

Power Quality
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Chapter - 15
Module - 04
Lecture - 45

Power Quality Improvement in Distributed Generation Sources Based Microgrids

Welcome to the course on Power Quality. Today we will be discussing Power Quality Improvement in Distributed Generation Sources Based Microgrid.

(Refer Slide Time: 00:27)

Outline

- ❑ Introduction to Microgrids
- ❑ Power Quality Improvement in Grid Integrated **Solar PV-Battery** based Microgrid
- ❑ Power Quality Improvement in Grid Integrated **Wind-Solar PV-Battery** based Microgrid
- ❑ Power Quality Improvement in Grid Integrated **Small Hydro-Solar PV-Battery** based Microgrid
- ❑ Power Quality Improvement in Grid Integrated **Wind-Solar PV- Battery-DG Set** based Microgrid
- ❑ Power Quality Improvement in Microgrids for **Electric Vehicle Charging Station**

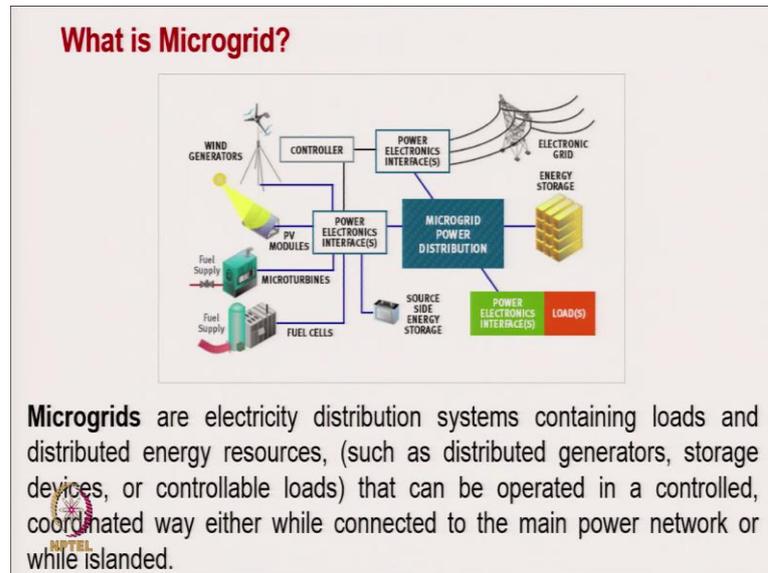


The outline of presentation is:

- Introduction to microgrid
- Power quality improvement in grid integrated solar PV based microgrid
- Power quality improvement in grid integrated wind solar PV and battery based microgrid
- Power quality improvement in grid connected small hydro solar PV and battery based microgrid

- Power quality improvement in grid connected wind solar battery and DG set based microgrid
- Power quality improvement in microgrid for electric vehicle charging station

(Refer Slide Time: 00:54)



This is typically the concept of microgrid. Microgrids are electrically distributed system containing loads, distributed energy sources; such as distributed generator storage device and controllable load, that can be operated in a control coordinated way either while connecting to the main power network or while islanded.

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How Does A Microgrid Work?

- The traditional grid connects homes, businesses and other buildings to central power sources.
- When part of the grid needs to be repaired, everyone is affected.
- Microgrid generally operates while connected to the grid, but importantly, it can break off and operate on its own using local energy generation in times of crisis like storms or power outages, or for other reasons.
- Microgrids fueled by:
 - Distributed generators
 - Batteries
 - Renewable resources



And how does microgrid work? The traditional grid connect homes business and other buildings to central power sources and when part of the grid needs to be repaired everyone is affected.

And microgrid generally operate while connected to the grid, but importantly it can break off and operate on its own using the local energy generation in times of crisis like a storm or power outage or for other reasons. And microgrid may be fueled by distributed generators, batteries and renewable energy sources.

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Benefits from Microgrid

- Utilities
 - Better power control and reliability
 - Reduced energy losses
 - Dynamic demand response
 - Realistic pricing model
 - Increased demand response capability
- Customers
 - Choices of differentiated services
 - Reduced prices
 - Improved reliability
- Society
 - Integration of green energy sources Solar, Wind, Biomass, Geothermal



And benefits from the microgrid for the utility are: better power control and reliability, reduced energy losses, dynamic demand response, realistic pricing model and increased demand response capability. And for customer it provides choices for differentiated services and reduce prices and improved reliability. And for society it is an integration of green energy sources like solar, wind, biomass, geothermal.

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Microgrid Projects in India



- Sixty three Solar Micro Grids Installed in India So Far.
- India now has the world's largest solar array at Kamuthi, Tamil Nadu.
- As of mid-2018, India scaled up its renewable energy goals from 175 GW to 227 GW over the next four years, with about 40 GW of that goal representing rooftop solar.

NPTEL
World's largest solar array at Kamuthi, Tamil Nadu

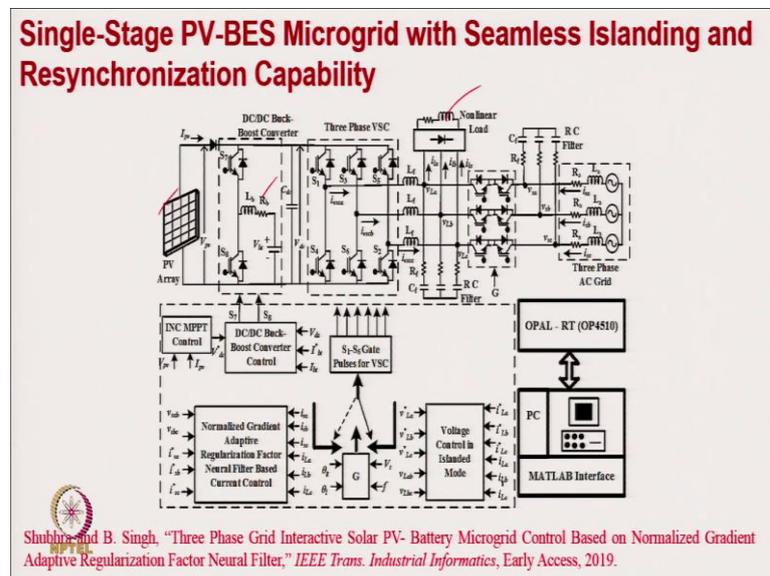
There are 63 solar microgrids installed in India. India now has the world's largest solar farm at Kamuthi, Tamil Nadu. As of 2018, India scaled up renewable energy goals from 175 gigawatt to 277 gigawatt over the next 4 years with about 40 gigawatt of the goal representing rooftop solar.

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Now, coming to the power quality improvement in grid integrated solar PV based microgrid.

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We have a single-stage solar PV array and BES is connected with the buck boost converter.

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Control Strategy

The control strategy of solar PV-BES microgrid has three main parts

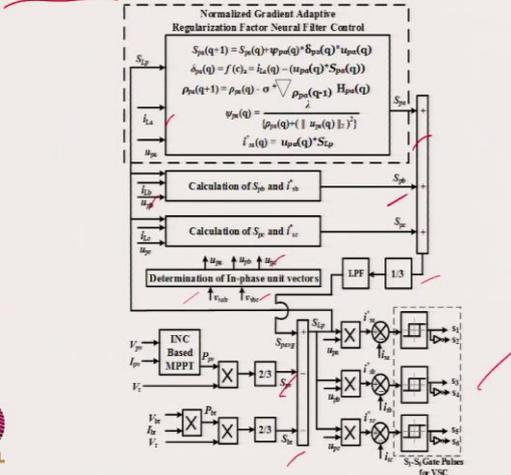
- The incremental conductance MPPT control for solar PV array
- Control for VSC
 - ❖ Current control for VSC
 - ❖ Synchronization controller
 - Phase angle checking
 - ❖ Voltage control for VSC
- Battery with bidirectional converter control



The details of the control strategy are provided in the screenshots herein.

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Current Control for VSC




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Current Control Technique for VSC

- Estimation of Unit Templates & Amplitude of Terminal Voltage
- Estimation of Active Power Components
- Generation of Reference Three-phase Grid Currents



- Generation of Gating Signals

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- The phase voltages are obtained from sensed grid line voltages (v_{sab}, v_{sbc})

$$\begin{bmatrix} v_{sa} \\ v_{sb} \\ v_{sc} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 2 & 1 & 0 \\ -1 & 1 & 0 \\ -1 & -2 & 0 \end{bmatrix} \begin{bmatrix} v_{sab} \\ v_{sbc} \\ 0 \end{bmatrix}$$

- The PCC voltage amplitude (V_t) is calculated as

$$V_t = \sqrt{\frac{2}{3}} * \sqrt{v_{sa}^2 + v_{sb}^2 + v_{sc}^2}$$

- The calculation of in-phase unit templates (u_{pa}, u_{pb}, u_{pc}) as,



$$u_{pa} = \frac{v_{sa}}{V_t}, u_{pb} = \frac{v_{sb}}{V_t}, u_{pc} = \frac{v_{sc}}{V_t}$$

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- Estimation of initial value of active power component for 'a' phase

$$S_{pa}(q+1) = S_{pa}(q) + \psi_{pa}(q) * \delta_{pa}(q) * (u_{pa}(q))$$
- The evaluation of variable step size for the adaption of regularization parameter

$$\psi_{pa}(q) = \frac{\lambda}{\rho_{pa}(q) + \|u_{pa}(q)\|_2^2}$$
- The computation of adaptive regularization parameter

$$\rho_{pa}(q+1) = \rho_{pa}(q) - \sigma * \nabla_{\rho_{pa}(q-1)} H_{pa}(q)$$
- The evaluation of current error $\delta_{pa}(q)$ of active constituent

$$\delta_{pa}(q) = f(c)_a = i_{La}(q) - (u_{pa}(q) * S_{pa}(q))$$



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- An average value of active load current (S_{pLavg}) is derived from I_{pLa} and I_{pLb} and I_{pLc} as,

$$S_{pavg} = \frac{S_{pa} + S_{pb} + S_{pc}}{3}$$
- The active part corresponding to the battery power (P_{bat}) is estimated as,

$$S_{pv} = \frac{2P_{pv}}{3V_t}$$
- The active part corresponding to the P_{pv} is estimated as,

$$S_{bt} = \frac{2P_{bt}}{3V_t}$$



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- The amplitude of grid reference current is evaluated as,

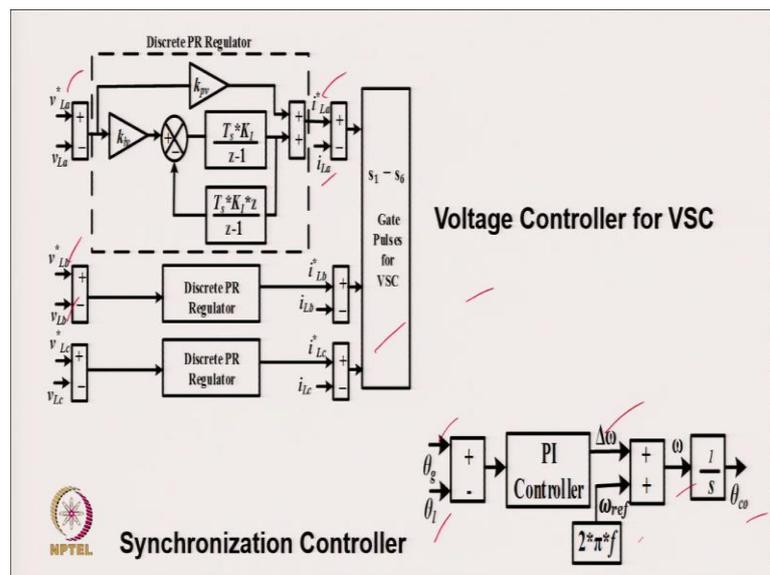
$$S_{Lp} = S_{pchg} - S_{pv} - S_{bt}$$
- The reference grid currents are evaluated as,

$$i_{sa}^* = S_{Lp} * u_{pa}, i_{sb}^* = S_{Lp} * u_{pb}, i_{sc}^* = S_{Lp} * u_{pc}$$
- These currents are compared with sensed grid currents (i_{sa} , i_{sb} , i_{sc}) and errors are generated as,

$$i_{ersa} = i_{sa}^* - i_{sa}, i_{ersb} = i_{sb}^* - i_{sb}, i_{ersc} = i_{sc}^* - i_{sc}$$
- These current errors are given to hysteresis controller, to produce switching pulses for VSC.



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Voltage Control Technique for VSC

- The reference load voltages (v_{La}^* , v_{Lb}^* , v_{Lc}^*) are generated as,

$$v_{La}^* = V_r \sin(\omega_{ref} t), v_{Lb}^* = V_r \sin\left(\omega_{ref} t - \frac{2\pi}{3}\right), v_{Lc}^* = V_r \sin\left(\omega_{ref} t + \frac{2\pi}{3}\right)$$
- The generation of error between reference load voltages and sensed loads voltages generates error,

$$v_{Lar}(p) = v_{La}^* - v_{La}, v_{Lbr}(p) = v_{Lb}^* - v_{Lb}, v_{Lcr}(p) = v_{Lc}^* - v_{Lc}$$
- These errors are given to PR regulator to give reference load current of phase a'

$$\Rightarrow i_{La}^* = \left[\frac{k_{iLae} * \left(\frac{T_s * k_1}{z-1} \right)}{1 + \left\{ W^2 * \left(\frac{T_s * k_1}{z-1} \right) * \left(\frac{T_s * k_1 * z}{z-1} \right) \right\}} \right] * v_{Lae} \quad T_{La}(z) = \frac{i_{La}^*}{v_{Lae}} = k_{pLae} + (k_{iLae} * C_1(z))$$

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- Similarly i_{Lb}^* and i_{Lc}^* are calculated. The sensed load voltages (i_{La}, i_{Lb}, i_{Lc}) are compared with i_{La}^* , i_{Lb}^* , i_{Lc}^* and the current errors are given to hysteresis controller to produce the switching pulses for VSC.

Bidirectional Converter Controller

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- The bidirectional controller consists of two main parts
 - The voltage control of DC link of VSC
 - The current control of the battery
- V_{dc}^* and V_{dc} are compared V_{dcr} is fed to a PI regulator
$$V_{dcr}(n) = V_{dc}^*(n) - V_{dc}(n)$$
- Generation of reference battery current (I_{bt}^*) is the output of PI regulator
$$I_{bt}^*(n+1) = I_{bt}^*(n) + k_{pdc} V_{dcr}(n+1) + k_{idc} \{V_{dcr}(n+1) - V_{dcr}(n)\}$$



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- Generation of error (I_{bte}) by comparing I_{bt}^* with sensed battery current (I_{bt})
$$I_{btr} = I_{bt}^* - I_{bt}$$
- The I_{btr} is given to PI regulator and its output current (I_{er}^*) is evaluated as,
$$I_{er}^*(n+1) = I_{er}^*(n) + k_{pbt} I_{btr}(n+1) + k_{ibt} \{I_{btr}(n+1) - I_{btr}(n)\}$$
- I_{er}^* is given as duty cycle for pulse width modulation (PWM) generator, which generates switching logic for buck-boost converter

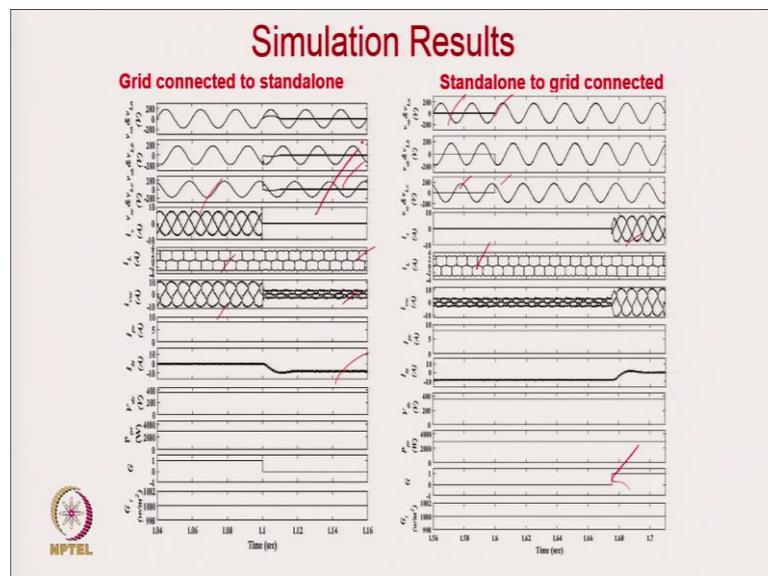


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Simulation System Parameters		
A.	Solar PV Array	$P_{pv} = 2.85 \text{ kW}$, $V_{oc} = 32.9 \text{ V}$, $I_{sc} = 8.21 \text{ A}$, $V_{mp} = 26.3 \text{ V}$, $I_{mp} = 7.61 \text{ A}$, $N_{ss} = 14$, $N_{pp} = 1$, $R_{ss} = 0.221 \Omega$, $R_{pp} = 415.405 \Omega$.
B.	BES	$V_{bt} = 240 \text{ V}$ and Ampere hour (Ah) = 7.
C.	Nonlinear Load: 3 phase diode bridge rectifier	$R = 20 \text{ ohm}$, $L = 0.2 \text{ H}$
D.	Interfacing inductors and ripple filter	$L_f = 3 \text{ mH}$, $C_f = 10 \mu\text{F}$ and $R_f = 5 \Omega$,
E.	Filter control parameter	$\lambda = 1.7$, $\sigma = 1$
F.	Bidirectional DC-DC converter	$k_{pdc} = 2$, $k_{idc} = 0.7$, $k_{pbt} = 0.2$ and $k_{ibt} = 0.4$, $L_b = 5 \text{ mH}$
G.	Voltage Controller PI gains	Voltage Controller PR gains; $k_{dpv} = 2$, $k_{div} = 0.2$

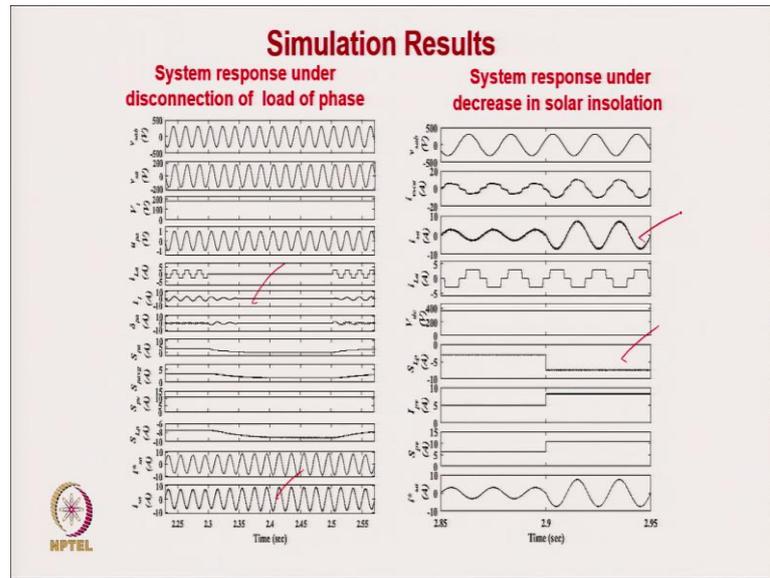
The parameters used for the simulation analysis are provided here.

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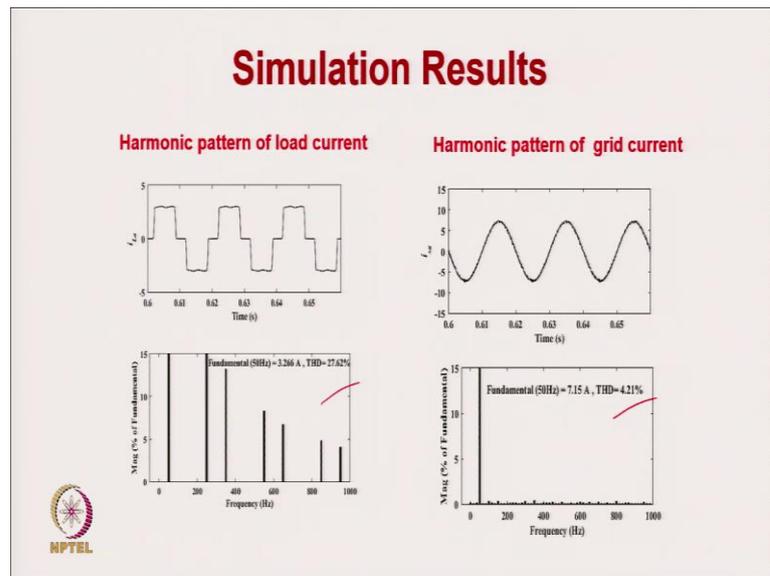


The simulation results are provided in the screenshots herein.

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Hardware Implementation

- System implemented with OPAL-RT (OP4510)
 - Sampling time of 20 μ s.
 - 4 Intel cores 3.30-GHz processor
- Control algorithm loaded into OPAL-RT(real time simulator).
- Opal-RT has
 - 32 digital inputs and outputs,
 - 16 analog inputs and outputs.
- Hall-Effect sensors utilized are
 - Voltage sensors (LV-25)
 - Current sensors (LA-55P)



The parameters used for the experimental analysis are provided here.

