases.

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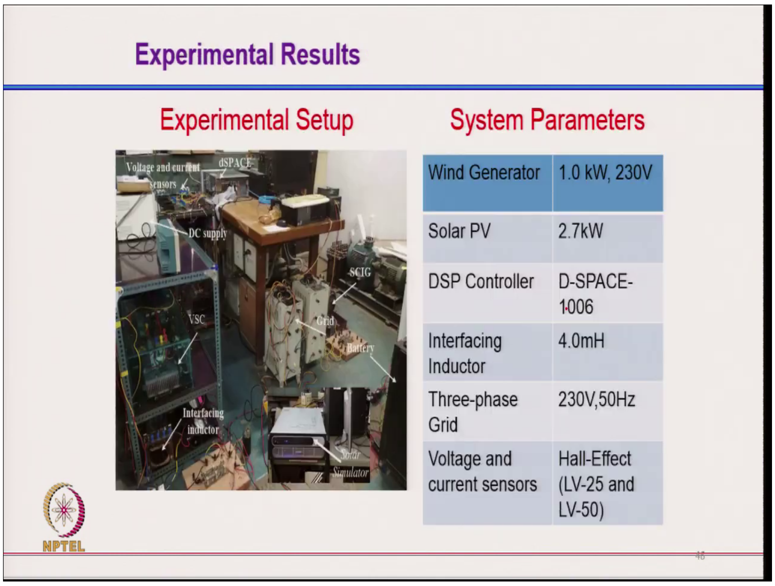

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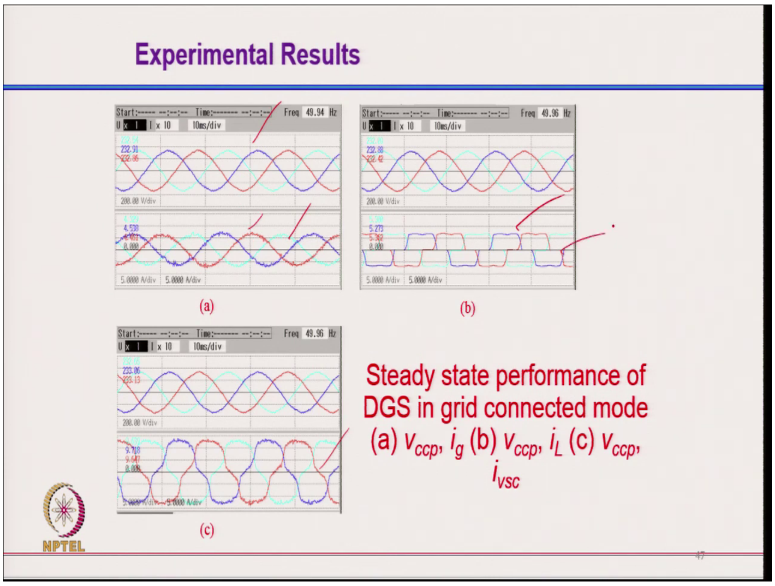

And this is typically the you can call it the setup on which [FL] you can say the grid current you have a load current and you have a I mean grid side converter current. [FL] you can have a grid current and grid voltage of sinusoidal and power quality is improved, in spite you are able to improve the power quality of the local connected load.

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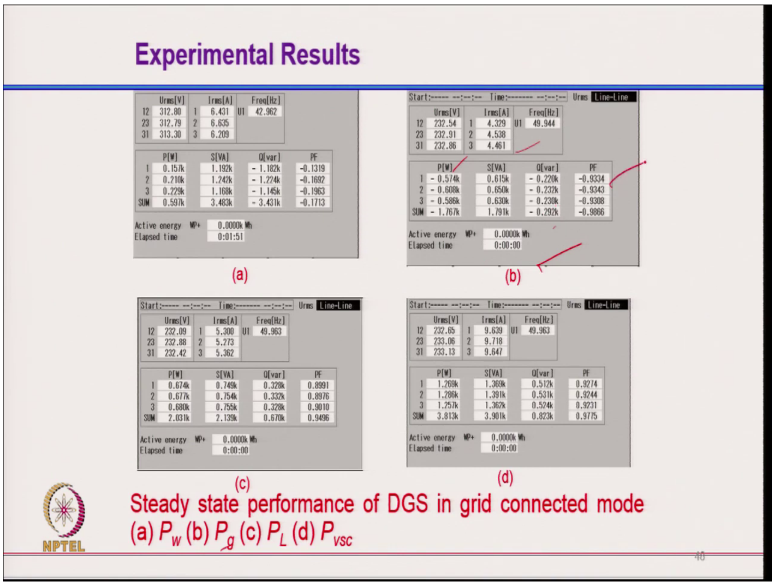

And these are the typical harmonic analysis corresponding to a your I mean in this case like [FL]. You have a typically the in b here the grid current typically the grid power and you can have a the quantity of the grid voltage grid current all the quantity here with the P and Q of the grid and power factor of the grid on closer to sinusoidal.

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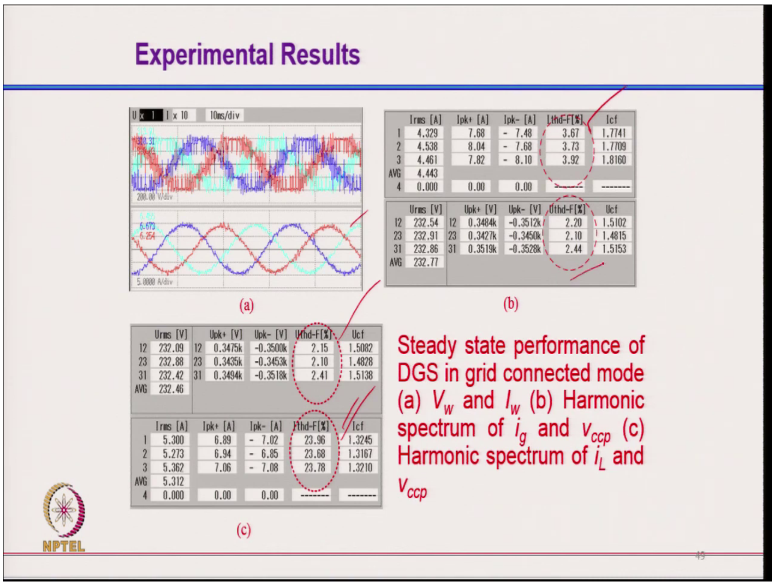

And this of course, even you have a kind of distorted voltage, still you have balance sinusoidal current or so. And you have a quite good THD typically of the voltage and current on the when you have a load current THD quite high, still you have a grid current THD quite typically less than 5 percent here. This is the voltage THD typically in iron mode and this is the voltage THD in grid current mode like.

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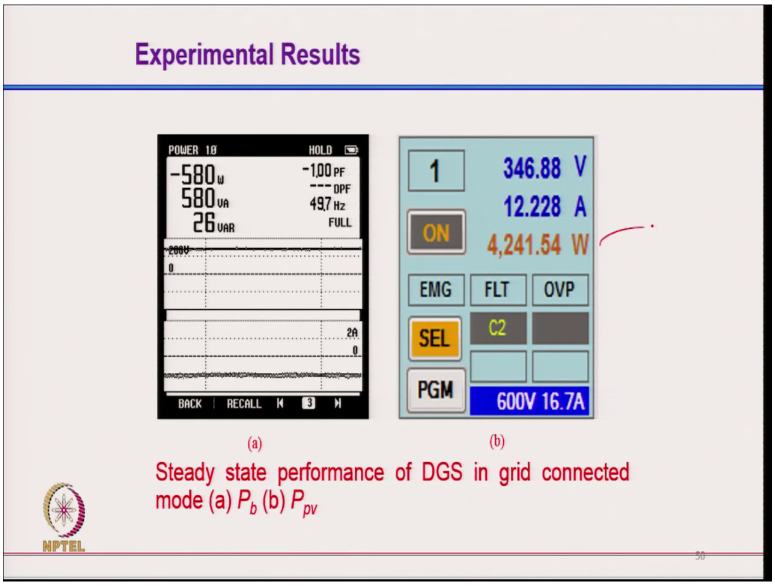

And this is typically the power corresponding to the you can call it the solar generation.

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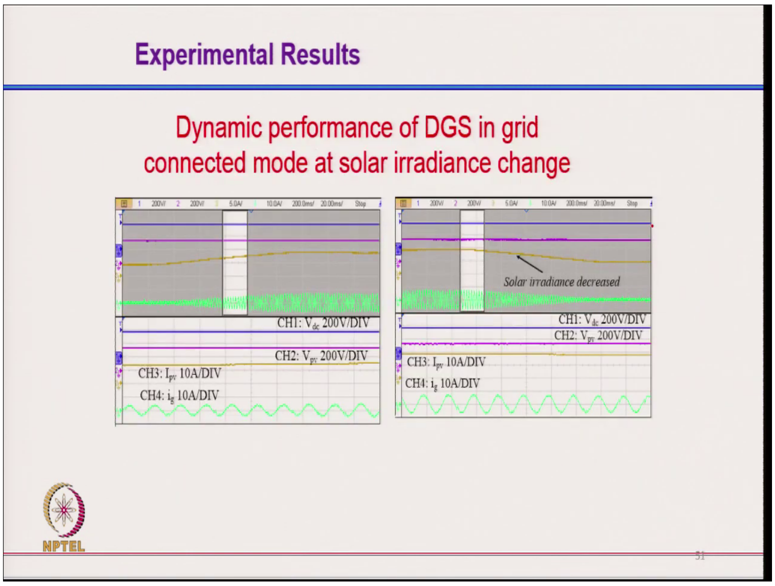

And then, this is dynamic performance when grid current solar irradiance changing in this hybrid system.

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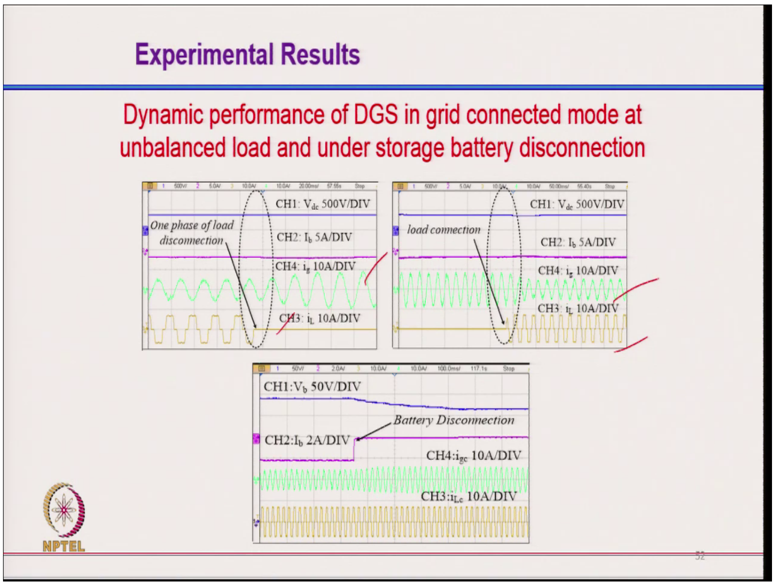

When the load is removed, grid current is increased because now load is not consuming the power. Similarly, when you start the load, the less current is reduced on the grid; but still you can call it voltage in current remain in the phase like typically.

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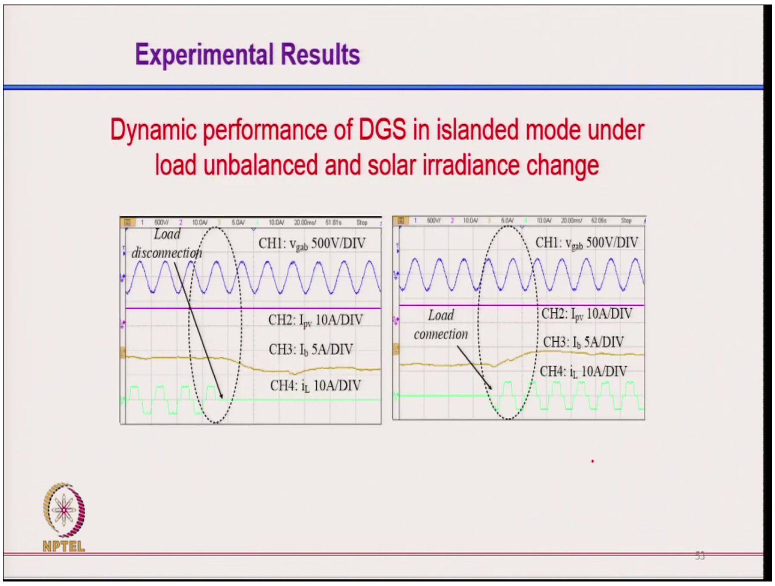

And here of course, if battery is not there, how it is the system is working, still it can work very well.

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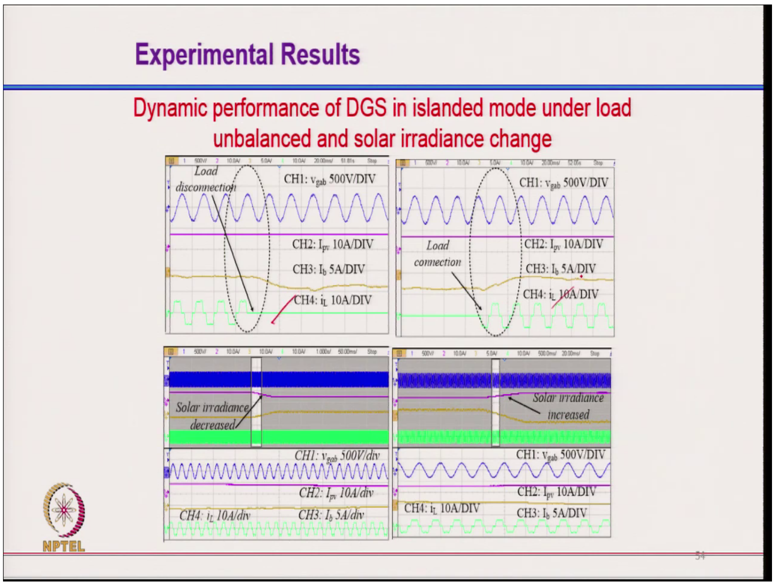

And with the load removal load addition how the performance is there of the your typical this system I mean like or so. [FL] load addition load removal and load addition performance (Reference Time: 19:18).

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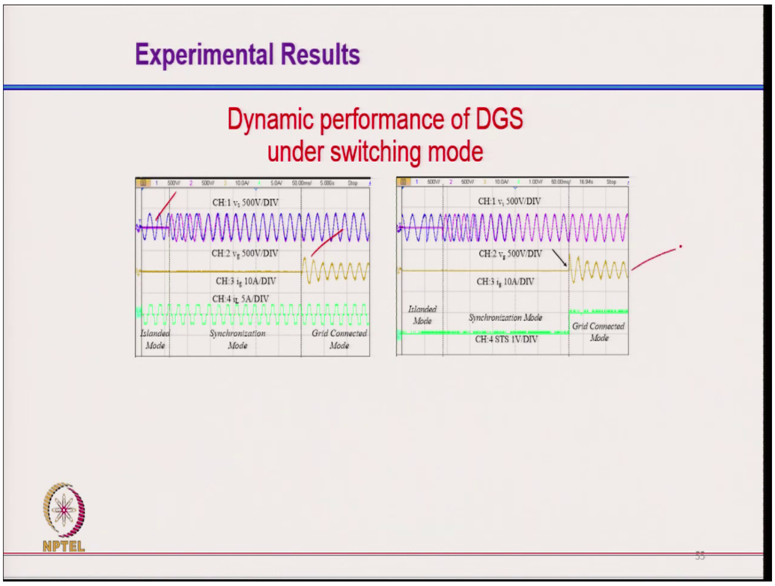

And then, typically you can call it grid is appearing here after free cycles grid is synchronized. The system is recognized to the grid [FL] grid current is start appearing, [FL] you have a very smooth switching of this distributed generator. You can call it wind energy conversion system to the grid without any tangents.

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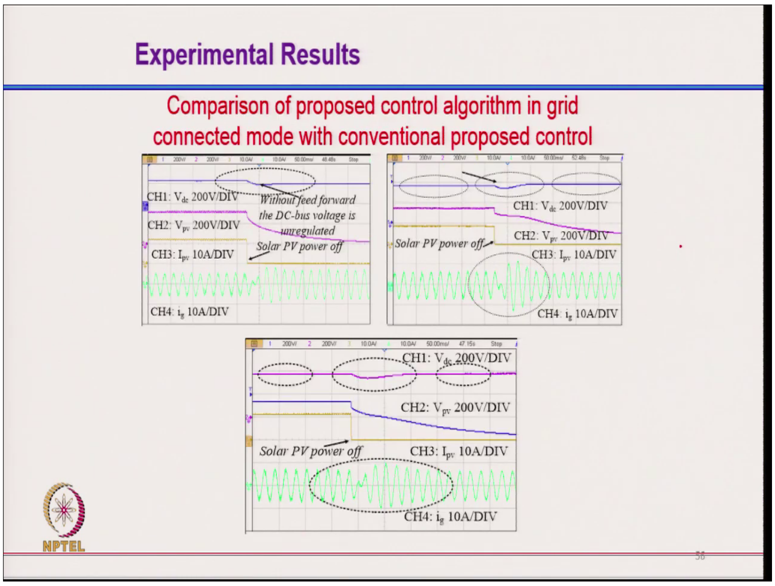

And similarly you can have like when this grid disappears, still you have a smooth operation of your typical system like I mean without any much problem I mean like.

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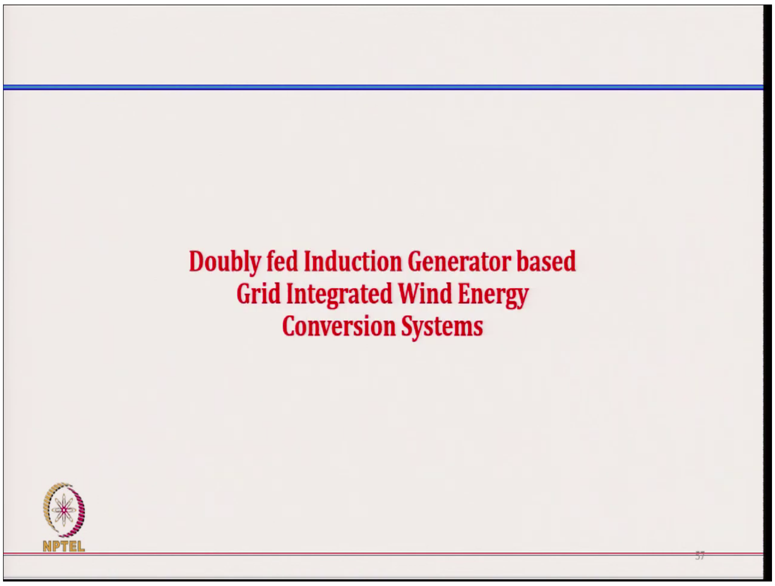

[FL] now coming to typically another wind generation system, we call doubly fed induction based grid integrated wind energy conversion system.

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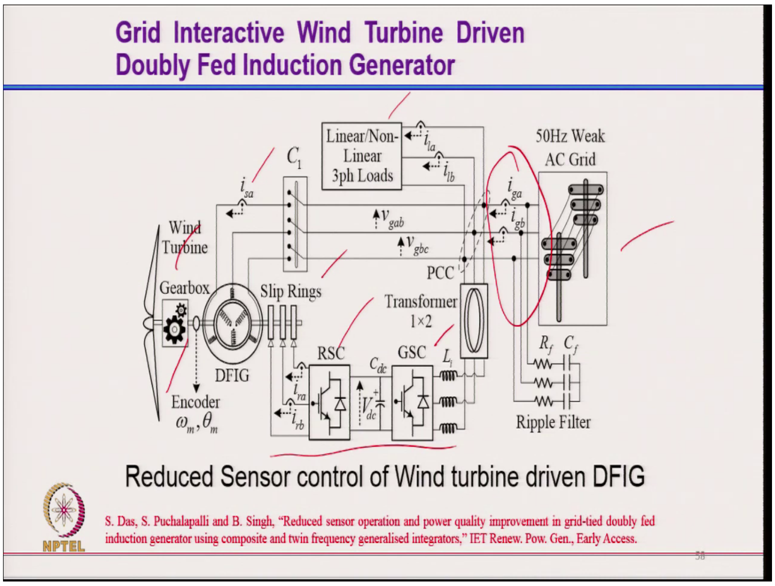

[FL] we have a here the DFIG with the gear which already and you have a rotor side converter, registered side converter; you have a synchronized switch here and you have a typically the grid here like I mean or so and you have a local load also. And certainly, we have to improve the power quality on the grid side in this case. And the very beauty of this is what we already discussed it.

