A 10kW Inverter for Variable Speed Wind Turbines

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- Functions of an Inverter
- Detailed Inverter Technologies
- Commercial Operation Experience
- Further Development
- Conclusions

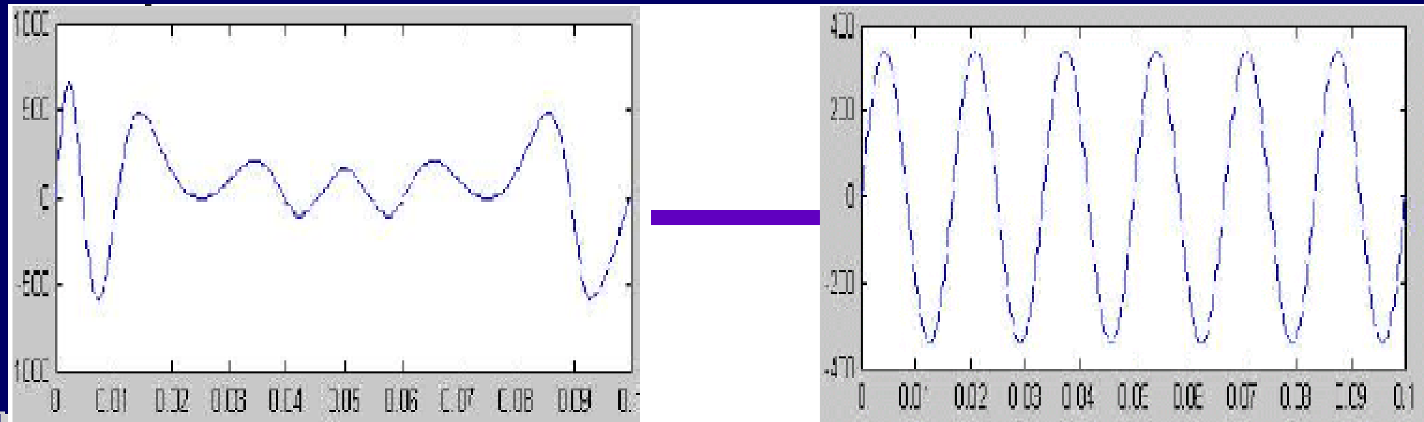
Small Wind Energy Industry

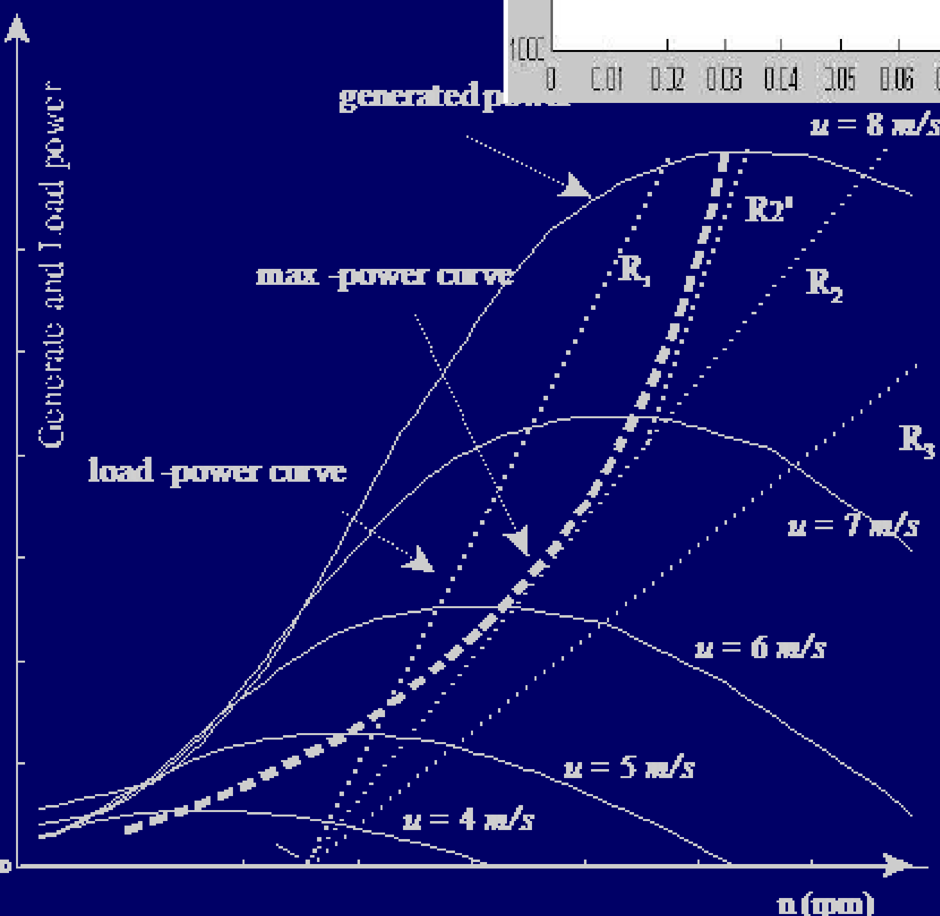
- Canadian Small wind industry (manufacturing, installation and operation) is about $20M/year
- N.A. mall wind market has traditionally grown at about 25%/year, and is experiencing accelerated growth recently due to incentive programs
- Small wind industry has two distinct major markets: grid-connected systems, and wind-diesel systems
- Challenges of small wind industry include higher costs, compromised reliability and output as compared to large wind systems.
- Canada has tremendous opportunities to be a leader in small wind (incl. wind-diesel) market

