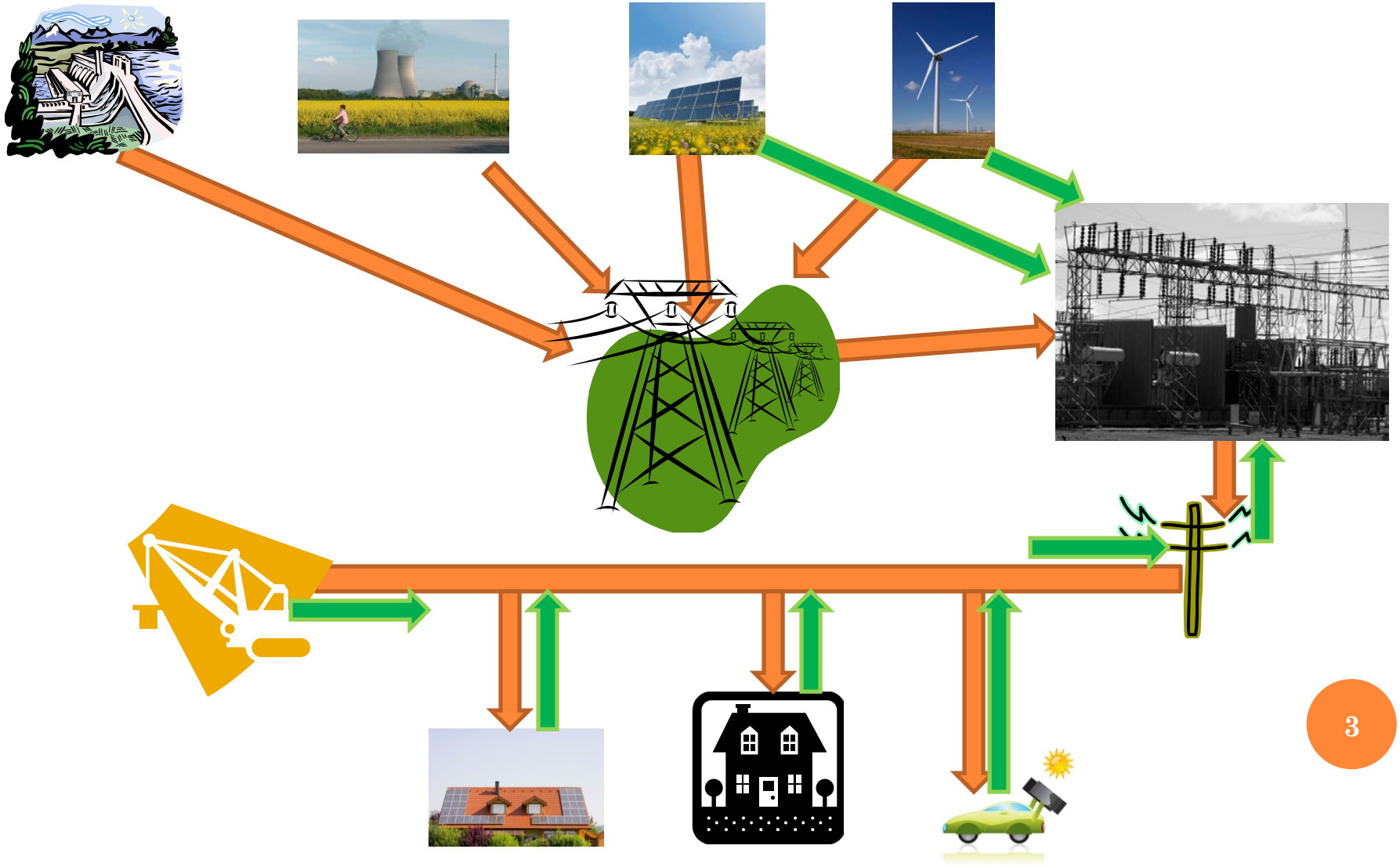
Grid Connection Issues for Distributed Generation - Review & Standards

Prof. Suryanarayana Doolla
Department of Energy Science and Engineering
Indian Institute of Technology Bombay

OUTLINE

- Intoduction
- Grid connection Requirements
  - Australia
  - Manitoba Hydro
  - Utilities in USA
  - CEA, India
- Summary

Modern Electricity System



Distributed Resource System

Fuel Source	Energy Conversion	Interconnection
Sun light	Solar Panel	DC-AC inverter
Hydrogen	Fuel cell	DC-AC inverter
Diesel	Reciprocating Engine	Synchronous generator
Natural gas	Turbine	Synchronous generator
Wind	Turbine	Induction Generator
Biomass	Sterling Engine	Induction Generator

ISSUES WITH DG

- Anti-Islanding protection
- Auto reconnection after a trip
- Short circuit capacity
- AC and DC Isolation
- Installation safety requirements
- Voltage regulation
- Harmonics
- Flicker, unbalance
- Over-voltage from direct/indirect lightning
- Transient over-voltage in grid
- DC injection and power factor.