The converter rating is quite low hardly around each converter have 40 percent rating, [FL] 80 percent rating compared to. In previous case, you have a 200 percent rating of the converter and you can still have a unity power factor on the stator side. [FL] this DFIG suits you one of the best way, typically you can call it like for wind power conversion system like.

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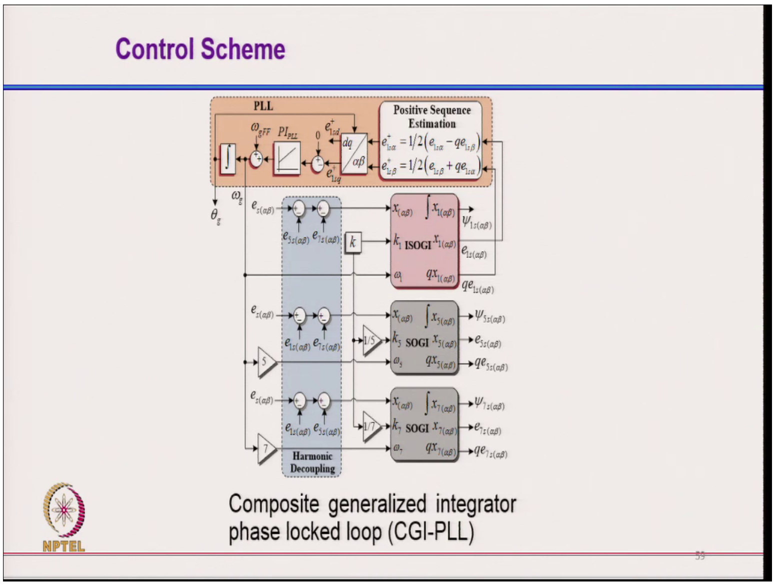

And this is the typically your algorithm for your typically for estimating the angle and frequency, I mean like in this system for estimating the your from the sense voltage or so.

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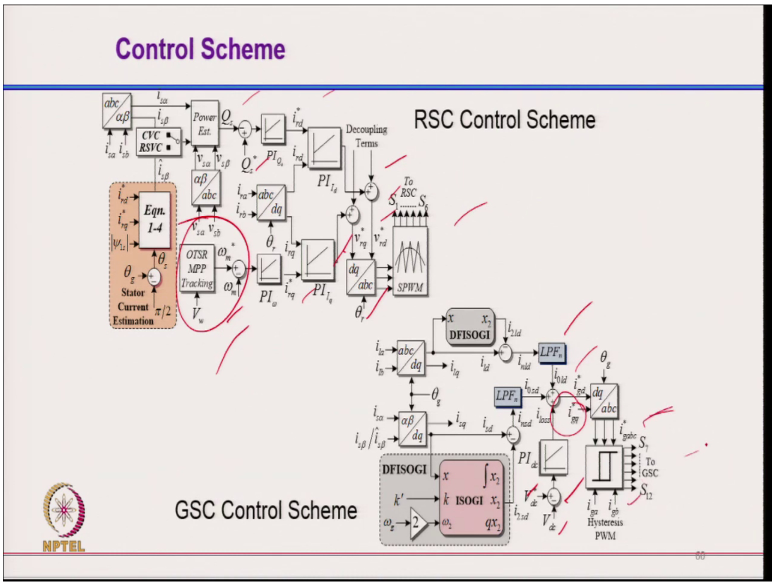

And this is typically for your control for rotor side converter which on not only takes a typically your MPPT, I mean this is your maximum power tracking algorithm, you take care. It also takes care even kind of generate the desired reactive power which may be 0 for unity power factor on the stator which give the rotor d-axis current and typically and the q-axis current is generated with the help of your vector control for maximum power tracking.

And then, you have a like a voltage, where it is a voltage control normally we use 1.8 kilowatt switching frequency for the rotor side converter. [FL], we have a normally voltage control after getting this. [FL] this vector control quantity of rotor voltage, we are convert from the slip angle into the three phase and then, we have a rotor side converter and power and this typically your good side converter control; I mean which again, we can have of course, here we this have to responsibility of the DC link voltage control; I mean reference DC link voltage. And this and you can generate even desired reactive power also required for the at the grid side like or so if you really need I mean.

And that is virtually again from vector control, we are able to get a two axis current, I mean we can have a reactive power; otherwise, we can have only the active power for regulating the DC link voltage and these are the grid reference current and we have a typically the sinusoidal grid current, [FL] we have getting signal for that. [FL] that is double.

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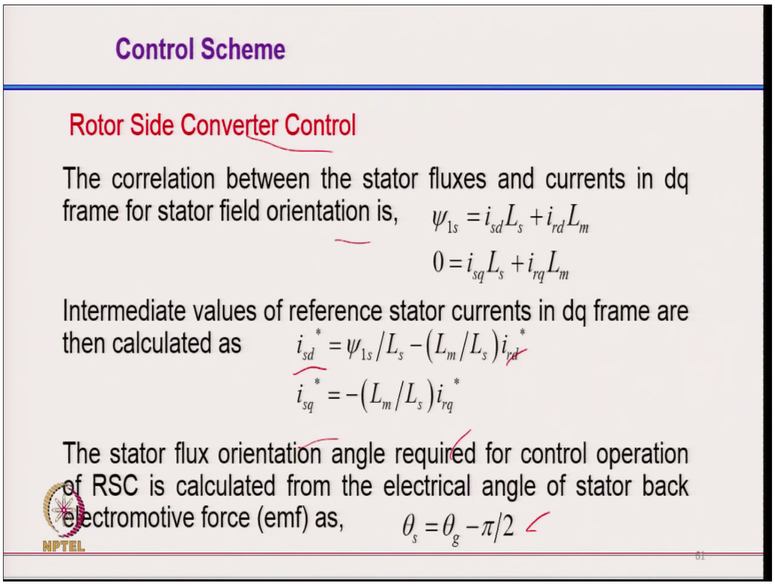

[FL] The rotor side converter control is typically between stator fluxes and we normally use the vector control in dq because these quantity become DC and design of the PI controller, you have a number of PI controller here becomes easier and this typically what you can call it the your d-axis current and q-axis current of the stator from the rotor d-axis and q-axis current and then, this is typically you can call it like a corresponding to your flux stator flux angle.

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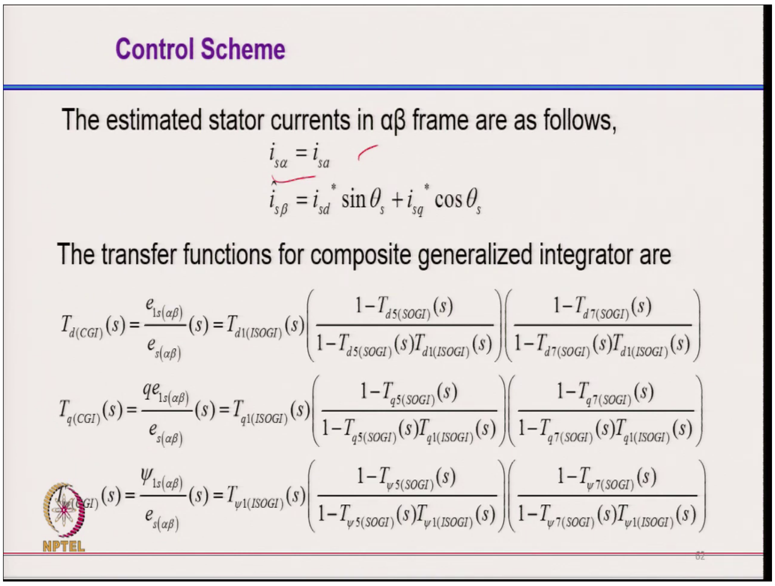

And you have a typically the currents corresponding to from your sense current to typically alpha beta currents and then, you are able to use the typically the transfer function for the typical control from these for here for alpha beta like or so.

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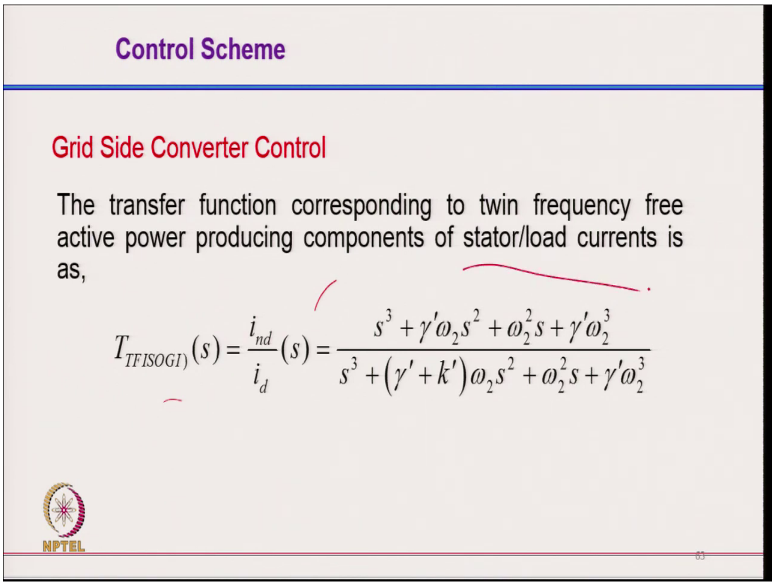

And grid side converter, again you have a similar filter for typically getting the your eliminating the your even the harmonics or unbalance into the current with using this filter like.

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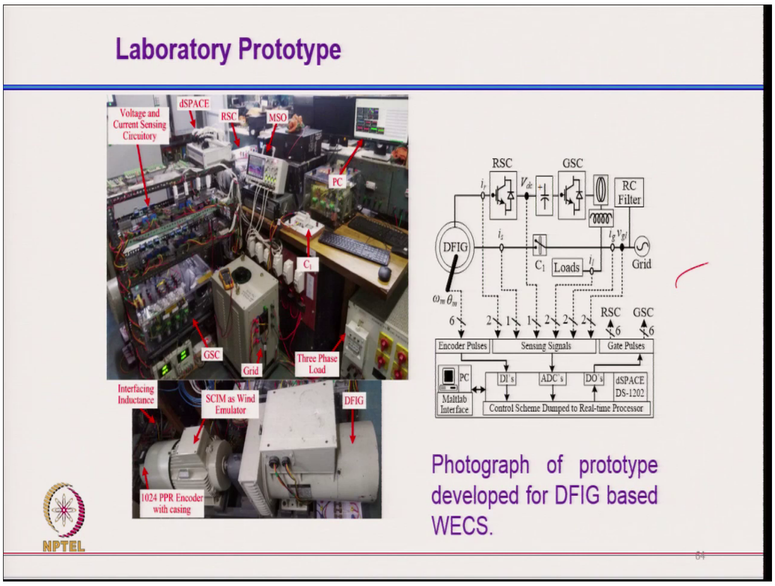

And these are typical system which are developed in the laboratory for the power quality improvement on the grid side from using the DFIG.

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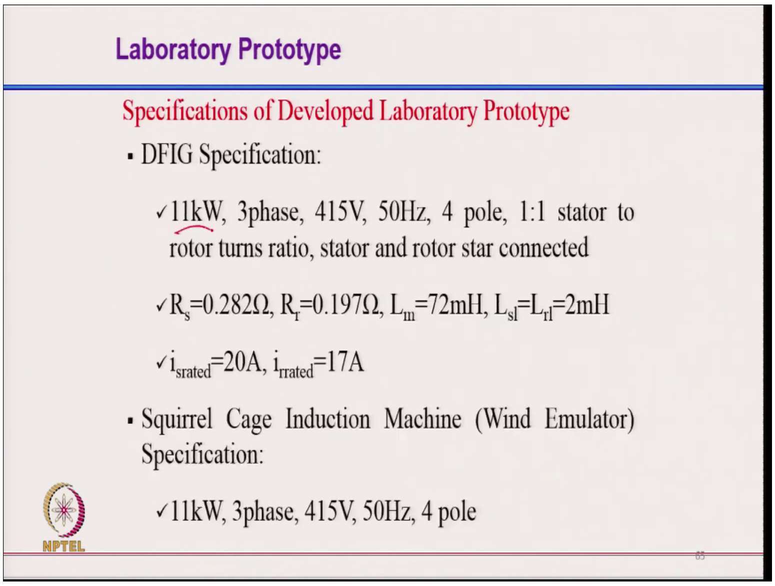

And these are typically the rating of the DFIG for which system is developed.

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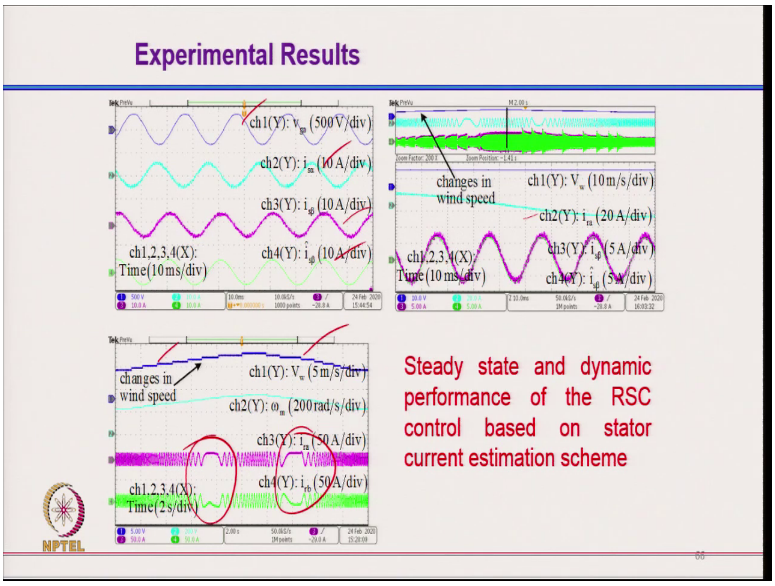

And these are you can clearly see the grid voltage grid current; I mean like of course, these are intermediate signal corresponding to your stator side and these are when the wind speed varying, how it is the typically the different quantity are changing like as your wind speed increasing and wind speed decreasing and you can clearly see the rotor current, I mean it passes through synchronous speed.

[FL], it runs at exactly single speed as the synchronous generator and it changes very smoothly over a wide range and but the stator, you can call it the you have a grid voltage already stable and you are able to generate the varying power with that.

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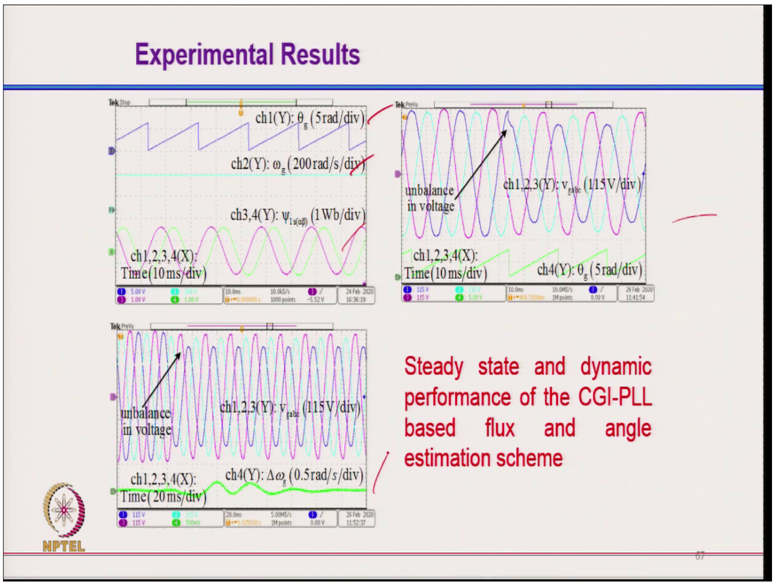

And these are of course, the intermediate signal which you are estimating typically the position as well as the you can position angle as well as the you are typically the speed I mean like. And you are able to have typically the fluctuation, how you are estimating the speed, those are the typical kind of intermediate signal or so in the system like I mean or so and during the change also.

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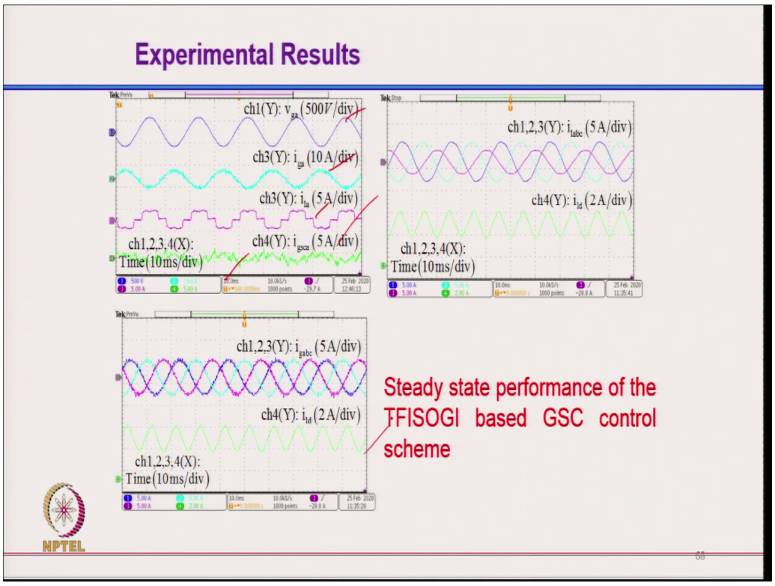

And when you have a nonlinear load, I mean the stator side converter is able to work as active filter I mean like and you have a grid current; typically, I mean grid current is still sinusoidal and with the sinusoidal grid voltage in phase with the out of the phase. Because it is generating the power and depends on the speed and these are typically again the your intermediate signal of the control like I mean or so.

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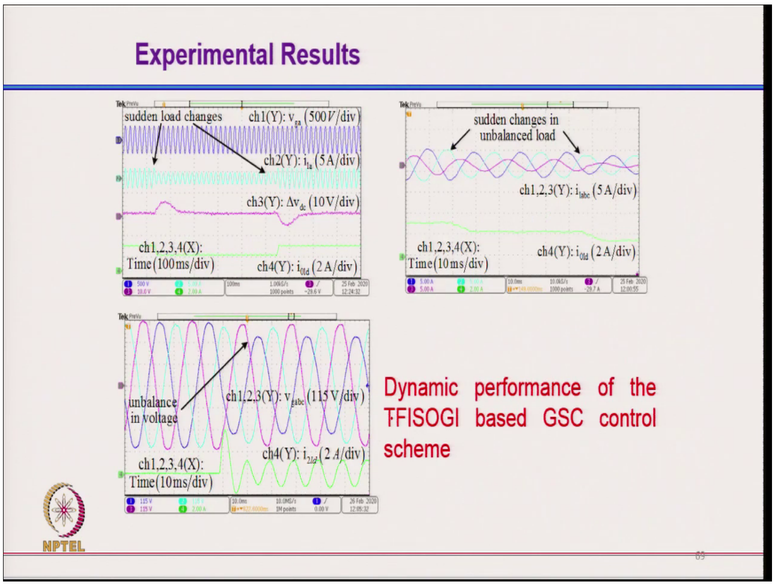

And this is typically the sudden change of the load, when you have a load change how the complete system is changing corresponding to that like.