Options of Drive Trains for Small Wind Turbines

- Induction generators + gears ➔ fixed speed operation, low cost
- <u>Direct drive permanent magnet synchronous generators (gearless) ➔ variable speed operation ➔ 10-15% more energy output</u>
- Variable speed operation requires a power conversion unit (or inverter) for grid connection (utility grid or wind-diesel grid)

Why Inverters are Needed?





- Basic needs:
  - Converting from VVVF (turbine) to FVFV (grid)
  - Maximizing energy output

Inverter Functions: All Control Requirements

- AC-DC-AC conversion: high power quality output to grid (low total harmonic distortion)
- Maximum power point tracking: maximized power output at variable speeds
- Grid interconnection: compliance with requirements of standards for interconnecting with power systems
- Communication and system controls: remote monitoring, control, diagnosis and upgrade

Development of a Drive Train of a 10kW Wind Turbine

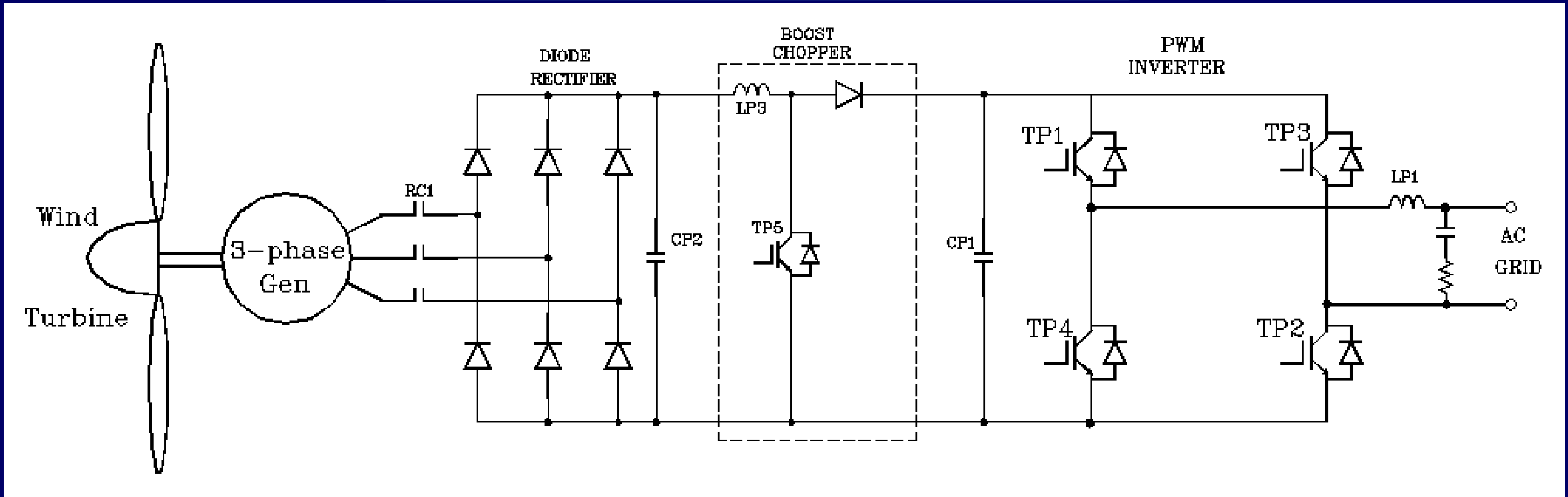
- Partnership with Ventera Energy Inc., MN (one of our partners)
- Variable speed, with a governor
- 10kW, single-phase, 240V/60Hz
- Permanent magnet synchronous generator
- 10kW IGBT inverter (integrated functions)

