

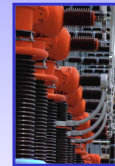
RTDS Technologies Inc.

New Developments at RTDS Technologies

Ming Yu, Ph.D., P.Eng.
Manager of Power System
Software Development
RTDS Technologies Inc.

Email: myu@rtds.com
Phone: (204) 989-9708

October 18, 2011



Real time digital simulation for the power industry

RTDS
Technologies

Good afternoon, everyone! I am very glad to have the opportunity to present new developments at RTDS Technologies.

RTDS Technologies Inc.

RTDS Technologies – The Company:

- Located in Winnipeg, Manitoba
- Current number of employees is 35
- Company Mandate
 - Continued development of RTDS hardware
 - Continued development of RSCAD software
 - Marketing and sales
 - Training and after sales technical support



Real time digital simulation for the power industry



RTDS is a Winnipeg company with 35 employees. It is the leader in real time digital simulation for the power industry. At RTDS, we work hard to meet the technological challenges of the industrial by developing new hardware and simulation models.

RTDS Technologies Inc.

3

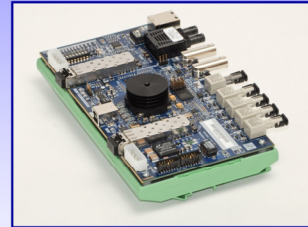
New Hardware



PB5 Processor Card



**GTNET Card for
Network Communication**



**GTSYNC Card for
Time Reference**



Real time digital simulation for the power industry

RTDS
Technologies

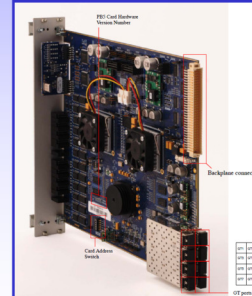
On the hardware side, we have developed the PB5 processor card, GTNET card for network communication and GTSYNC card for time reference.

Simulation Hardware - PB5

Processing power:

PB5 – Processor Card for RTDS:

- Latest Processing Technology - Introduced May 2011
- Same assembly instruction set as GPC
- Additional power utilizing two Power PC RISC processors each running at 1.7 GHz
- Additional communication ports for direct processor to processor data exchange
T-lines between Small-dt sub-systems
- Increased network solution and component modeling capacity



Real time digital simulation for the power industry

RTDS
Technologies

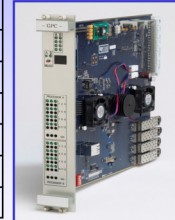
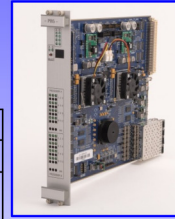
PB5 is our newest processor card. It has the same assembly instruction set as the GPC card. With its increased computing power and additional communication ports, we can simulate larger networks and more than one small time step sub-systems in a rack.

Simulation Hardware - PB5

5

Comparison Table: PB5 versus GPC

Card Type	PB5	GPC
Year of Production	2011	2005
Processor type	Freescale MC7448 RISC	IBM 750GX RISC
Clock speed	1.7 GHz	1.0 GHz
No. of processors per card	2	2
Load units per processor	12	10
Network solution (max nodes)	$72 \times 2 = 144 = 48 \text{ buses}$	66 = 22 buses
No. of I/O fibre ports	2	2
No. of comm. Ports	6	2
No. of 12 bit d/a's	24	24



Real time digital simulation for the power industry

RTDS
Technologies

Here is comparison with GPC card. The clock speed is 1.7 GHz compared with 1GHz for GPC. The load units per processor is 12 instead of 10. PB5 can handle 2 network solutions each with 72 nodes (or 24 buses), much larger than the 66 nodes for the GPC. It has 6 communication ports which can be used for inter-card communications, such as small dt T-lines.

GTNET Card

GPC Network Communication - GTNET:

- GTNET provides a mechanism to communicate with external devices over the ETHERNET (i.e. the LAN)
 - 100BASE-TXRJ45 Ethernet port, or
 - 100BASE-FX (optical) Ethernet port
- Originally developed for IEC 61850 communication now being adopted by the protection industry
- Additional communication protocols implemented in response to customer requests
- Up to 4 communication protocols can be installed on a single GTNET card
- Only one protocol can be active during a simulation case (user selectable)



Protocol Indicator

Protocol Selector



Real time digital simulation for the power industry

RTDS
Technologies

GTNET is a network communication card originally developed for IEC 61850. We have been adding new protocols in response to customer requests. Currently, up to 4 communication protocols can be installed on a single GTNET card. However, only one protocol can be active during a simulation run.