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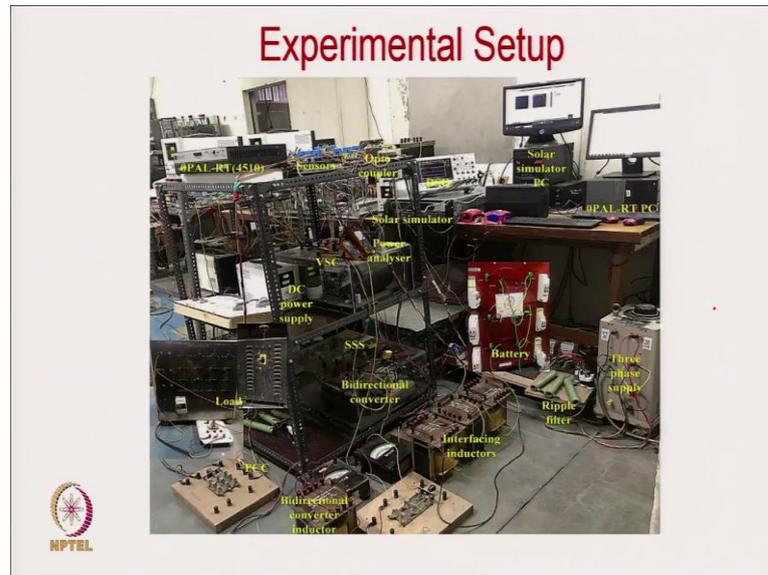
Experimental System Parameters

A.	Solar PV Array	$P_{pv} = 2.116 \text{ kW}$, $V_{oc} = 418 \text{ V}$, $I_{sc} = 6.2 \text{ A}$, $V_{mp} = 360 \text{ V}$, $I_{mp} = 5.87 \text{ A}$,
B.	BES	$V_{bat} = 240 \text{ V}$ and Ampere hour (Ah) = 35
C.	Nonlinear Load: 3 phase Diode bridge rectifier	$R = 60 \Omega$, $L = 0.2 \text{ H}$
D.	Interfacing inductors and ripple filter	$L_f = 5 \text{ mH}$, $C_f = 10 \mu\text{F}$ and $R_f = 5 \Omega$,
E.	Filter control parameters	$\lambda = 1.7$ and $\sigma = 1$
F.	Synchronization controller PI parameter	$k_p = 1$, $k_i = 0.07$
G.	Bidirectional DC-DC converter	$k_{pdc} = 0.25$, $k_{idc} = 0.01$, $k_{pbt} = 0.15$ and $k_{ibt} = 0.003$, $L_b = 6 \text{ mH}$
H.	Voltage Controller PI gains	$k_{apv} = 0.9$, $k_{ain} = 0.01$
I.	3 phase grid voltage	220 V rms (L-L)



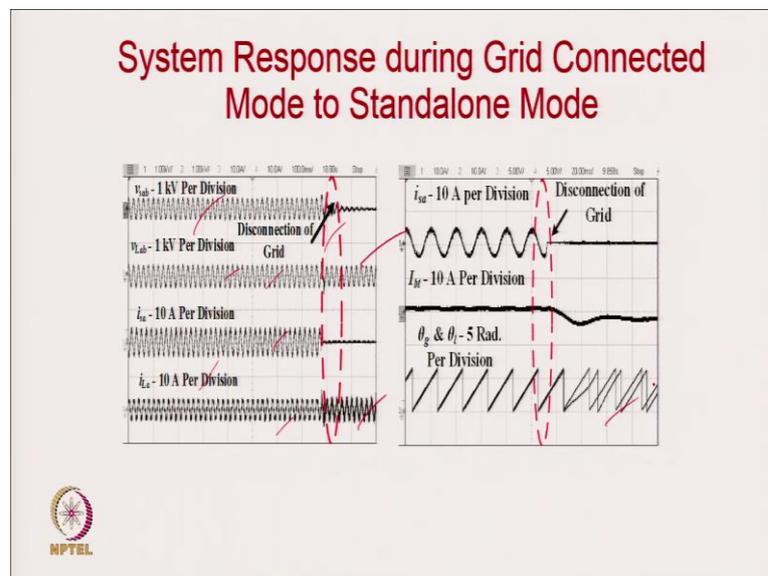
And these are the data of practical system.

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This is the photograph of the practical system.

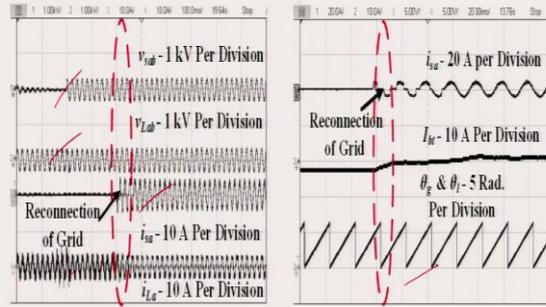
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The simulation results are provided in the screenshots herein.

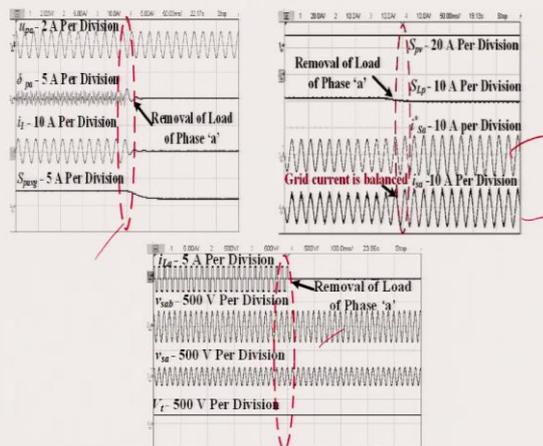
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System Response during Standalone Mode to Grid Connected Mode

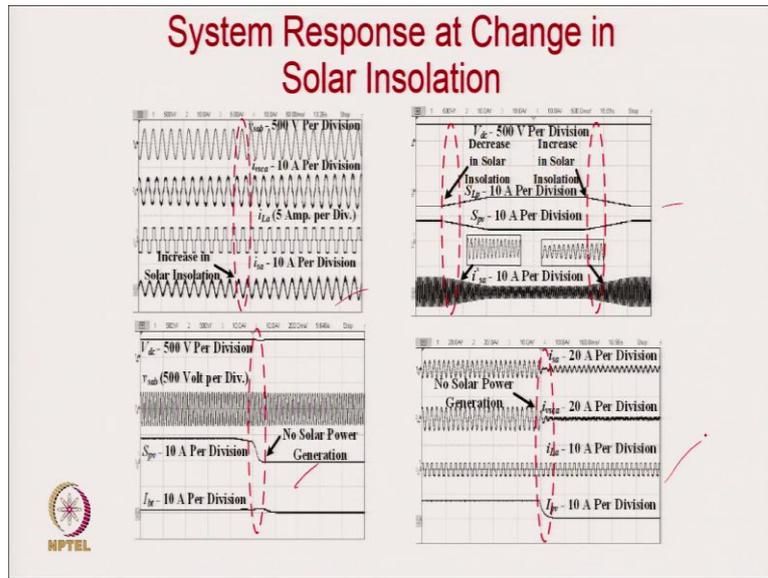


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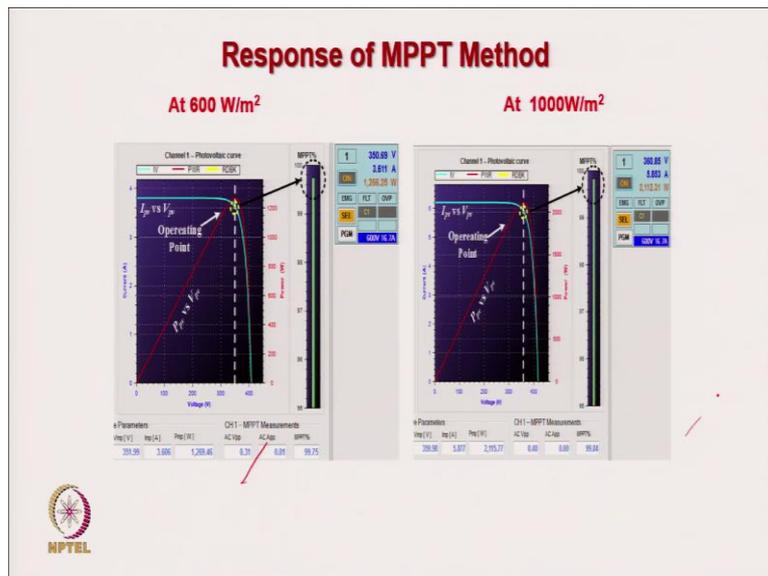
System Response Under Removal of Phase 'a' Load



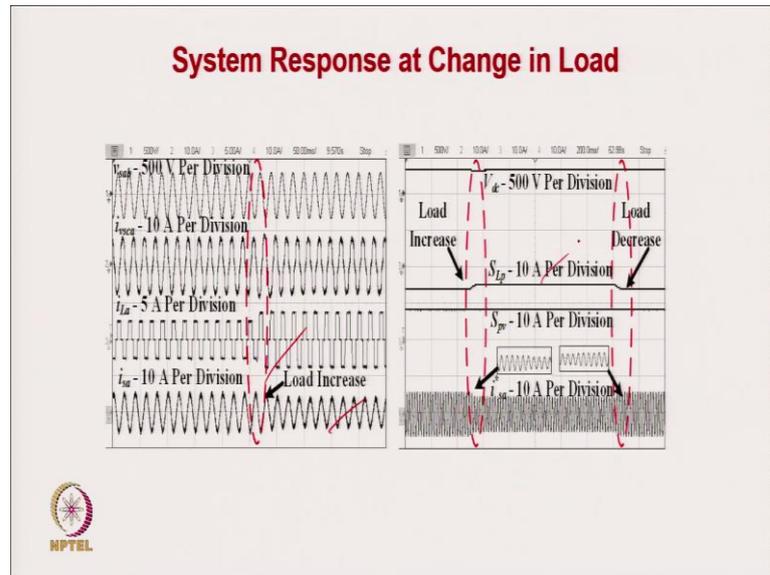
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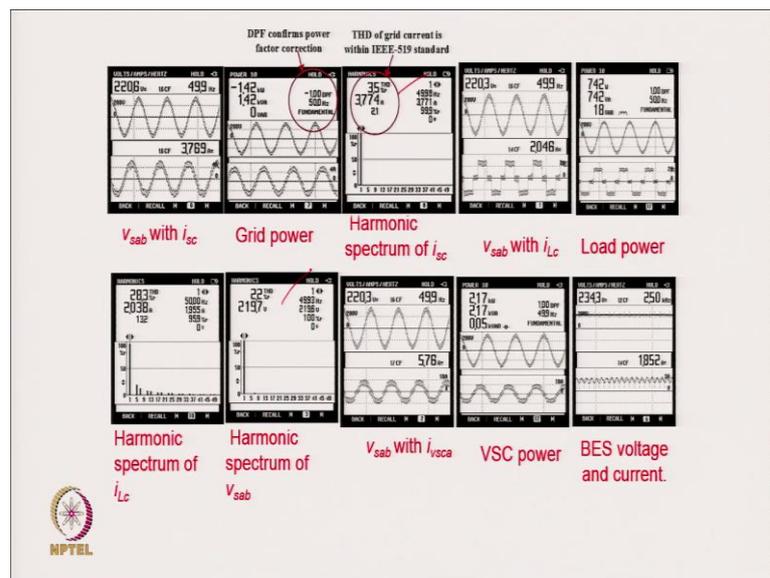
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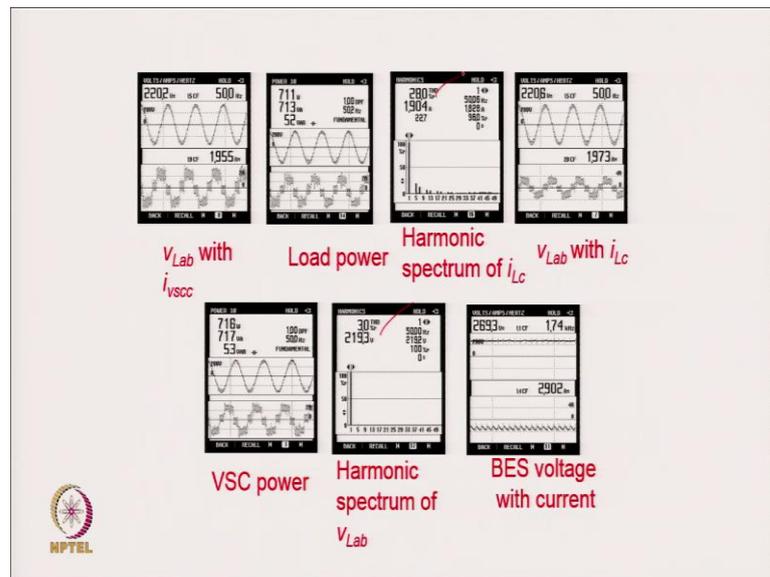
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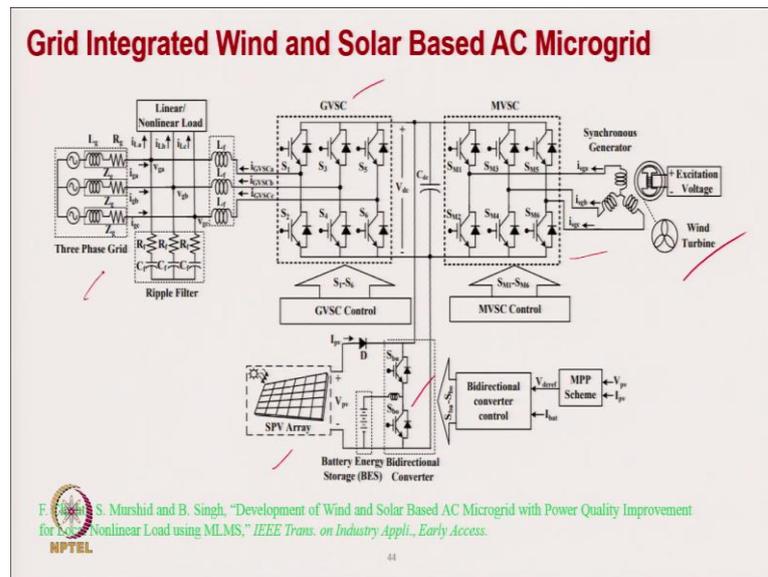
Power Quality Improvement in Grid Integrated Wind-Solar PV-Battery based Microgrid

NPTEL

43

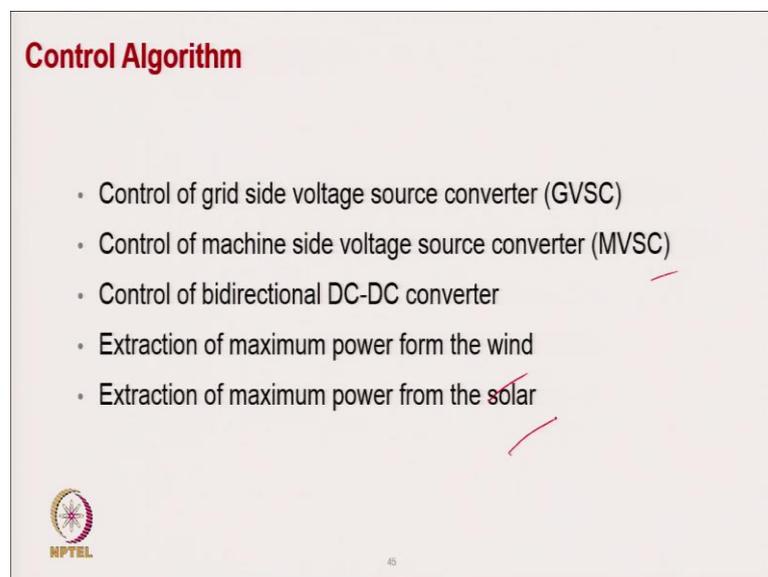
Now, coming to power quality improvement in the wind solar PV with battery based microgrid.

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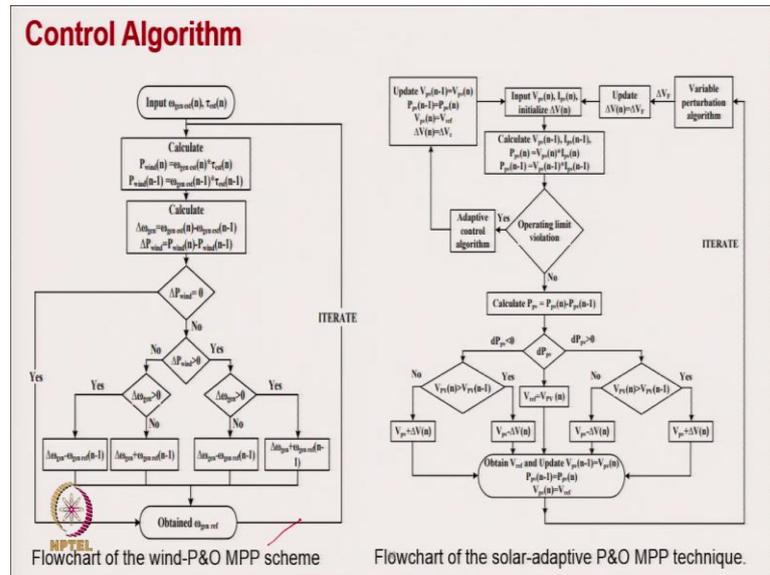
Here is the system where we have wind generation from synchronous generator with variable speed generation. SPV array is connected at DC link. And here on the DC link we are keeping a battery with the buck boost converter.

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The control algorithm is explained herein.

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Control Algorithm

MPPT Control

The governing equations are given as for Wind MPPT are,

$$\omega_{\text{gen ref}}(n) = \omega_{\text{gen ref}}(n-1) + \Delta\omega_{\text{gen}};$$

$$\text{if } \begin{cases} \Delta P_{\text{gen}} > 0 \text{ and } \Delta\omega_{\text{gen est}} > 0 \\ \Delta P_{\text{gen}} < 0 \text{ and } \Delta\omega_{\text{gen est}} < 0 \end{cases}$$

$$\omega_{\text{gen ref}}(n) = \omega_{\text{gen ref}}(n-1) - \Delta\omega_{\text{gen}};$$

$$\text{if } \begin{cases} \Delta P_{\text{gen}} > 0 \text{ and } \Delta\omega_{\text{gen est}} < 0 \\ \Delta P_{\text{gen}} < 0 \text{ and } \Delta\omega_{\text{gen est}} > 0 \end{cases}$$

49

(Refer Slide Time: 18:26)

Control Algorithm

The governing equations are given as for Solar MPPT are,

$$V_{\text{ref}} = V_{\text{pv}}(n) + \text{sign}\{V_{\text{pv}}(n) - V_{\text{pv}}(n-1)\} * \text{sign}(\Delta P_{\text{pv}}) * \Delta V(n).$$


50

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Control Algorithm

GVSC Switching Control

Phase voltages are computed from two sensed line voltages as,

$$v_{\text{ga}} = \left(\frac{2}{3}\right) [v_{\text{gab}} + v_{\text{gbc}}]; v_{\text{gb}} = \left(\frac{2}{3}\right) [-v_{\text{gab}} + v_{\text{gbc}}]$$
$$v_{\text{gc}} = \left(\frac{2}{3}\right) [-v_{\text{gab}} - v_{\text{gbc}}].$$

The terminal voltage amplitude is computed as,

$$V_t = \sqrt{\frac{2}{3}(v_{\text{ga}}^2 + v_{\text{gb}}^2 + v_{\text{gc}}^2)}$$


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Control Algorithm

Evaluation of DC Active Loss Component,

$$V_{dce}(n) = V_{dcref}(n) - V_{dc}(n)$$

Wind Feed-Forward Term,

$$w_{wff}(n) = \frac{2P_{wind}(n)}{3V_t}$$

Solar Feed-Forward Term,

$$w_{pvff}(n) = \frac{2P_{PV}(n)}{3V_t}$$


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Control Algorithm

The fundamental active components for each phase of load currents are,

$$w_{pa}(n+1) = w_{pa}(n) + 2\xi e_{pa}(n)u_{pa}(n) + \alpha[w_{pa}(n) - w_{pa}(n-1)]$$

$$w_{pb}(n+1) = w_{pb}(n) + 2\xi e_{pb}(n)u_{pb}(n) + \alpha[w_{pb}(n) - w_{pb}(n-1)]$$

$$w_{pc}(n+1) = w_{pc}(n) + 2\xi e_{pc}(n)u_{pc}(n) + \alpha[w_{pc}(n) - w_{pc}(n-1)].$$

$$e_{pa}(n) = i_{La}(n) - u_{pa}(n) \times w_{pa}(n)$$

$$e_{pb}(n) = i_{Lb}(n) - u_{pb}(n) \times w_{pb}(n)$$

$$e_{pc}(n) = i_{Lc}(n) - u_{pc}(n) \times w_{pc}(n)$$


53

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Control Algorithm

The load current weight component is calculated as,

$$w_L = \frac{w_{pa} + w_{pb} + w_{pc}}{3}$$

The net weight component is calculated as,

$$w_{net} = w_L + w_{loss} - w_{pvff} - w_{wff}$$

Estimation of Reference Grid Current,

$$i_{g,ref} = u_{pa} \times w_{net}; i_{gb,ref} = u_{pb} \times w_{net}; i_{gc,ref} = u_{pc} \times w_{net}$$


54

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Control Algorithm

MVSC Switching Control

The speed error is calculated as,

$$\omega_{gen\ error} = \omega_{gen\ ref} - \omega_{gen\ est}$$

The PI speed controller governing equation is given as,

$$I_{q\ ref}(n) = I_{q\ ref}(n-1) + k_{igen} \{ \omega_{gen\ error}(n) - \omega_{gen\ error}(n-1) \} + k_{pgen} \{ \omega_{gen\ error}(n) \}$$


55

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Control Algorithm

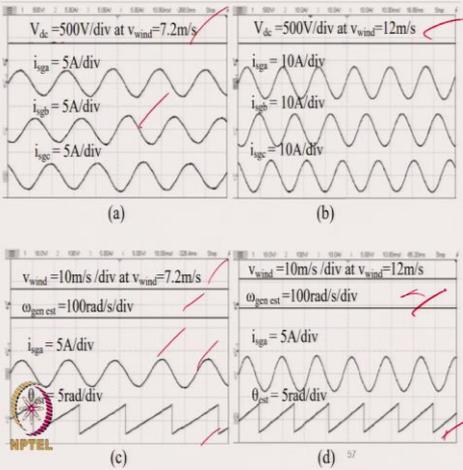
The $I_{d\text{ref}}$ component is obtained as,

$$I_{d\text{ref}} = \frac{\psi_r - \sqrt{\psi_r^2 - 4L_dL_qi_q^2}}{2L_d}$$


56

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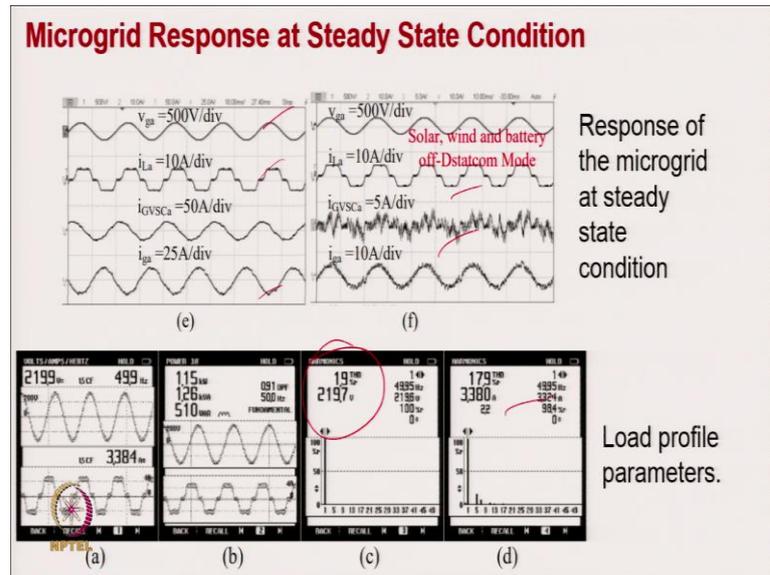
Microgrid Response at Steady State Condition



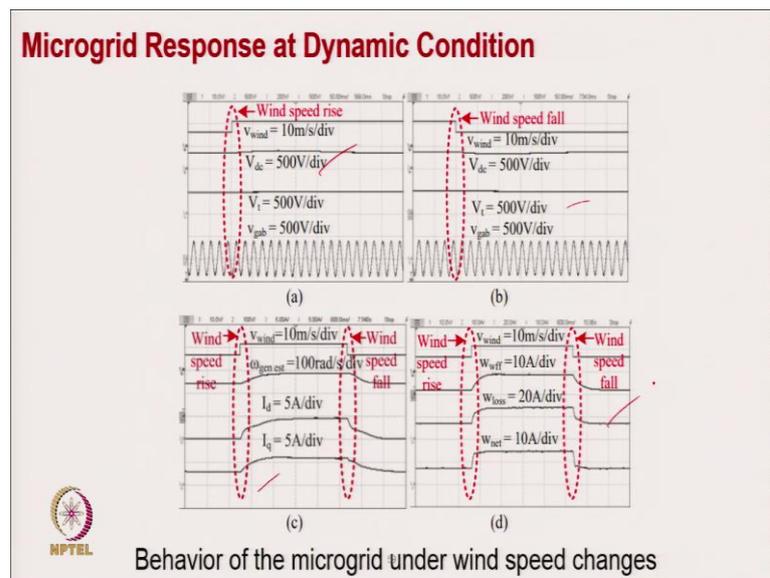
Response of the microgrid at steady state condition

The experimental results are displayed in the screenshots herein.