STANDARDS AVAILABLE

- Australian Standard AS 4777 Parts 1, 2 and 3 (Grid Connection Of Energy Systems Via Inverters)
- Utilities in US have different standards
- IEEE 1547 is believed to be the most general standard
- Separate standards followed for connecting PV (IEEE Std 929-2000)(???)
- VDE-AR-N-4105

AUSTRALIAN STANDARD – DG VIA INVERTER

Voltage (V)	Time Limit (s)	Frequency (Hz)	Time Limit (s)
< Vmin	2.0	<fmin	2.0
Vmin-Vmax	No limit	fmin-fmax	No limit
>Vmax	2.0	>fmax	2.0

Voltage (V)	Time Limit (s)	Frequency (Hz)	Time Limit (s)
$< V_{min}$	2.0	$<f_{min}$	2.0
$V_{min}<V<87\%V_n$	1 min		
$87\%V_n<V<106\%V_n$	No limit	f_{min}-f_{max}	No limit
$106\%V_n<V<V_{max}$	1 min		
$>V_{max}$	2.0	$>f_{max}$	2.0

Ref: E.D. Spooner, A NEW AUSTRALIAN STANDARD FOR SMALL GRID-CONNECTED RENEWABLE GENERATION SYSTEMS CONNECTED VIA INVERTERS

CONNECTION REQUIREMENTS - AUSTRALIA

- Impulse voltage withstanding
  - 0.5 Joule, 5kV, 1.2/50 waveform to AS1931 Part 1 or in accordance with IEC 60255-5.
- Power Factor
  - Between 0.8 leading and 0.95 lagging for outputs from 20% to 100% of rated VA
- Voltage fluctuation and Flicker
  - Equipment shall confirm to AS/NZ 61000.3.3 or 3.5
- DC current injection
  - It is recommended to use transformer at output of inverter
  - Shall not exceed 0.5% of its rated output current or 5 mA, whichever is the greater.

Connection Requirements - Australia

- Harmonics

Current Harmonic Number	Limit based on % of fundamental
3 – 9th	<4%
11 – 15th	<2%
17 – 21st	<1.5%
23 – 33rd	<0.6%
above 33rd	<0.3%
Even harmonics	< 25% of equivalent odd harmonics
Total Harmonic Distortion (THD)	<5%

- Harmonics

Duration (Seconds)	Instantaneous Voltage	
	Line-to-Neutral (Volts)	Line-to-Line (Volts)
0.0002	910	1580
0.0006	710	1240
0.002	580	1010
0.006	470	810
0.02	420	720
0.06	390	670
0.2	390	670
0.6	390	670

HARMONICS

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Above 33rd	<0.3%
Even harmonics	<25% of equivalent odd harmonics
THd	<5%