GTNET Card

7

GTNET Communication Protocols

IEC 61850

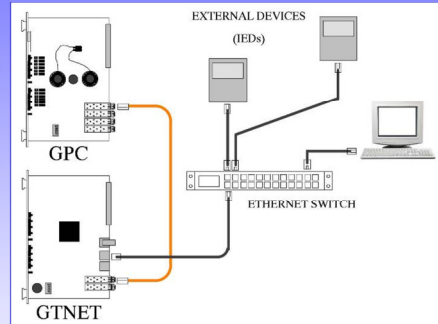
- ❑ GSE: IEC 61850 GSSE or GOOSE messages
 - GSSE - Generic Substation State Events
 - GOOSE - Generic Object Oriented Substation Events
 - to send up to 64 binary output points, or
 - to receive a total of 64 binary inputs from 8 unique IEDs, or
 - to send and receive up to 8 analog GOOSE messages
- ❑ SV: IEC 61850-9-2 sampled values
 - 4 voltage + 4 current signals synchronized
 - to an internal or external 1PPS signal
 - 80 samples per cycle

Distributed Network Protocol (DNP3 IEEE 1815)

- ❑ GTNET – DNP
 - DNP for SCADA interface

COMTRADE PLAYBACK (our protocol)

- ❑ GTNET – PB
 - For very large data set playback



Real time digital simulation for the power industry

RTDS
Technologies

The first two protocols on the GTNET are related to IEC 61850: GTNET-GSE for GSSE or GOOSE messages and SV for sampled values. GTNET-DNP implements the Distributed Network Protocol which can be used for SCADA interface. GTNET-PB is our own protocol. It is used to play back a large set of slow changing data.

GTNET Card

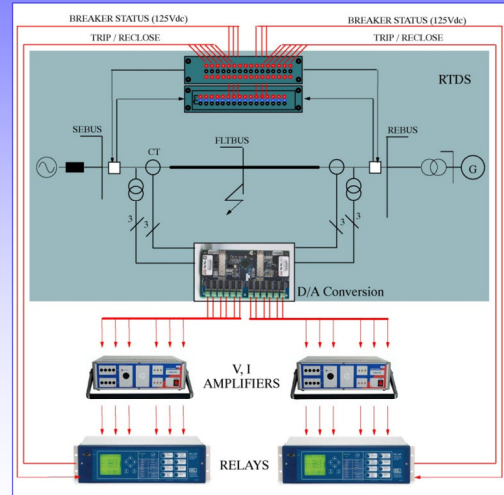
GTNET – Closed Loop Testing of Protection Systems

Traditional Closed Loop Relay Test Set-Up



Signal Exchange

- ❑ Digital
 - Relay Trip
 - Relay Reclose
 - Circuit Breaker Status
- ❑ Analogue
 - Measured Voltage & Current



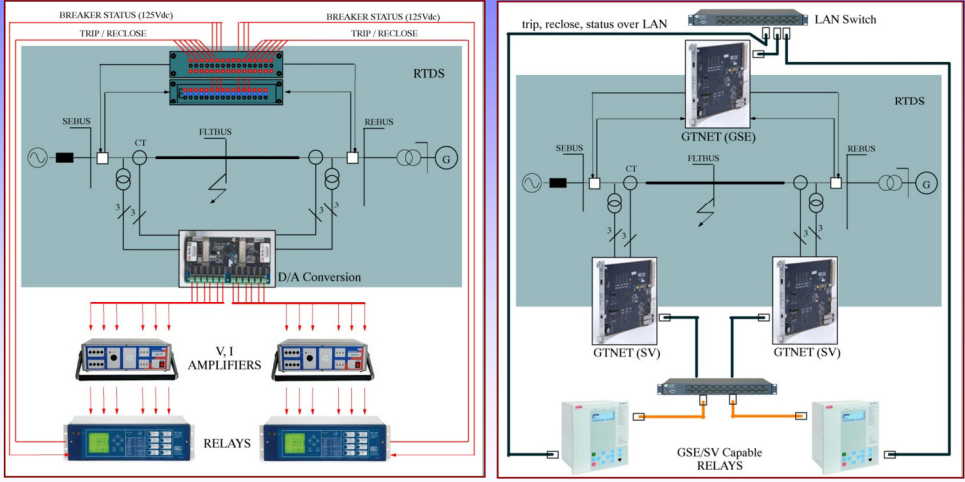
Real time digital simulation for the power industry

