

GRID CONNECTION ISSUES FOR DISTRIBUTED GENERATION - REVIEW & STANDARDS

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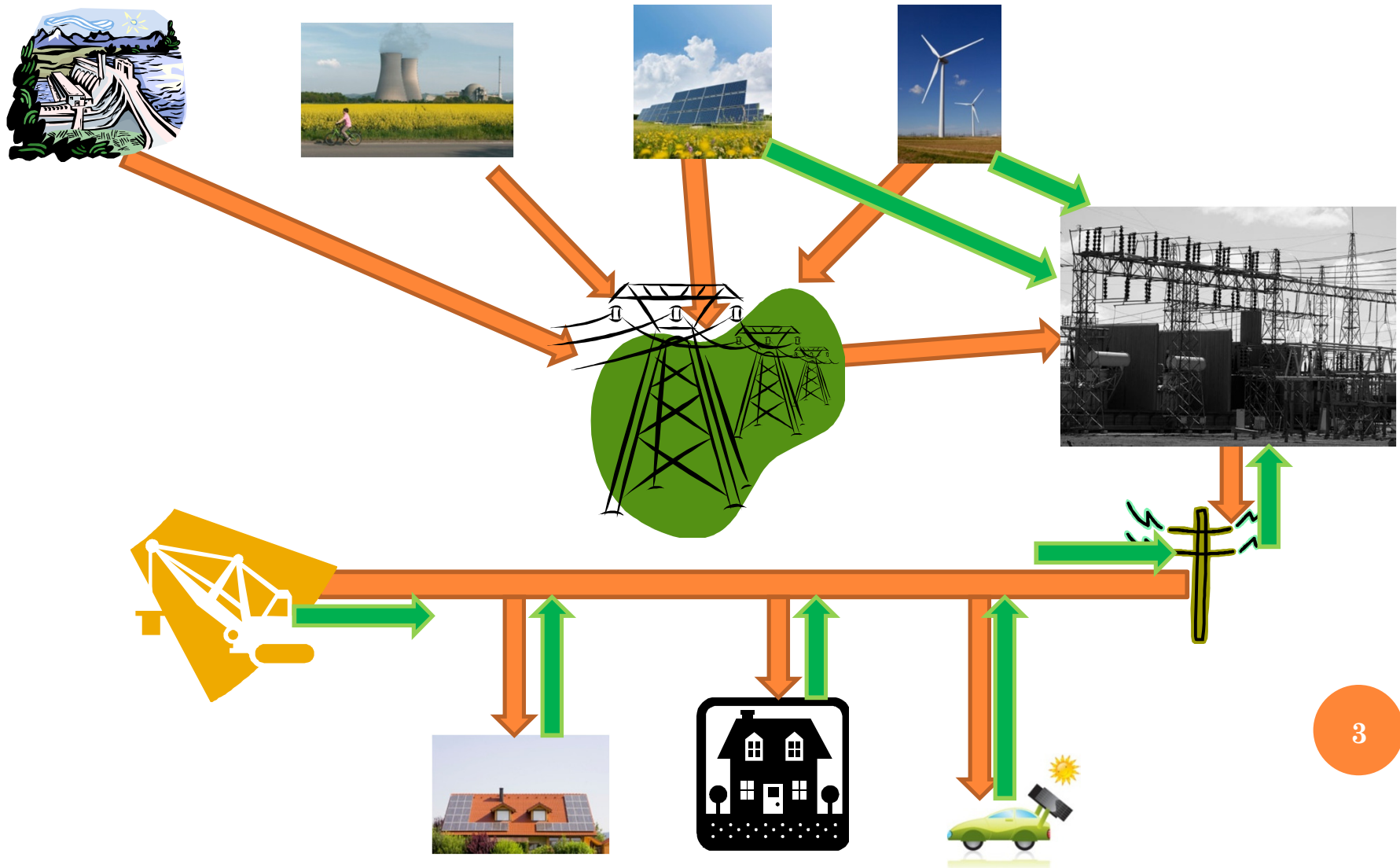
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OUTLINE

- Introduction
- Grid connection Requirements – International Std
 - Australia
 - Manitoba Hydro
 - Utilities in USA
 - Comparison with IEEE 1547
- 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
Water	Turbine	Synchronous 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)
- Technical Requirements For Connecting
Distributed Resources To The Manitoba Hydro
Distribution System DRG2003, revision 2.1
January 2011
- IEEE Std. 1547-2003

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.