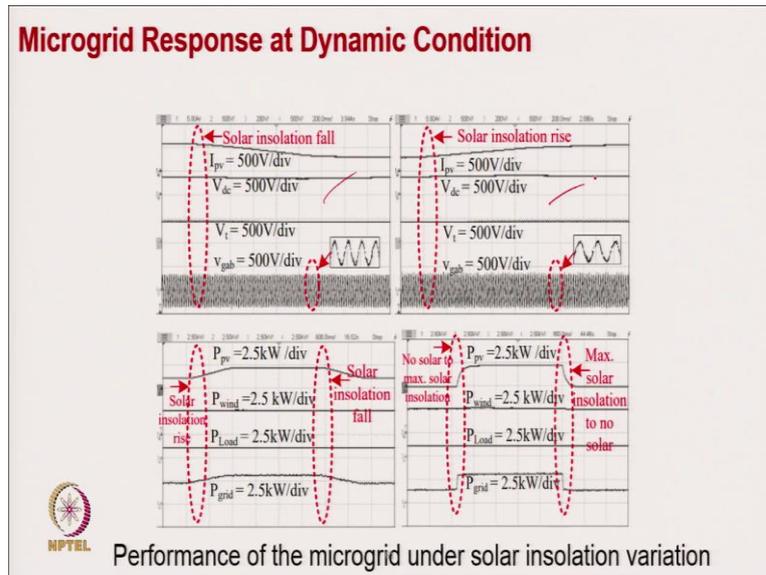
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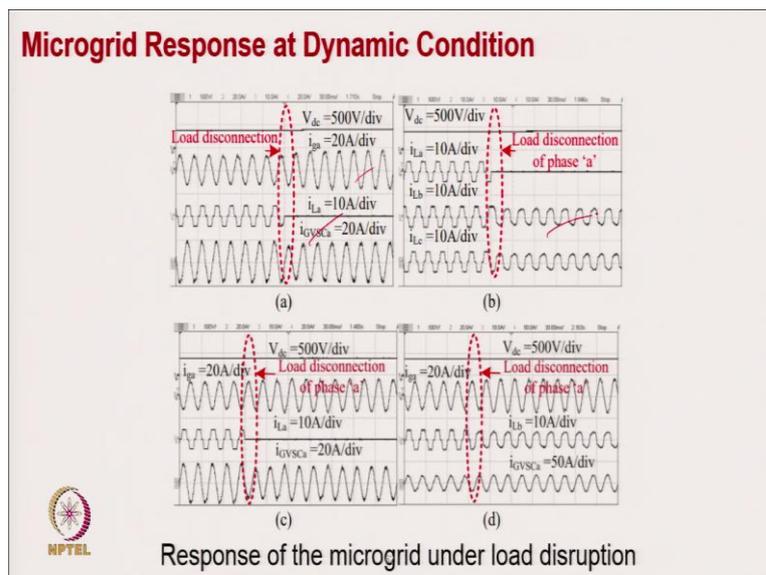
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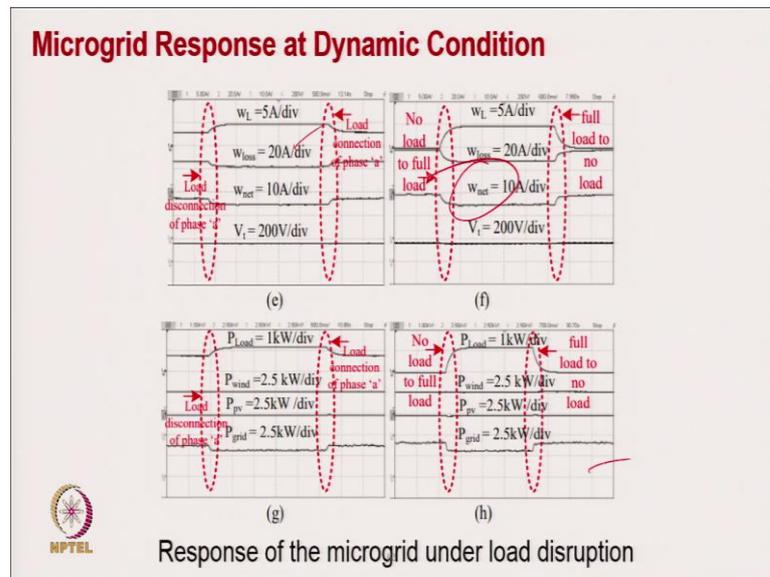
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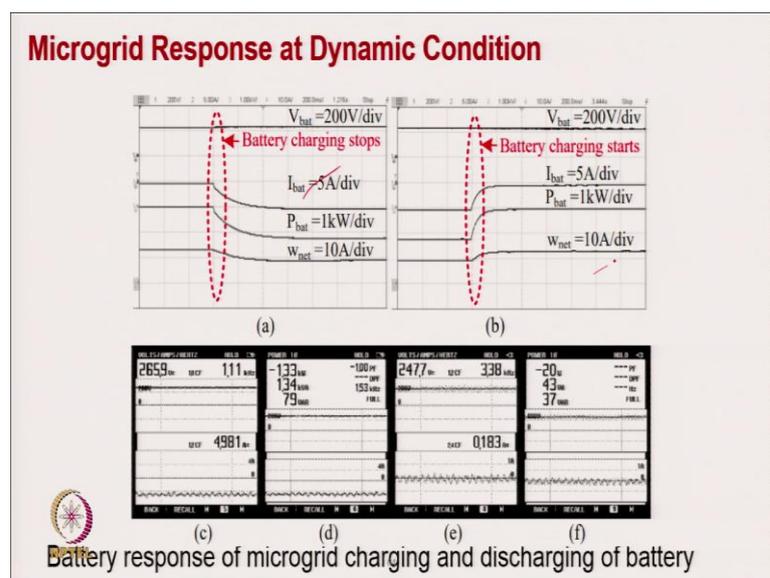
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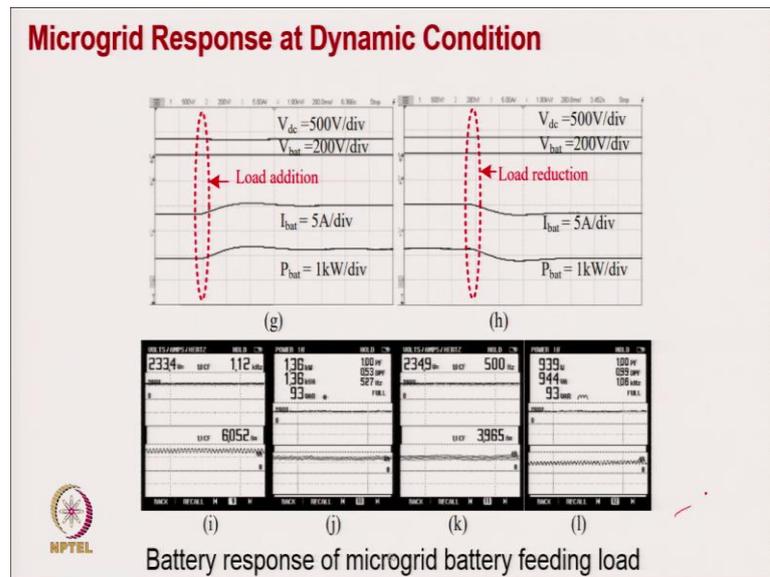
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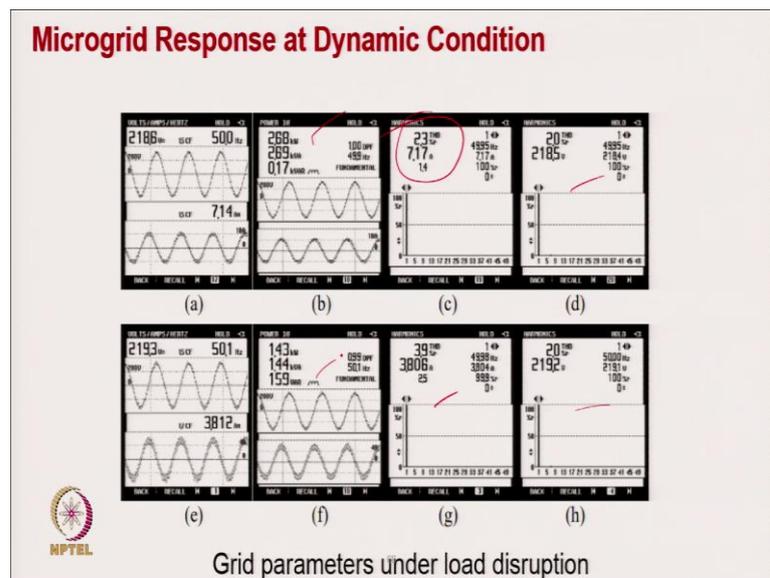
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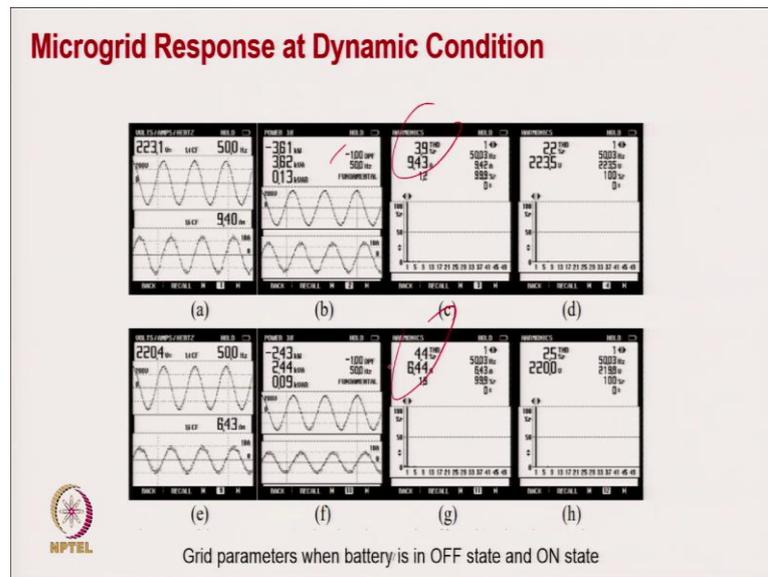
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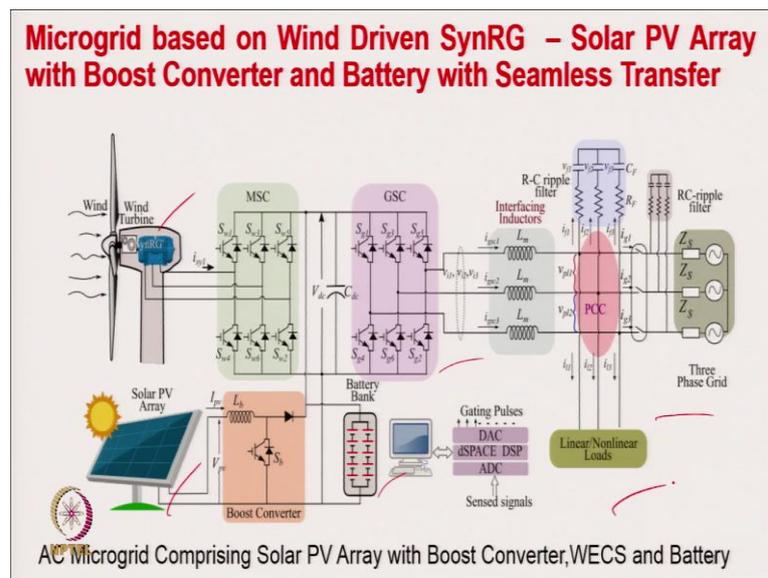
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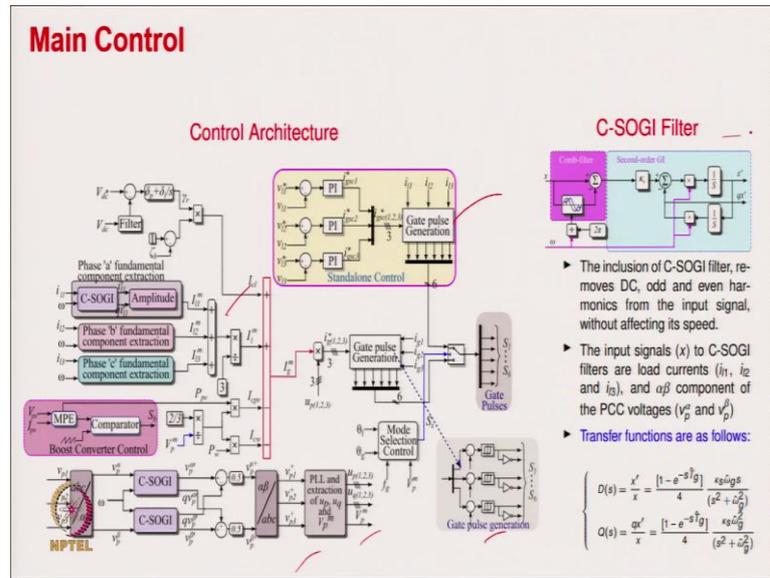


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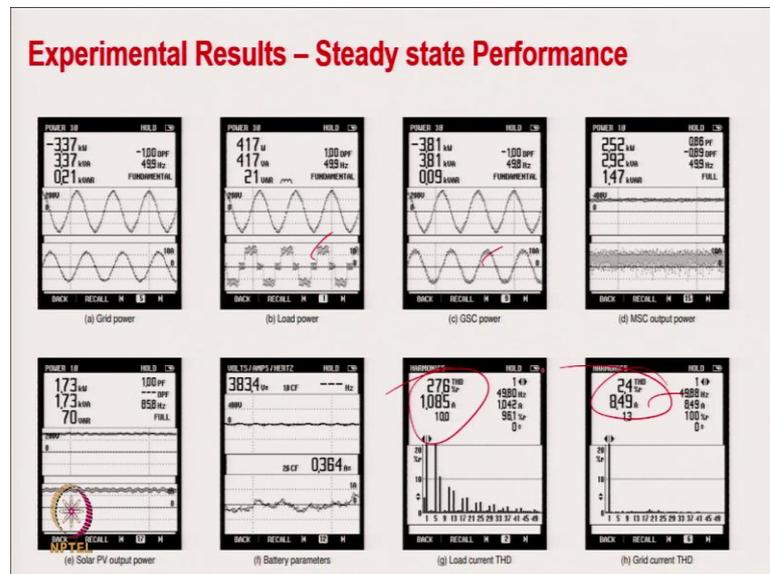
Now coming to another topology of microgrid; microgrid based on wind driven synchronous reluctance generator and solar PV array. And then we have a the battery here connected on the DC link.

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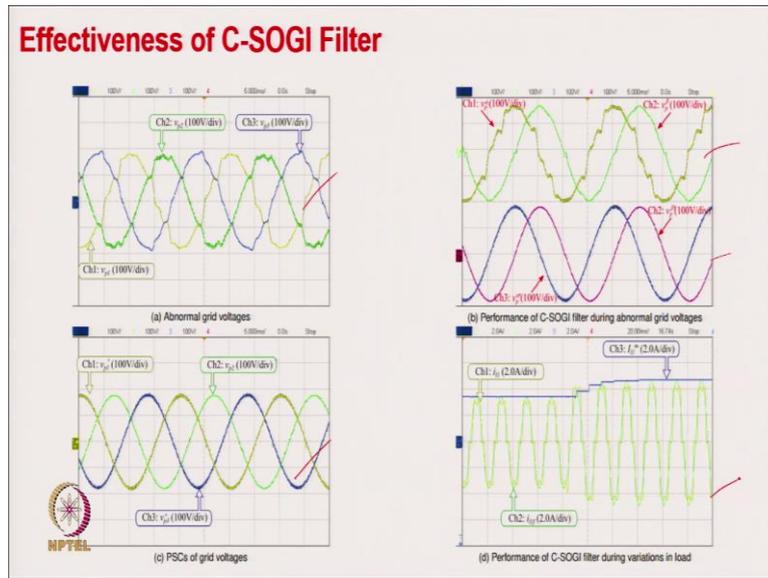


The control strategy and experimental results are displayed in the screenshots herein.

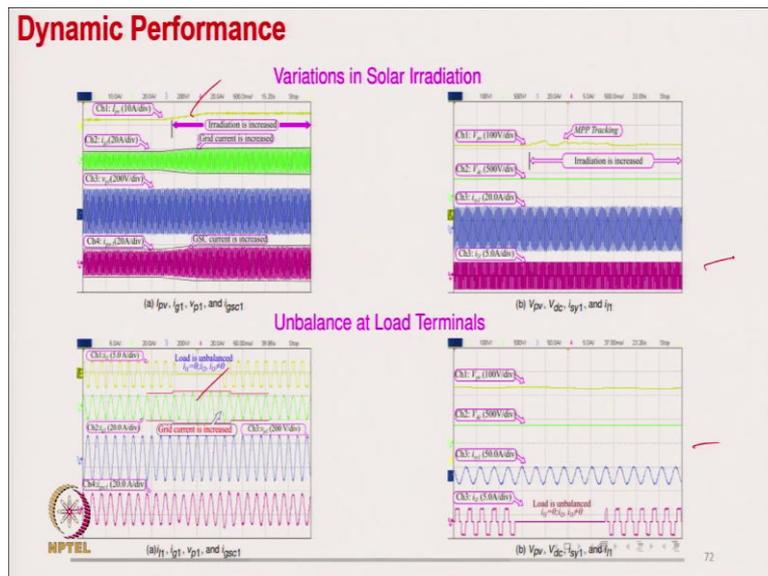
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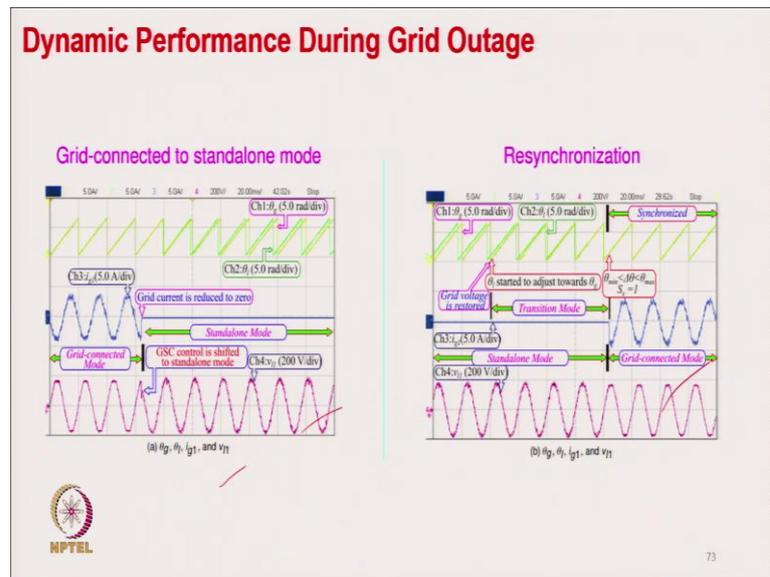
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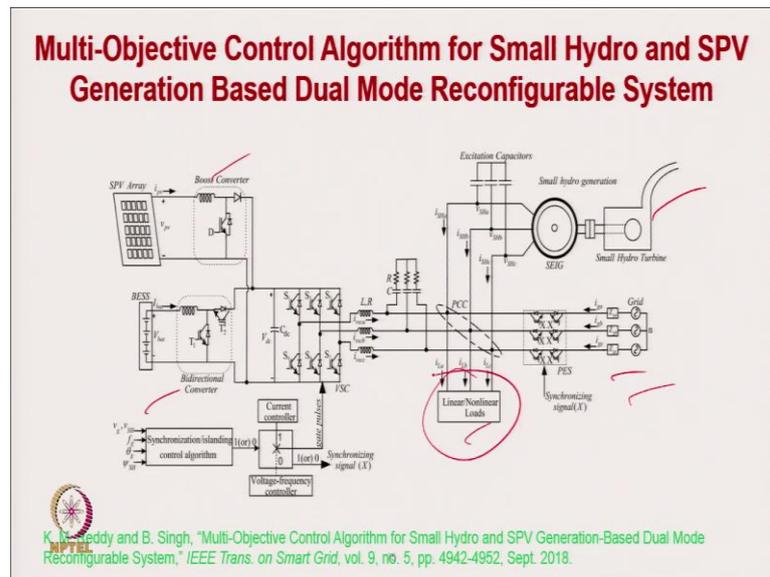


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Coming to the power quality improvement in grid integrated small hydro solar PV battery microgrid.