RTDS
Technologies

Here is the setup for traditional relay testing: voltage and current signals from power systems simulated on the RTDS are sent out to the relays through D/As and amplifiers, breaker control signals are sent back to the RTDS from the relays, forming a closed loop.

GTNET Card

GTNET – IEC61850 Communication Protocols



Real time digital simulation for the power industry

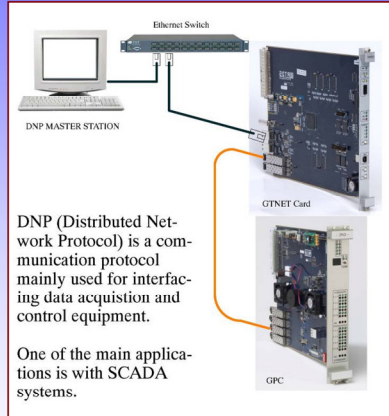


With GTNET, all the signals are sent with through GTNET cards, simplifying wire connections and removing the requirements for voltage and current amplifiers.

GTNET Card

10

GTNET – DNP Communication Protocol



DNP (Distributed Network Protocol) is a communication protocol mainly used for interfacing data acquisition and control equipment.

One of the main applications is with SCADA systems.

One GTNET can accommodate the following signals:

- Binary Status: 1024
- Binary Control: 512
- Analogue Status: 500
- Analogue Control: 100

Status Signals originate in the RTDS simulator and are sent to the DNP Master.

Control Signals originate in the DNP Master and are sent to the RTDS GTNET Card.

GTNET Compatibility:

- Binary Signals are packed as 32 bits
- Analogue Signals are 32 bit IEEE Format
- Binary Signal update frequency is 1000 Hz
- Analogue Signal update frequency is 4 Hz
- GTNET must always operate as DNP Slave (not as Mater)

For DNP standards and terminology, visit www.dnp.org



Real time digital simulation for the power industry

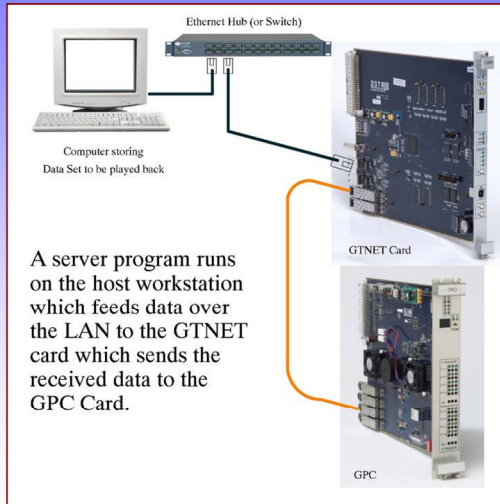


GTNET can send binary and analogue status signals to the DNP master and receive binary and analogue control signals from the DNP master. For DNP protocol, GTNET can only be operated as DNP slave.

GTNET Card

11

GTNET – PB Communication Protocol



The GTNET Playback Protocol allows stored waveforms to be played *INTO* the on-going simulation case

File sizes of 100's of Mbytes representing extended periods of time can be accommodated

Typical Application:

- Arc Furnace Flicker mitigation through introduction of SVC and/or STATCOM



Real time digital simulation for the power industry

RTDS
Technologies

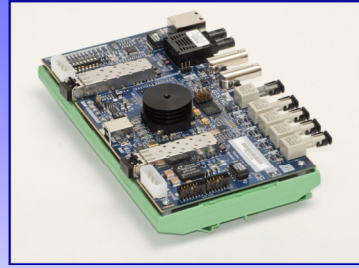
The playback protocol can feed data stored on a PC to an running simulation case. A typical application is arc furnace flicker mitigation with SVC or STATCOM.