10kW Inverter Design

Energy Management System

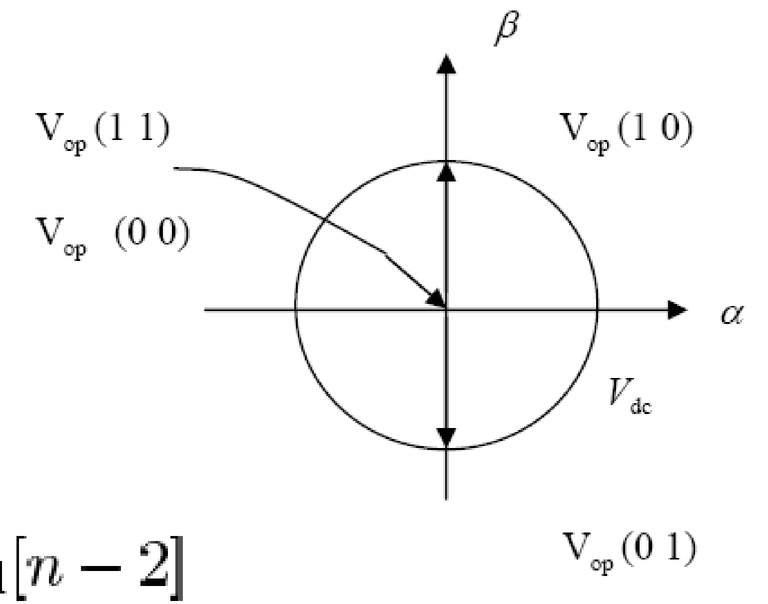
Communication & Control

DSP Low Level Control



Predictive Current PWM

- The conduction of IGBTs is determined by the desired output current and the real-time grid voltage waveforms
- Realtime computation