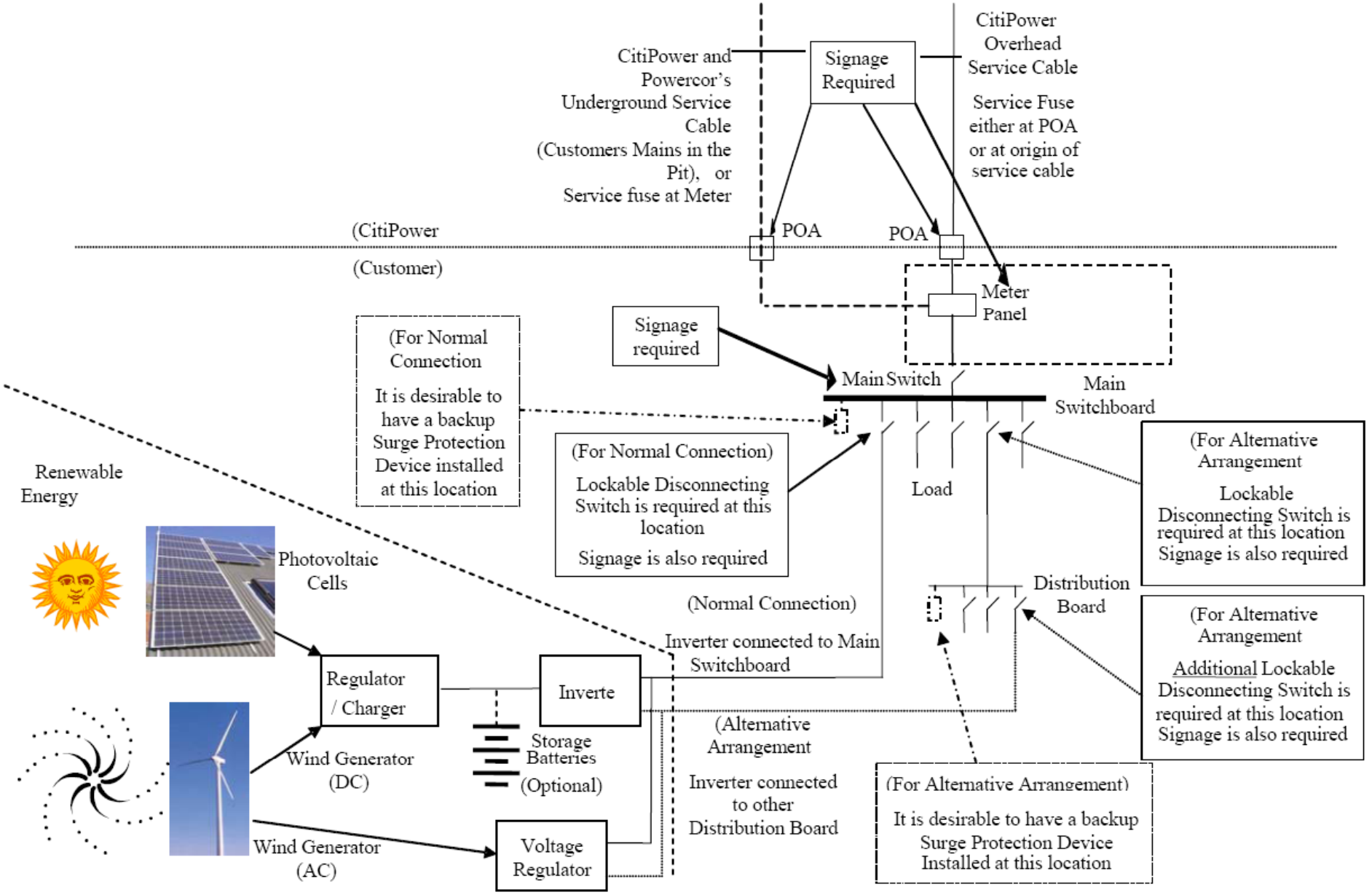
PROTECTION

- Over current protection
  - shall operate when the output from the inverter / regulated energy system is greater than 100% of the inverter rating.
- Isolate the inverter/DG
  - The supply from the grid is disrupted;
  - Over-Voltage Protection: V_{grid} > 265 V (phase) or 458 volts (line)
  - Under-Voltage Protection: V_{grid} <195 volts (phase) or 337 volts (line)
  - Over Frequency Protection: F_{grid} >51.5 Hz
  - Under-Frequency Protection: F_{grid} < 48.5 Hz
- Any one islanding detection technique
- The total protection operation and disconnection time shall not exceed 2 seconds after grid failure.

RECONNECTION

- Automatic reconnection of inverter / regulated energy system(s) onto the grid shall only occur if:
  - Voltage requirements
    - 200 < Vgrid < 260 volts (phase)
    - 346 < Vgrid < 450 volts (phase-to-phase);
  - Frequency requirements
    - 49 Hz $< F_{grid} <$ 51 Hz
- The above conditions have been maintained for a minimum duration of 1 minute
- The inverter / DG system and the grid are synchronized and in-phase with each other.

Typical Single line Diagram



MANITOBA HYDRO DISTRIBUTION SYSTEM

- Scope

Voltage	Generator	Size
Upto 50 kV	Single phase	50 kW
	Three phase	10 MW

- Interconnection of inverter-based and generator-based DR systems

Technical Requirements For Connecting Distributed Resources To The Manitoba Hydro Distribution System DRG2003, revision 2.1 January 2011

Power Quality

- Flicker

Changes/min	-ΔV/V (%)
<10	0.4%
10 to 200	0.2%
>200	0.1%

- Voltage regulation and power factor
  - Sync Generator
    - Generator bus voltage set point shall be stable at 95% and 105%
  - Inverters
    - Power factor to be adjusted to ±0.90 or better at PCC
- DC current injection: Does not allow any DC offset
- Speed regulation
  - Speed regulation with freq as reference is required for large synchronous generators (> 1MW)

POWER QUALITY

- Harmonics

$V_{bus} \leq 69kV$						
I_{sc}/I_L	<11	11≤h<17	17≤h<23	23≤h<35	35≤h	TDD
<20*	4.0	2.0	1.5	0.6	0.3	**5.0**
20 - 49	7.0	3.5	2.5	1.0	0.5	**8.0**
50 - 99	10.0	4.5	4.0	1.5	0.7	**12.0**
100 - 1000	12.0	5.5	5.0	2.0	1.0	**15.0**
>1000	15.0	7.0	6.0	2.5	1.4	**20.0**