(Refer Slide Time: 24:14)



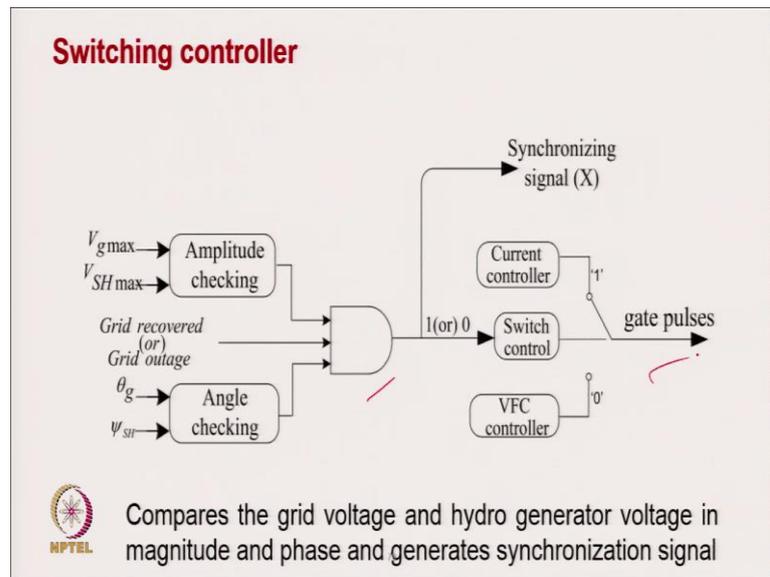
Here is a small hydro connected to the solar PV, and we have a battery connected to the system.

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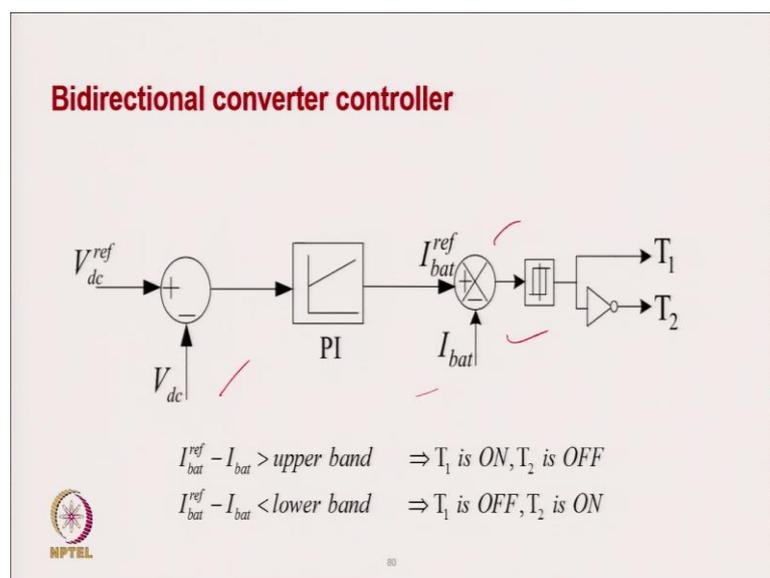
- ### Control Technique
- MPPT controller for SPV
 - VSC control Algorithm
 - Current control Algorithm (grid connected mode)
 - Voltage and frequency control
 - Switching control algorithm
 - Bidirectional converter control
- NPTEL
- 76

The control strategy is described in the screenshots herein.

(Refer Slide Time: 26:06)



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(Refer Slide Time: 26:24)

Expressions for Control Algorithm

Grid Connected Mode

In phase unit templates for current controller are estimated as,

$$k_{ai} = \frac{v_{ga}}{V_{gmax}}, k_{bi} = \frac{v_{gb}}{V_{gmax}}, k_{ci} = \frac{v_{gc}}{V_{gmax}}$$

Where, $V_{gmax} = \sqrt{\frac{2}{3} \{ (v_{ga})^2 + (v_{gb})^2 + (v_{gc})^2 \}}$

The feed-forward current components of small hydro generation and SPV generation contributions are estimated as,

$$I_{SHff} = 2P_{SH}/V_{gmax} = \frac{2 \times 3}{2V_{gmax}} (V_{\alpha SH} I_{\alpha SH} + V_{\beta SH} I_{\beta SH})$$

$$I_{pvff} = 2P_{pv}/V_{gmax} = 2V_{pv} I_{pv} / V_{gmax}$$



(Refer Slide Time: 26:35)

Expressions for Control Algorithm

The current component corresponding to the contribution of the battery power is calculated,

$$I_{batff} = 2P_{bat}/V_{gmax} = 2V_{bat} I_{batt} / V_{gmax}$$

The amplitude of reference grid currents is estimated as,

$$I_{gi} = \frac{1}{3} (I_{Lai} + I_{Lbi} + I_{Lci} - I_{pvff} - I_{SHff} + I_{batff})$$

The instantaneous reference currents of grid are,

$$i_{ga}^{ref} = I_{gi}^{*} k_{ai}, i_{gb}^{ref} = I_{gi}^{*} k_{bi}, i_{gc}^{ref} = I_{gi}^{*} k_{ci}$$



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Expressions for Control Algorithm

Islanded Mode

In phase unit templates for voltage/frequency control are estimated as,

$$z_{ai} = \frac{v_{SHa}}{V_{SHmax}}, z_{bi} = \frac{v_{SHb}}{V_{SHmax}}, z_{ci} = \frac{v_{SHc}}{V_{SHmax}}$$

Where,
$$V_{SHmax} = \sqrt{\frac{2}{3} \{ (v_{SHa})^2 + (v_{SHb})^2 + (v_{SHc})^2 \}}$$

The quadrature unit templates are,

$$z_{aq} = (-z_{bi} + z_{ci})/\sqrt{3}, z_{bq} = (3z_{ai} + z_{bi} - z_{ci})/2\sqrt{3},$$
$$z_{cq} = (-3z_{ai} + z_{bi} - z_{ci})/2\sqrt{3}$$

(Refer Slide Time: 27:00)

Expressions for Control Algorithm

An error of the frequency is computed as,

$$err_f(r) = \omega_{SH}^{ref}(r) - \omega_{SH}(r)$$

The frequency loop PI controller output is,

$$I_f(r) = I_f(r-1) + k_{pf} \{ err_f(r) - err_f(r-1) \} + k_{if} err_f(r)$$

An error of the voltage is computed as,



$$err_v(r) = V_{SHmax}^{ref}(r) - V_{SHmax}(r)$$

(Refer Slide Time: 27:09)

Expressions for Control Algorithm

The voltage PI controller output is as,

$$I_v(r) = I_v(r-1) + k_{pv}\{err_v(r) - err_v(r-1)\} + k_{iv}err_v(r)$$

The amplitude of active reference currents of hydro generator is,

$$I_{SHi} = \frac{1}{3}(I_{Lai} + I_{Lbi} + I_{Lci}) - I_f$$

The amplitude of reactive reference currents of hydro generator is,



$$I_{SHq} = I_v$$

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Expressions for Control Algorithm

The instantaneous reference currents of hydro generator are,

$$\begin{aligned} i_{SHa}^{ref} &= i_{SHai}^{ref} + i_{SHaq}^{ref}, i_{SHb}^{ref} = i_{SHbi}^{ref} \\ &+ i_{SHbq}^{ref}, i_{SHc}^{ref} = i_{SHci}^{ref} + i_{SHcq}^{ref} \end{aligned}$$

The input for the PI controller of synchronization loop is,

$$e_{\Delta}(r) = \sin(\theta_g(r) - \psi_{SH}(r)) \approx \theta_g(r) - \psi_{SH}(r)$$



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Expressions for Control Algorithm

The PI controller output for synchronization loop is,

$$\omega^{comp}(r) = \omega^{comp}(r-1) + k_{ps}\{e_{\Delta}(r) - e_{\Delta}(r-1)\} + k_{is}e_{\Delta}(r)$$

Where,

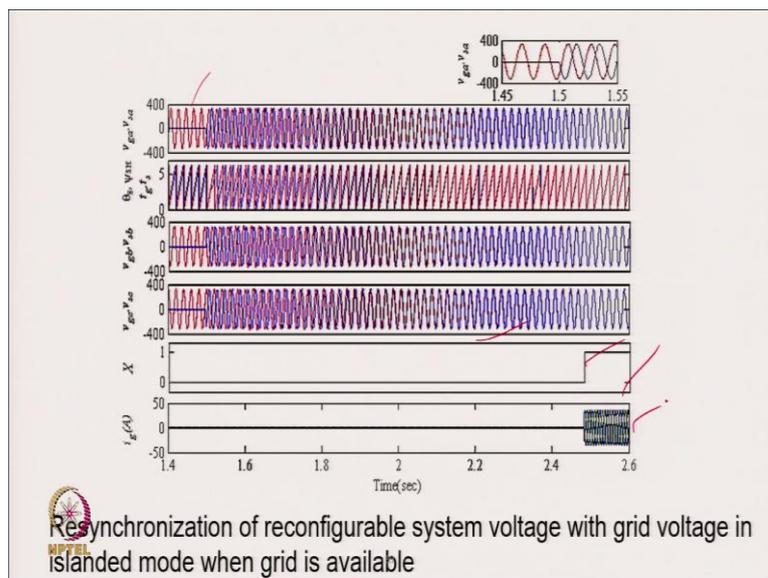
$\omega_{SH}^{ref} = 314.16$ rad/sec, when the grid is not available in islanded mode.

$\omega_{SH}^{ref} = 314.16 + \omega^{comp}$, when the grid is available in islanded mode.



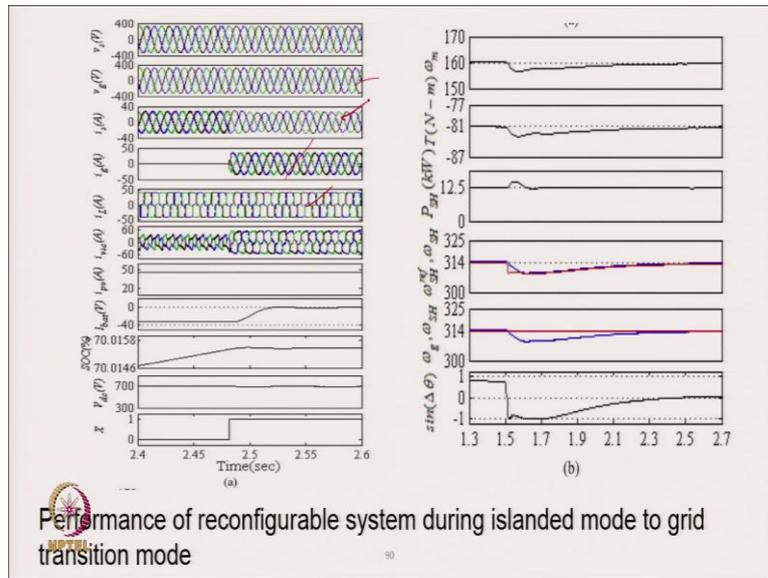
88

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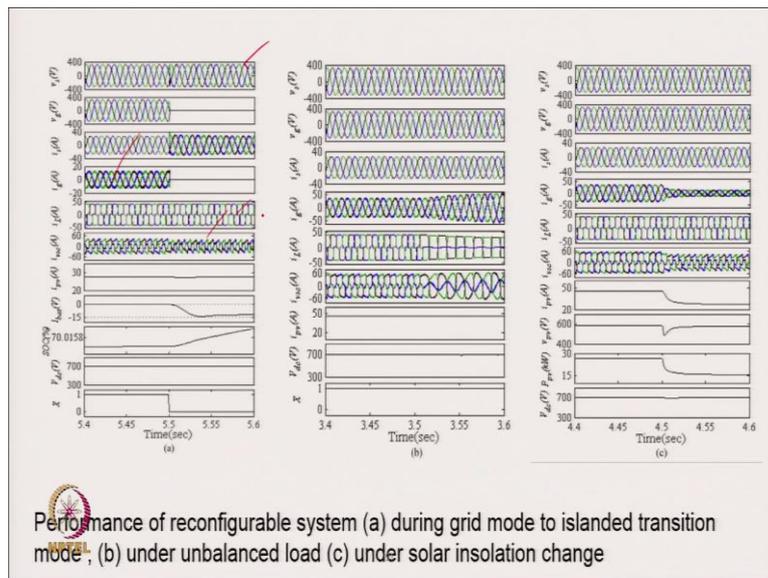


The simulation results are presented in the screenshots herein.

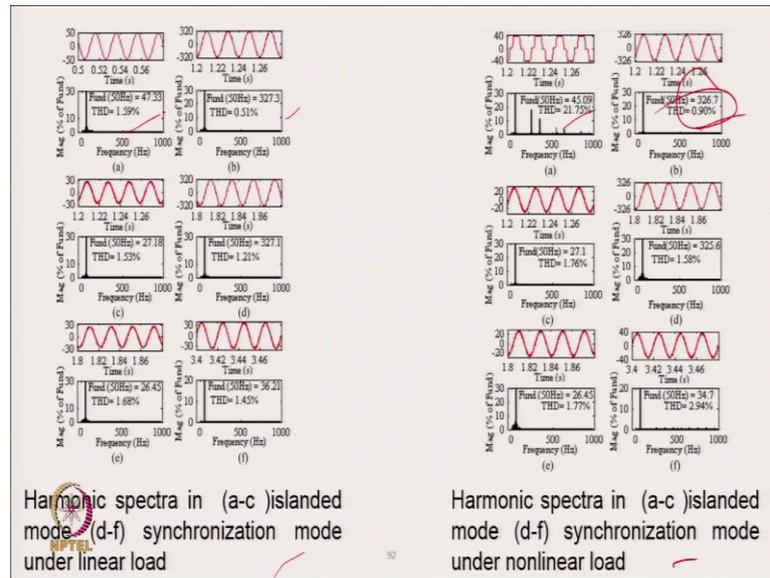
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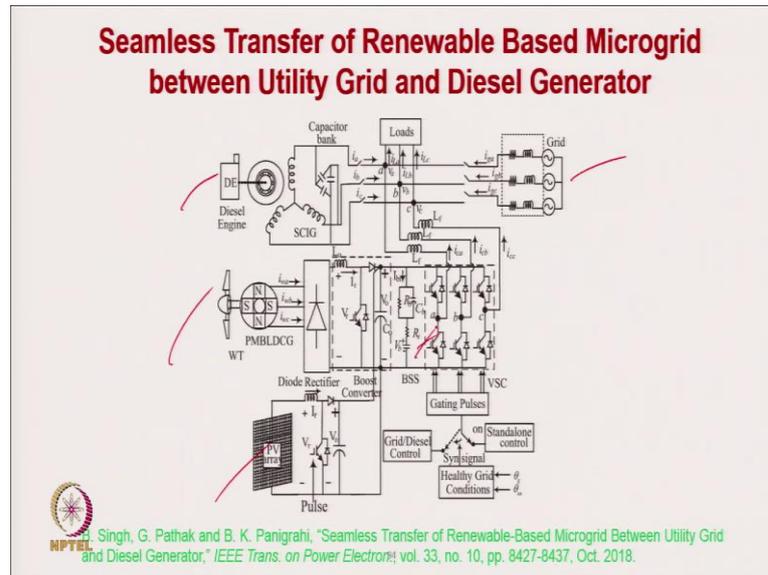
Power Quality Improvement in Grid Integrated Wind-Solar PV-Battery-DG Set based Microgrid



93

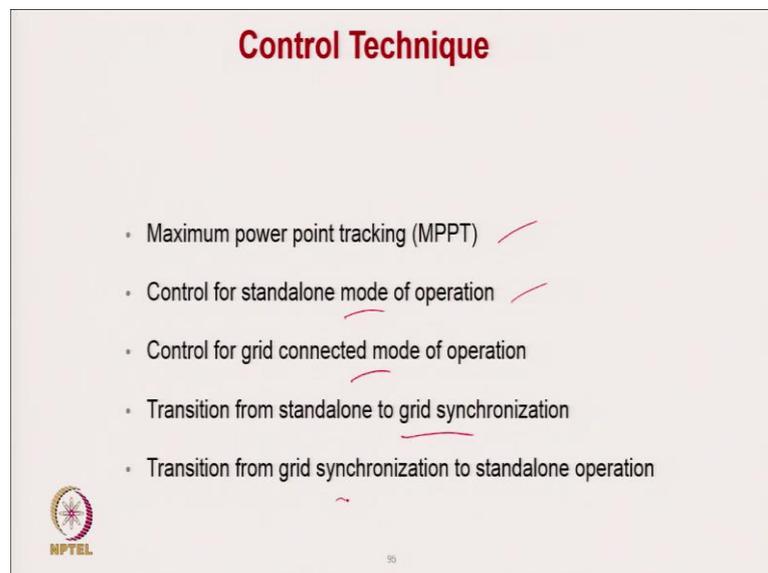
Now, coming to power quality improvement in the grid connected wind solar PV battery based DG set based microgrid.

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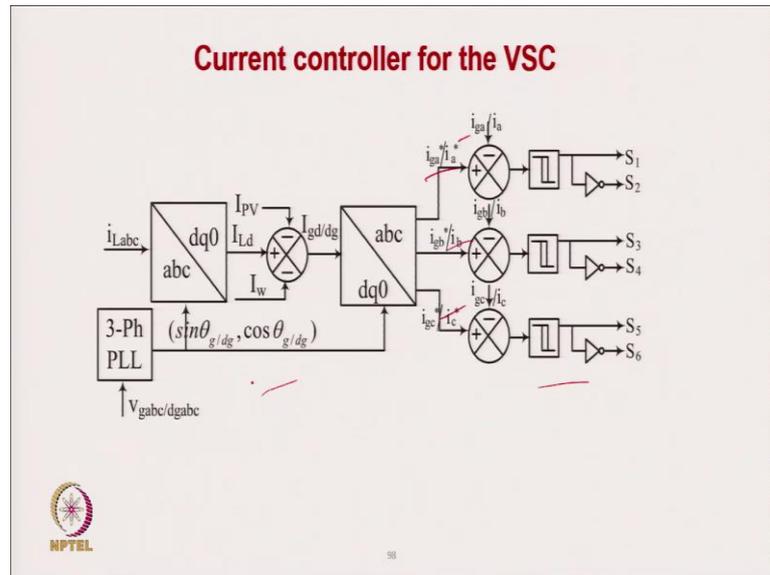
The system configuration is shown in the above screenshot.

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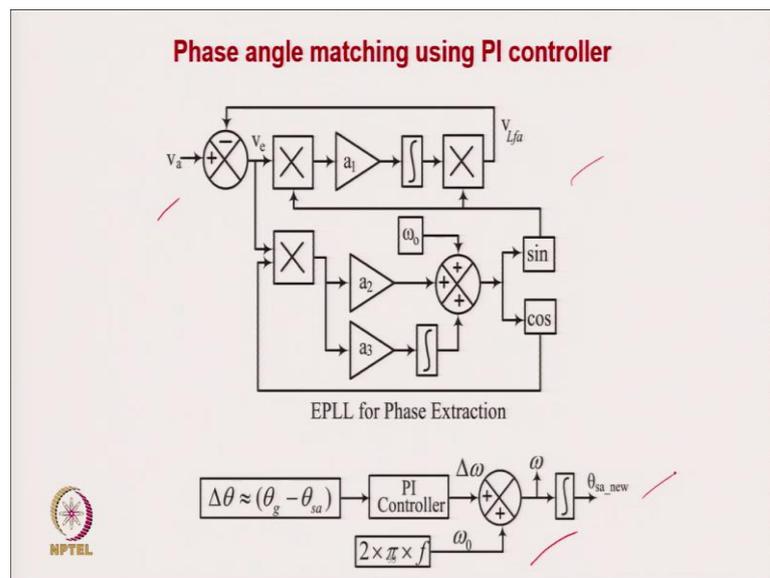


The control strategy is briefly described in the screenshots herein.