GTSYNC CARD

12

GTSYNC:

- GPS external time reference (+/- 1ppm) via
 - 1PPS (in/out via BNC or ST fibre)
 - IEEE 1588 (via RJ45 or ST fibre) with date stamp
 - IRIG-B (future development)
- Adjusts master simulation timestep (Δt) clock
 - RTDS time step clock has an accuracy of +/-100 ppm
 - Δt adjusted in ns range for smooth synchronization
 - Master timestep clock synchronizes the entire simulation to one reference
- Ensures repeatable results with known time reference
 - Does not rely on component tolerances (e.g. oscillator) or ambient conditions (e.g. temperature)



Real time digital simulation for the power industry

RTDS
Technologies

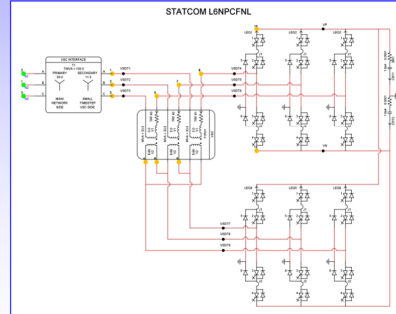
GTSYNC card is designed to provide 1PPS time reference signals to PMUs and other devices. The 1PPS signal is also used to adjust the simulation time step clock on the RTDS to synchronize the entire simulation to the same reference and to produce repeatable results with known time reference.

New Simulation Models

13

Recently developed models for GPC/PB5 card:

- PMU Wide Area Measurement Model
- Modular Multi-level Converter Model
- Capacitor Commutated Converter Model
- Frequency Dependent PI Section Model
- Embed Electrical Machine Model
- Some Renewable Energy Model



Real time digital simulation for the power industry

RTDS
Technologies

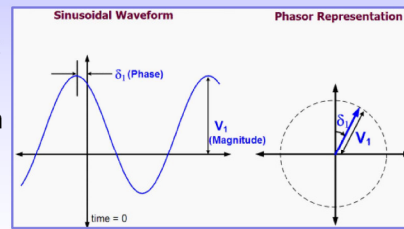
On the software or model side, we have developed the following new models:

PMU and Synchrophasers

14

PMU & Synchrophasers:

- The concept of using Phasor for AC system analysis was first proposed in 1893 by Charles Proteus Steinmetz
- Measurement defined in IEEE C37.118
- Synchrophasor is defined as magnitude and angle of a cosine function with an absolute time reference
- Phasor measurement units (PMU's) are installed at different points in the network
- PMU's provide information about the voltage and current at point of installation in the form of phasors
- PMU's being deployed for many years for system monitoring



Real time digital simulation for the power industry

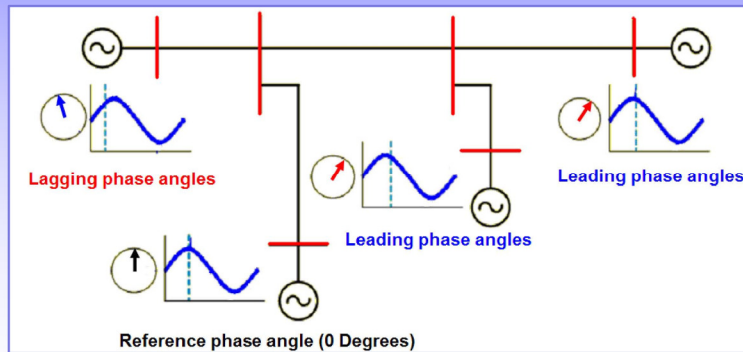
RTDS
Technologies

PMUs are phasor measurement units. They provide information about the voltage and current at point of installation in the form of phasors. It has been deployed for many years for system monitoring.