HARMONICS

Current harmonic number	Limit based on % of fundamental
3-9 th	<4%
11-15 th	<2%
17-21 st	<1.5%
23-33 rd	<0.6%
Above 33 rd	<0.3%
Even harmonics	<25% of equivalent odd harmonics
THd	<5%

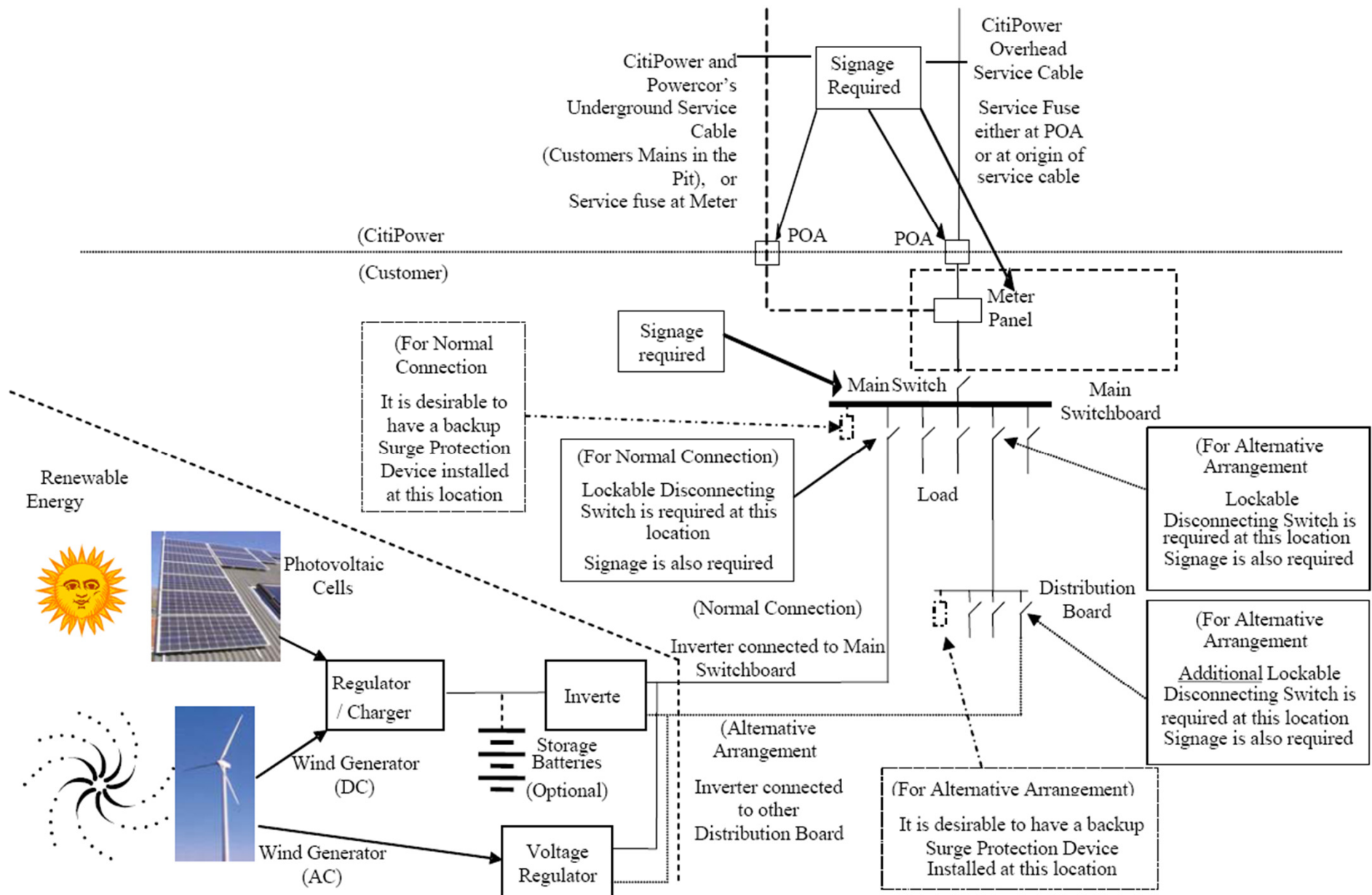
PROTECTION

- 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: $V_{\text{grid}} > 265 \text{ V}$ (phase) or 458 volts (line)
 - Under-Voltage Protection: $V_{\text{grid}} < 195 \text{ volts}$ (phase) or 337 volts (line)
 - Over Frequency Protection: $F_{\text{grid}} > 51.5 \text{ Hz}$
 - Under-Frequency Protection: $F_{\text{grid}} < 48.5 \text{ Hz}$
- 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
 - $200 < V_{\text{grid}} < 260$ volts (phase)
 - $346 < V_{\text{grid}} < 450$ volts (phase-to-phase);
 - Frequency requirements
 - $49 \text{ Hz} < F_{\text{grid}} < 51 \text{ Hz}$
- 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