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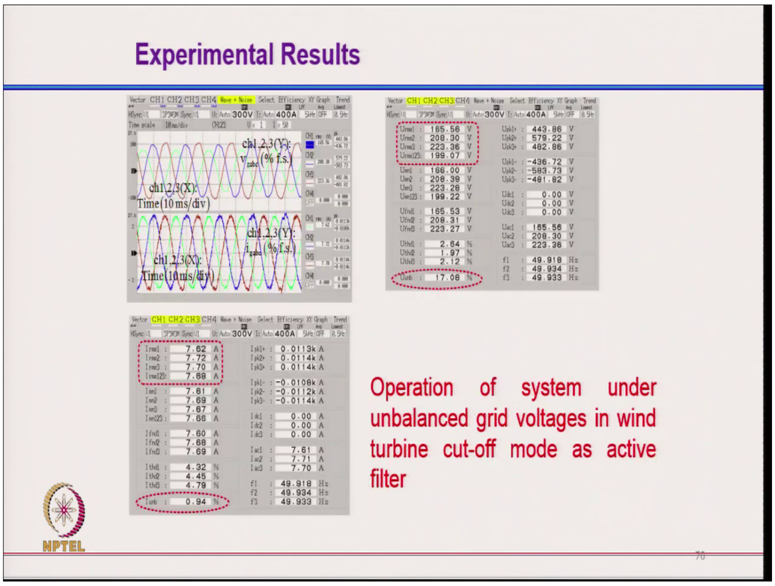

And these are the three phase voltage and currents of.

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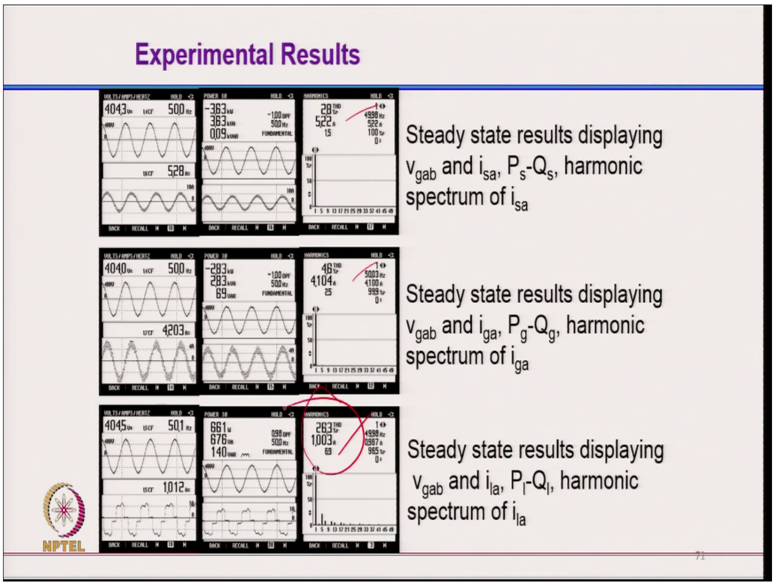

And the total harmonic distortion here in the current is typically less than 5 percent. I mean the typically on the grid side, where the load current is quite high order of 26 percent or so.

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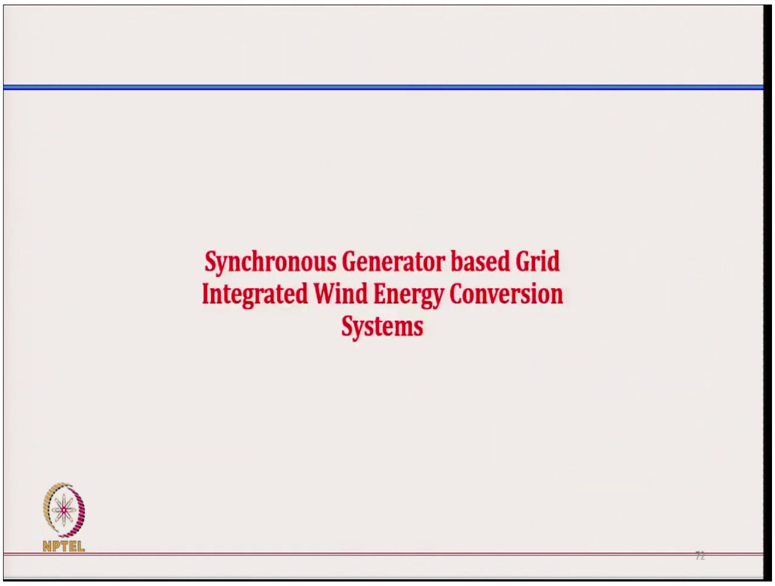

[FL] that is about DFIG. Now, coming to synchronous generator with grid integrated system with typically the enercon is still using.

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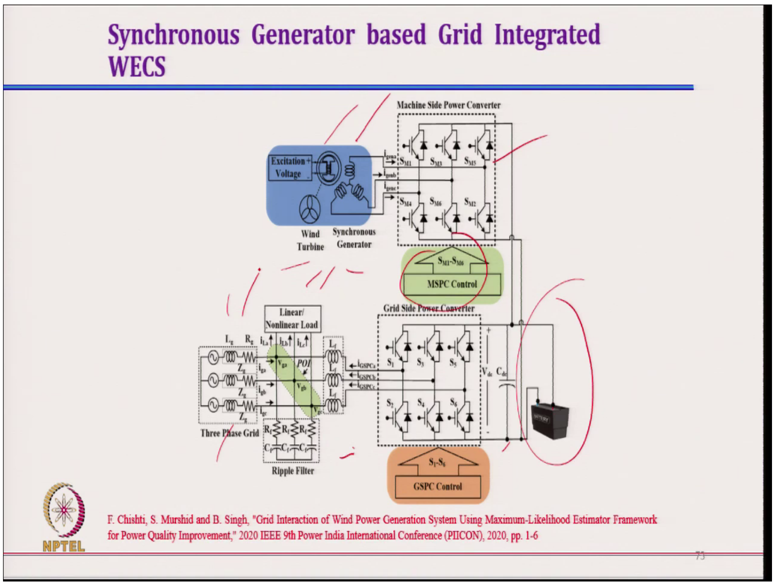

But here we have a let us again the wind energy conversion system with the conditional synchronous generator; but we are using voltage source converter, machine side converter here with the vector control again with the sensor less and of course, we use the maximum power tracking algorithm for the wind power generation. And then, we put on the DC link and which feeds to the power to the grid. Of course, you can have a local load for compensation also, but the grid current sinusoidal and unity power factor.

Of course, you can use the energy storage here so that the fluctuation is either of the typically of the wind generation or the load is not reflected on the grid, [FL] you can feed the even the constant power to the grid like on.

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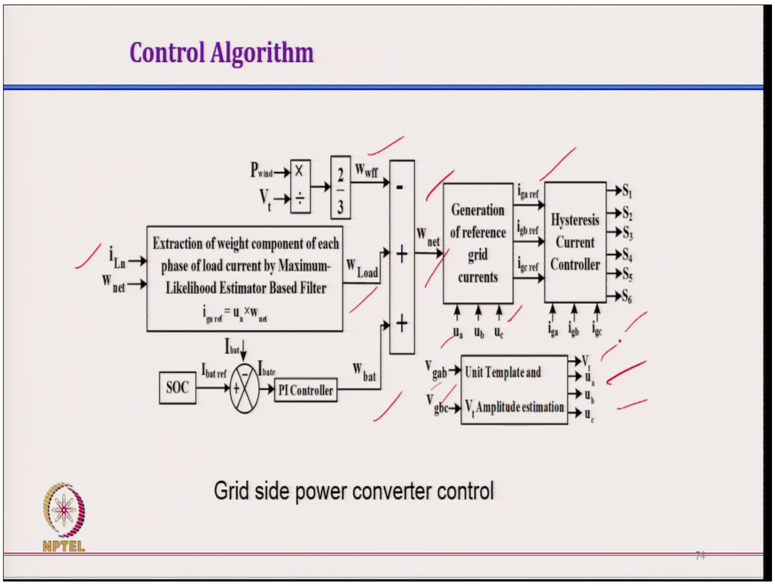

And this is the typical algorithm that you have a fundamental extraction from the your load current, you have wind with forward term and you can feed the fixed power from the given power from the battery also. I mean [FL] that is coming from there, [FL] you have a net you can call it the weight corresponding to genetic and you have a that is the amplitude we consider on the grid current, you have a template of the grid current and you have a reference grid current.

You send the grid current, [FL] you are able to put I mean the this power to the grid with the sinusoidal current and balance current at unity power factor. Because you are generating in reference to the typically in the grid voltage, [FL] line two line voltage are sense and which are converted into phase voltage and from phase voltage, we generate template as well as the amplitude of the voltage like.

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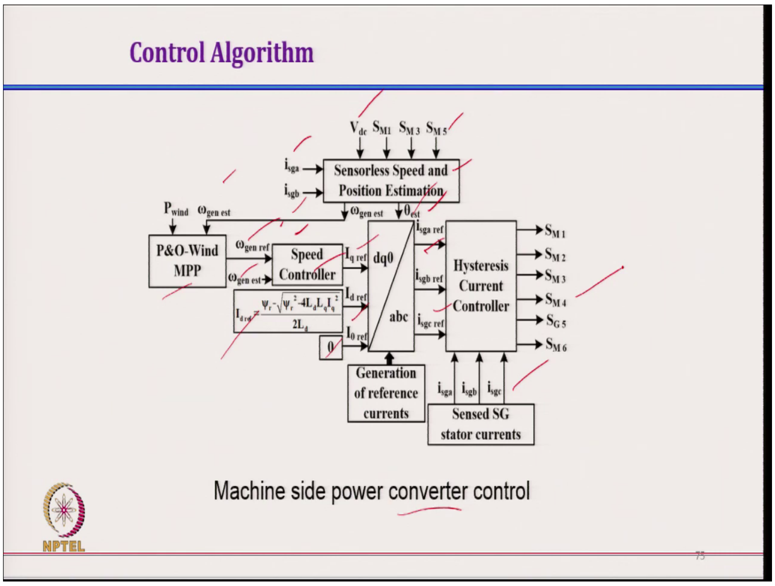

And this is the typical algorithm corresponding to machine side power control. [FL], there are typically you can call it the we have a by sensing the DC link and two generator current, we are able to have from the switching the estimation of speed and position; I mean we have a position and a speed estimator and from speed and from this, we are able to get perturbing observed maximum power tacking algorithm which gives the wind speed.

We have typically a estimated you can say this is estimated speed, [FL] we have a speed controller to have indirectly implementing the this maximum power tracking which give a torque producing component and we have a flux producing component for unity power factor, here for conventional synchronous machine.

And of course, zero sequence is 0, [FL] this d q is converted from typically from position angle two into three phase reference, typically the synchronous generator current and we have a sense synchronization for vector control and which generate typically the gating signal for this maximum power tracking for the wind power generation machine side control.

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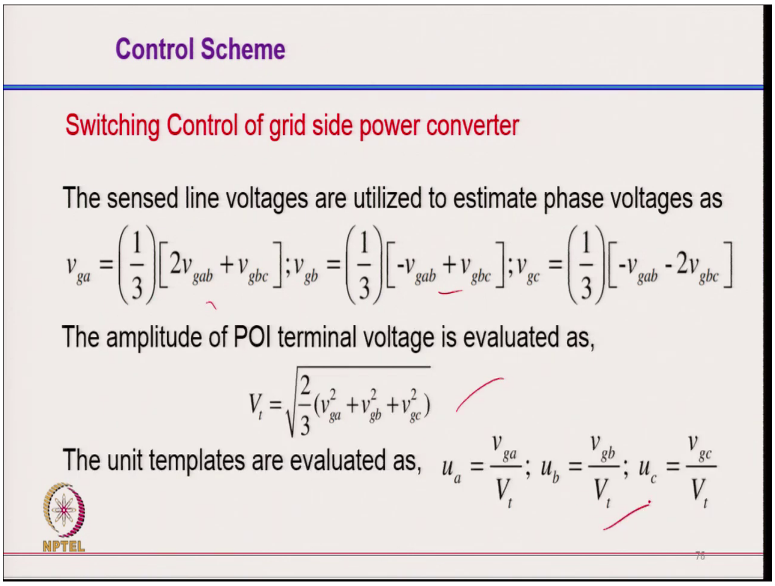

And this grid side converter which sense the typically the line voltage and convert to phase voltage. Then we calculate the amplitude and we calculate the amplitude on grid side converter.

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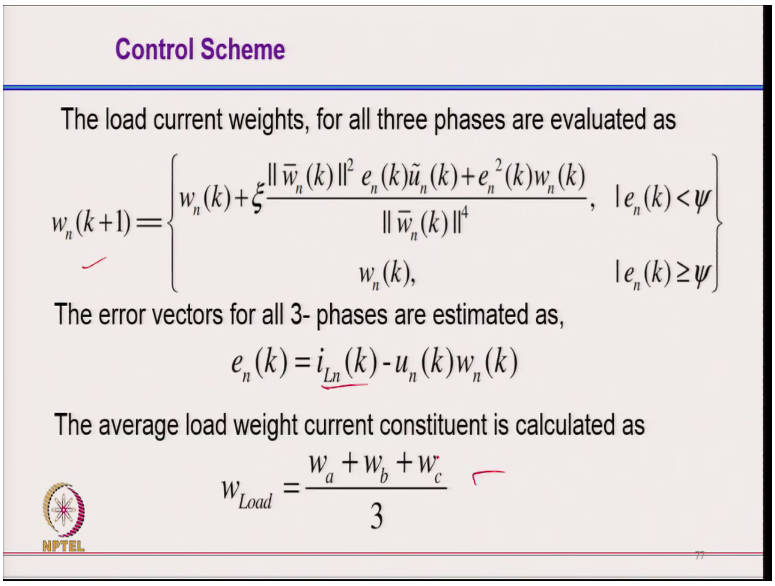

And we extract certainly the fundamental component from the load current; I mean that is typically the load current, we extract from using this filter and we average it for load balancing.

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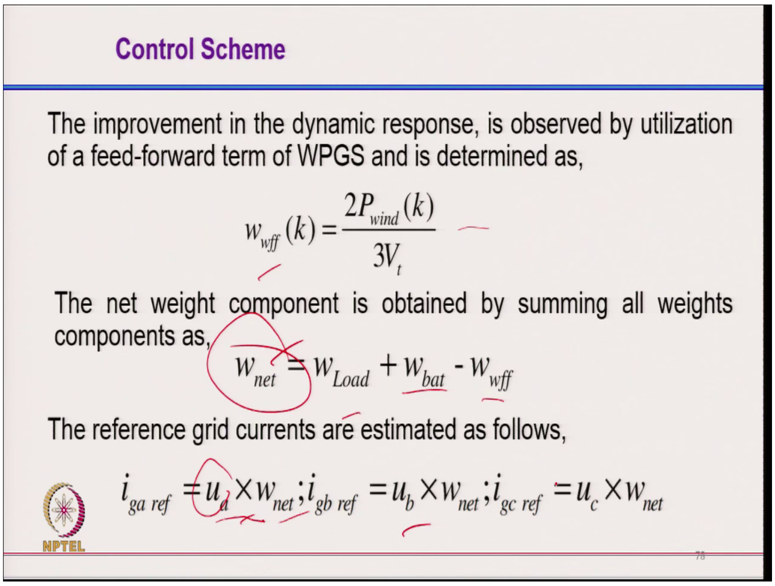

And then, this is the feed forward term for the wind and we have a feed forward term from the battery and wind and this the load. [FL], this we get the weight corresponding to grid current and then, we have a reference grid current multiplying the weight and this weight and from the template. [FL], these three phase grid current are compared with the sense grid current and we generate the gating signal like.

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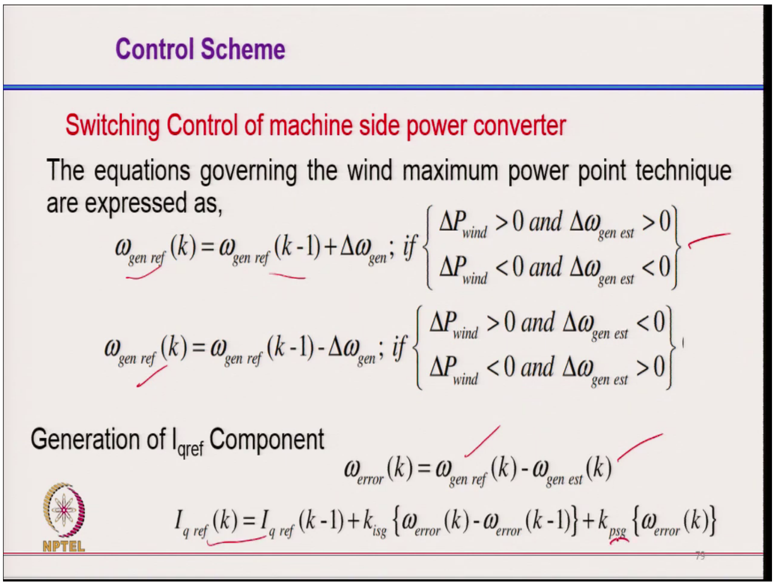

This is typically switching of machine side control for maximum power tracking how the maximum power tracking algorithm is utilized for the estimating the speed, reference speed for wind power generator; I mean depending upon the similar to like what we do even for even the solar in the same manner. And then, we are able to have a from reference speed, we are generating from maximum power tracking algorithm and we have a extremity speed and we are able to have a torque producing component from using the PI controller that is the torque producing component of your synchronous machine.

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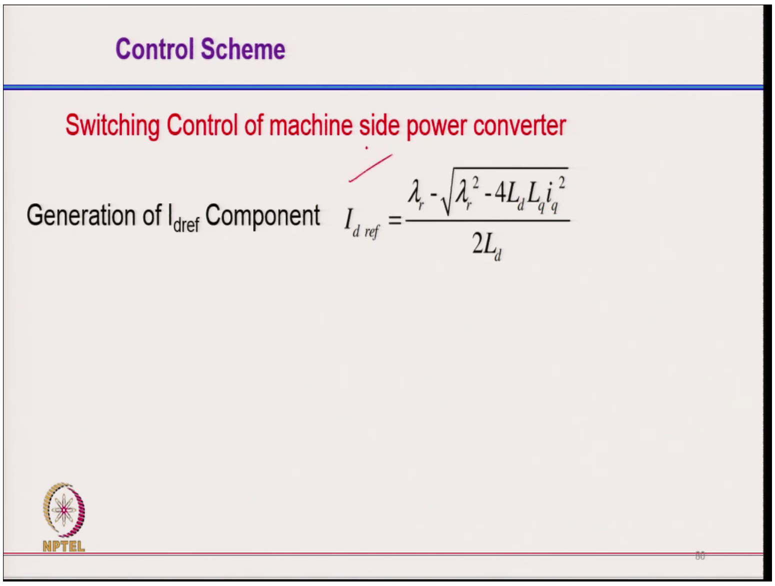

And we have a d-axis component corresponding to unity power factor.