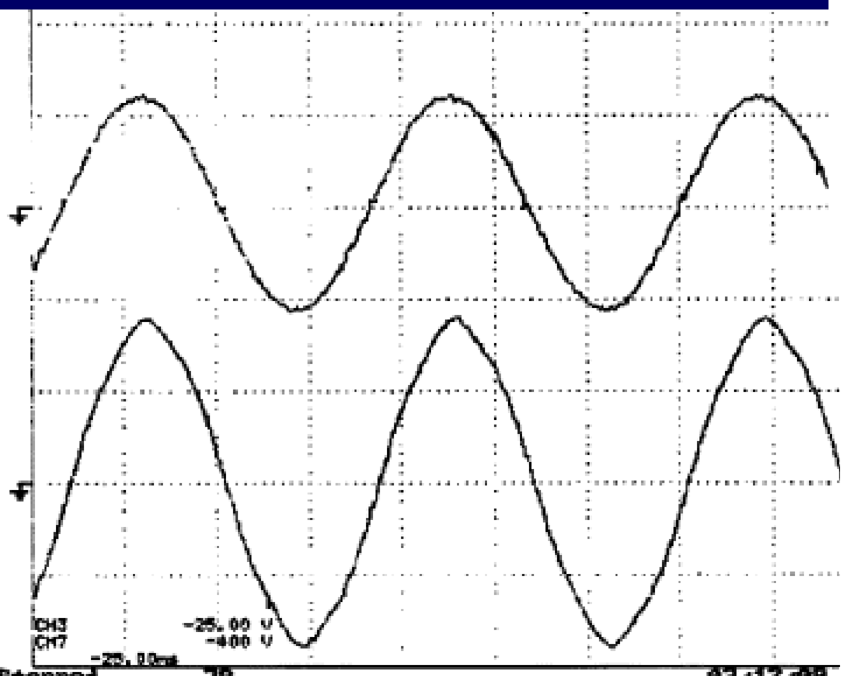


Mode	T_1	T_2	T_3	T_4	D_3	D_4	V_{op}	I_{load}
1	ON	OFF	OFF	ON	OFF	OFF	V_{dc}	pos
2	ON	OFF	OFF	OFF	ON	OFF	0	pos
3	OFF	ON	ON	OFF	OFF	OFF	$-V_{dc}$	neg
4	OFF	ON	OFF	OFF	OFF	ON	0	neg

$$V_{\text{op\_av}}[n] = 4V_{\text{grid}}[n-1] - 2\,V_{\text{grid}}[n-2] - V_{\text{op\_av}}[n-1] + L\frac{I_{\text{ref}}[n+1] - I_{\text{load}}[n-1]}{T_{\text{period}}}$$

Result: High Power Quality

- Low current THD even when the grid voltage has significant harmonics (THD 2.6%)

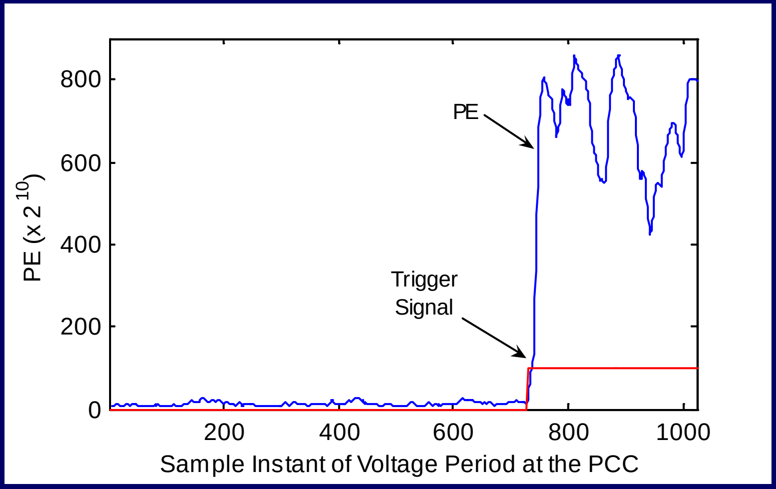


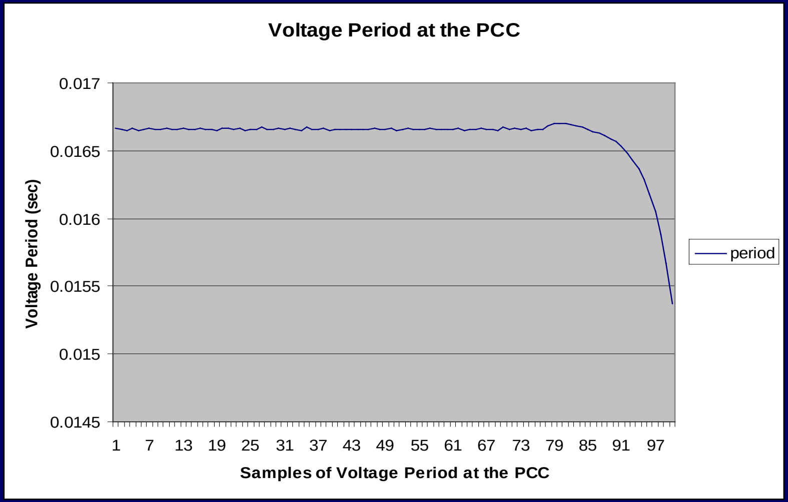
P_{op} (kW)	3.0	5.0	7.0	10.0
V_{dc} (V)	360.0	402.0	401.0	401.0
THD (%)	2.9 %	1.9 %	1.4 %	0.9 %