POWER QUALITY

○ Flicker

Changes/min	$-\Delta V/V$ (%)
<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 ($> 1\text{MW}$)

POWER QUALITY

○ Harmonics

$V_{bus} \leq 69kV$						
I_{sc}/I_L	<11	$11 \leq h < 17$	$17 \leq h < 23$	$23 \leq h < 35$	$35 \leq h$	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
$V \leq 50\%$	Instantaneous
$50\% < V < 90\%$	120 cycles
$90\% < V < 106\%$	Normal Operation
$106\% < V < 120\%$	30 cycles
$V \geq 120\%$	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)	($\Delta V\%$)	$\Delta\phi$ ($^\circ$)
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)

IEEE STD. 1547 - 2003

- IEEE Standard for interconnection of DR with electric power systems
- Requirements relevant performance, operation, testing, safety consideration and maintenance of interconnection
- Requirements contained are universally needed for interconnection of DR including
 - Synchronous machines
 - Induction Machines
 - Inverters/converters

IEEE 1547 REVIEW

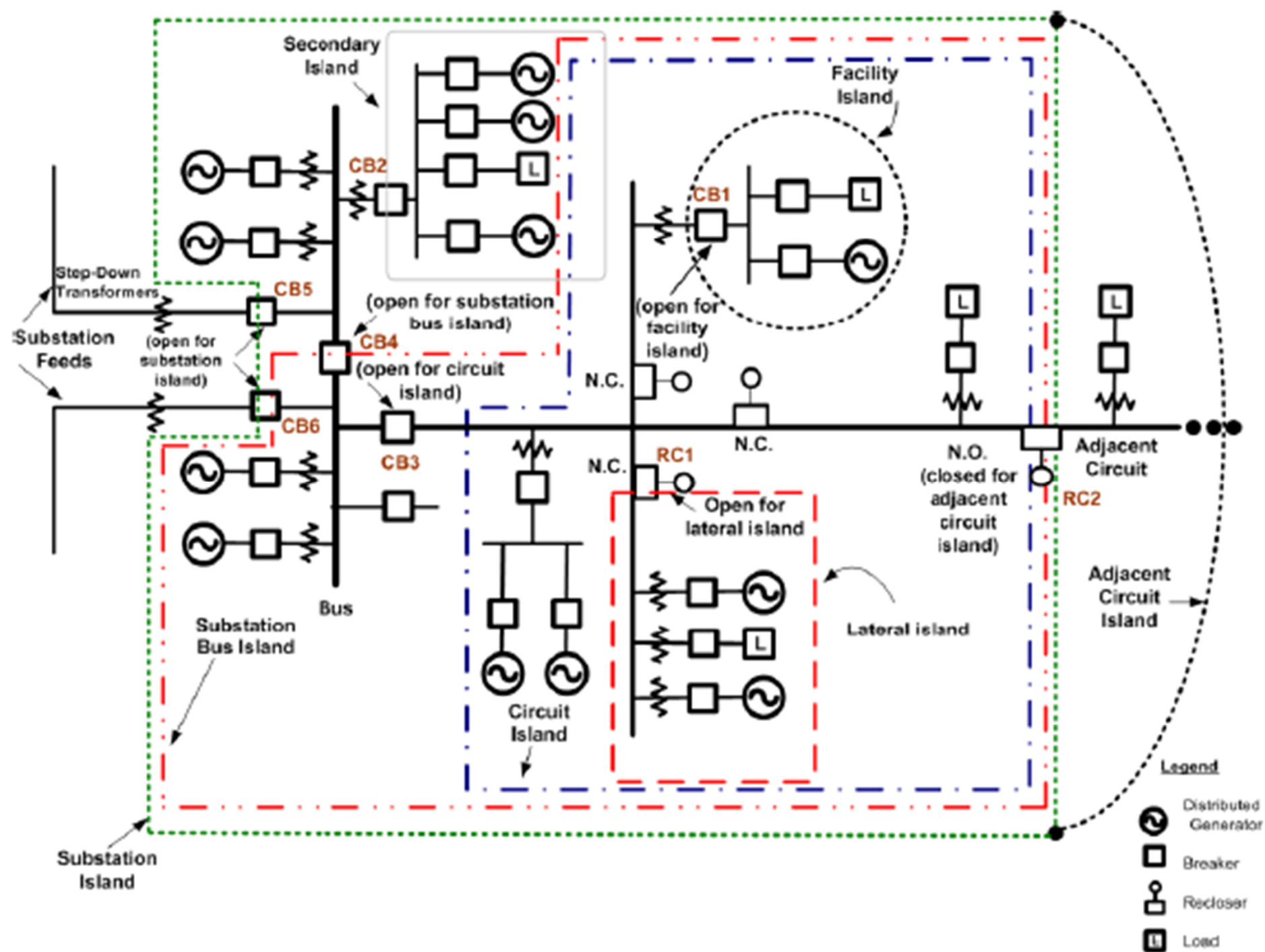
- Utilities require implementation of IEEE 1547
 - PacificCorp and New York State Public Utility Commission (Completely)
 - Otter Tail Power (Partial)
- Universally accepted provision
 - To have accessible switch at PCC with the utility
 - Field testing for DR before released for operation (partial)
- Most Utilities concern
 - Voltage fluctuation and flicker caused by Dr
 - Some utilities make blank statement “no abnormal voltages”