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(Refer Slide Time: 30:20)

Control Algorithm Expressions

The reference voltages for an islanded mode are derived as,

$$v_{La}^* = V_p^* \sin(\omega_0 t)$$
$$v_{Lb}^* = V_p^* \sin\left(\omega_0 t - \frac{2\pi}{3}\right)$$
$$v_{Lc}^* = V_p^* \sin\left(\omega_0 t + \frac{2\pi}{3}\right)$$

The load currents in the three phases are converted into the d-q-0 frame using,


$$\begin{bmatrix} i_{Ld} \\ i_{Lq} \\ i_{L0} \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos \theta_g & -\sin \theta_g & \frac{1}{2} \\ \cos\left(\theta_g - \frac{2\pi}{3}\right) & -\sin\left(\theta_g - \frac{2\pi}{3}\right) & \frac{1}{2} \\ \cos\left(\theta_g + \frac{2\pi}{3}\right) & \sin\left(\theta_g + \frac{2\pi}{3}\right) & \frac{1}{2} \end{bmatrix} \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix}$$

(Refer Slide Time: 30:27)

Control Algorithm Expressions

The reference active components of source is estimated as,

$$I_{Tp} = (I_{Ld} - I_w - I_{PV})$$

The active component of wind current is,

$$I_w = \frac{P_w}{3V_t}$$

The active component of solar PV current is,


$$I_{PV} = \frac{P_{PV}}{3V_t}$$

(Refer Slide Time: 30:40)

Control Algorithm Expressions

Using inverse Park transform, reference grid currents are,

$$i_{ga}^* = \frac{2}{\sqrt{3}}(I_d \sin \theta_g + I_q \cos \theta_g)$$
$$i_{gb}^* = \frac{2}{\sqrt{3}}[I_d \sin(\theta_g - 2\pi/3) + I_q \cos(\theta_g - 2\pi/3)]$$
$$i_{gc}^* = \frac{2}{\sqrt{3}}[I_d \sin(\theta_g + 2\pi/3) + I_q \cos(\theta_g + 2\pi/3)]$$

Where,

 $I_d = I_{gt}$ and $I_q = 0$

102

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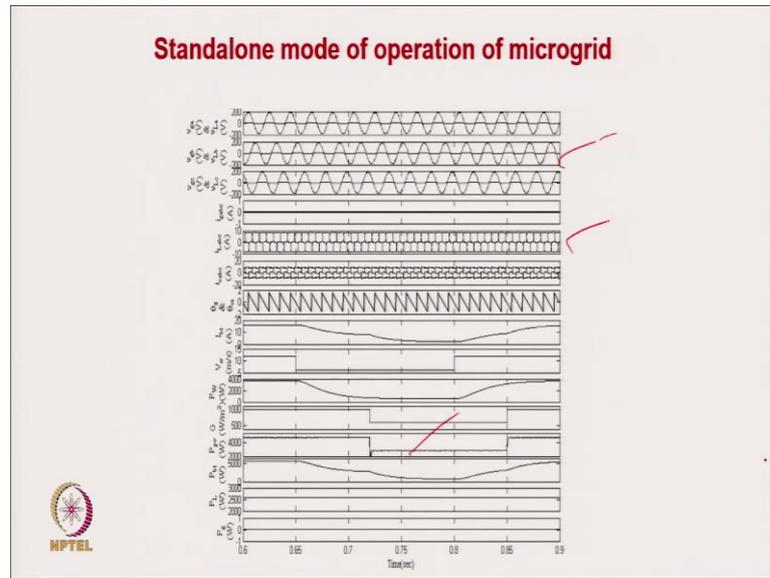
Control Algorithm Expressions

The angle error is estimated as,

$$\sin(\theta_g - \theta_{sa}) \approx (\theta_g - \theta_{sa}) = \Delta\theta$$

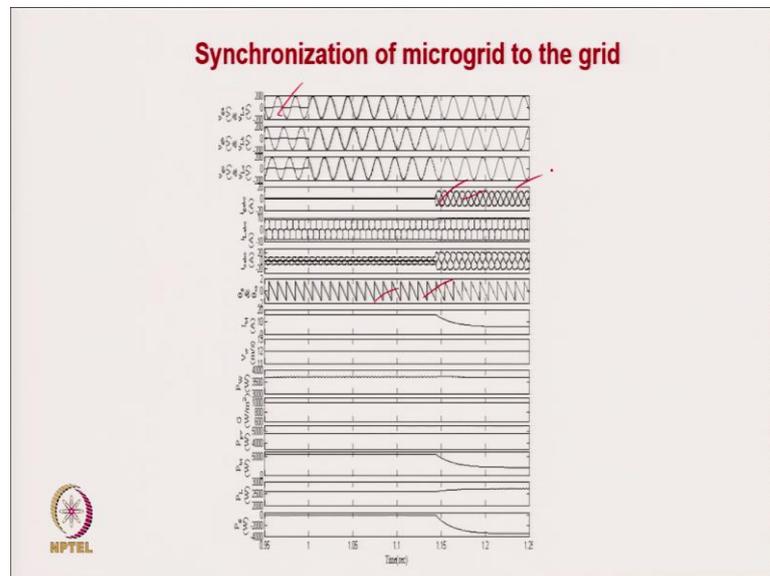


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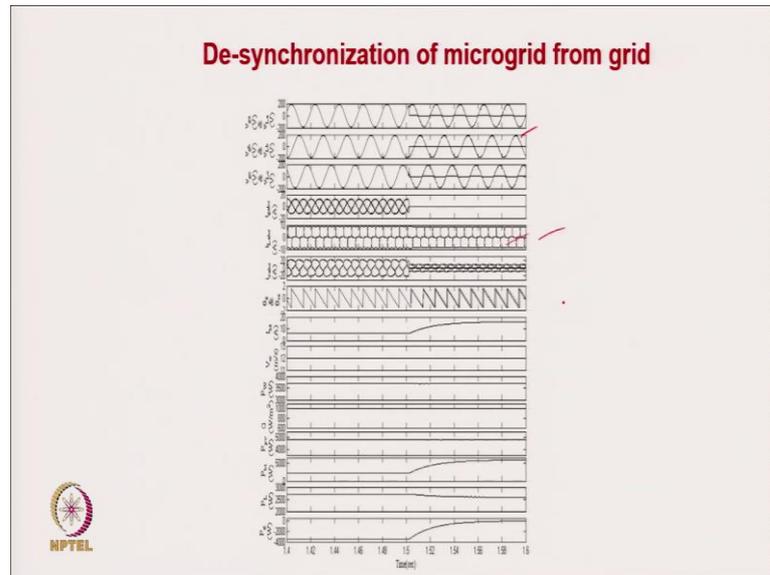


The simulation results are provided in the screenshots herein.

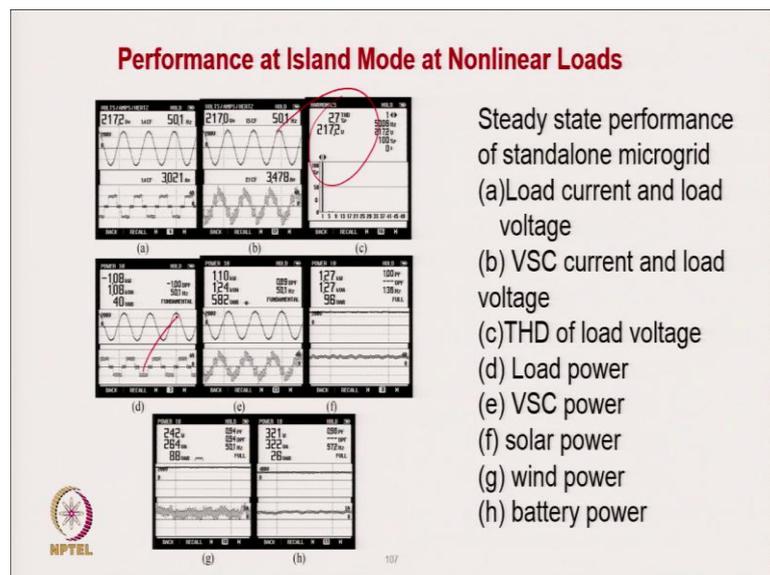
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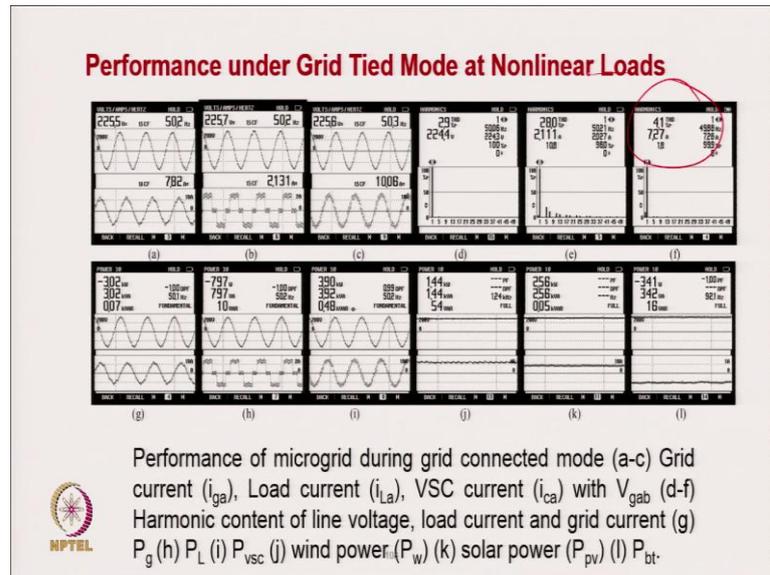
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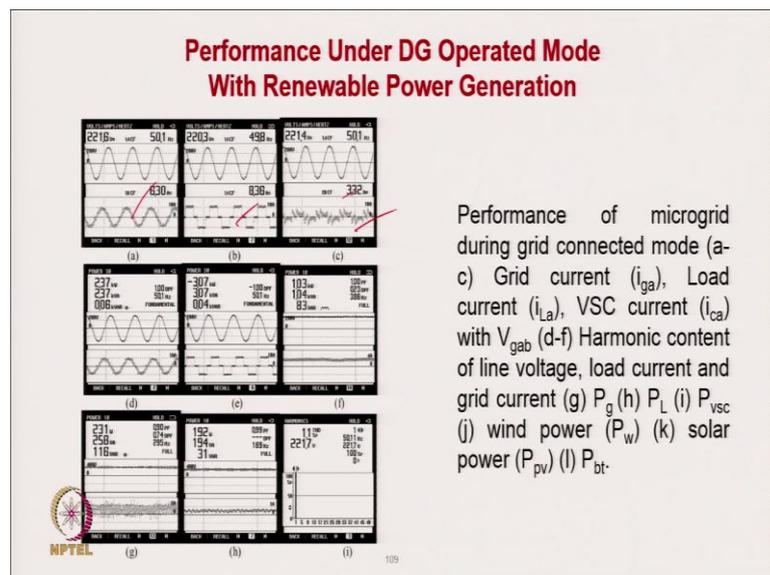
- Steady state performance of standalone microgrid
- (a) Load current and load voltage
 - (b) VSC current and load voltage
 - (c) THD of load voltage
 - (d) Load power
 - (e) VSC power
 - (f) solar power
 - (g) wind power
 - (h) battery power

The experimental results are provided in the screenshots herein.

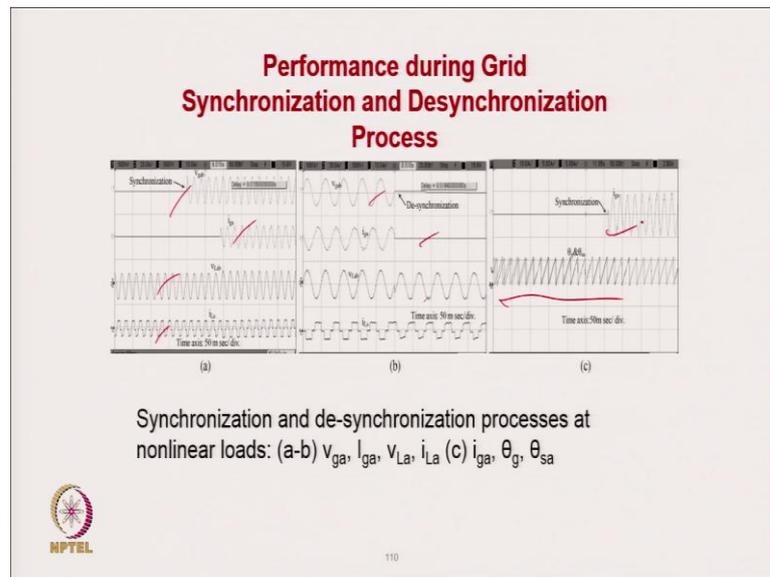
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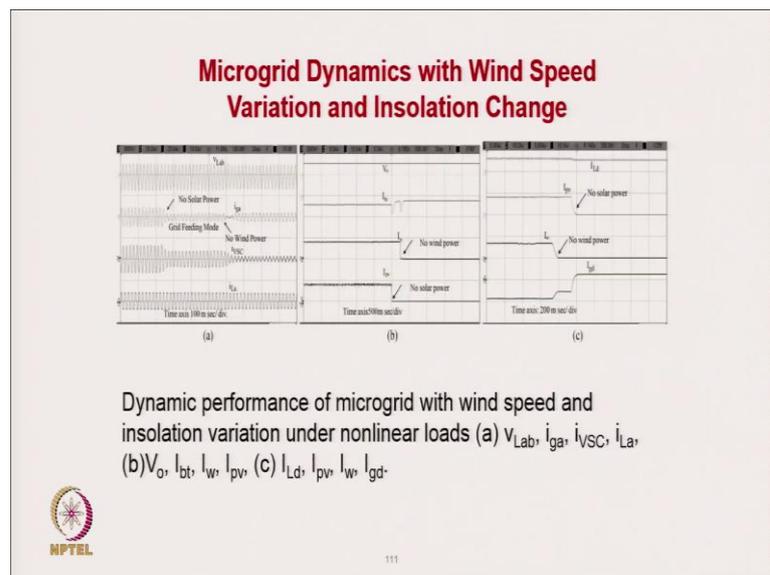
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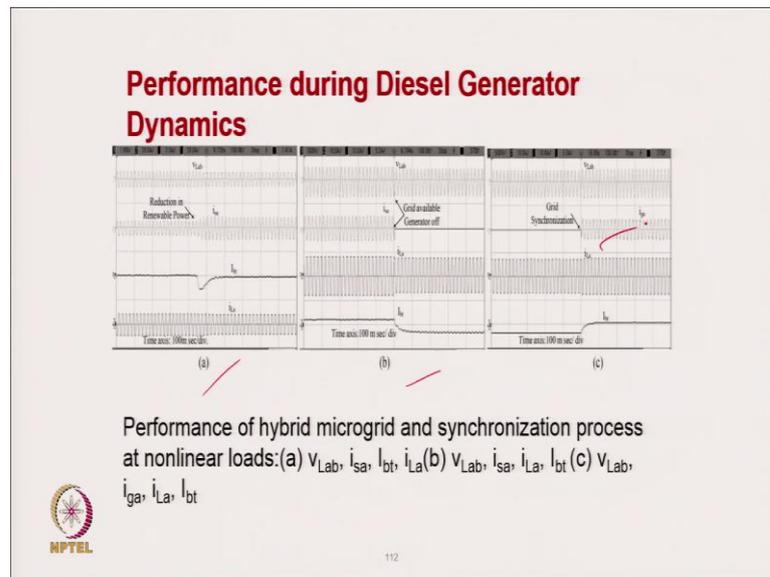
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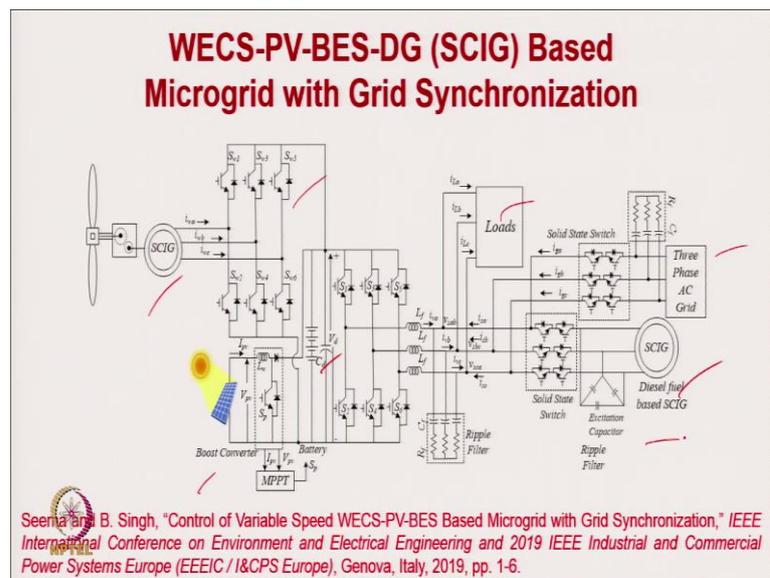
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This is another configuration whose control strategy, simulation results and experimental results are described in the screenshots herein.

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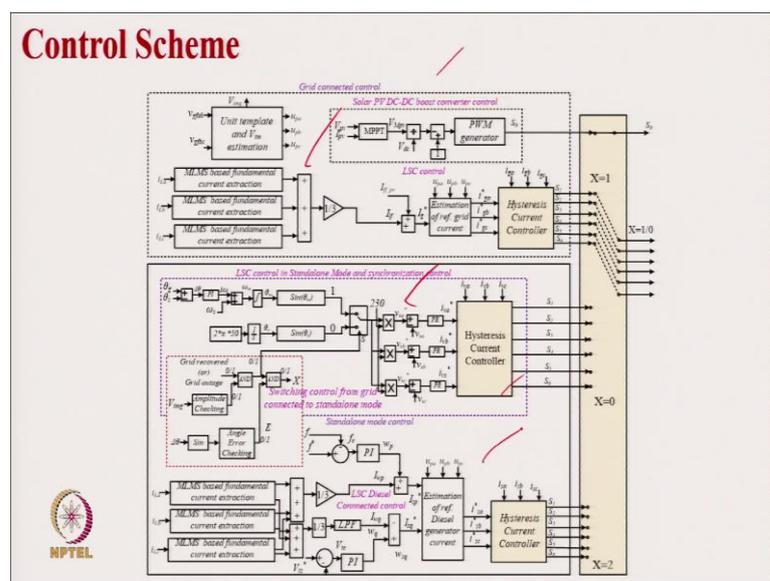
Features

The control strategy is categorized into three different parts such as

- (1) LSC control for standalone and synchronization control
- (2) LSC control for grid connected mode
- (3) MSC and solar PV control



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Machine Side VSC Control Algorithm

- The machine side VSC is controlled through indirect FOC (Field Oriented Control), and this algorithm is based on flux inverse dynamic of the model.
- In indirect FOC, the rotor flux orientation is in d- axis of the frame. Since the rotor flux is aligned to the d-axis, therefore,

$$\psi_r = \psi_{dr} \quad \psi_{qr} = 0 \quad T_{em} = \frac{3}{2} P \frac{L_m}{L_r} [\psi_r I_{qs}^*]$$
- In FOC, the torque and flux are used for estimating the reference (I_{ds}^* and I_{qs}^*) current, which are given as follows,

$$I_{ds}^* = \left(\frac{1 + s\tau_r}{L_m} \right) \psi_r^* \quad I_{qs}^* = \frac{2L_r T_e}{3PL_m \psi_r^*}$$

$T_e(m) = T_e(m-1) + k_{piv} \{(\omega_{re}(m) - \omega_{re}(m-1))\} + k_{iw} \{\omega_{re}(m)\}$

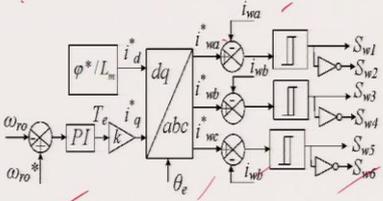


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Machine Side VSC Control Algorithm

- The reference three-phase generator currents are estimated as,

$$i_{sa}^* = \left(\sin(\theta_e) I_{ds}^* + \cos(\theta_e) I_{qs}^* \right) \quad i_{sb}^* = \left(\sin\left(\theta_e - \frac{2\pi}{3}\right) I_{ds}^* + \cos\left(\theta_e - \frac{2\pi}{3}\right) I_{qs}^* \right) \quad i_{sc}^* = \left(\sin\left(\theta_e + \frac{2\pi}{3}\right) I_{ds}^* + \cos\left(\theta_e + \frac{2\pi}{3}\right) I_{qs}^* \right)$$



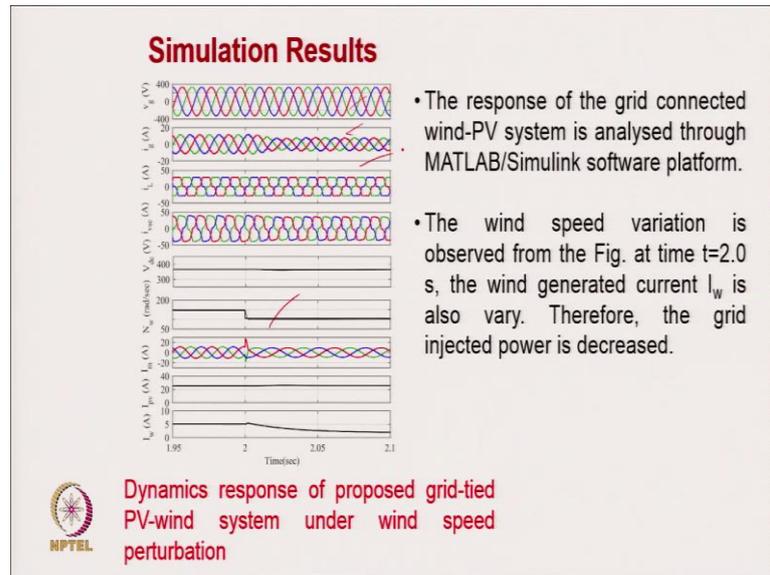
Block diagram of machine side VSC control