DC link voltage, output power / THD / Controllers	V_{dc}=350V P_{op}=3kW	V_{dc}=380V P_{op}=5kW	V_{dc}=500V P_{op}=7kW	V_{dc}=600V P_{op}=10kW
Hysteresis Controller	10.4%	7.9%	8.0%	6.9%
Traditional Predictive Controller	4.1%	3.3%	2.9%	2.7%
Improved Predictive Controller	4.4%	3.0%	1.9%	1.6%

Compliance with Interconnection Standards

- Grid voltage window (under- & over-V)
- Grid frequency window (under- & over-F)
- Anti-islanding (proportional power spectral density and accelerated phase-shift methods)





RD^3: Research, Development, Demonstration & Deployment

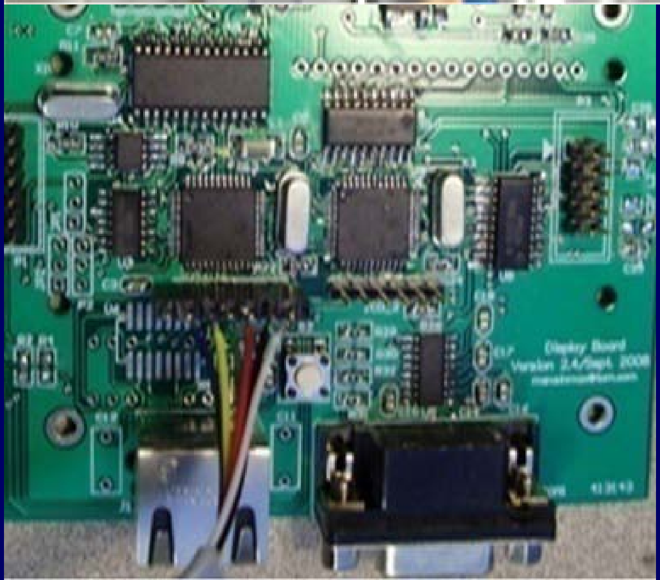
- 44 inverters and generators have been produced
- 150 additional units are in production (2009)
- 11 turbines have been delivered in Saskatchewan
- 25 additional units are back-ordered in Saskatchewan
- 1472kWh/month in Saska. Mar.-May 09
- Transferred to PV

On-going Work: Communication via Internet

Inverter Monitoring | LogoOut

Status of PV System

Mode&Display	Mode	Display
Inverter:Null	Set	Run Stop
LCM	Display	Now Display:666666
IP Address	Connected	131.202.9.1 dynamic
MAC Address	Set	00:0F:1F:76:A4:95
LED1	STATE	OFF
LED2	STATE	ON
LED3	STATE	ON
SPI	STATE	NORMAL
SCI	STATE	NORMAL
FAULT	STATE	SPI Fault
Output Power	kW	0.0000
Output Energy	kWhr	0.0000
Grid Voltage	V	0.00
Grid Current	A	0.00
PV Voltage	V	11223344
PV Current	A	55667788
Current time	hh:mm:ss	T1:0:0:3:32
Accumulated Running Time	hh:mm:ss	T2:0:0:3:32