IEEE STD.1547 REVIEW

- Harmonics
 - Compliance with IEEE Std. 519
- Disagreement
 - Tripping because of frequency variation
 - 1547 recommends removal of DR while many utilities would like to keep DR for abnormal frequency event
- Protection
 - Over/under voltage, over/under frequency, ground fault protection, generation protection (additional by utilities)
- Some utilities have stringent requirements compared to IEEE Std. 1547

COMPARISON

Requirement	1547	XCEL	Otter Tail Power	Salt River Project
DR shall not regulate voltage at PCC	YES	May be allowed	NO	YES
Harmonics	IEEE 519	NO	IEEE 519	NO
Governor operation	NO	YES	NO	NO
Protection for DR equipment	NO	YES	YES	> 50 kW
System study required	NO	YES	NO	NO
Shall trip if $F > 60.5$ Hz and $F < 59.3$ Hz	YES	Not permitted	Not permitted	NO



SUMMARY

- To encourage DR penetration a broad standard/guidelines are required
- It is important that utility have control over the DR (at PCC)
- Islanding should be encouraged
- System study is required (% of feeder)
- Testing of DR is required before placing the DR into operation

THANK YOU

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<http://www.es.e.iitb.ac.in/~suryad/>

IEEE STD. 1547-2003

- Interconnection system response for voltage abnormalities

Voltage range (% of base voltage ^a)	Clearing time(s) ^b
$V < 50$	0.16
$50 \leq V < 88$	2.00
$110 < V < 120$	1.00
$V \geq 120$	0.16

- Interconnection system response for frequency abnormalities

DR size	Frequency range (Hz)	Clearing time(s) ^a
$\leq 30 \text{ kW}$	> 60.5	0.16
	< 59.3	0.16
$> 30 \text{ kW}$	> 60.5	0.16
	$< \{59.8 - 57.0\}$ (adjustable set point)	Adjustable 0.16 to 300
	< 57.0	0.16

AUSTRALIAN STANDARD – DG VIA INVERTER

Voltage (V)	Time Limit (s)	Frequency (Hz)	Time Limit (s)
$< V_{min}$	2.0	$< f_{min}$	2.0
$V_{min}-V_{max}$	No limit	$f_{min}-f_{max}$	No limit
$> V_{max}$	2.0	$> f_{max}$	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

CONNECTION REQUIREMENTS - AUSTRALIA

○ Harmonics

Current Harmonic Number	Limit based on % of fundamental
3 – 9 th	<4%
11 – 15 th	<2%
17 – 21 st	<1.5%
23 – 33 rd	<0.6%
above 33 rd	<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

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)	($\Delta V\%$)	$\Delta\phi$ ($^\circ$)
0-500	0.3	10	20
>500-1500	0.2	5	15
>1500-10000	0.1	3	10