Wide Area Protection and Control¹⁵

Wide Area Protection and Control Based on PMU data:

- Use information provided by PMU's to make decisions on how to operate the network



Real time digital simulation for the power industry

RTDS
Technologies

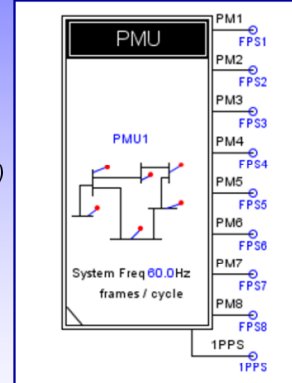
For wide area protection and control, PMUs can be installed at key locations to help operators make decisions.

PMU and GPS Synchronization

15

PMU Modeling and GPS Synchronization:

- Provides PMU metering function
- Up to 8 PMU models per processor
 - Realistic to include >100 PMU's in test systems
- Designed according to IEEE C37.118
 - Voltage and current phasors
 - Polar or rectangular output format formats
 - Frame rates from 1 – 60/sec (higher rates possible)
- C37.118 data stream output
 - Required to connect to external PDC (Phasor Data Concentrator)
- GPS time synchronization
 - Absolute requirement for TVE (Total Vector Error) testing
 - Ensure repeatable results
 - Allows integration of simulated and physical devices in one simulation using common time reference



Real time digital simulation for the power industry

RTDS
Technologies

RTDS PMU model can provide PMU metering function. Up to 8 PMU models can be simulated on a processor which makes it possible to have over 100 PMU's in the test systems. The PMU models are designed according to IEEE standard. The measurements can be synchronized with 1PPS signal allowing simulated and physical devices in one simulation using common time reference.

GTNET Support for PMU

17

GTNET – PMU protocol:

- IEEE C37.118 data stream output
 - One card supports output from 8 x PMU's simultaneously at 1 – 60 frames/sec
 - Floating point or integer
 - Support TCP or UDP protocols
- Data provided from PMU model
 - Supports output from 8 x PMU's simultaneously
- Timestamp passed from GTSYNC via PB5 card
- Excellent reference signal with TVE < 0.01%
- Protocol release – imminent



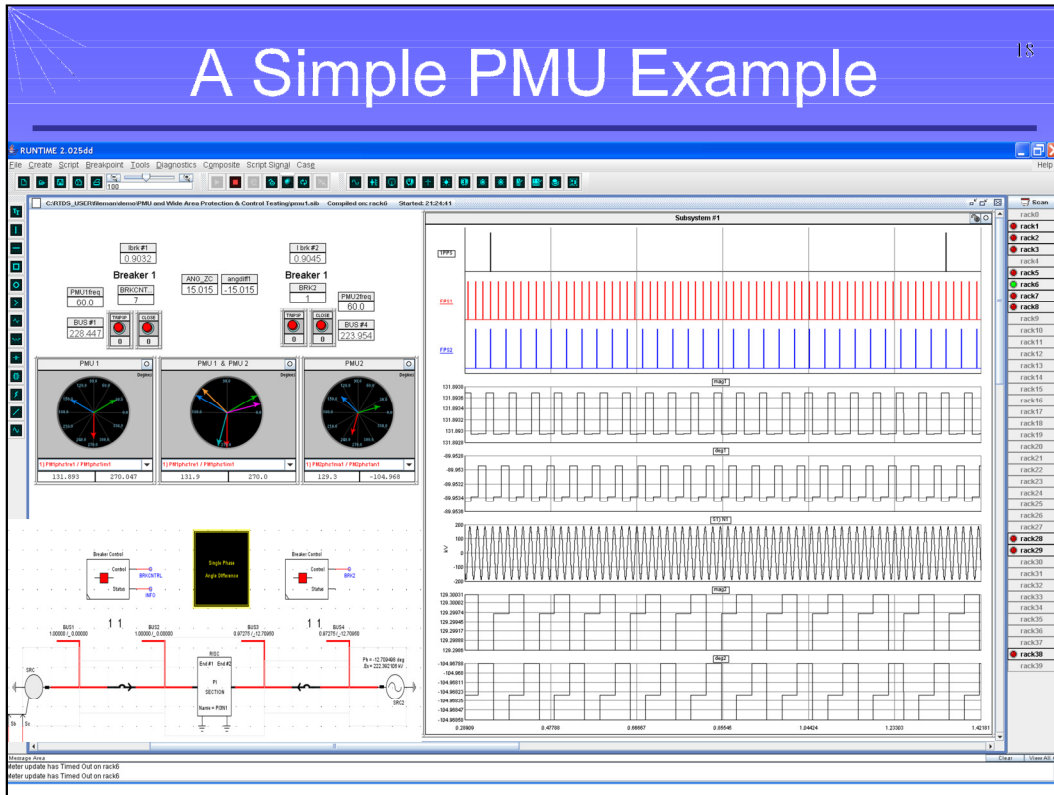
Real time digital simulation for the power industry