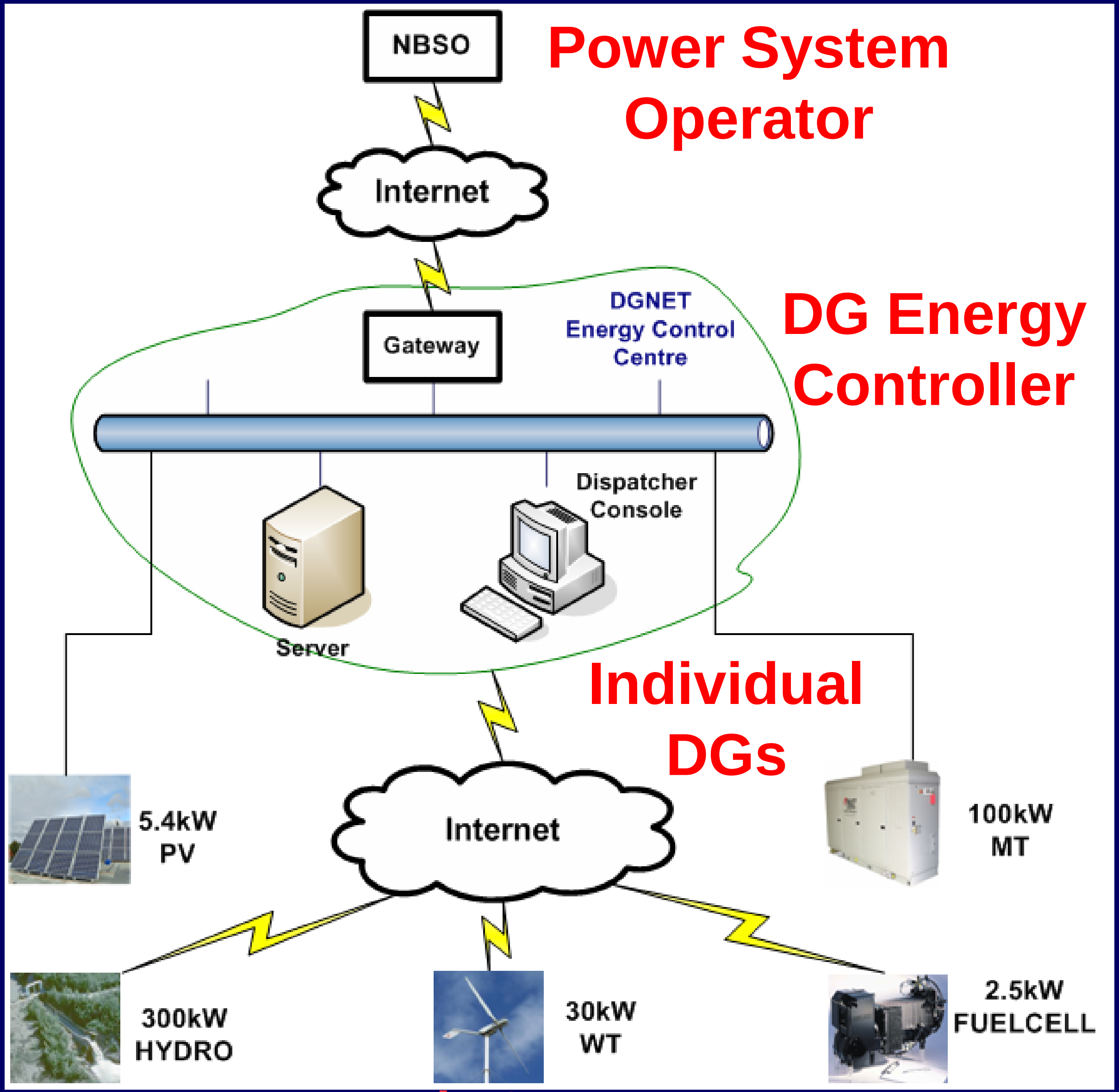


Dispatchable DG Networks

Enhanced value for distributed generators:

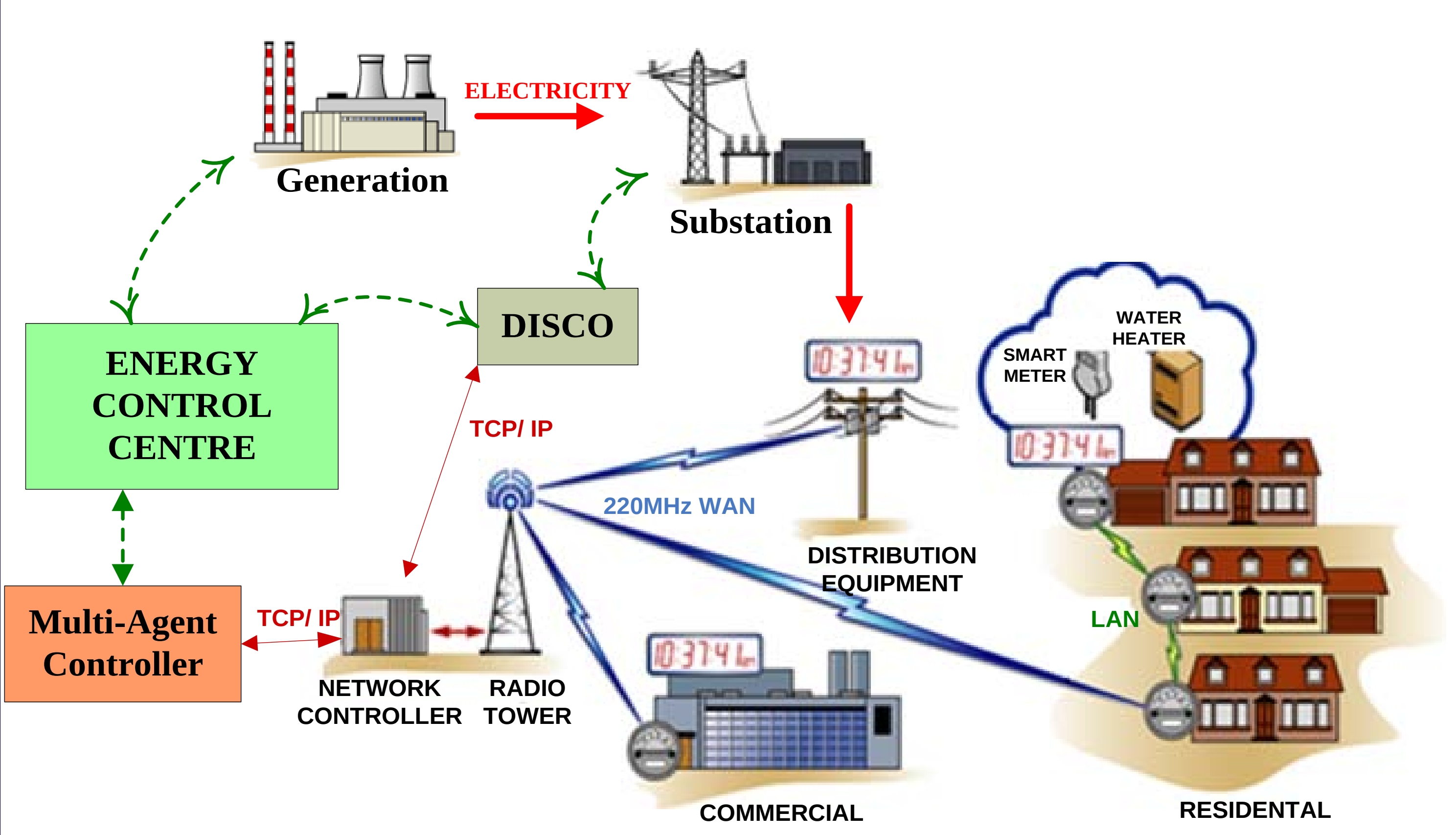
Transform individual DGs into a virtual large generator to seek added value such as bidding in a power pool, providing some ancillary services etc.

- **→On a continuing basis**
- **→Located in wide areas**
- **→Interactive with SO**