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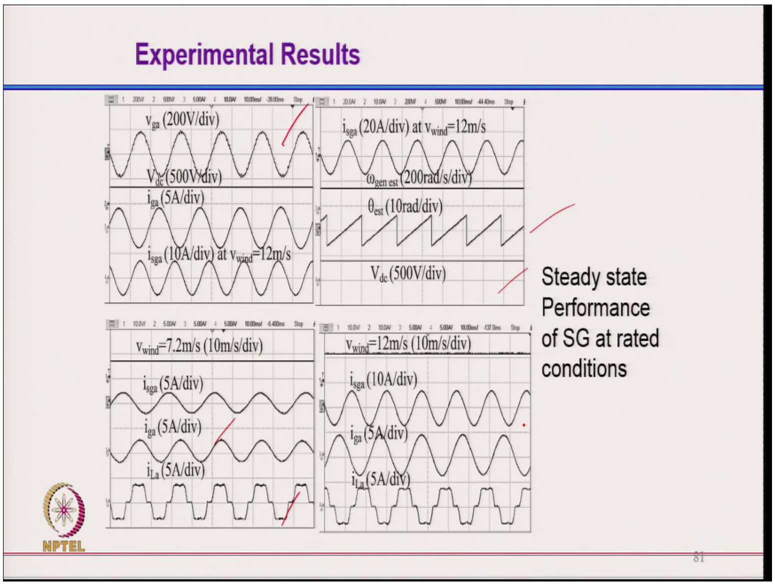

And that algorithm is implemented and these are the typical result of you can call it the typical grid voltage grid current, I mean like here and the typically, estimated position and typically the DC link voltage, load current, and the grid current. Load current is non-sinusoidal, but grid current is sinusoidal and these are the typically the signal corresponding to reference current and grid current like.

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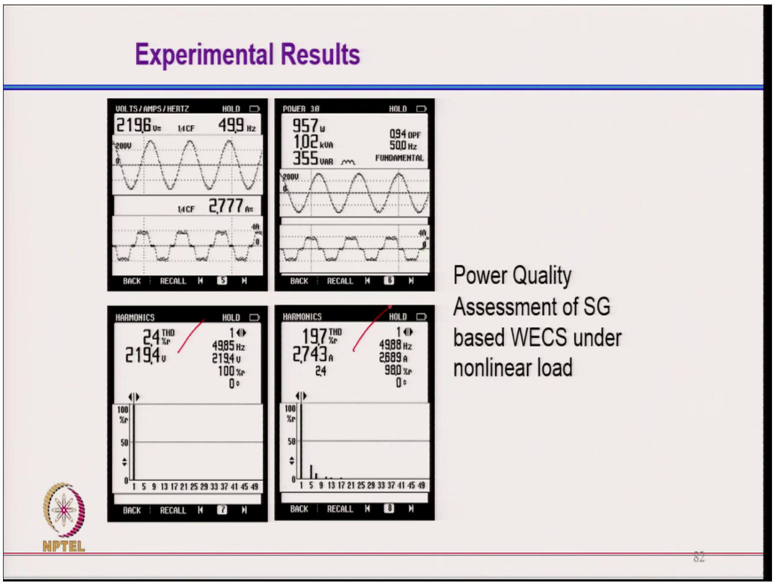

And these are you can clearly see here the t THD of the in islanding mode is THD 2.4 percent, when the your load current THD is 19.7 percent like is able to improve the power quality.

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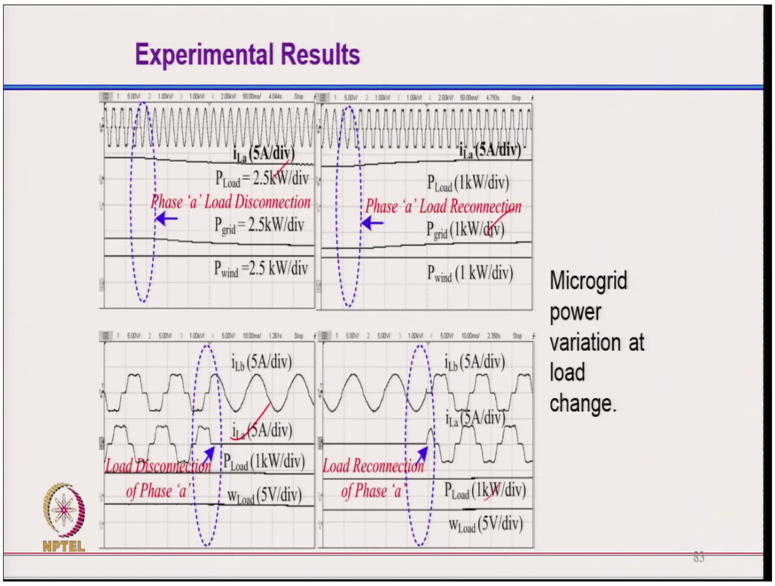

And when you are having a typically varying the here the load, I mean like load change; I mean when you have a load change, I mean like [FL] reference load current for intermediate signal is change here, when you apply the load it increases. And accordingly, the your reference grid currents are changing like.

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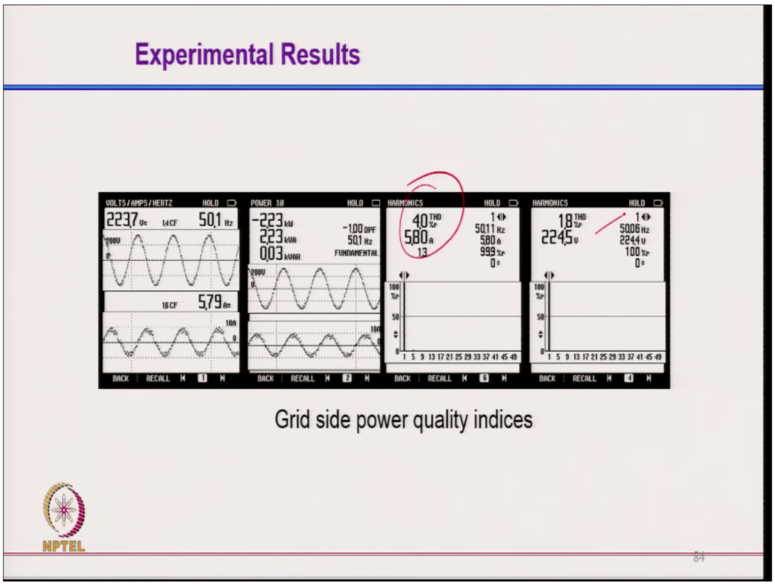

I mean typically like and these are you can clearly see the THD of the grid current is 4 percent, where the voltage is also only you can call it 1.8 percent like.

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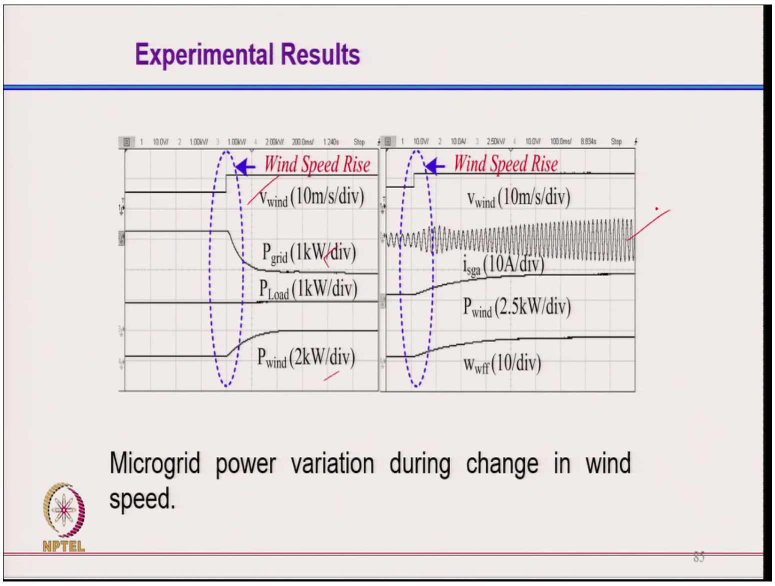

And this is the variation when the wind speed increases, [FL] the grid power is also increases; the total power remains, [FL] because the wind generation have increased and how the grid current is increasing because of the increase wind generation like.

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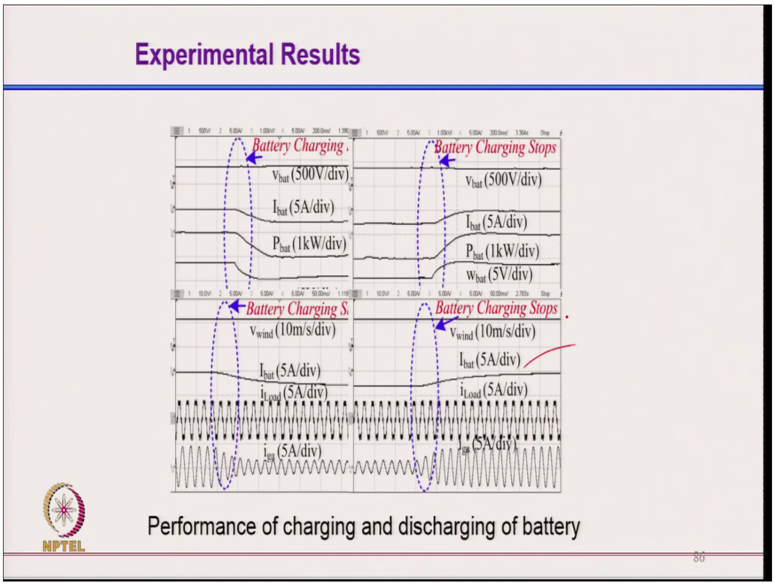

And then, when you have a decrease typically the batteries start typically charging and discharging depending upon the your power generation from the wind generation like.

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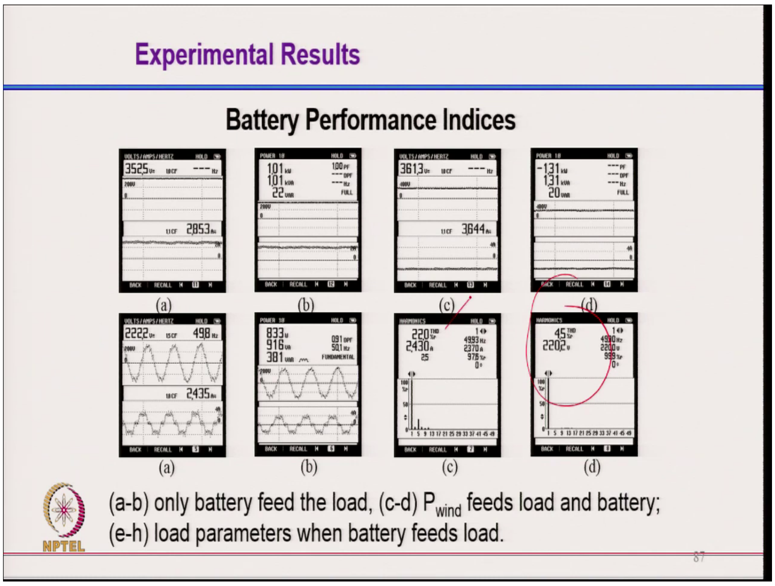

And these are the battery performance, you can clearly see here how the battery is feeding the power and this time and here, the your typically you have a THD of the voltage of 4.4 percent, where the load THD is 22 percent or so.

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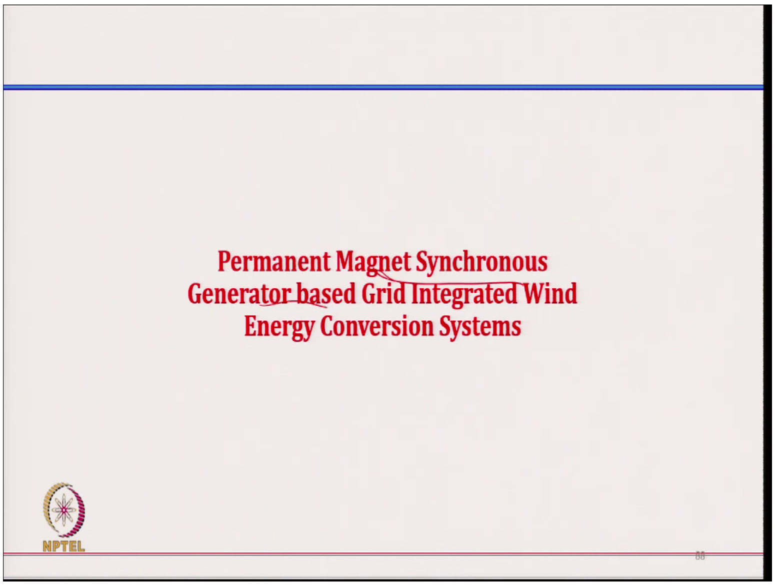

Now, coming to another wind energy conversion system using permanent synchronous generator, why we are taking this permanent generator because it does not it is a you can run even without gear also that is the one of the major benefit and of course, the highest efficiency like I mean.

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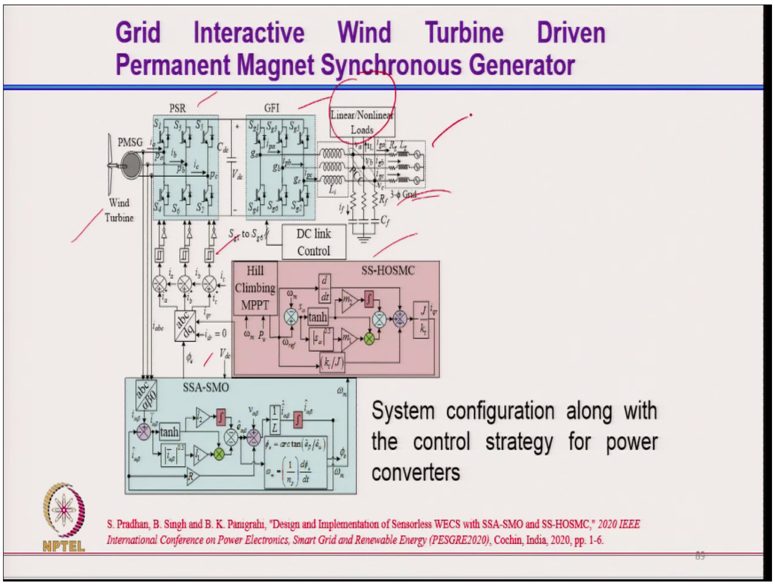

[FL] you have a typically permanent synchronous generator which can run without the gear. If you design really at low speed and then, you have a your machine side converter and grid side converter to feed the power to the grid and you can have a typically where also the sensor less control, I mean typically for maximum power tracking algorithm using this your sliding mode observer like I mean which use here.

[FL] for machine side control, again we use the vector control and for grid side converter we of course, typically maintain the DC link voltage from this because from the wind generation how much power, we are generating that virtually the grid converter will be able to know by control of DC link voltage. And then, we are able to have a load compensation also and to put the grid current at constant, where you can call it sinusoidal and balance current like I mean.

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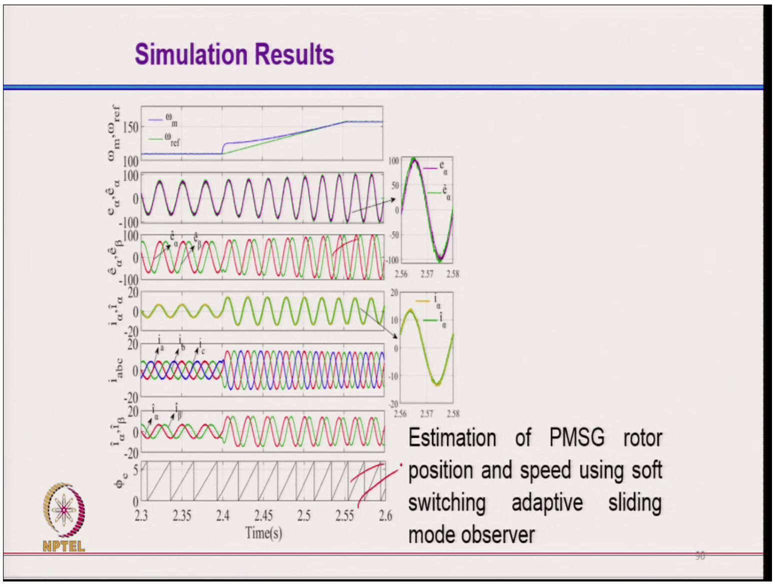

And this is typically you can clearly see the how the estimation is there of the angle as well as position, [FL] we are typically I mean estimating the fluxes, I mean we are sensing the current and DC link voltage, [FL] you can see the estimated speed and position here like I mean.

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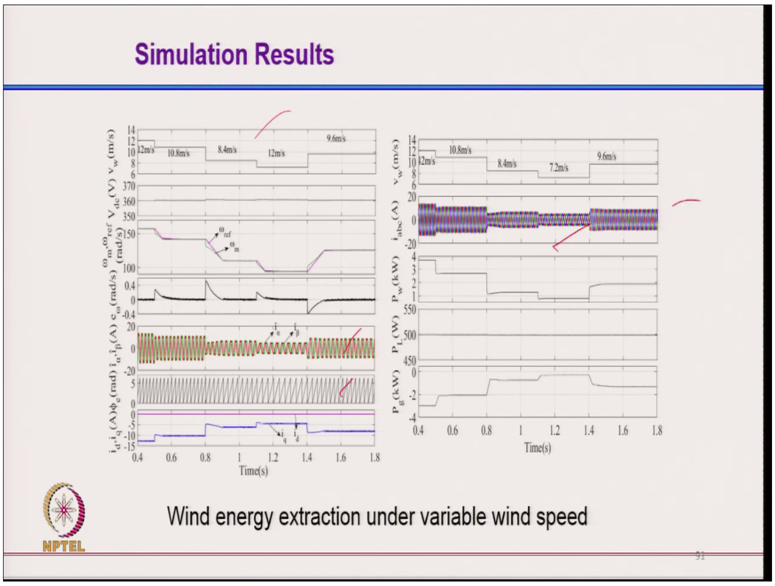

And these are typically the variation in wind energy, wind speed, how the you can call it the even your current of the generators are varying and position is changing like and how the other your typically the your three-phase current of machine are changing with respect and power changing.

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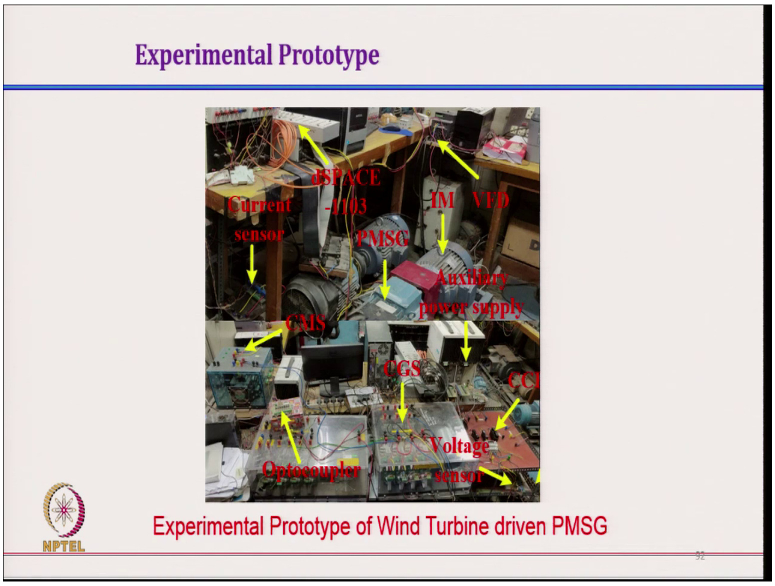

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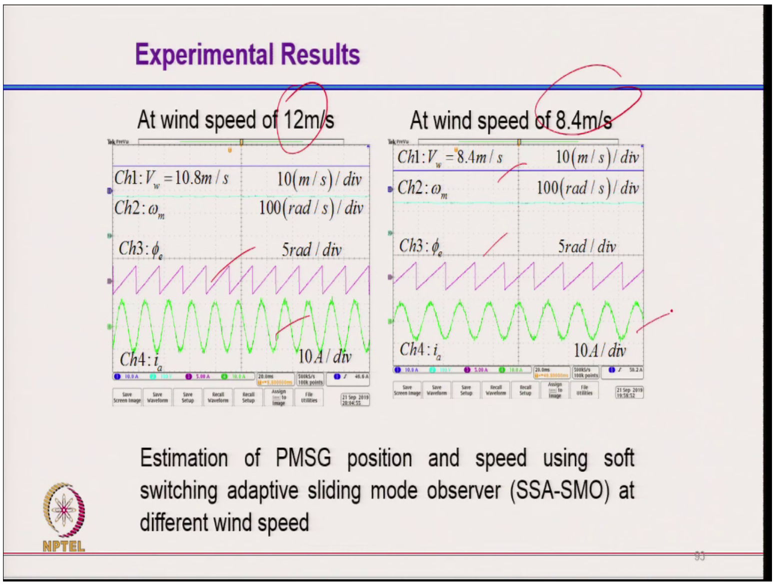

[FL] with the typical setup on which this algorithm is completely tested, [FL] these are the position and you have a current corresponding to the of the generator for a varying wind speed of 12; 12 meter per second and 8.4 meter per second; I mean estimated speed and estimated position for a given wind velocity and then, the of course, the current of the PMSG.