- Where θ_e is the synchronous frame rotor axis angle and it is estimated as,

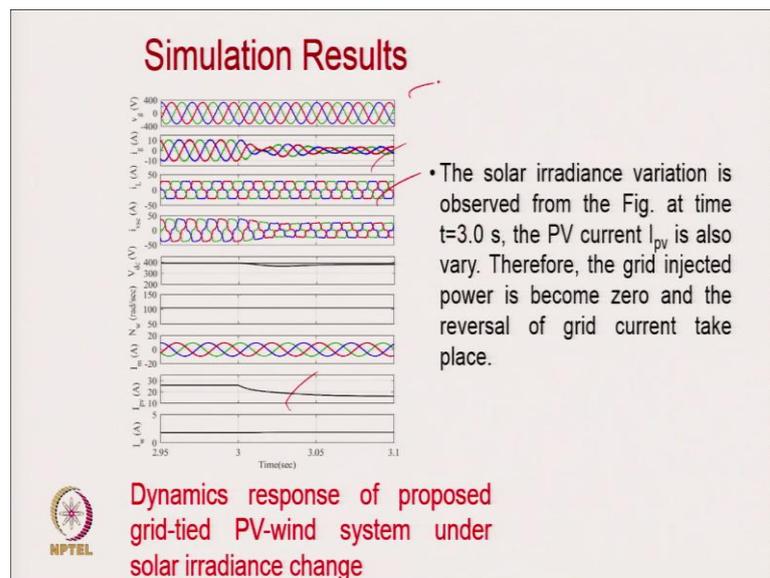
$$\theta_e = \int \omega_r dt + \int (\omega_e - \omega_r) dt = \theta_{ro} + \int S \omega_e dt = \theta_{ro} + \frac{R_r}{L_r} \int I_{qs}^* \frac{L_m}{\psi_{dr}^*} dt = \theta_{ro} + \frac{1}{T_r} \int I_{qs}^* dt$$



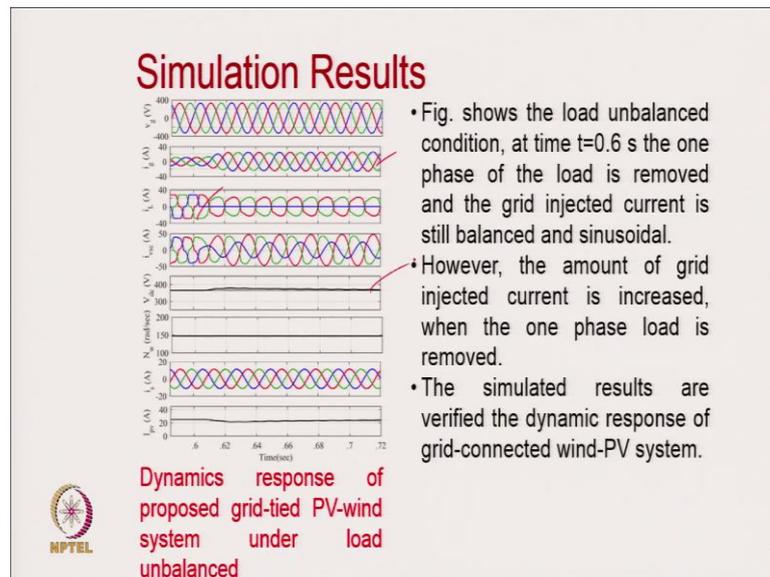
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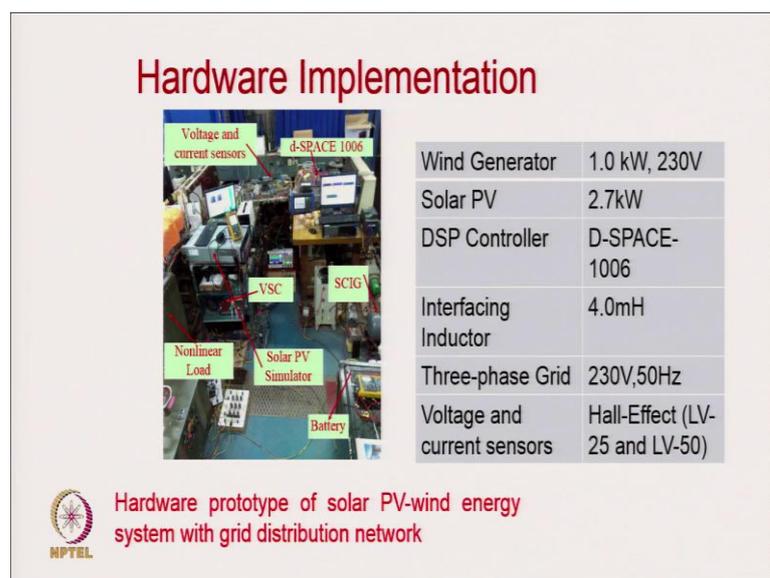
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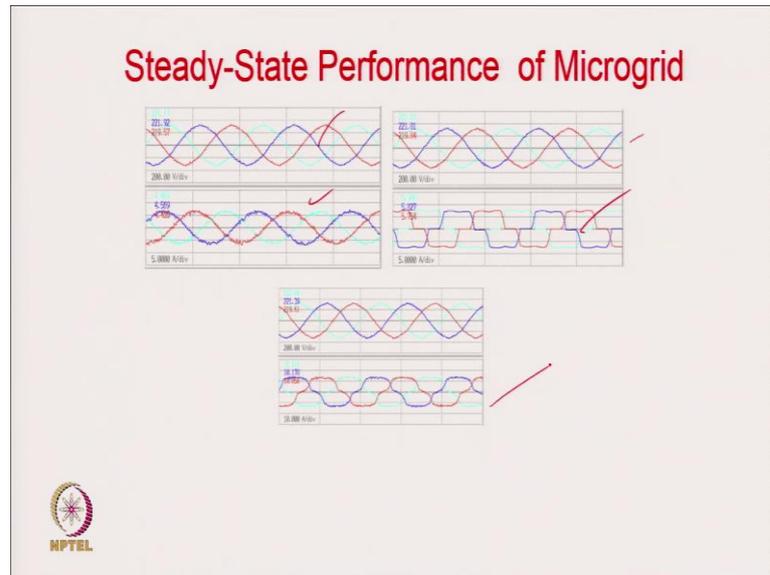


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These are typically the hardware of the prototype developed for the system.

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Power Quality Indices

Urms[V]	Irms[A]	Uthd-F[%]	Ithd-F[%]
12 221.17	1 4.469	2.56	4.19
23 221.32	2 4.569	2.31	4.43
31 219.57	3 4.455	2.47	4.34

Urms[V]	Irms[A]	Uthd-F[%]	Ithd-F[%]
12 221.21	1 5.906	2.63	22.91
23 221.81	2 5.827	2.40	22.68
31 219.84	3 5.754	2.54	23.00

P[W]	S[VA]	Q[var]	PF
1 - 0.559k	0.599k	- 0.216k	-0.9328
2 - 0.582k	0.624k	- 0.224k	-0.9331
3 - 0.553k	0.598k	- 0.222k	-0.9281
SUM - 1.694k	1.721k	- 0.304k	-0.9843

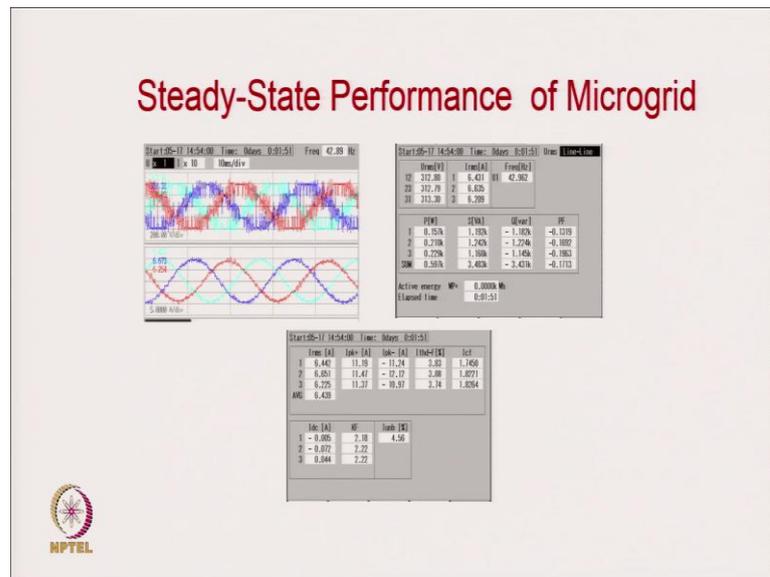
P[W]	S[VA]	Q[var]	PF
1 0.713k	0.792k	0.346k	0.8999
2 0.718k	0.795k	0.346k	0.9036
3 0.689k	0.770k	0.343k	0.8950
SUM 2.120k	2.231k	0.695k	0.9503

Urms[V]	Irms[A]	Uthd-F[%]	Ithd-F[%]
12 221.00	1 10.162	2.54	12.95
23 221.39	2 10.178	2.38	12.64
31 219.61	3 10.050	2.52	13.08

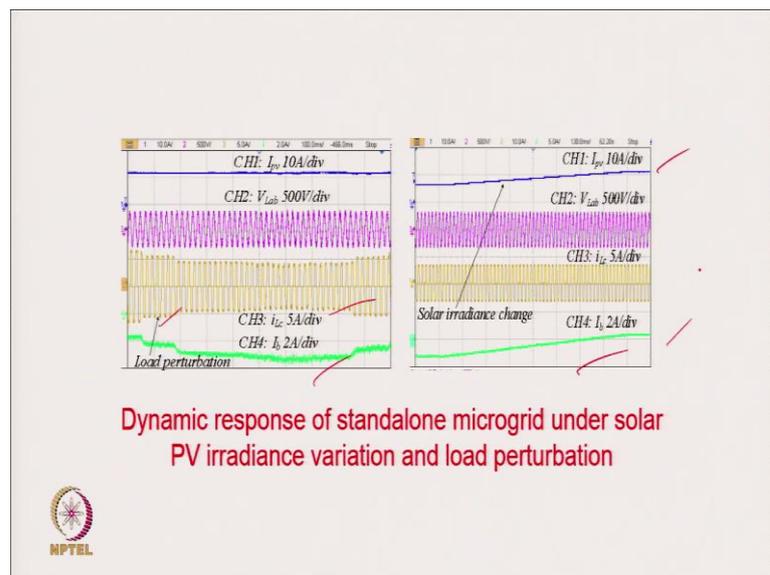
P[W]	S[VA]	Q[var]	PF
1 - 1.258k	1.364k	- 0.528k	-0.9221
2 - 1.276k	1.388k	- 0.546k	-0.9194
3 - 1.233k	1.343k	- 0.533k	-0.9181
SUM - 3.768k	3.872k	- 0.892k	-0.9731

The NPTEL logo is located in the bottom left corner of the slide.

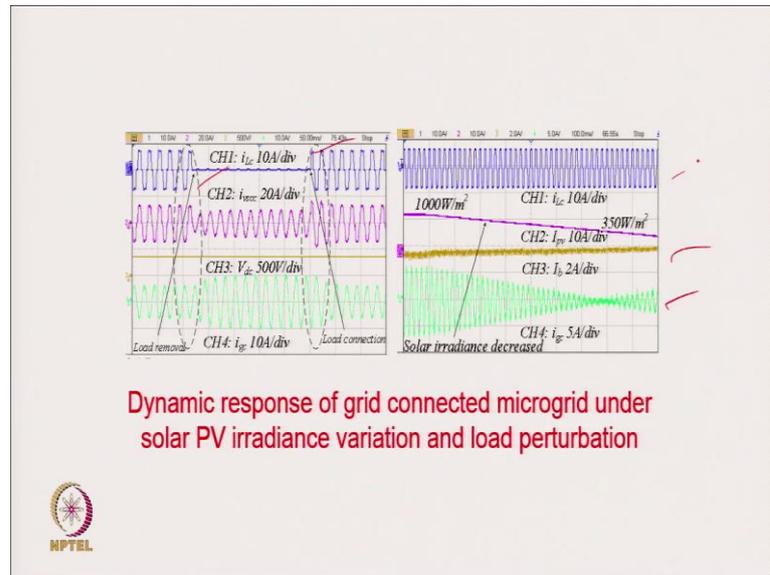
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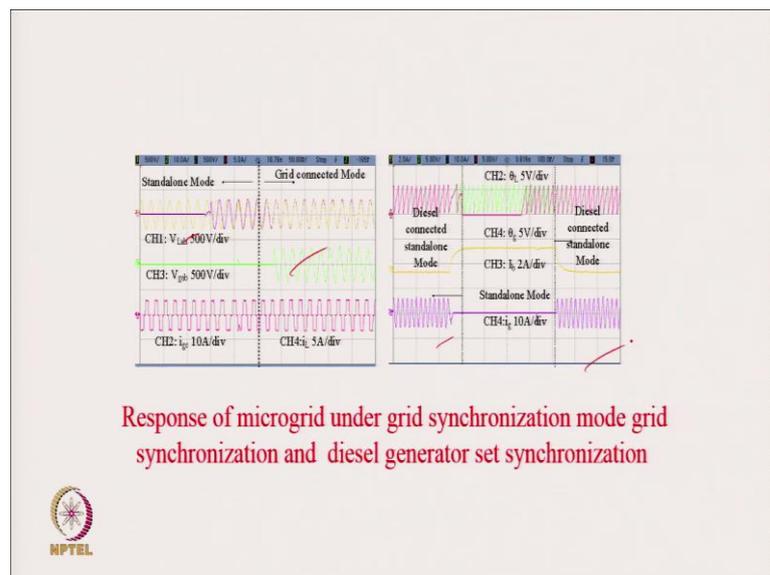
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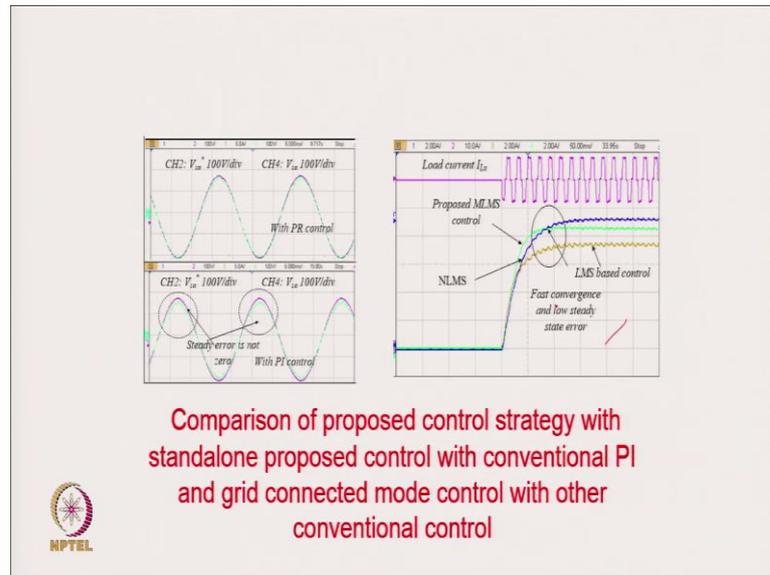
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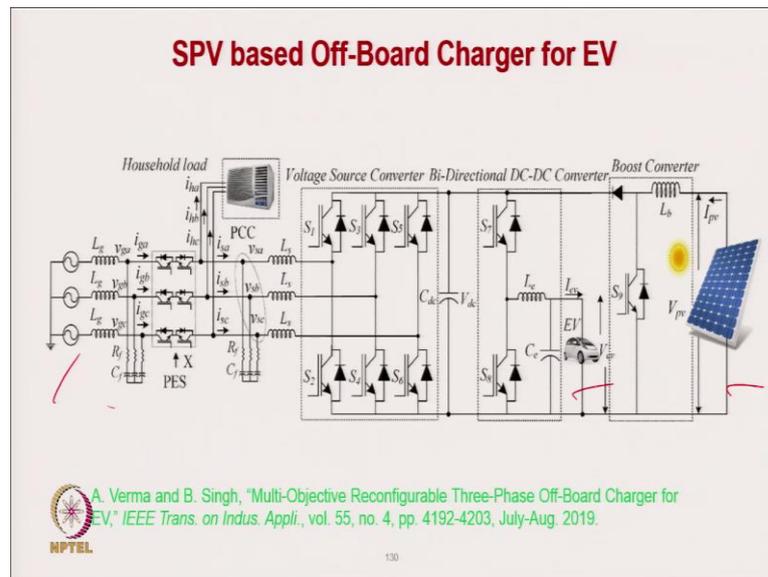
Power Quality Improvement in Microgrids for Electric Vehicle Charging Station

NPTEL

129

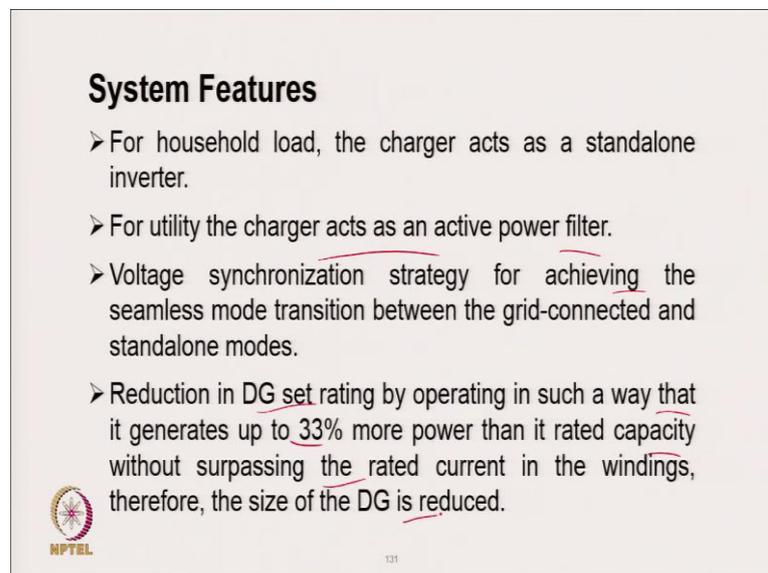
Now, coming to power quality improvement in microgrid for electric vehicle charging station.

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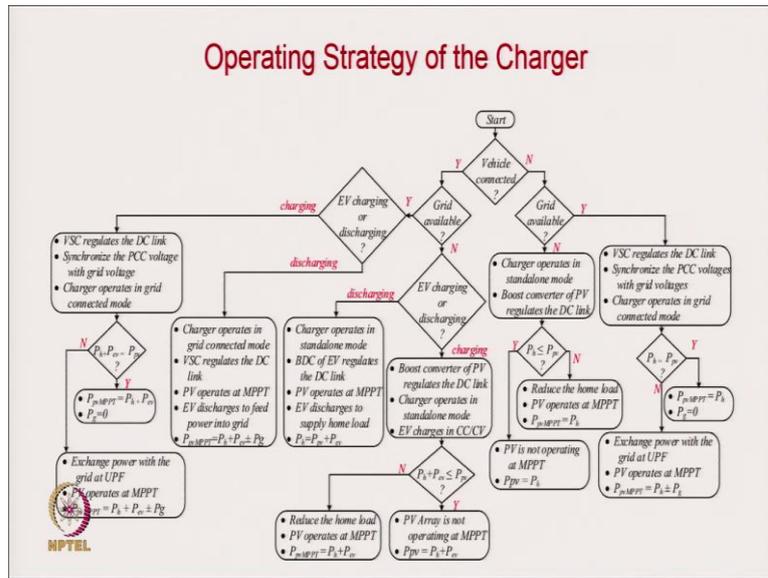
The charging station configuration is described in the screenshot herein.

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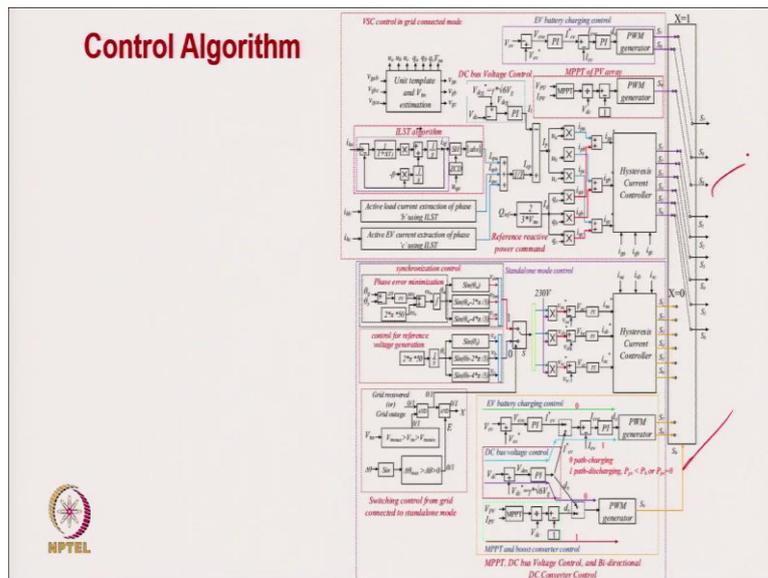


The system features and operational criterion are described here.

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(Refer Slide Time: 36:17)



The control strategy are described in the screenshots herein.