Aggregated Load Control

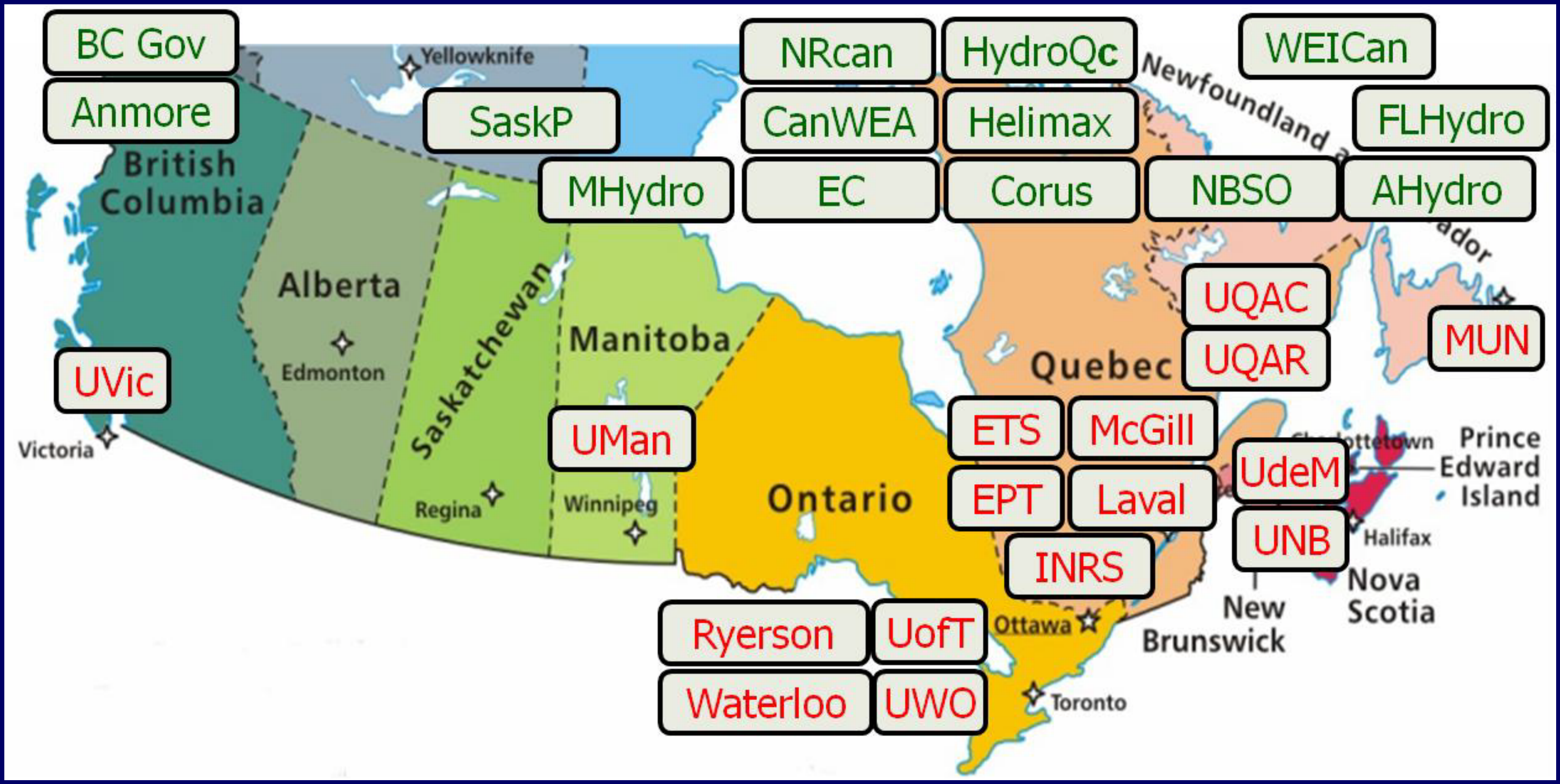
- Aggregated domestic water heaters controlled by smart meters, and a central controller
- Benefits through peak load shaving, synchronous reserve and frequency regulation



UNB

Wind Energy Strategic Network (WESNet)

- 39 researchers of 16 universities: wind R&D
- $6.3M in 5 years funded by partners & NSERC



Conclusions

- A single-phase IGBT inverter has been developed for variable speed wind turbines
- The inverter integrated multiple functions
- RD^3 approach has led to strong partnerships with industry for commercialization of new technologies in the growing small wind market
- Aggregated energy systems have more values
- Complex technical systems necessitate multi-disciplinary R&D partnerships