PROTECTION AT PCC

- Balanced and unbalanced system faults (i.e. line-ground, line-line, and three phase faults)
- Frequency variations

Minimum Time	Under Freq Limit	Over Freq Limit
Continuous operating range	59.0 – 60.0 Hz	60.0 – 61.5 Hz
10 minutes	58.7 – 58.9 Hz	61.6 – 62.0 Hz
30 seconds	58.0 – 58.6 Hz	62.1 – 63.5 Hz
Instantaneous trip	< 58.0 Hz	> 63.5 Hz

PROTECTION AT PCC

- Under-Voltage/ Over Voltage Protection

PU Voltage	Trip Time
V≤ 50%	Instantaneous
50%<V<90%	120 cycles
90%<V<106%	Normal Operation
106%<V<120%	30 cycles
V≥120%	Instantaneous

- Islanding is usually not allowed
  - Prevent safety hazards created by back feeding isolated portions
  - Add redundancy to generator protection internal to DR facility
  - Anti islanding protection is to be provided

SYNCHRONIZATION

- Limit values for synchronous interconnection between MG and main grid (Sync generator).

Total DG Rating (kVA)	ΔF (Hz)	(ΔV%)	Δø (^{0})
0-500	0.3	10	20
>500-1500	0.2	5	15
>1500-10000	0.1	3	10

- Induction generator do not require sync facilities, but they must not violate voltage sag/flicker criteria

STANDARDS FOR INTERCONNECTING DG - USA

- Utilities in US have different standards
- IEEE 1547 is believed to be the most general standard
- Separate standards followed for connecting PV (IEEE Std 929-2000)(????)
- IEC 61727 - Photovoltaic (PV) systems – Characteristics of the utility interface
- VDE-AR-N-4105

http://www.nationalgridus.com/non_html/Interconnect_stds_MA.pdf

SYNCHRONIZATION

- Re/connection is made when the main grid and MG are synchronized at the PCC in terms of voltage, frequency and phase angle
- Limit values for synchronous interconnection between MG and main grid.

Total DG Rating (kVA)	ΔF (Hz)	(ΔV%)	Δø (^{0})
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CEA Draft Guidelines-Technical Standards for Connectivity of the Distributed Generation Resources, 2012

- Objective
  - The aim of these regulations is to ensure the safe operation, integrity and reliability of the grid.
  - The new connection shall not cause any adverse effect on the grid. The grid shall continue to perform with specified reliability, security and quality as per the Central Electricity Authority (Grid Standards) Regulations, 2010 as amended from time to time. However, these regulations are not to be relied upon to protect the plant and equipment of the Applicant or user.
  - A Applicant is required to be aware, in advance, of the standards and conditions his system has to meet for being integrated into the grid.

CEA Draft Guidelines-Standards for DG Resources

- Harmonic current injections from a generating station shall not exceed the limits specified in IEEE 519.
- The distributed generating resource shall not inject DC current greater than 0.5% of the full rated output at the interconnection point.
- The distributed generating resource shall not introduce flicker beyond the limits specified in IEC 61000.
- Every distributed generating resource will be equipped with automatic synchronization device.
  - Provided that induction generators, except self-excited induction generators, shall not require a synchronizing device.
  - Provided further that distributed generation resources using inverters shall not be required to have separate synchronizing device, if the same is inherently built into the inverter.

CEA Draft Guidelines-Standards for DG Resources

- DG Shall be equipped with following functions:
  - Over and under voltage trip functions if voltage reaches above 110% or below 80% respectively with a clearing time of 2 seconds
  - Over and under frequency trip functions, if frequency reaches 50.5 Hz and below 47.5 Hz with a clearing time of 0.2 seconds
  - The distributed generation resource shall cease to energise the circuit to which it is connected in case of any fault in this circuit.
  - A function to prevent the distributed generation resource from contributing to the formation of an unintended island, and cease to energise the electricity system within two seconds of the formation of an unintended Island.

CEA Draft Guidelines-Technical Standards for Connectivity of the Distributed Generation Resources, 2012

- Every time the generating station is synchronized to the electricity system, it shall not cause voltage fluctuation greater than ± 5% at the point of connection.
- Paralleling-device of distributed generation resource shall be capable of withstanding 220% of the nominal voltage at the interconnection point
- "Interconnection point" means a point on the electricity system, including a substation or a switchyard, where the interconnection is established between the facility of the Applicant and the electricity system and where electricity injected into the electricity system can be measured unambiguously for the Applicant

THANK YOU

- Slides are available at

http://www.ese.iitb.ac.in/~suryad/publications.html