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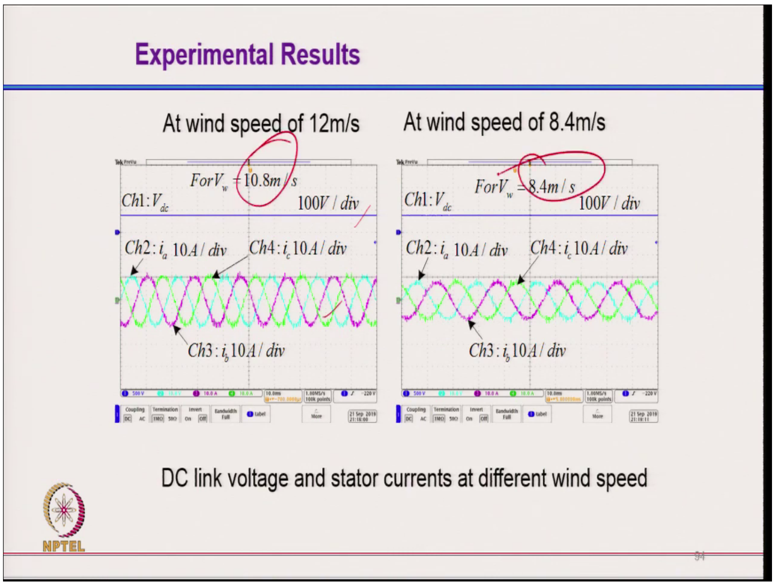

And then, typically you are having a here the again the your DC link voltage and your inverter current for three phases for two different speed variation I mean here.

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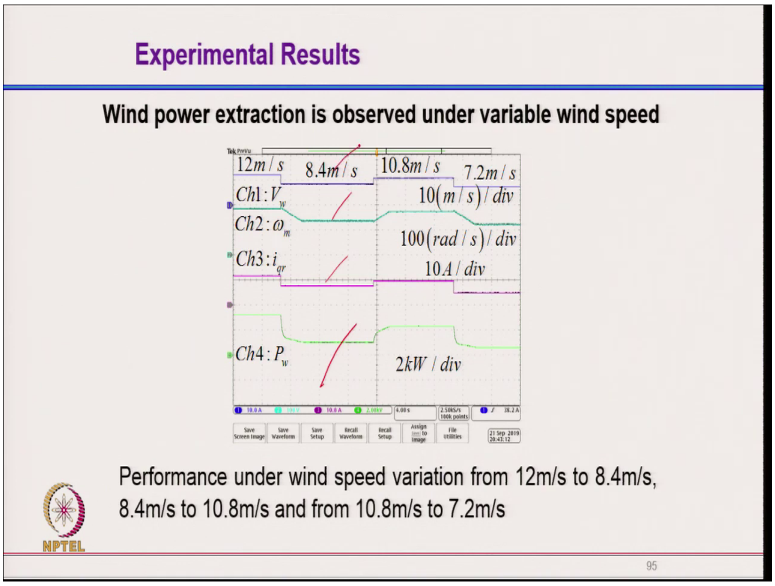

And then, how the you can call it power of the wind generator, you can call it the typically of your reference current wind speed, your estimated speed as well as the wind speed is varying. [FL] that is the effect of dynamics you can call it like.

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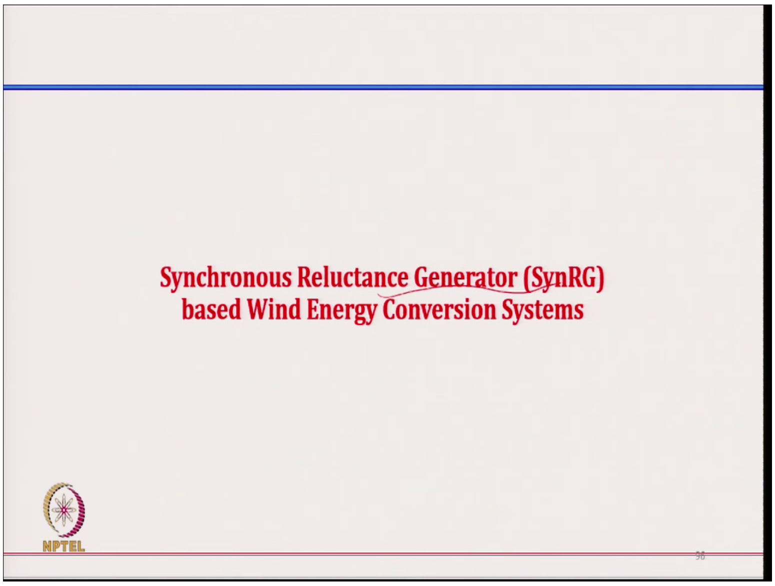

Now, coming to the another generator which have recently come very much by I mean siemen’s (Refer Time: 33:03) which called synchronous reluctance generator which have higher efficiency than your induction is called induction generator because there are no losses.

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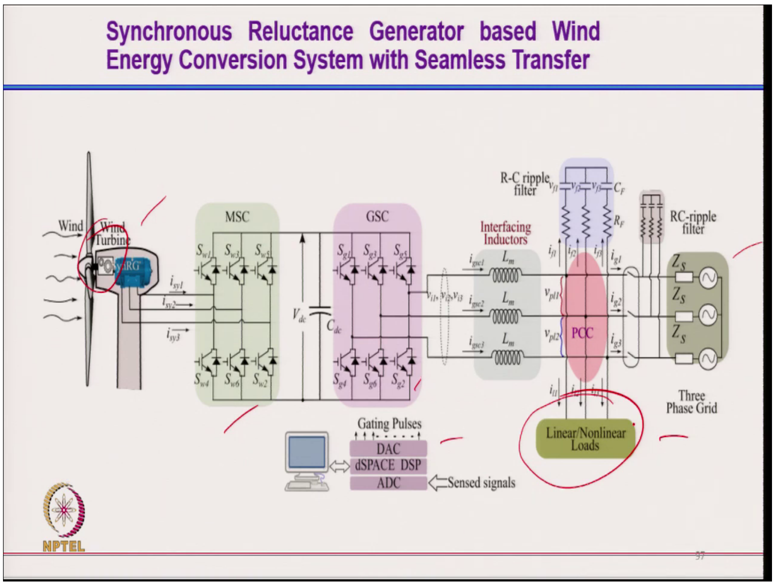

So, this is typically the wind generation with the gearbox and you have a machine side converter, grid side converter connected to the grid. Of course, it feeds at unity power factor sinusoidal, but you have you even you can compensate by this converter, the local load also after that whatever is the fed local load that can go to the typically the grid like I mean.

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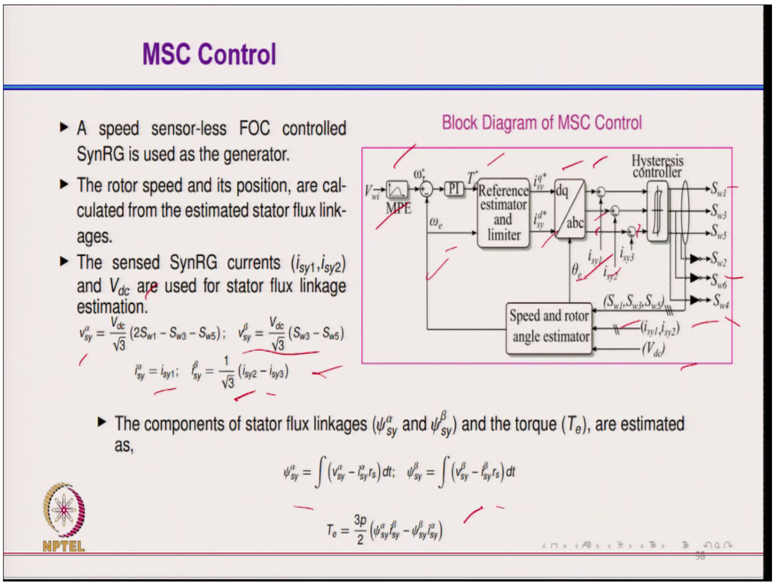

[FL] here you have again concept of maximum power taking from the wind speed, you have estimated speed from your DC link voltage and the two current, you are estimating the speed; you have a reference speed from maximum power tracking algorithm. [FL] you have a speed controller, your torque producing component and from this error we are able to get your two vector control quantity which convert from the position which you estimated to into three phase current of the generator.

And from sense current of the wind generator, you are able to get gating signal for the machine side converter and these are the typical algorithm from DC link voltage, how we are getting the three phase, you can call it the alpha beta voltage and we are sensing the current. [FL] we are getting alpha beta component of the current and from which we are calculating alpha beta component of the flux. And the we are estimating the torque like.

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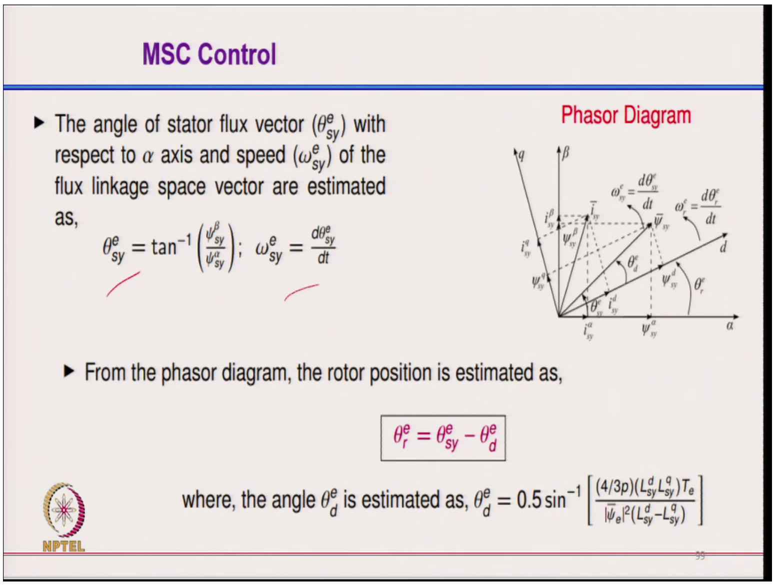

And then, we are able to estimate the position as well as the speed of this like I mean or for that like I mean. [FL] that is typically from the phasor diagram, you are able to get different angles.

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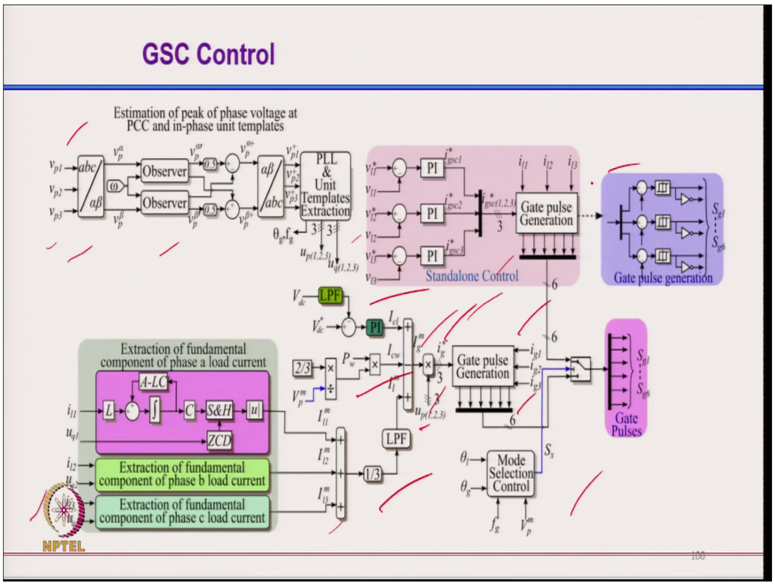

And these are of course, the you can call it like a typically the estimation of the point of common coupling voltage, we are sensing and from this observer, we are able to estimate again here alpha, beta and from which we are able to get PLL. [FL], we get the typically frequency and phase for the kind of synchronization as well as for the control like. [FL] this is typically grid current I mean reference and we have a sense grid current and we control this converter and this is the typically the you can call it load current extraction which is required typically.

[FL] we have a DC link voltage control, we have a wind free power term and we have a load I mean local load feeding, [FL] we get a reference grid current ok. Here, amplitude multiplied the phase, [FL] we get three phase rate, you can call it grid current and we have a sense grid current, [FL] we get the gating signals over the switches like I mean which even you can synchronize with the this these signals like that operates in typically in islanding mode like.

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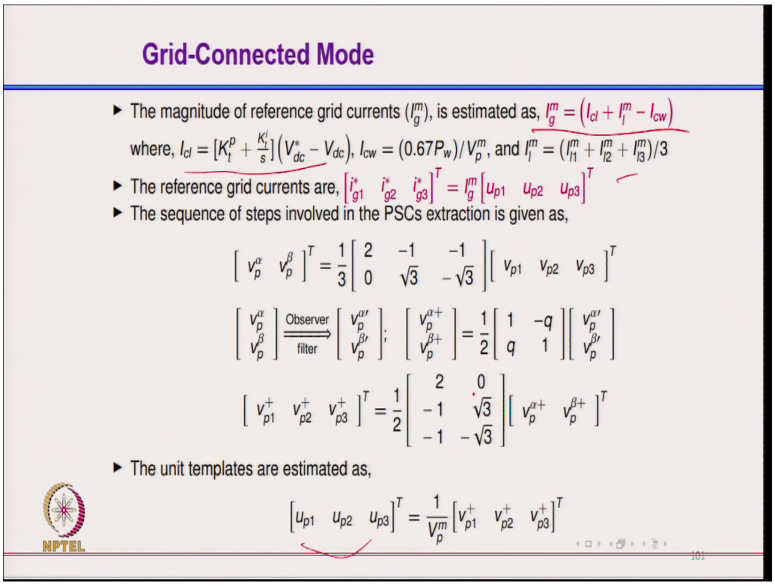

[FL] these are this typically that your having a DC link voltage controller, I mean from PI controller. Then, you have a typically corresponding to the wind generation. This is for load compensation and that is your reference grid current multiplying the template, you get the three phase current. These are the template calculation from the sense voltage, phase voltage, line voltage.

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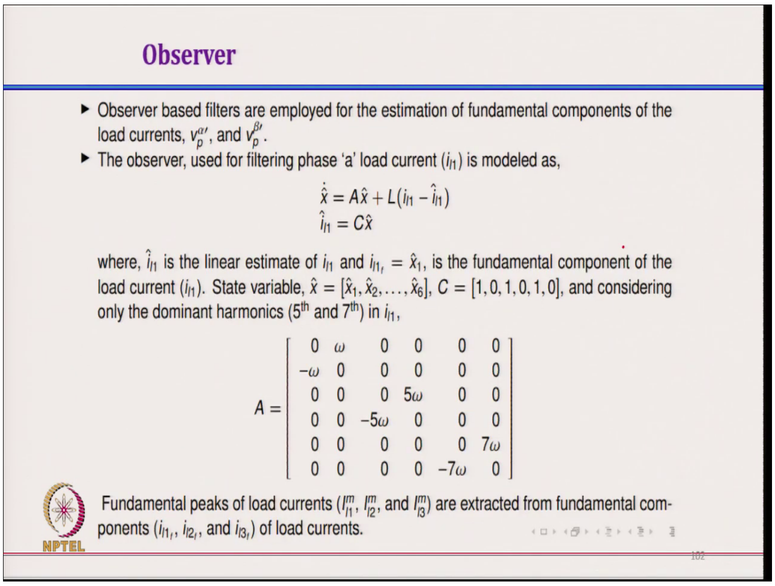

And this is the typically the observer from which we are getting the position and speed from this observer.

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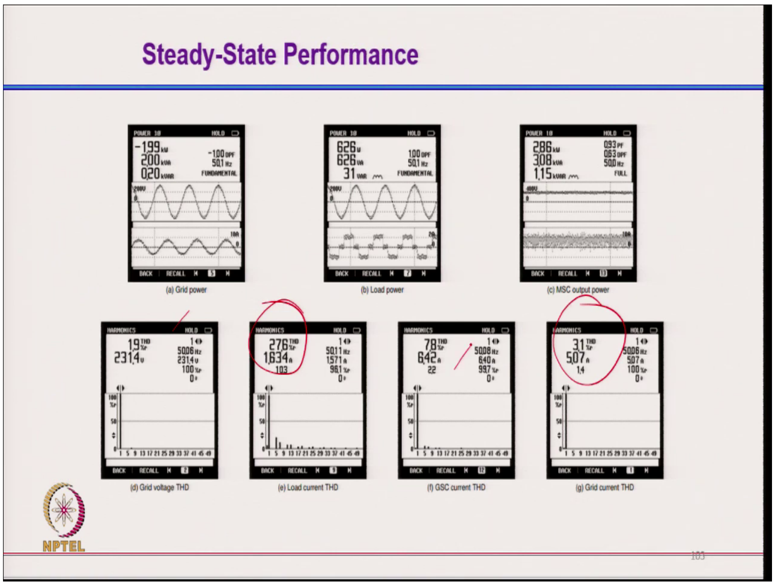

And this of course, this is tested; [FL] you have a typically you can call it here the your voltage THD and it is a load THD, I mean like and here the you can call it the grid current THD. This is of course, converter current THD or so.

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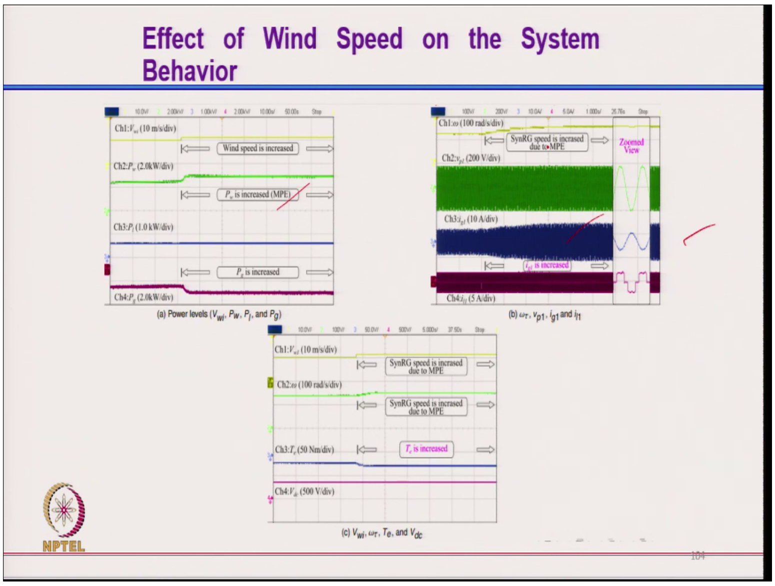

And then, this is the dynamics when you have a change in the your wind generation as wind speed increases, wind generation increases and these are the typical currents like on the grid side which increases and grid voltage remain the same like I mean or so.