RTDS
Technologies

GTNET has been programmed to support PMUs: 1 GTNET card can send out measurements from 8 PMUs. GTSYNC can provide an external 1PPS signal to all the PMUs both simulated and physical.

A Simple PMU Example

15

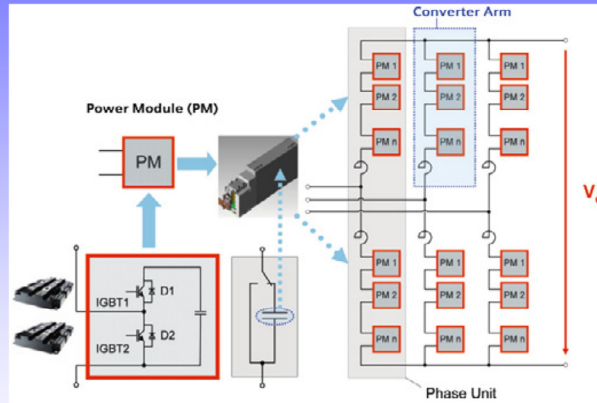


GTNET has been programmed to support PMUs: 1 GTNET card can send out measurements from 8 PMUs. GTSYNC can provide an external 1PPS signal to all the PMUs both simulated and physical.

New Simulation Models

19

MMC – Modular Multi-level Converters



M. Davies, M. Dommaschk, J. Dorn, J. Lang, D. Retzmann, D. Soerangr,

“HVDC PLUS – Basics and Principle of Operation”

http://www.energy.siemens.com/mx/pool/hq/power-transmission/HVDC/HVDC_Plus_Basics_and_Principle.pdf



Real time digital simulation for the power industry

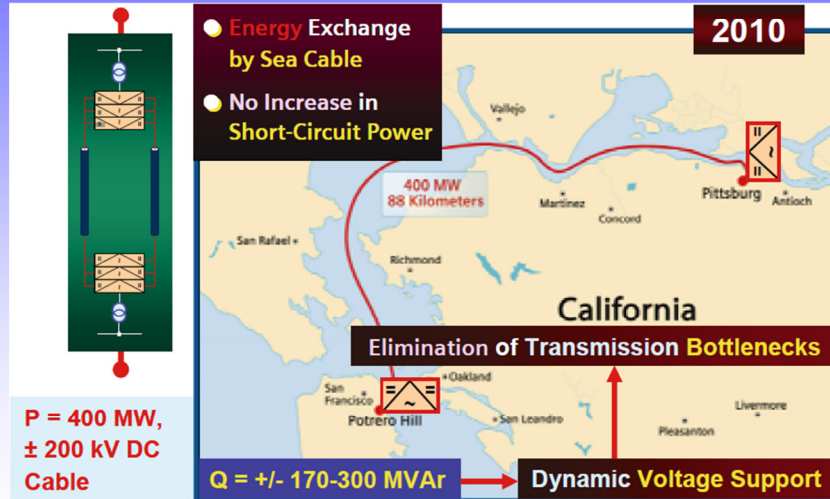
RTDS
Technologies

MMC or Modular Multi-level Converters are a hot topic nowadays. A good reference by Siemens is listed here.

New Simulation Models

20

The Trans Bay HVDC Project (Bay of San Francisco)



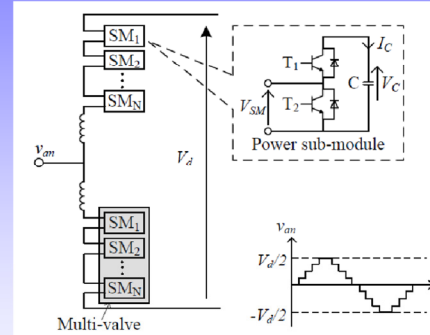
Real time digital simulation for the power industry

RTDS
Technologies

The first commercial MMC project was built by Siemens in the Bay of San Francisco. It is rated at $\pm 200\text{ kV}$ transferring 400MW of power through 88 km of sea cable.