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Control Algorithm

Standalone Control

The reference sinusoidal signals of unit amplitude are obtained as,

$$v_a = \sin(\theta_s), v_b = \sin(\theta_s - 2\pi/3)$$
$$v_c = \sin(\theta_s - 4\pi/3)$$

The modified frequency is estimated as,

$$\omega_m = \omega_o + \Delta\omega.$$


134

(Refer Slide Time: 37:26)

Control Algorithm

Grid Connected Control,

The ILST algorithm closed loop transfer function is as,

$$\frac{i_h}{i_{hf}} = \frac{s\alpha}{s^3T_1 + s^2 + (\beta T_1 + \alpha)s + \beta}$$

The active current per phase is obtained as,

$$I_{ep} = \frac{I_{epa} + I_{epb} + I_{epc}}{3}$$


135

(Refer Slide Time: 37:33)

Control Algorithm

The total active current per phase is given as

$$I_p = I_{ep} - I_l$$

The current corresponding to the reference reactive power is obtained as,

$$I_q = \frac{2Q_{\text{ref}}}{3V_{tm}}$$

The amplitude of the PCC voltage is,


$$V_{tm} = \sqrt{\frac{2}{3} (v_{ga}^2 + v_{gb}^2 + v_{gc}^2)}$$

(Refer Slide Time: 37:39)

Control Algorithm

The phase voltages are obtained from the line voltages using,

$$v_{ga} = \frac{1}{3} (2v_{gabp} + v_{gbc p}), v_{gb} = \frac{1}{3} (-v_{gabp} + v_{gbc p})$$
$$v_{gc} = \frac{1}{3} (-v_{gabp} - 2v_{gbc p})$$

The sinusoidal currents corresponding to active power and reactive power,


$$i_{pa} = I_p * u_a, i_{pb} = I_p * u_b, i_{pc} = I_p * u_c,$$
$$i_{qa} = I_q * q_a, i_{qb} = I_q * q_b, i_{qc} = I_q * q_c.$$

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Control Algorithm

The in-phase unit templates and quadrature phase unit templates are obtained as,

$$u_a = \frac{v_{ga}}{V_{tm}}, u_b = \frac{v_{gb}}{V_{tm}}, u_c = \frac{v_{gc}}{V_{tm}}$$

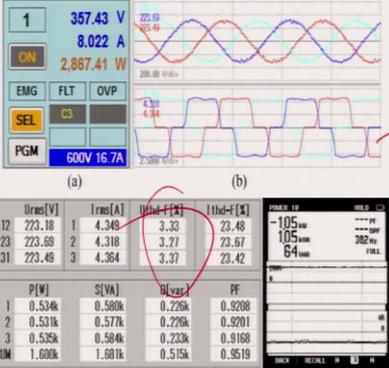
$$q_a = -\frac{u_a}{\sqrt{3}} + \frac{u_c}{\sqrt{3}}, q_b = \frac{\sqrt{3}u_a}{2} + \frac{(u_b - u_c)}{2\sqrt{3}}$$

$$q_c = -\frac{\sqrt{3}u_a}{2} + \frac{(u_b - u_c)}{2\sqrt{3}}$$


138

(Refer Slide Time: 37:49)

Steady State Performance in Standalone Mode



U rms [V]	I rms [A]	U thd-F [%]	I thd-F [%]
12 223.18	1 4.348	3.33	23.48
23 223.69	2 4.318	3.71	23.67
31 223.49	3 4.364	3.37	23.42

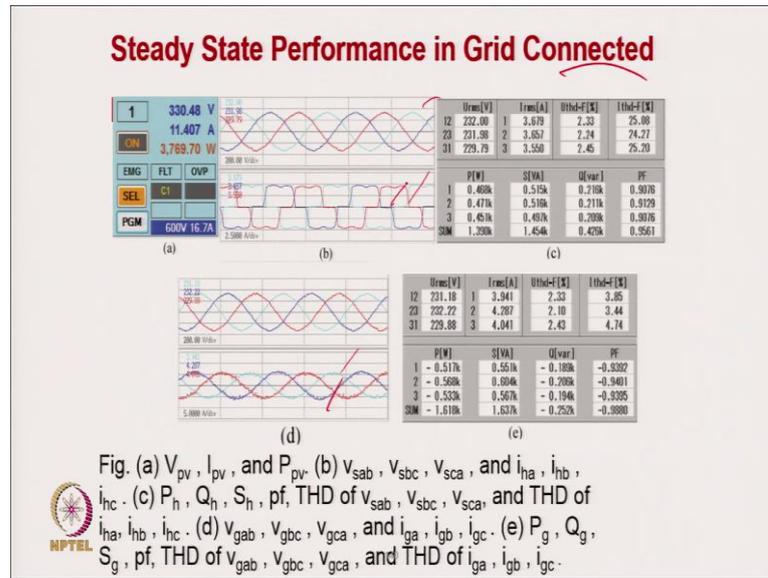
P [W]	S [VA]	U [V]	PF
1 0.534k	0.580k	0.226k	0.9208
2 0.531k	0.577k	0.226k	0.9201
3 0.535k	0.584k	0.233k	0.9168
SUM 1.600k	1.681k	0.515k	0.9519

Fig. (a) V_{pv} , I_{pv} , and P_{pv} . (b) v_{sab} , v_{sbc} , v_{sca} , and i_{ha} , i_{hb} , i_{hc} . (c) P_h , Q_h , S_h , pf, THD of v_{sab} , v_{sbc} , v_{sca} , and THD of i_{ha} , i_{hb} , i_{hc} . (d) V_{ev} , and I_{ev} , and P_{ev} .

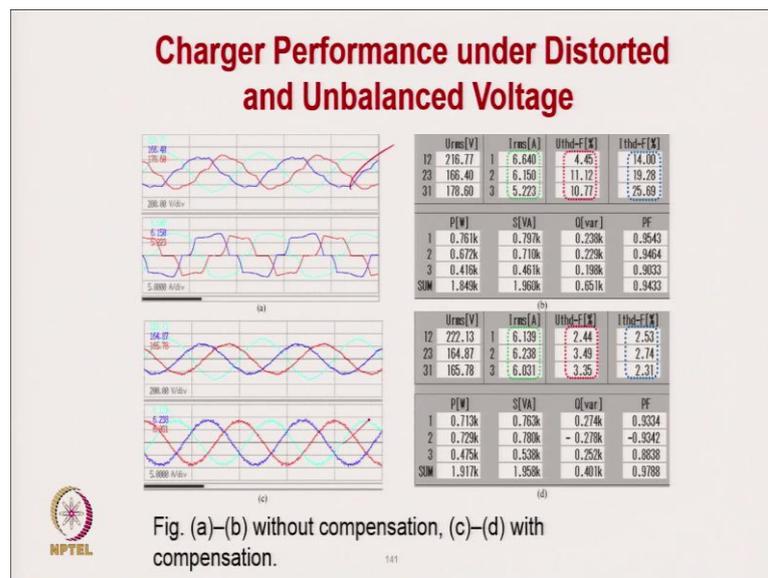


These screenshots present the experimental results.

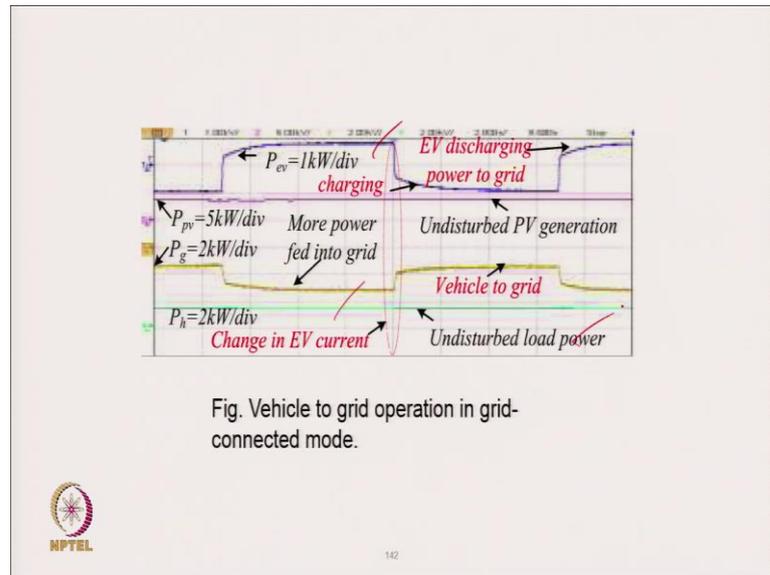
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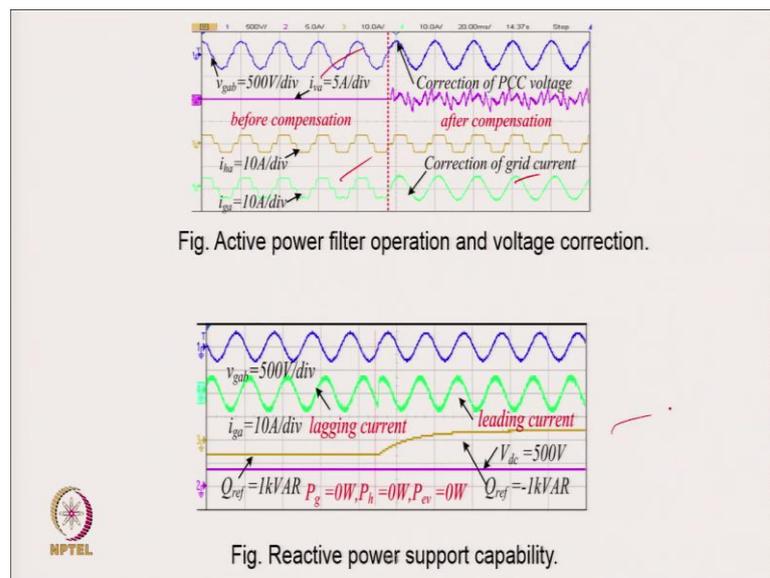
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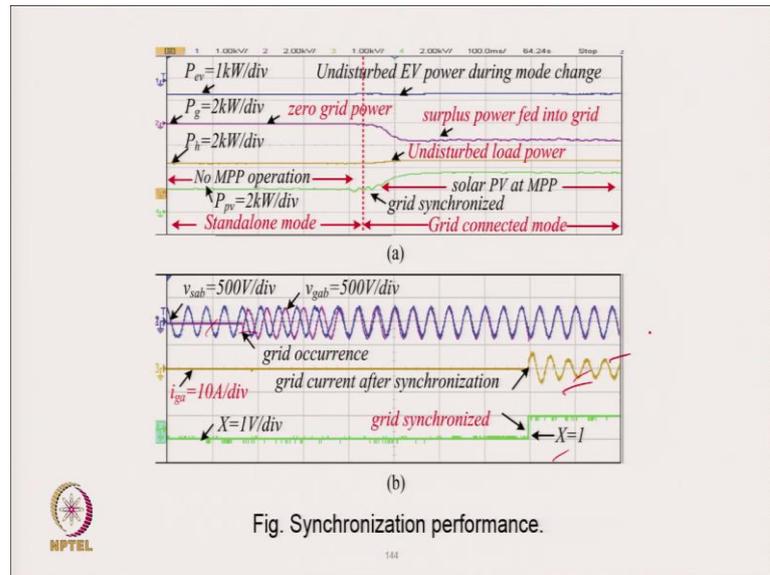
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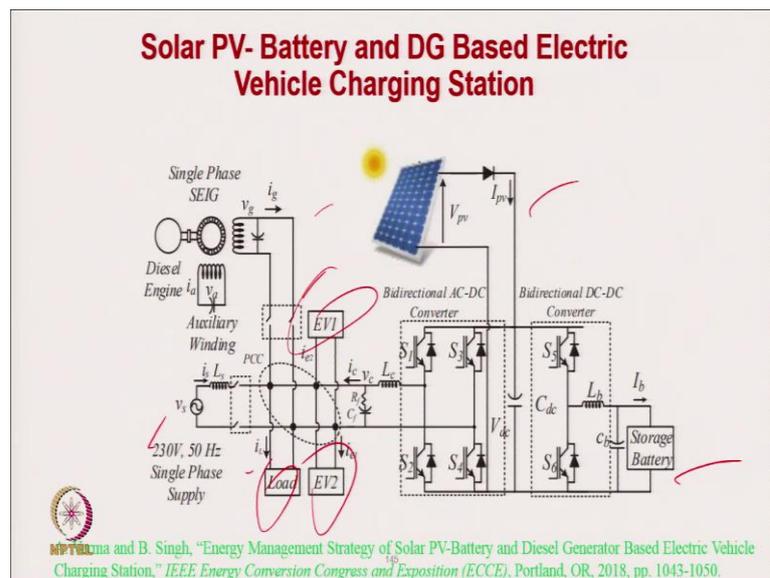
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This is another charging station configuration. Its description, operational criterion, control strategy, and experimental results are presented herein.

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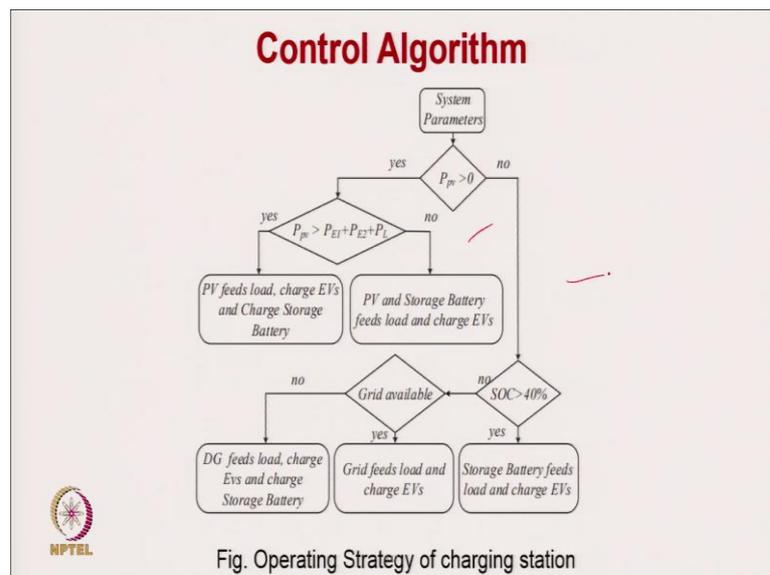
System Features

- Power management among different energy sources and charging the electric vehicles.
- Regulation of voltage and frequency of the generator, harmonics current compensation of nonlinear loads.
- The charging strategy is designed such that it primarily takes power from the solar photovoltaic (PV) array and a storage battery. In absence of these two sources, the charging station wisely takes power from the grid and the squirrel cage induction generator (SEIG) based diesel generator (DG) set.
- Reduction in DG set rating by operating in such a way that it generates up to 33% more power than it rated capacity without surpassing the rated current in the windings, therefore, the size of the DG is reduced.

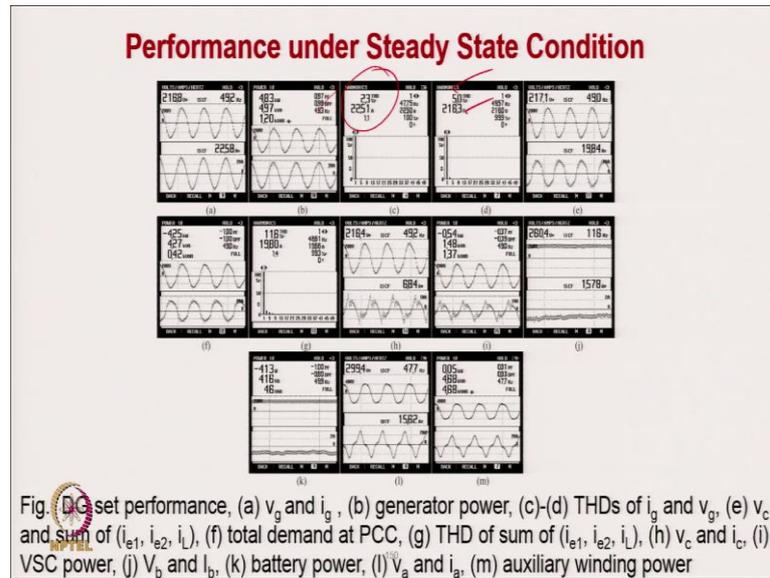


146

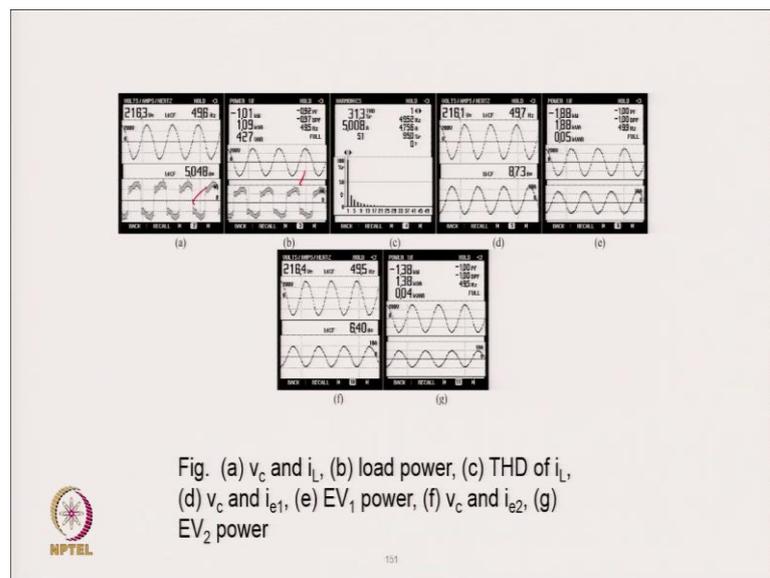
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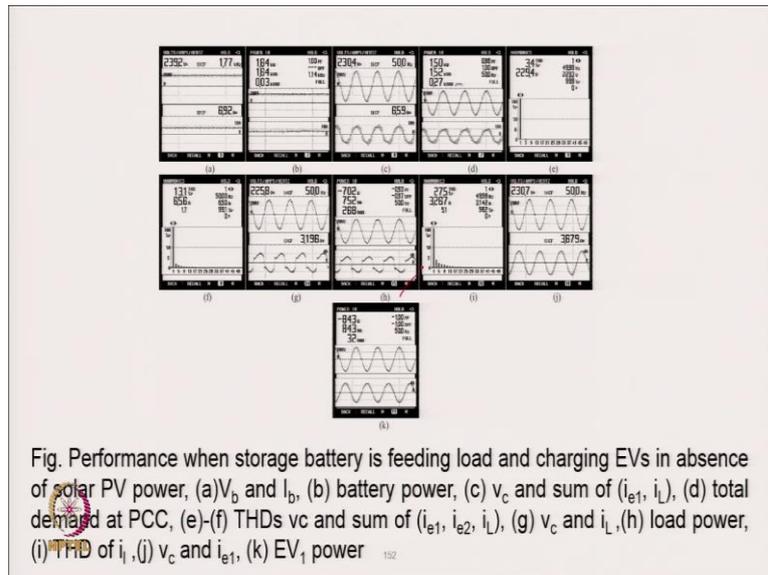
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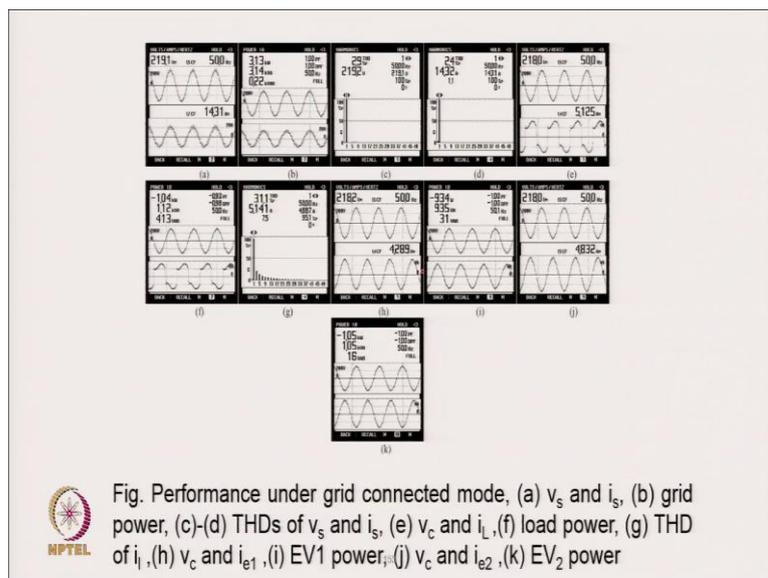
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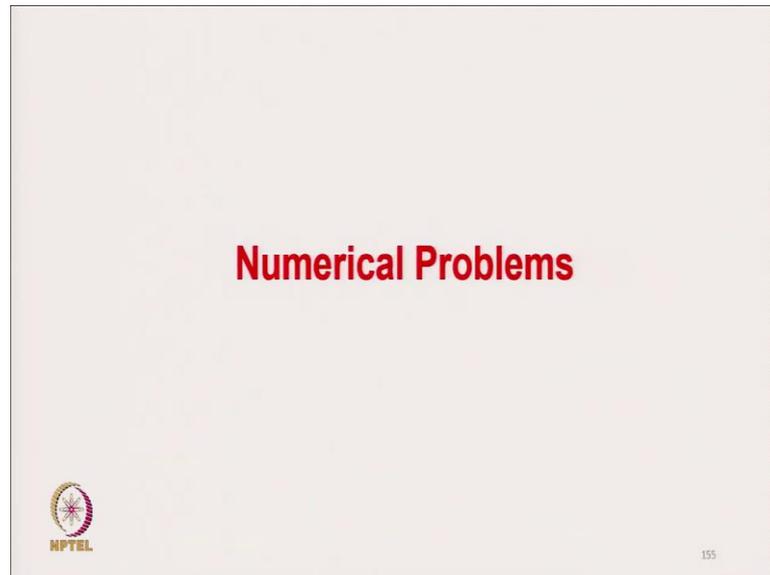
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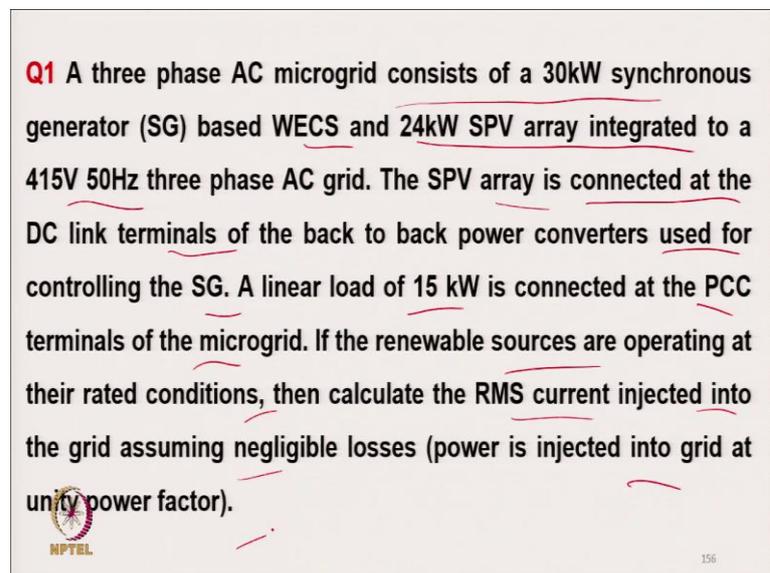


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Now, coming to the numerical problems.