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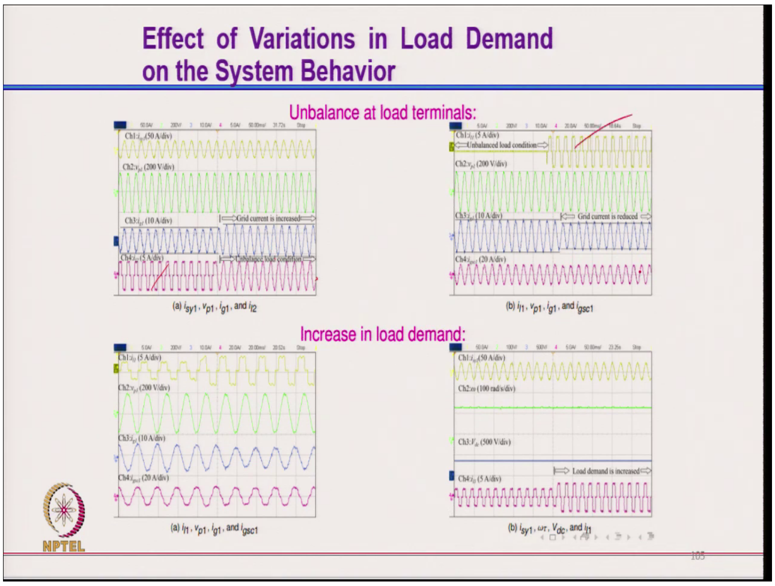

And during, this is typically the enlarged waveform for typically you can call it the variation on the load demand and load changing. I mean like one phase load is removed that is the reason form square waves go to typically quasi square wave to go to closer to like a. And here the load is you can call it is removed. Here load is applied. [FL], these are dynamic performance because of the load change, here like all load increase.

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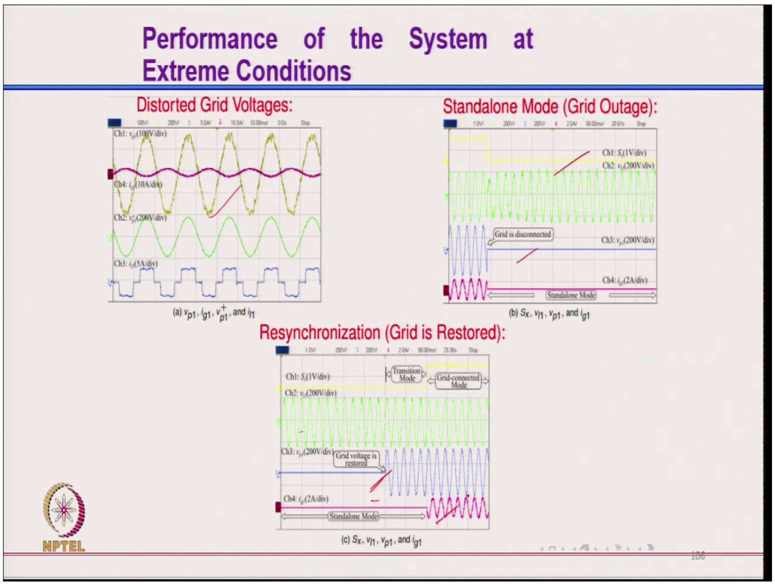

[FL] and how the different quantity of the complete load is removed, load is added I mean synchronization. I mean this is standalone mode; this is I mean distorted grid voltage and here, it is the synchronization. When you are having grid voltage here, typically grid is appearing here and grid current is starting, [FL] it takes four to five cycle to grid synchronization.

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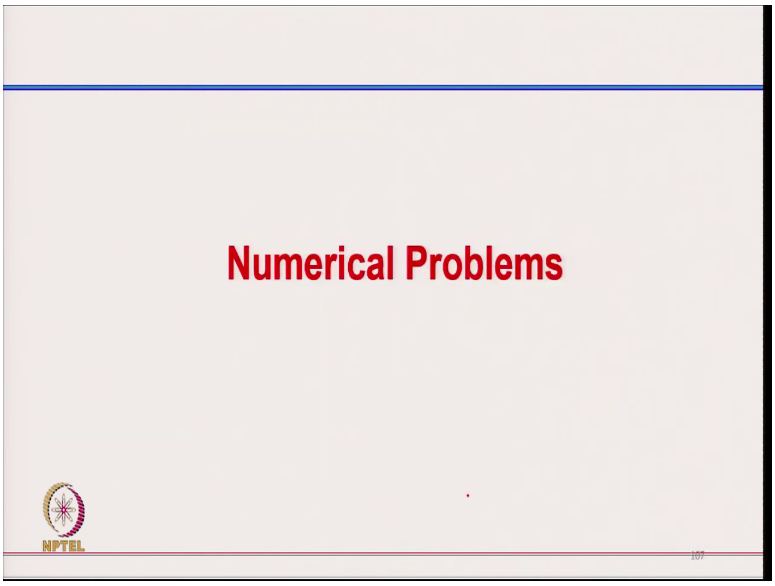

[FL] these are typically the different wind energy conversion system where power quality improvement, let us come to the numerical problem.

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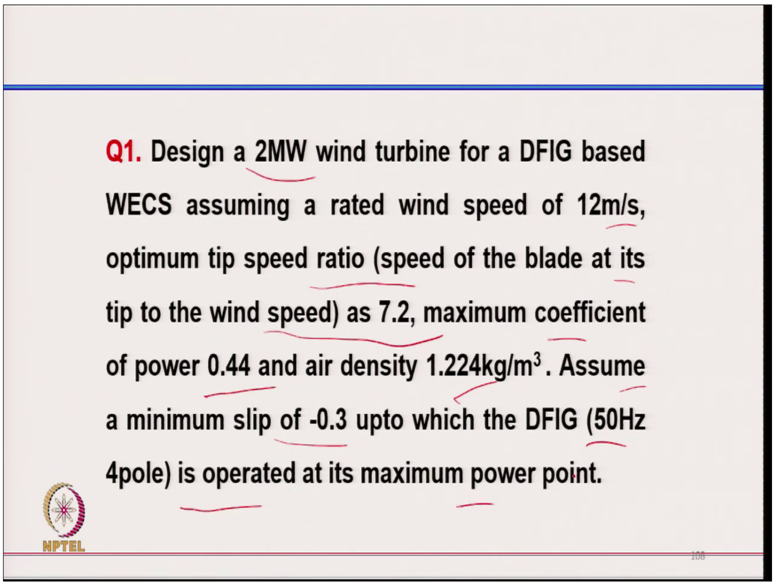

[FL] coming to first, design a 2 megawatt wind turbine for a doubly fed induction generator based wind energy conversion system considering a rated speed of 12 meter per second with optimum speed ratio of speed of blade at tip angle of 7.2. And maximum power maximum coefficient of power is 0.44 and air density is 1.244 kg meter square. Assume a minimum slip of minus 0.3 percent up to which the DFIG, 50 hertz 4 pole is operated its maximum power point.

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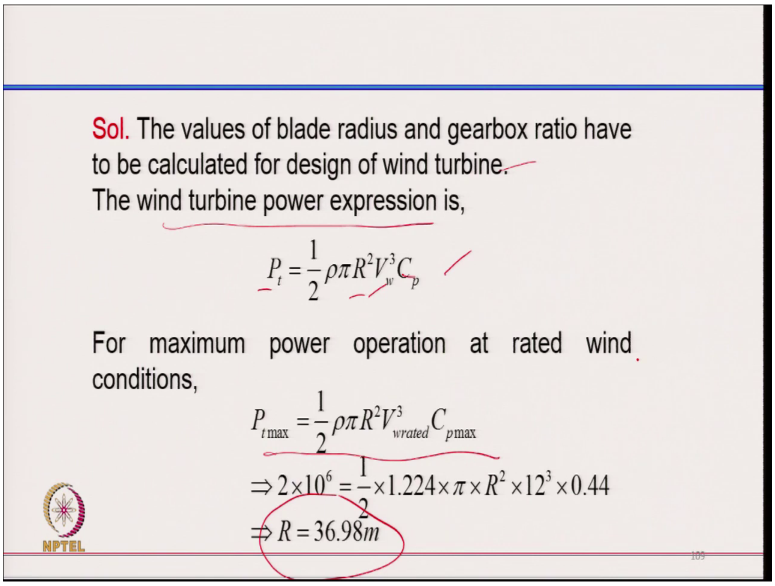

And typically, the here the solution. The value of the blade radius and gearbox have to be calculated for the design turbine. [FL] this is the wind turbine power extraction, where these are the wind velocity; I mean diameter of the wind and this is the output power with the coefficient of I mean. [FL] from here, in putting all the data relation, we get the typically the here the you can call it the radius of the wind turbine from the for given power like of. Here, about 2 megawatt I mean like so here.

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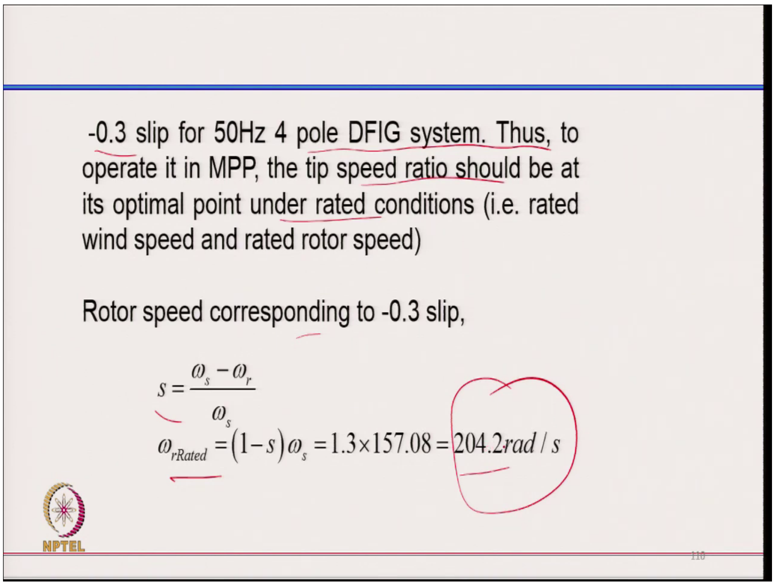

And coming to with the 0.3, minus 0.3 slip for 50 hertz 4 pole DFIG, operate it at MPP, the tip speed ratio will be optimum. [FL] from this slip relation, we are able to get the you can call it rated speed from this and we get the here, the speed of the machine 204.2 radian per second.

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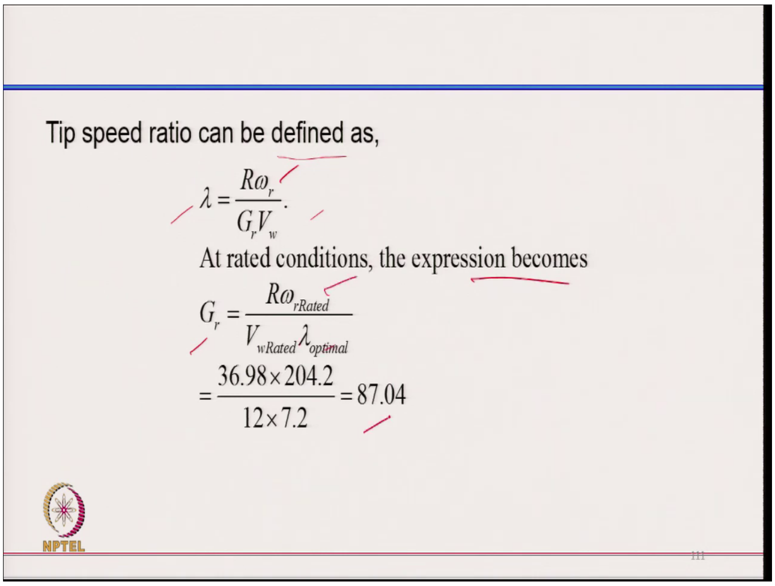

And the speed ratio can be calculated from the radius and the rotor speed and wind velocity can coefficient. [FL], we get from here the expression becomes for this coefficient, it comes from putting the value, becomes 87.04.

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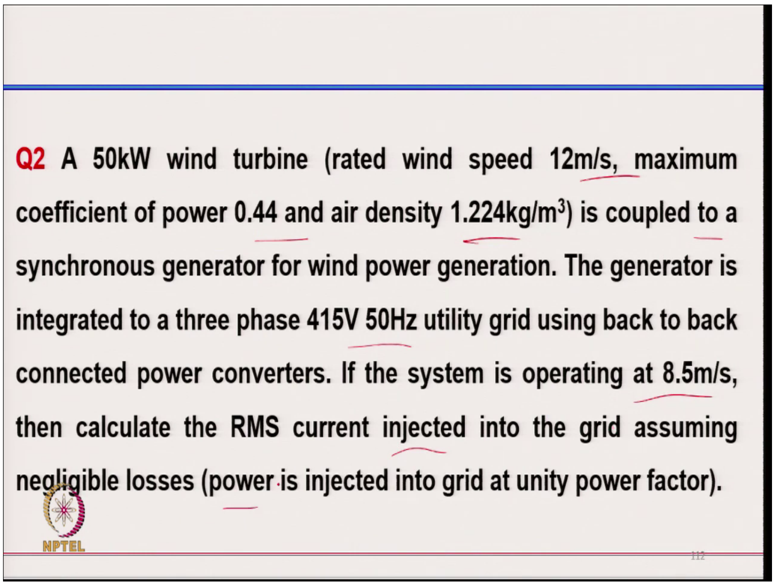

Now, coming to second example. A 50 kilowatt wind turbine rated wind speed of 12 meter per second, maximum coefficient of 0.44 and the air density of 1.224 kg meter cube is coupled to a synchronous generator for wind power generation and the generator is indicated to three phase 415 volt, 50 hertz utility grid using a back to back connected power converter. If the system is operating at 8.5 meter per second, then calculate the RMS current injected into the grid assuming negligible losses and power injected into grid at unity power factor.

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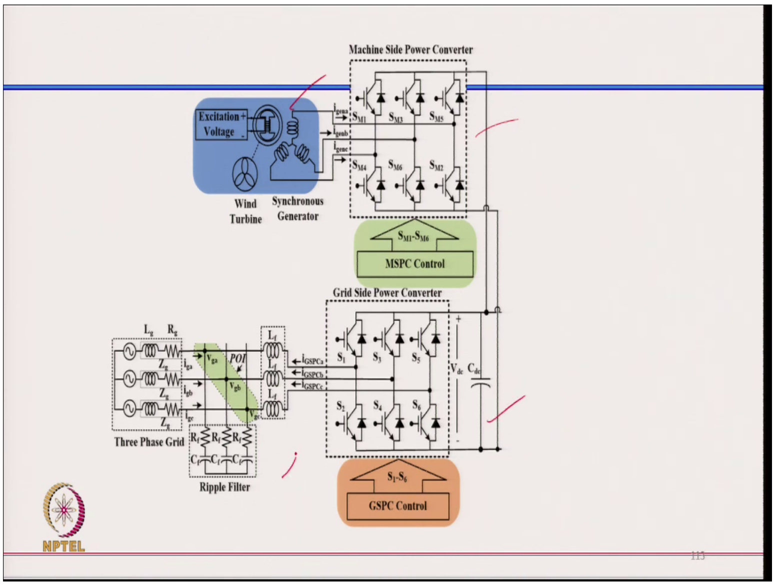

The typical system that we have a synchronous generator with a converter and this is grid current side converter, this is a machine side converter and connected to the grid.

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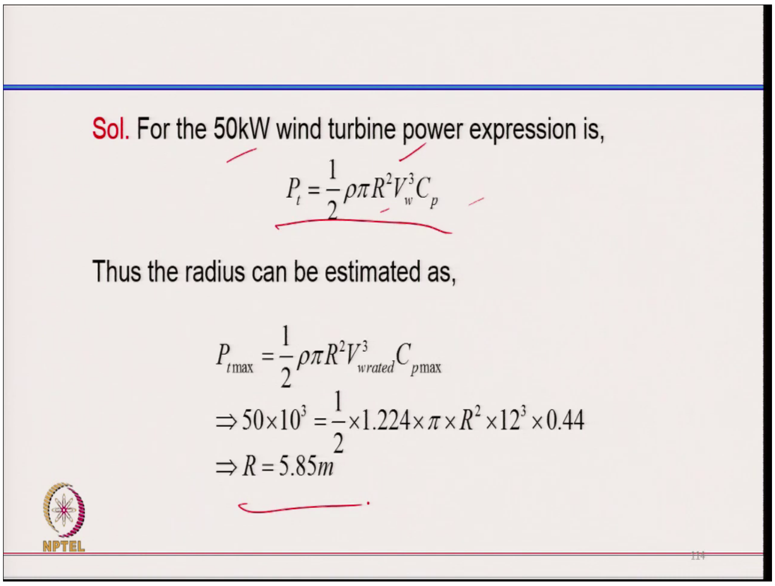

And for a 50 kilowatt, this is the power relation in terms of wind velocity, radius of the wind turbine and coefficient power coefficient and from this, we can find out the radius of typically of the wind turbine.

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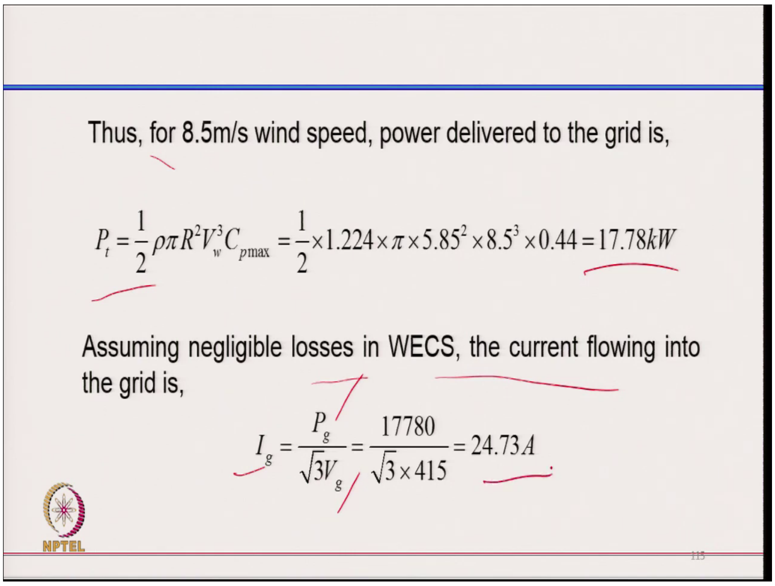

And from this same power relation for another speed, I mean we are able to get the power for another speed 17.78 kilowatt and assuming the lossless, I mean negligible losses, we are able to get the grid current from power and from this voltage that is the typically grid current of 24.73 ampere.

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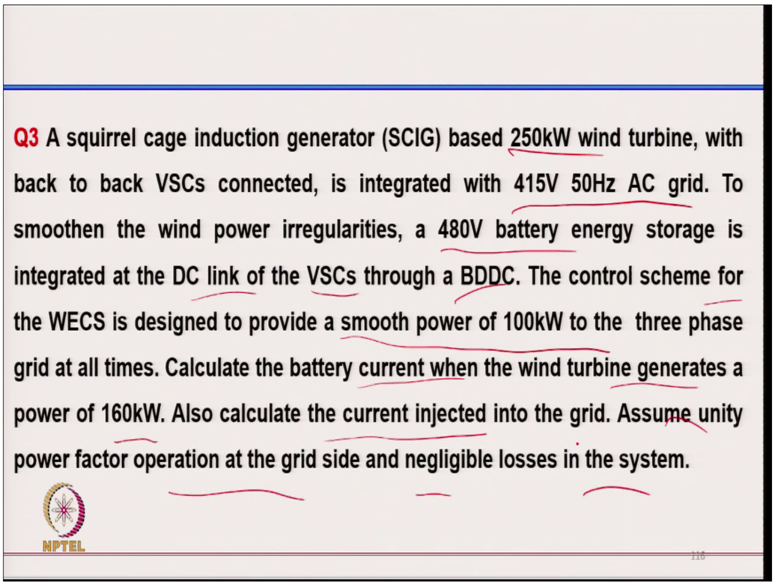

[FL] coming to an third example. A squirrel cage induction generator based 250 kilowatt wind turbine, with the back to back connected converted is integrated to 415 volt, 50 hertz supply. To smoothen the wind power irregularities, a 480 volt battery energy storage system is integrated at the DC link of the voltage source converter through a bidirectional DC-DC converter and control scheme for the wind energy conversion system designed to provide a smooth power of 100 kilowatt to the three phase grid at all time.