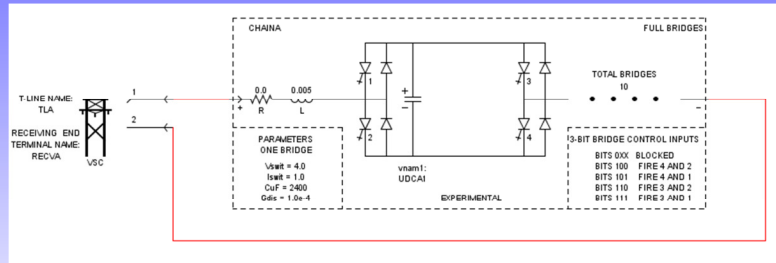
Advantages of Modular Multi-level Converter:

- **Redundant, Modular Design:**
 - High Reliability
 - Low Maintenance Requirements
- **Small Converter AC Voltage Steps**
 - Low Generation of Harmonics
 - Low HF Noise
 - No requirements for AC filters
- **Low Switching Frequency**
 - In normal operation, no more than one level per converter arm switches at any given time
 - Low switching Loss



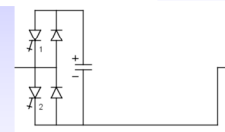
MMC has redundant, modular design, resulting in high reliability and low maintenance requirements. With larger number of modules in each converter arms, there steps in the AC voltages are very small. Consequently, the harmonic contents are low and no AC filters are required. In normal operation, no more than one level per converter arm switches at any given time, resulting in low switching loss.

MMC Model in Small Time Step



MMC Model on RTDS

- Runs on with small time step on GPC/PB5
- Can host up to 56 levels on each processor
- One time step TLINE can be used to connect more levels
- Very high efficient algorithm

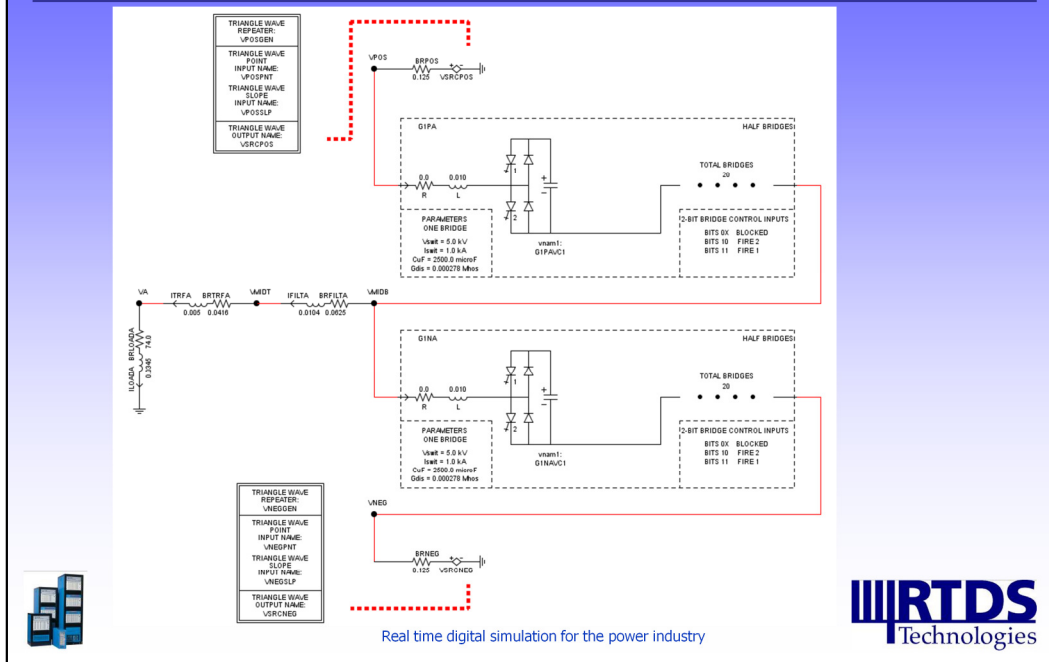


The RTDS small time step MMC model can have up to 56 levels of half or full bridges for each converter arm. One time step T-line can be used to connect more levels.