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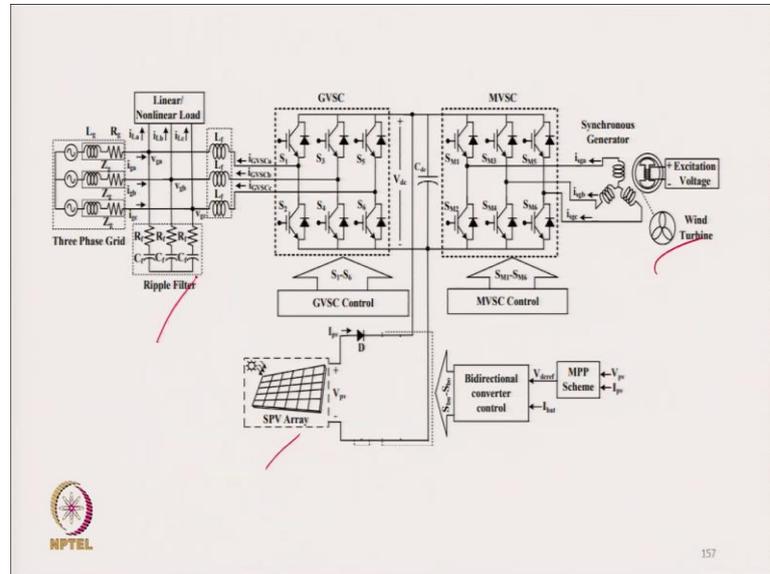


Three phase AC microgrid consists of 30 kilowatt synchronous generator based on wind power energy convergence 24 kilowatt solar PV array integrated to 415 volts 50 hertz three phase AC grid. And solar PV array is connected at the DC link terminal of the back to back connected power converter used for controlling the synchronous generator.

A linear load of fifteen kilowatt is connected at the PCC terminal of the microgrid and if renewable sources are operating at that rated condition. Then calculate the RMS current

injected into the grid assuming negligible losses power injected into grid at unity power factor.

(Refer Slide Time: 40:56)



The solution to the numerical example is detailed in the screenshots herein.

(Refer Slide Time: 41:08)

Sol. Power delivered by the SG based WECS,

$$P_w = 30kW$$

Power delivered by the SPV array,

$$P_{pv} = 24kW$$

Power fed to load,

$$P_l = 15kW$$

Net Power fed to the grid,

$$P_g = P_w + P_{pv} - P_l = 39kW$$

The NPTEL logo is in the bottom left, and the slide number '158' is in the bottom right.

(Refer Slide Time: 41:17)

Assuming negligible losses in WECS, the current flowing into the grid is,

$$I_g = \frac{P_g}{\sqrt{3}V_g} = \frac{39000}{\sqrt{3} \times 415} = 54.257 A$$


159

(Refer Slide Time: 41:23)

Q2 A wind turbine coupled to a doubly fed induction generator (4 pole 50Hz) has the following specifications,

Wind Turbine	Blade Radius	3.126m	Optimal Tip Speed Ratio	7.2
	Gearbox ratio	7.37	Rated wind speed	12m/s
	Max Power Coefficient	0.44	Minimum Slip	-0.3

It is coupled with a solar photovoltaic array having the following specifications,

SPV Module	OC voltage	36.3V	MPP voltage	29V
	SC current	7.84A	MPP current	7.35A
	Series modules	9	Parallel strings	8

The back to back converters of microgrid are connected to the 415V 50Hz three phase grid using a step up (2:1) transformer. The SPV array is connected to DC link of power converters through a DC-DC boost converter. If the DC link voltage of the power converters are maintained at 360V and the renewable energy sources are operated at 10m/s wind speed and rated solar irradiations, (a) calculate the required rotor speed and (b) calculate the required duty ratio of the boost converter for maximum power transfer from SPV array and wind turbine.

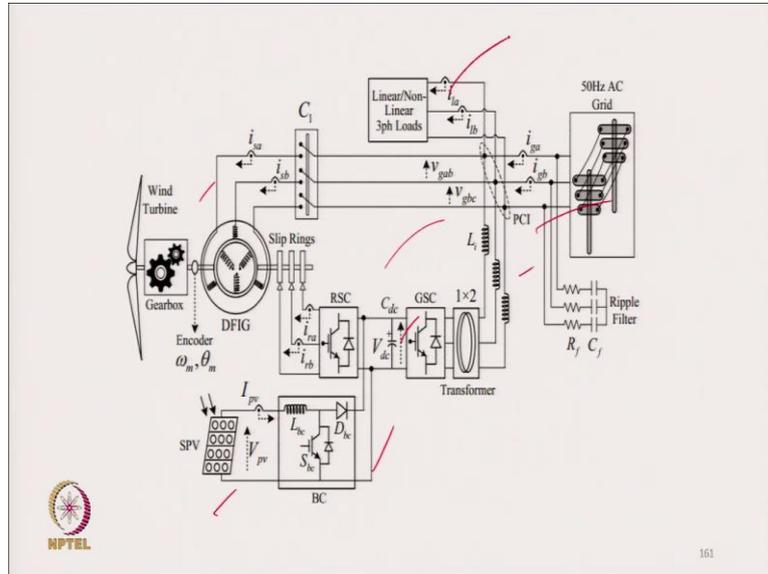
160

A wind turbine compared to doubly fed induction under 4 pole 50 hertz. These are typically that are of blade radius gearbox and maximum power coefficient slip maximum slip corresponding to your rated wind speed. And these are the PV array open circuit PV module current and MPPT voltage for PV module.

Back to back converters of microgrid connected to 415 volt 50 hertz three phase step up 2 to 1 transformer and SPV array connected to the DC link up through DC DC boost converter. And DC link voltage of the power converter are made at 360 volt with the

renewable research operator 10 meter per second wind speed and rated solar period. And calculate the required rotary speed, calculate the required duty ratio of the boost converter for maximum power from solar PVR and wind turbine.

(Refer Slide Time: 42:07)



The solution to the numerical example is detailed in the screenshots herein.

(Refer Slide Time: 42:19)

Solution-

(a) Thus, for maximum power transfer from wind turbine, the tip speed ratio should be at its optimal point.

$$\lambda_{opt} = \frac{R\omega_r}{G_r V_w}$$

$$\text{Thus, } \omega = \frac{\lambda_{opt} G_r V_w}{R} = \frac{7.2 \times 7.37 \times 10}{3.126} = 169.75 \text{ rad/s}$$

Thus, for a wind speed of 10m/s, if the DFIG rotor speed is controlled at 169.75 rad/s then maximum power will be transferred.



(Refer Slide Time: 42:28)

(b) SPV array voltage for operation at the maximum power point is calculated as,

$$V_{pv} = N_s * V_{mpp} = 9 * 29 = 261V.$$

Thus based on the duty cycle expression for boost converter,

$$\frac{V_{dc}}{V_{pv}} = \frac{1}{1-D}$$
$$\text{Thus, } D = \frac{V_{dc} - V_{pv}}{V_{dc}} = \frac{360 - 261}{360} = 0.275$$


163

(Refer Slide Time: 42:43)

Q3 A 80kW synchronous reluctance generator based WECS is integrated with a solar PV array with a peak power of 120kW. The microgrid is connected to a 84kW local load operating at 0.8 power factor. The net power is injected into the grid. If the renewable energy sources are operating at their rated conditions, calculate the grid RMS current and the voltage, current and KVA rating of grid side VSC (a) If reactive power compensation is provided by the microgrid and (b) If no reactive power compensation provided.

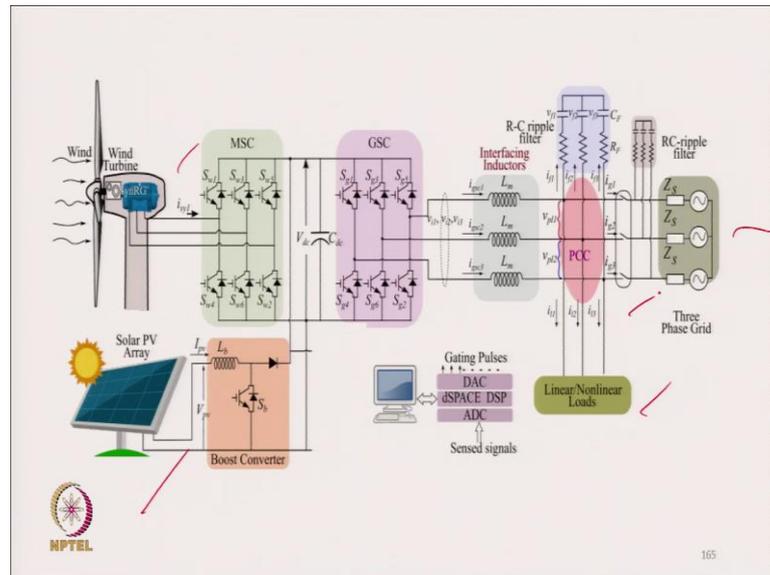


164

A 80 kilowatt synchronous reluctance generator base wind generator integrated system with the PV array with the peak power of 120 kilowatt. And the microgrid is connected to 84 kilowatt local load operating at 0.8 lagging power factor.

Net power is injected into the grid if the renewable energy source is operating at the rated condition calculate the grid RMS current and the voltage current. And KVA rating of the grid side voltage source converter a the reactive power compensation is provided by the microgrid and no reactive power compensation provided microgrid.

(Refer Slide Time: 43:15)



The solution to the numerical example is detailed in the screenshots herein.

(Refer Slide Time: 43:23)

Sol. Power delivered by the SyRG based WECS,

$$P_w = 80kW$$

Power delivered by the SPV array,

$$P_{pv} = 120kW$$

Active Power fed to load,

$$P_l = 84kW$$

Net Active Power fed to the grid,

$$P_g = P_w + P_{pv} - P_l = 116kW$$

Reactive power requirement of load,

$$Q_l = P_l \tan \phi = 63kVAR$$

The NPTEL logo is visible in the bottom left corner of the slide.

(Refer Slide Time: 43:42)

(a) RMS current flow in grid with compensation

$$I_g = \frac{P_g}{\sqrt{3}V_g} = \frac{116 \times 1000}{\sqrt{3} \times 415} = 161.38 \text{ A}$$

The kVA rating of GVSI is,

$$S_{\text{gvsi}} = \sqrt{Q_{\text{gvsi}}^2 + P_{\text{gvsi}}^2} = \sqrt{Q_f^2 + (P_w + P_{pv})^2} = \sqrt{63^2 + (120+80)^2} = 209.688 \text{ kVA}$$

Voltage rating of the VSI is, $V_{\text{gvsi}} = 239.6 \text{ V}$

Current rating of the VSI is, $I_{\text{gvsi}} = 209688 / (3 \times 239.6) = 291.72 \text{ A}$



167

(Refer Slide Time: 44:06)

(a) RMS current flow in grid without compensation

$$I_g = \frac{\sqrt{P_g^2 + Q_g^2}}{\sqrt{3}V_g} = \frac{\sqrt{116^2 + 63^2} \times 1000}{\sqrt{3} \times 415} = 183.64 \text{ A}$$

The kVA rating of GVSI is,

$$S_{\text{gvsi}} = \sqrt{Q_{\text{gvsi}}^2 + P_{\text{gvsi}}^2} = \sqrt{0 + (P_w + P_{pv})^2} = \sqrt{(120+80)^2} = 200 \text{ kVA}$$

Voltage rating of the VSI is, $V_{\text{gvsi}} = 239.6 \text{ V}$

Current rating of the VSI is, $I_{\text{gvsi}} = 200000 / (3 \times 239.6) = 278.242 \text{ A}$



168

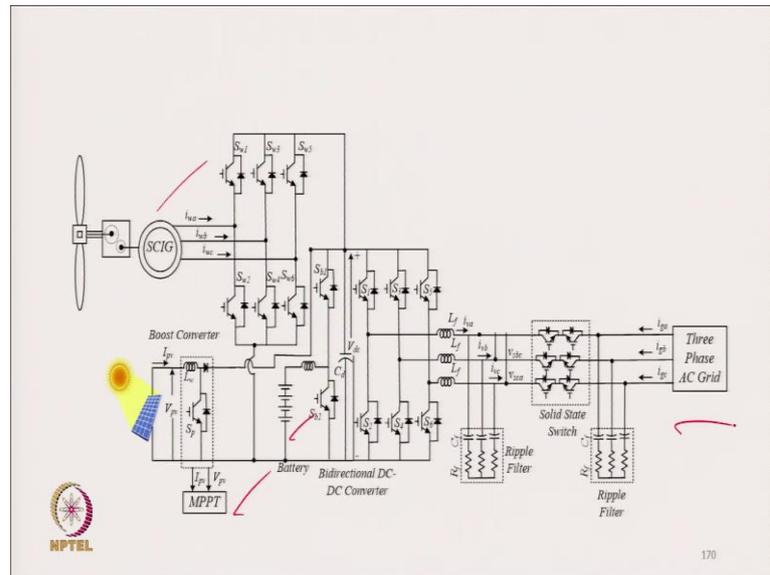
(Refer Slide Time: 44:25)

Q4 An AC microgrid with a 120kW (at rated wind speed 12m/s) squirrel cage induction generator (SCIG) based wind turbine and a 100kW (at 1000W/m² irradiation) SPV array is feeding power to a three phase 400V 50Hz grid. The SCIG is connected to the grid using back to back VSCs. The SPV array is integrated at the common DC link of VSCs through a boost DC-DC converter. A 480V battery energy storage is integrated with the microgrid through a bidirectional DC-DC converter to smoothen the wind and solar power irregularities. The microgrid control scheme is designed to provide a smooth power of 150 kW to the three phase grid at all times. Calculate the battery current when the wind speed is 8.5m/s and irradiation is 600W/m². Also calculate the current injected into the grid. Assume negligible losses, unity power factor operation at the grid side and linearly varying SPV array power with irradiation.

An AC microgrid with 120 kilowatt at rated wind speed of 12 meter per second is squirrel cage induction generator based on wind turbine. And a 100 kilowatt at 1000 (Refer Time: 44:37) solar PV range fitting power to the three phases of 400 volt 50 hertz squirrel. And squirrel cage generator to the grid using back to back voltage source converter and SPV array is integrated to the common DC link of VSC through boost convertor.

A 480 volt standard battery energy storage system integrated with the microgrid through bidirectional DC DC converter which smoothen the wind and solar irregularity. The microgrid control scheme is to provide a smooth power of 150 kilowatt to three phase grid at all time. Calculate the battery current when the wind speed is 8.5 meter per second and the solar radiation 600 watt per meter. Also, calculate the current injected into the grid also assume negligible losses unity power factor operation at the grid side can be varying the linear variation of solar PV power with irradiation.

(Refer Slide Time: 45:17)



The solution to the numerical example is detailed in the screenshots herein.

(Refer Slide Time: 45:23)

Solution- Since the power supplied by the PV array is directly proportional to solar insolation,

$$P_{600W/m^2} = (600 / 1000) P_{1000W/m^2} = 0.6 \times 100kW = 60kW$$

Assuming maximum power tracking operation of WECS, the total power of wind turbine is related as the cube of wind speed as evident in,

$$P_t = \frac{1}{2} \rho \pi R^2 V_w^3 C_p$$

$$P_{8.5m/s} = (8.5 / 12)^3 P_{12m/s} = 0.355 \times 120kW = 42.64kW$$

Thus, total generated power of microgrid = $P_{pv} + P_w = 60 + 42.64 = 102.64 kW$

(Refer Slide Time: 45:42)

Thus, the power required from the battery for smoothening,
 $P_b = P_g - P_{\text{microgrid}} = 150 - 102.64 = 47.36 \text{ kW}$

Thus battery is discharged.

The current injected by the battery is calculated as,
 $I_b = 47360 / 480 = 98.67 \text{ A}$

The current flowing into the grid is,

$$I_g = \frac{P_g}{\sqrt{3}V_g} = \frac{150000}{\sqrt{3} \times 415} = 216.5 \text{ A}$$


172

(Refer Slide Time: 46:07)

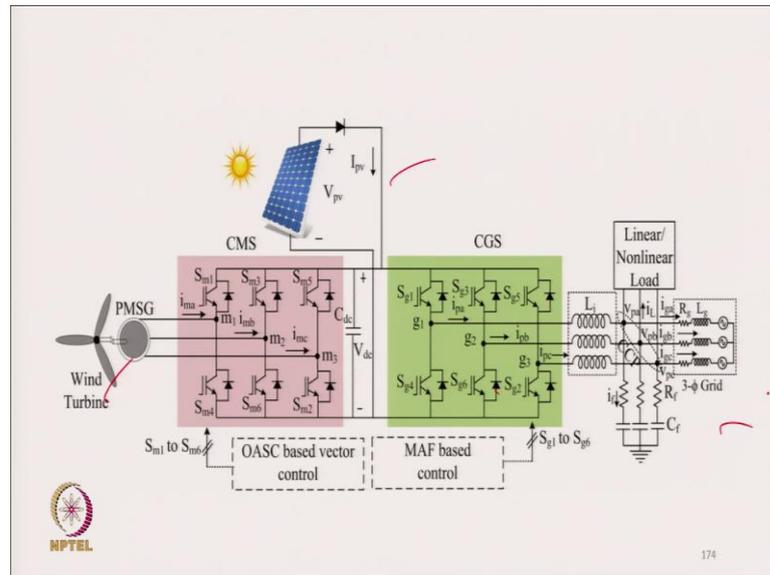
Q5. A 12 kW SPV array is connected at the DC terminals of power converters used for control of a wind driven 25 kW PMSG. The microgrid is supplying a linear load of 8.5 kW and 5.8 kVAR and the remaining power is exchanged with 415V 50Hz three phase grid. The grid side VSC control scheme ensures that the grid always operates at UPF. The grid VSC losses can be assumed to be 5 percent of its power. Estimate (a) the load current and the grid current under the rated conditions, (b) Calculate the grid power factor and phase shift in grid VSC phase currents with respect to phase voltages.



173

A 12 kilowatt solar PV array is connected to the DC terminal of power converter used for the control of wind driven 25 kilowatt permanent magnet synchronous generator. The microgrid is supplying the linear load of 8.5 kilowatt and 5.8 kVAR. And remaining power is exchanged with the 415 volt three phase grid the grid side voltage source converter ensure the grid always operate at UPF. And the grid voltage source converter losses can be assumed 5 percent of the estimate a the load current and the grid current under the rated condition b calculate the grid power factor and the phase angle shift between AC current with respect to the voltage.

(Refer Slide Time: 46:44)



The solution to the numerical example is detailed in the screenshots herein.

(Refer Slide Time: 46:52)

Sol. (a) SPV array and WECS is operating at rated conditions. Thus the net power supplied by the WECS is 25 kW and by SPV array is 12 kW.

Considering the inverter losses as 5%, Net grid VSC active power supplied = $0.95 \times (P_w + P_{pv}) = 0.95 \times (25 + 12) = 35.15$ kW.

The Load active power = 8.5 kW.

Thus, the net power fed to the grid = $35.15 - 8.5 = 26.65$ kW.

Since the grid voltage is 415 V (line to line, RMS), the current flowing in the load can be computed as,

$$I_{Load} = \frac{S(3\phi)}{\sqrt{3}V_{line-line}} = \frac{\sqrt{8.5^2 + 5.8^2 \times 10^3}}{\sqrt{3} \times 415} = 14.32 A$$

The diagram includes the NPTEL logo in the bottom left corner and the slide number 175 in the bottom right corner.

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Since the grid voltage is 415 V (line to line, RMS), the current in the grid can be computed as

$$I_{Grid, line} = \frac{P(3\phi)}{\sqrt{3}V_{line-line}} = \frac{26.65 \times 10^3}{\sqrt{3} \times 415} = 37.08 A$$

It is note-worthy that only the three phase active power (P) is considered for calculating the grid line current. This is because the VSC is ensuring the UPF operation always.

(b) Since the VSC control scheme ensures that the grid always operates at UPF, the grid line currents are always in phase with the corresponding voltages.



176

(Refer Slide Time: 47:51)

However, in this case, since the power is being fed back to the grid the grid power factor is negative. Thus, grid power factor = -1.

Owing to UPF operation of grid, the grid VSC supplies total load reactive power of 5.8 kVAR. Since the active power fed through VSC is 35.15 kW, the phase shift in VSC phase currents with respect to phase voltages can be computed as,

$$\phi = \tan^{-1}(Q/P) = \tan^{-1}(5.8/35.15) = 9.37^\circ$$


177

(Refer Slide Time: 48:17)

Summary

- Basic power quality related challenges in microgrids have been discussed.
- Control scheme and performance evaluation for power quality improvement in grid integrated solar photovoltaic array and battery energy storage based microgrid have been presented.
- Control scheme and performance evaluation for power quality improvement in grid integrated solar photovoltaic array, wind energy conversion system and battery energy storage based microgrid have been presented.



178

To summarize: Basic power quality relative challenges have been discussed. Control scheme and performance evaluation of power quality improvement grid integrated solar PV array battery base energy system based micro would have been presented. Control scheme and performance of evaluation of power quality improvement grid integrated and wind generation convergence system battery have been discussed.

(Refer Slide Time: 48:40)

Summary

- Control scheme and performance evaluation for power quality improvement in grid integrated solar photovoltaic array, small hydro generator and battery energy storage based microgrid have been presented.
- Control scheme and performance evaluation for power quality improvement in grid integrated solar photovoltaic array, wind energy conversion system, diesel generator and battery energy storage based microgrid have been presented.
- Control scheme and performance evaluation for power quality improvement in microgrids for Electric Vehicle Charging Station have been presented.



179

Control scheme and performance evaluation of power quality improvement grid integrated solar PV small hydro and battery energy storage system based microgrid are

presented. Control scheme performance evaluation of grid connected indicators solar PV wind energy conversion system DG set, battery energy storage microgrid have been I mean discuss. Control scheme and performance evaluation of power quality improvement with the electric vehicle charging station have been presented.

(Refer Slide Time: 49:06)

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And these are the some of the references.

Thank you.