Calculate the battery current when the wind turbine generates the power of 160 kilowatt. Also, calculate the current injected into the grid. Assume the unity power factor operation grid side and negligible losses.

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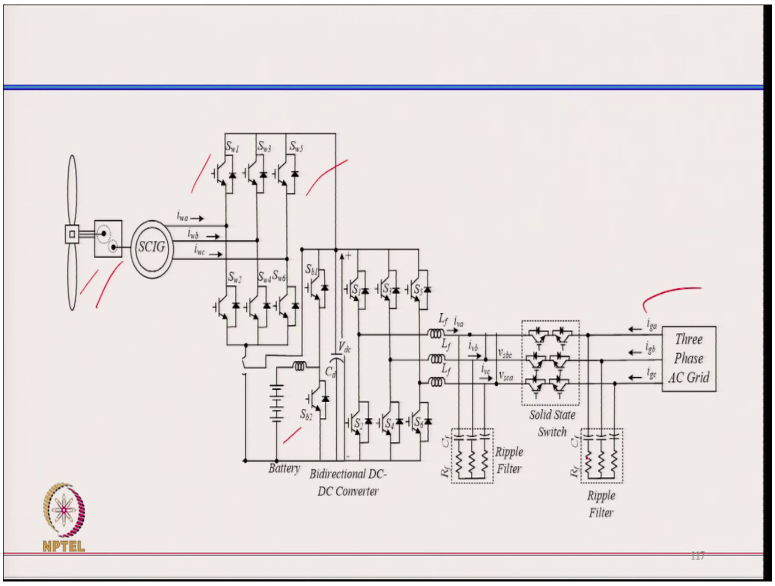

[FL] these are typical system, we have a squirrel cage machine with the gearbox wind turbine and then, we have a machine side converter, we have a battery which is smoothen the power which required the DC generating typically 160 kilowatt; but we want 100 kilowatt on the grid side, [FL] this is a typical total system.

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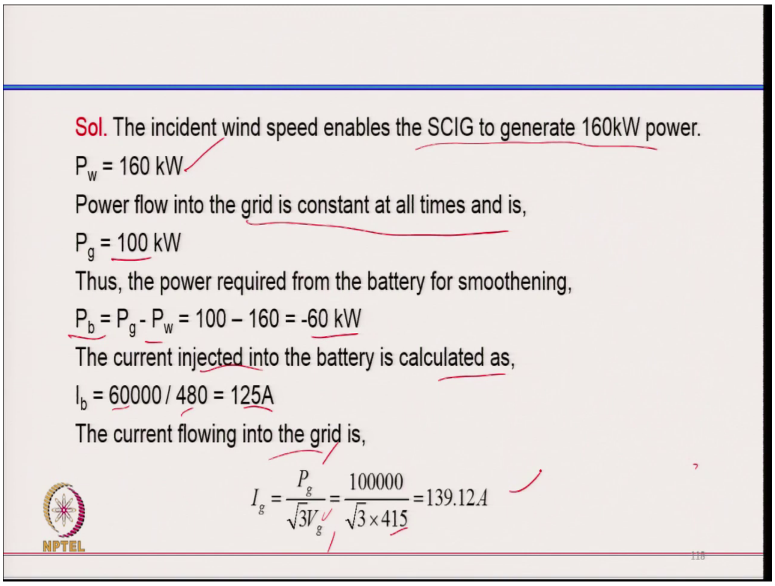

And coming to the solution part. The incident, we dispute actually enable squirrel cage generator to generate 160 kilowatt power that is given and power flow to the grid is 100 kilowatt. [FL] we know the battery power from P g minus P l, [FL] which comes with minus 60 kilowatt and the current injected to the battery from power divided by voltage, [FL] it is 125 ampere and the grid current from power divided by at unity power factor root 3 into your grid voltage RMS. [FL] it comes 139.12 ampere like.

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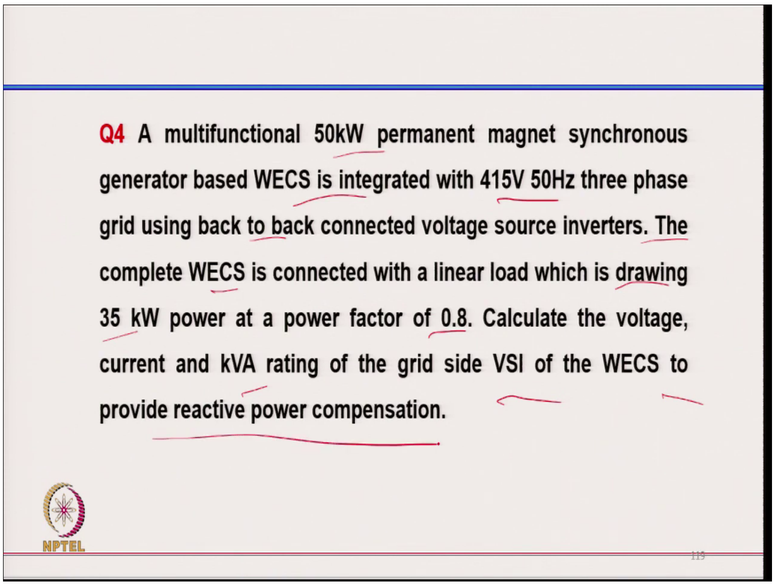

[FL] coming to fourth example. A multifunctional 50 kilowatt permanent magnet synchronous generator based wind energy conversion system is integrated with 415 volt, 50 hertz three phase grid using the back to back connected voltage source converter and the complete energy conversion system is connected with a linear load which is drawing 35 kilowatt power at a power factor of 0.8. Calculate the voltage current, kVA rating of the grid side voltage source converter of the energy conversion system to provide reactive power compensation.

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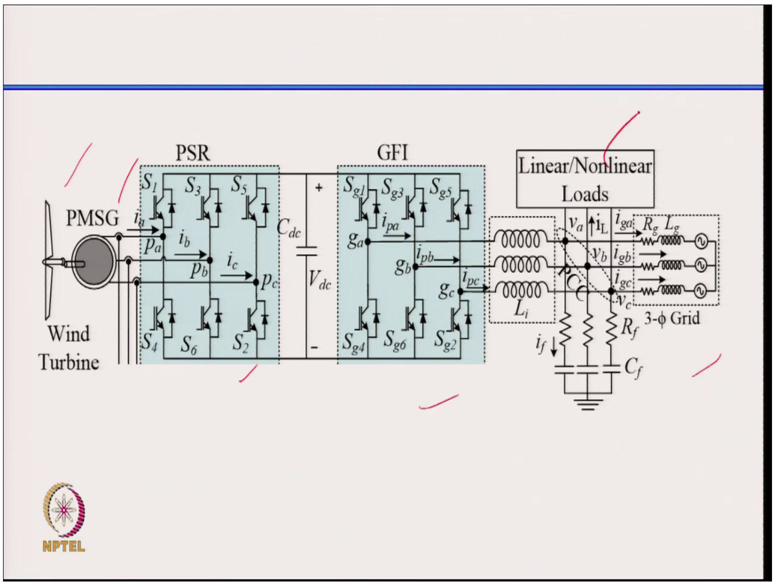

[FL] this is the typical system. We have a wind turbine with permanent synchronous generator and we have a this you can call it the machine side converter and you have a grid side grid fed converter, fitting there, we have a local load fitting this grid side; so, that the system.

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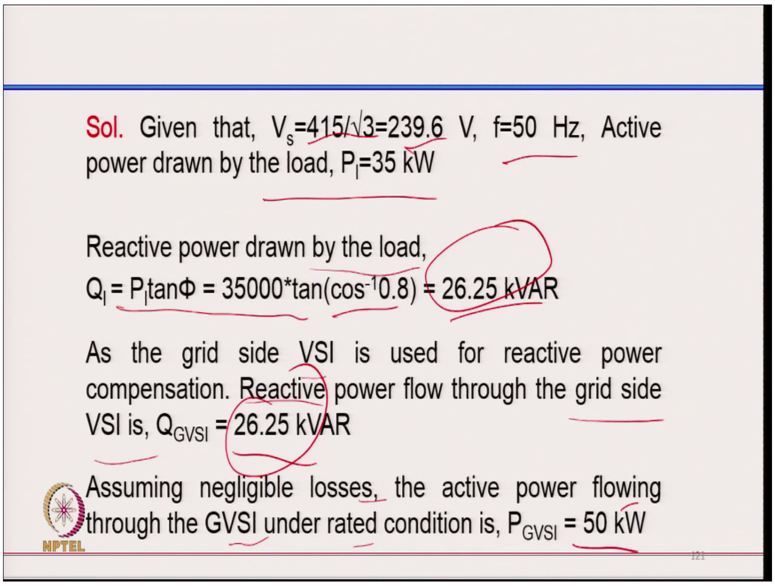

So, we have a line voltage 415 on the grid side, [FL] phase voltage becomes 239.6, frequency is 50 hertz and active power drawn by the load is 35 kilowatt, [FL] reactive power drawn by the load is we can find out from point eight lagging power factor. [FL], this comes 26.25 kVAR. As the grid side voltage source converter is used to reactive power compensation, [FL] reactive power through the grid voltage source converter is this; typically, the load reactive power and assuming the negligible losses, the active power flowing through the grid, so volt grid fed voltage source converter is the typically the power 50 kilowatt.

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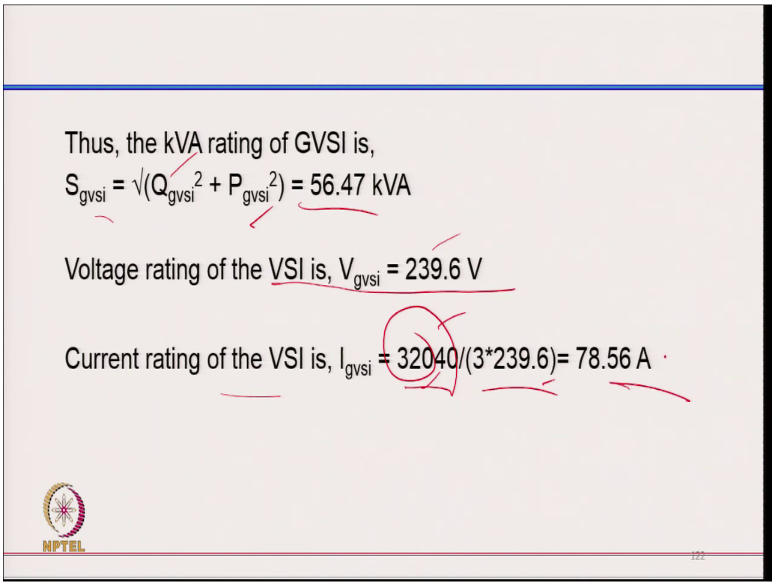

And we can find out the grid side voltage source converter p Q square plus P square. It come putting the value fifty 56.47 kVA and voltage rating of course, of VSI is same as the grid voltage that is phase voltage 239.6 volt and the current rating, we can calculate from the power divided by 3 into kVA divided by typically from 3 into its unity power factor with the power, [FL] 78.56 ampere.

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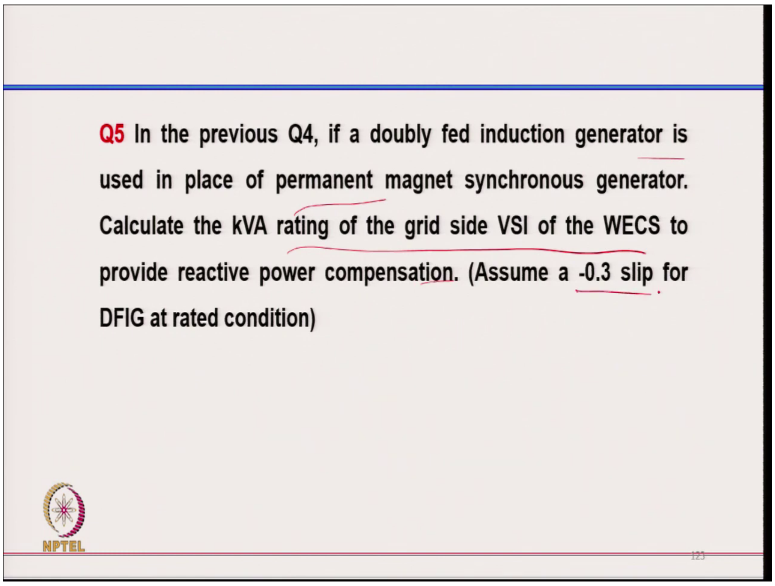

[FL] coming to fifth example. In the question 4, if the doubly fed induction generator is used in place of magnet synchronous generator. Calculate the kVA rating of the grid side voltage side conversion of the wind energy conversion system to provide reactive power compensation. Assume a slip of point minus 0.3 per unit for the DFIG at rated condition.

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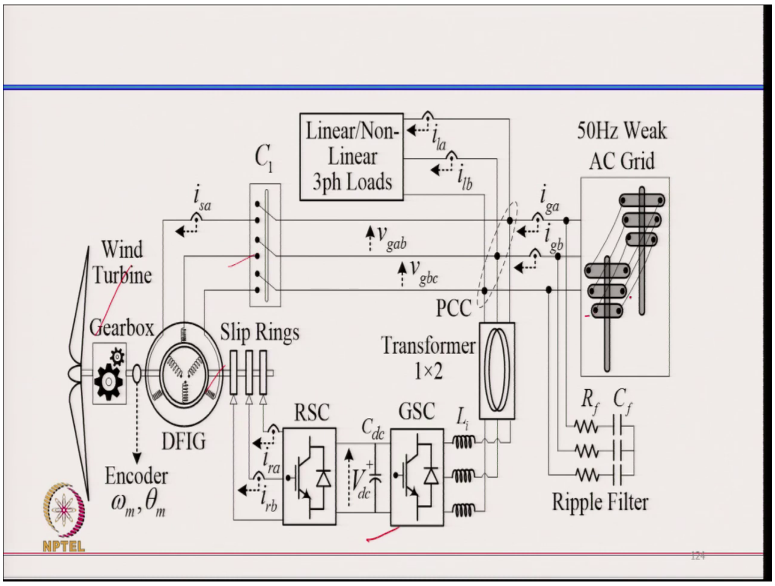

So, this is a typical system. We have a with the gearbox DFIG and we have a of course, the converter on the double converter on rotor side and the resister side connected to the grid; I mean here and of course, we have a typically local load.

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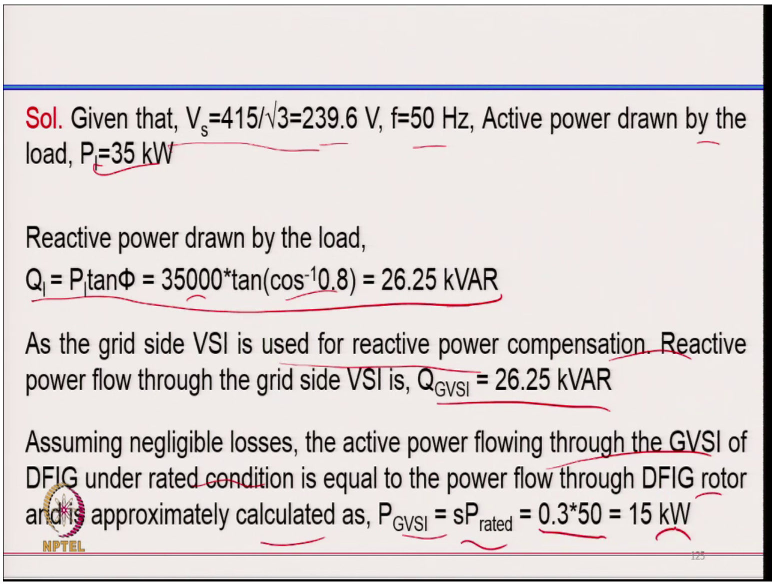

[FL] here, the given that the V s equal to 415 by root 3, 239.6, 50 hertz and active power drawn by the load is 35 kilowatt, [FL] we can calculate the load reactive power. P 1 tan phi I mean the typically reactive power 35 kilowatt into tan inverse cos. So, it comes 26.25 kVAR. And the grid side VSI used for reactive power compensation, [FL] reactive power of the grid side converter is same as the load reactive power.

Assuming negligible losses, the active power flow through the grid side converter of DFIG rated equal to the power flow of the DFIG equal to slip power rated, [FL] its 0.3 50, 15 kilowatt.

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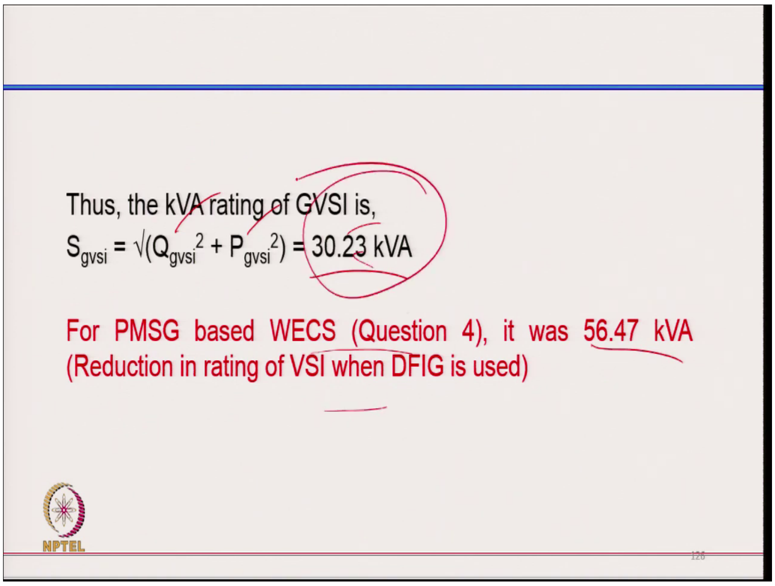

And the kVA rating of grid side converter will be k your reactive power square plus active power square that comes 32.23 kVA. [FL] for PMSG based WECS, it was 56.47 kVA. Here, the reduction of the converter is to only 32 30.23 kVA in DFIG.

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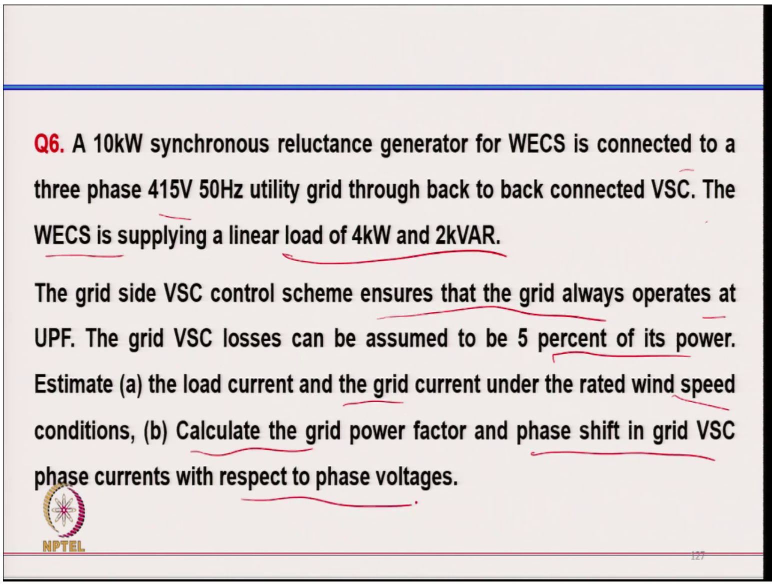

[FL] coming to 6th example. A 60 kilowatt synchronous electron generator for wind energy conversion system connected to three phase 415 volt 50 hertz utility grid through the back to back connected voltage source converter and wind energy conversion is supplying a linear load of 4 kilowatt and 2 kVAR reactive power. And the grid side voltage source converter ensure that the grid is always operate at the unity power factor and grid voltage source converter losses can be assumed to be 5 percent of its power.

Estimate the load current and the grid current under rated wind speed; b, calculate the grid power factor and the phase shift in the grid voltage and with respect to the phase voltage.

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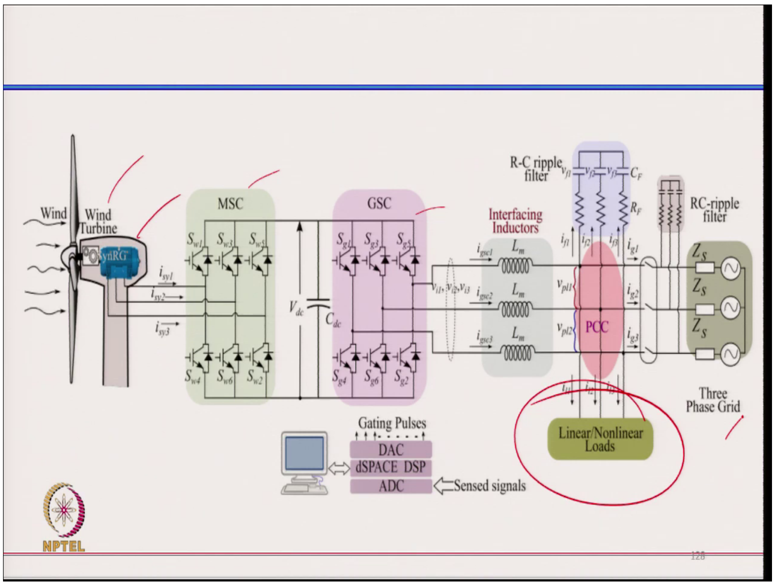

With the typical system, we have with the gearbox, the synchronous electron generator with the machine side converter and grid side converter and we have a local load here which connected at the point of common coupling and these is a typically the grid like.

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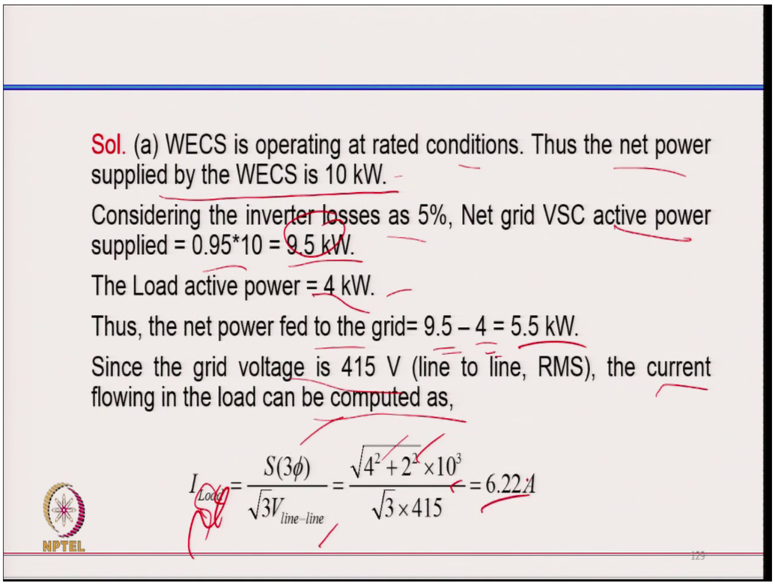

[FL] coming to solution part of energy conversion system is operating at rated condition. Thus, the net power supplied by the wind is 10 kilowatt and considering the loss is 5 percent, [FL] net VSC active power is 0.95 times 10. So, it is a 9.5 kilowatt load power. Load active power is 4 kilowatt. [FL] net power going to the grid is 9.5, this power minus the typically this load power, [FL] its 5.5 kilowatt.

Since the grid voltage 415 line RMS, [FL] current and the grid can be calculated typically from here your S divided by line. So, you have a 4 typically k for the load and 2 kVAR. [FL], you can find out the load current, 6.22 ampere.

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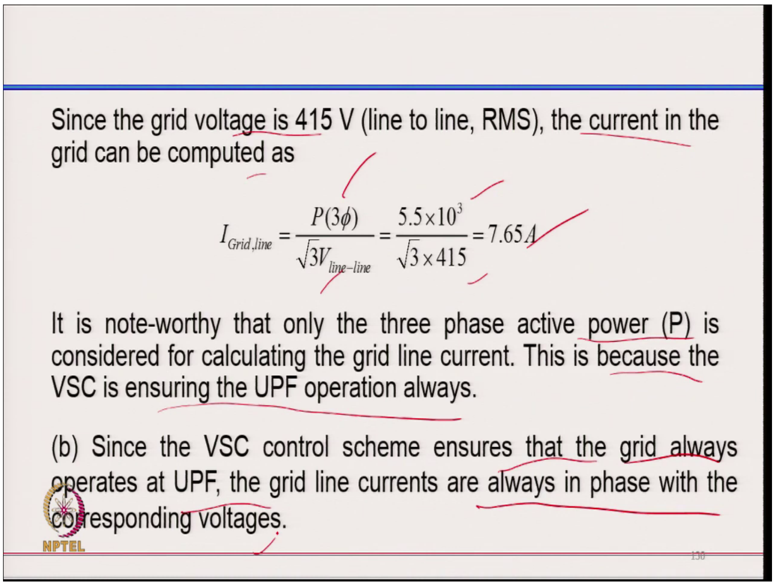

And then, we can find out the grid side the current to be computed for the grid. [FL] you have P because we are maintaining unity power factor divided by root 3 line voltage, [FL] from putting the value we get 7.65 ampere active current. And its note-worthy that the only three phase active power is considered for calculating the grid side line current and this is because the voltage source converter is ensuring unity power factor operation all the time and since the VSC control scheme ensure that the grid always operates at UPF, the grid line current are always in phase with the corresponding phase voltage.

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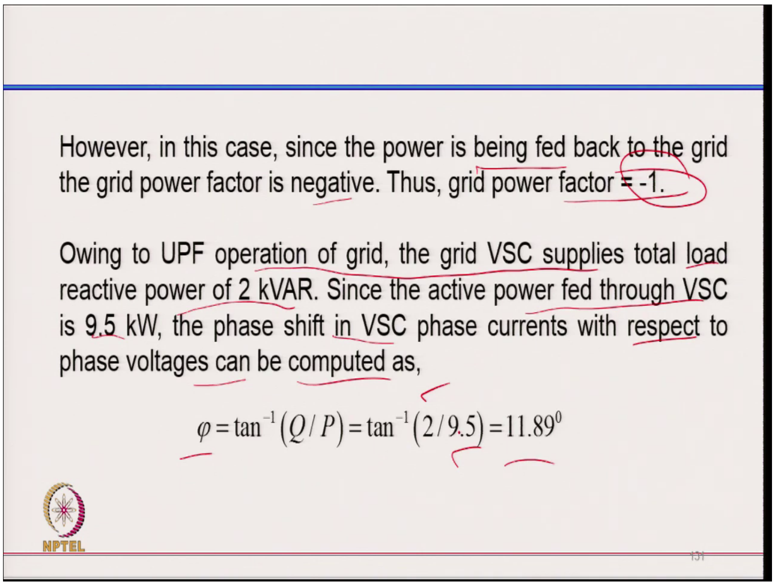

And; however, in this case since the power fed is being fed to the grid at unit at grid power factor is negative, thus the grid power factor would be grid power is negative. [FL] that the power factor will be minus 1. [FL] into the unity power factor of the grid, the grid voltage source converter supply the total reactive power of 2 kVAR. Since the active power fed through VSC 9.5 kilowatt, the phase shift in the VSC phase current with respect to the phase voltage can be computed from the reactive power divided by active power. [FL] it comes like 11.89 degree.

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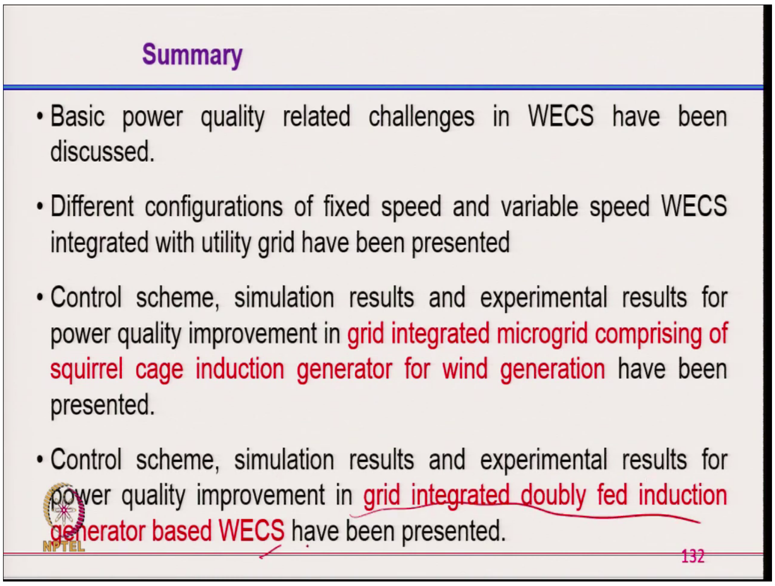

[FL], now coming to summarize the typically for wind energy conversion system, so basic power quality related changes in wind energy conversion systems have been discussed and different configuration of fixed speed and variable speed wind generation system, integrated with the circular grid have been presented.

And control scheme simulation results and experimental results of power quality improvement in grid integrated system comprising the squirrel cage generator for wind energy generation have been presented. And controlled scheme simulation results and experimental results for the power quality improvement, grid integrated doubly fed WECS have been presented.

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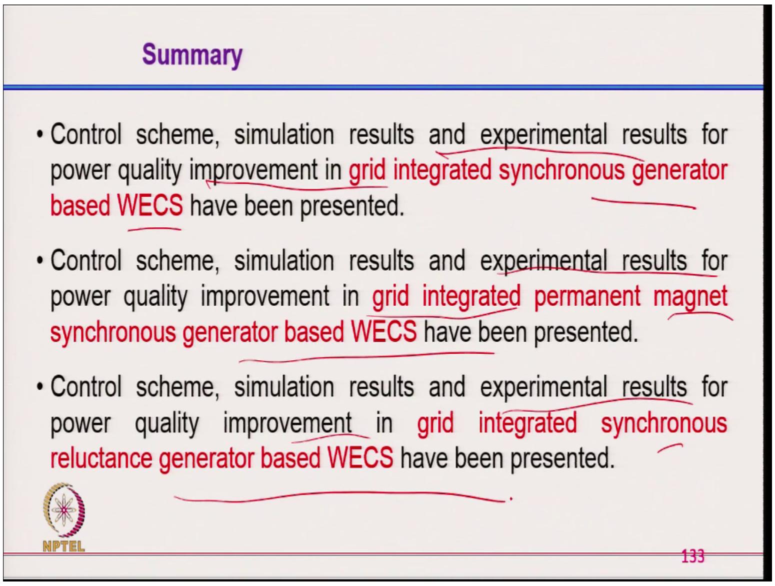

And control, simulation results and experimental results of power quality improvement in grid synchronous generator based wind energy conversion system is also given here. And control scheme, simulation results and experiment results of grid connected permanent magnet synchronous generator based wind energy conversion also presented. And control scheme, simulation and experimental results and for power quality improvement grid integrated synchronous reluctance generator have been presented.

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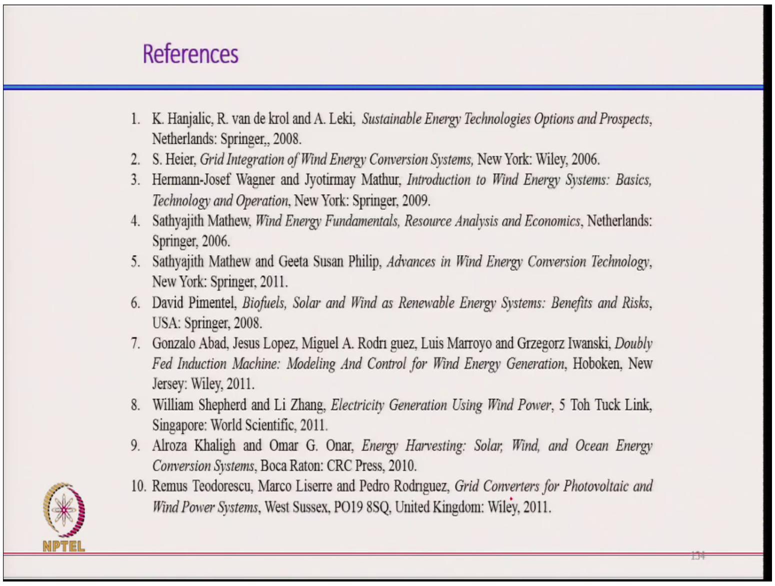

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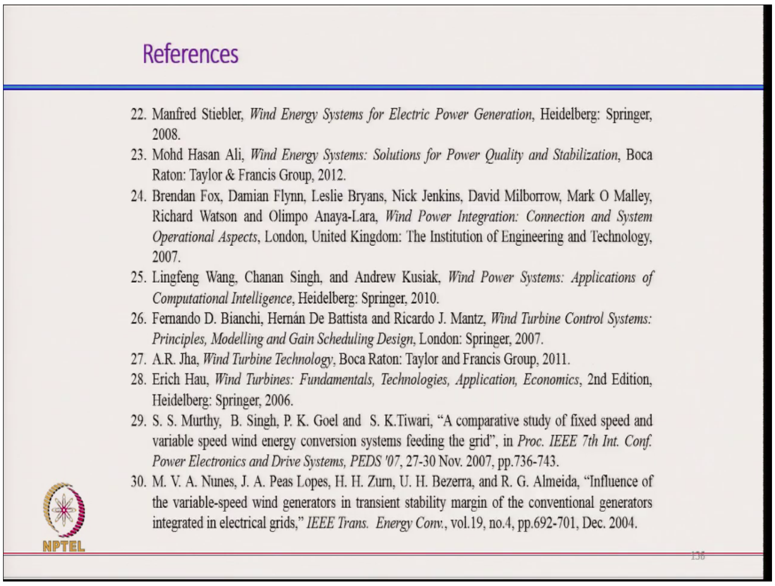

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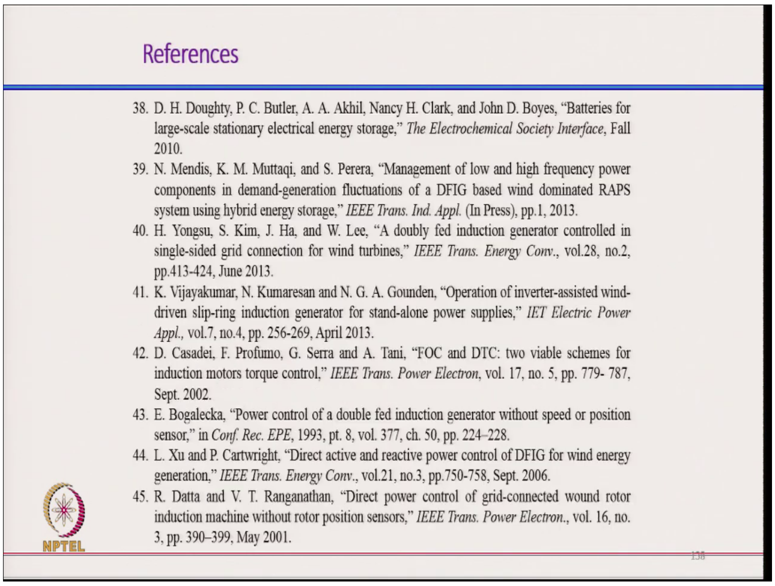

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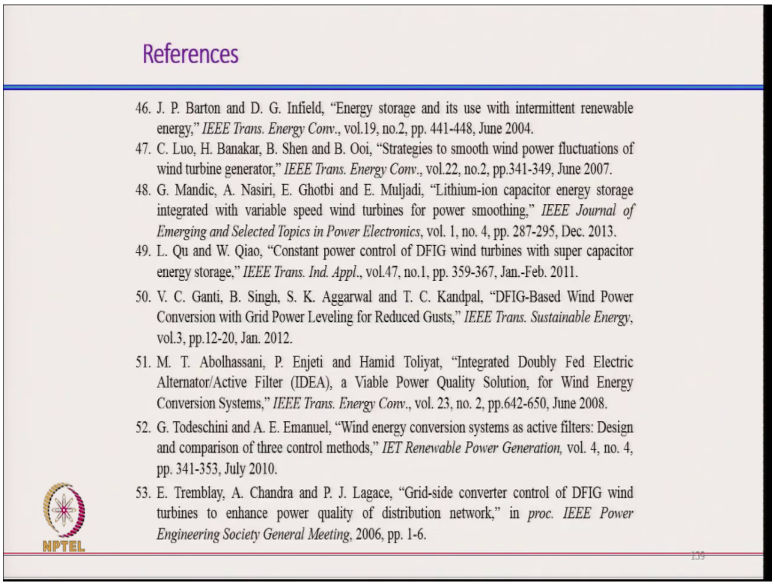

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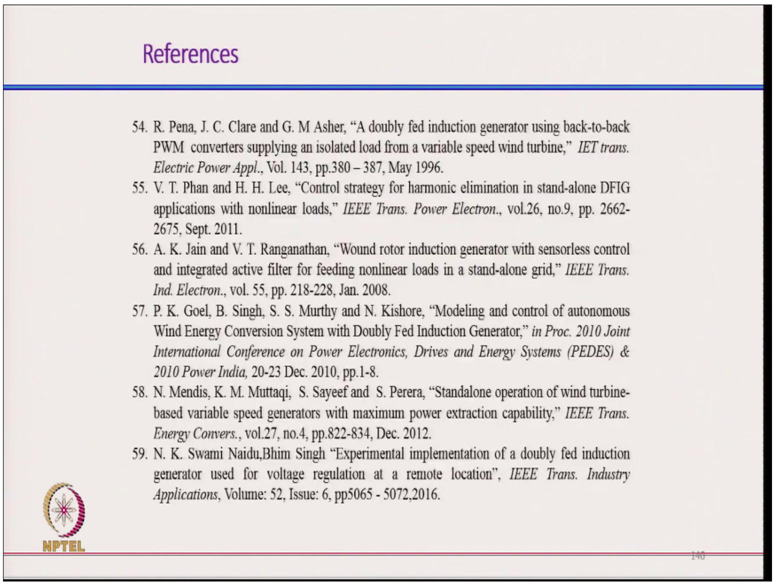

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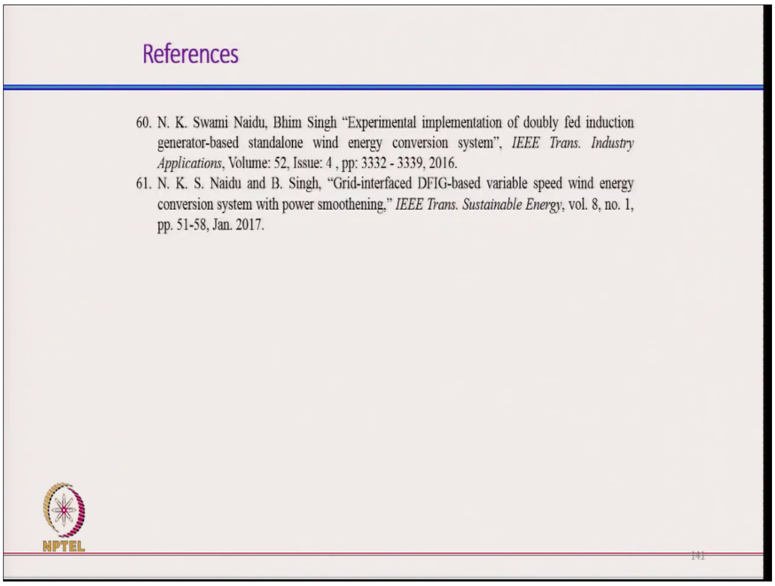

And these are the some of the references on which this common presentation is made and.

Thank you very much.