There is also an averaging model which can simulate up to 640 levels.

A SINGLE PHASE MMC INVERTER

23



This is a single phase MMC inverter example. It is a small time step case. VSRCPOS and VSRCNEG provide the DC voltage for the converter. VA is the output AC voltage. There are 20 levels in each of the converter arms.

A SINGLE PHASE MMC INVERTER

24

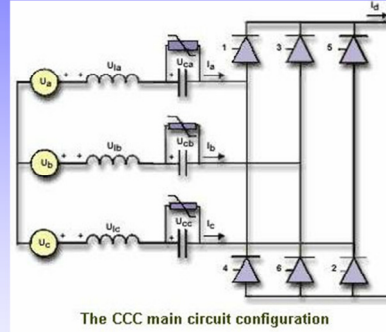


This is the RunTime screen shot. The plots on the left are firing pulses for the converter. The first plot on the right is the voltage on one of the capacitors in the upper arm. The second plot is the voltage on one of the capacitors in the lower arm. The third plot is the AC output voltage (VA).

New Simulation Models

25

CCC - Capacitor Commutated Converters



Reference article by ABB: "Capacitor Commutated Converter, CCC"
[http://www05.abb.com/global/scot/scot221.nsf/veritydisplay/302fc0a0fbc89556c125721a0032e2f7/\\$file/ccc%20concept.pdf](http://www05.abb.com/global/scot/scot221.nsf/veritydisplay/302fc0a0fbc89556c125721a0032e2f7/$file/ccc%20concept.pdf)

M. Meisingset, A.M. Golé, "A COMPARISON OF CONVENTIONAL AND CAPACITOR COMMUTATED CONVERTERS
BASED ON STEADY-STATE AND DYNAMIC CONSIDERATIONS"



Real time digital simulation for the power industry

RTDS
Technologies

CCC or Capacitor Commutated Converters have certain advantages. Commutation capacitors are added between converter transformer and the valves.

New Simulation Models

26

CCC - Capacitor Commutated Converters

Commutation Capacitors between converter transformer and the valves:

- reduced converter transformer rating
- Higher immunity to commutation failures
- Improved stability of long cable transmissions
- Economical applications in very weak AC systems



Real time digital simulation for the power industry

RTDS
Technologies

The capacitors provide reactive power to the converter, reducing converter transformer rating. The voltages on these capacitors also aid in the commutation process thus resulting in a more robust converter with higher immunity to commutation failures, making it suitable for applications with long cable or weak AC systems.

New Simulation Models

28

Frequency Dependent PI Section Model

- In small time step VSC based HVDC simulation, frequency dependent characteristic is important
- Phase domain FD-TLINE is not possible to be used at the small time step
- Using fitting technique to develop a frequency dependent PI section

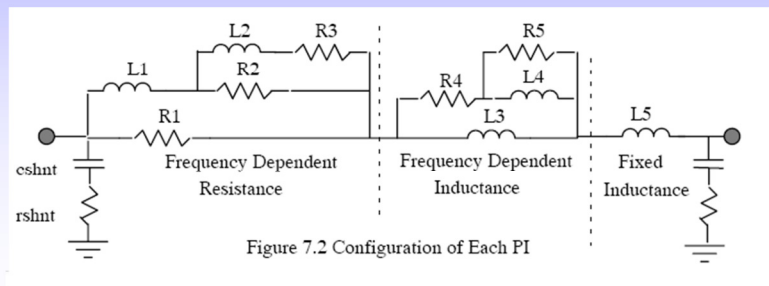
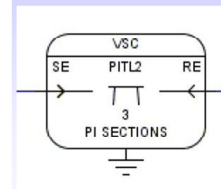


Figure 7.2 Configuration of Each PI



Real time digital simulation for the power industry

RTDS
Technologies

In small time step simulation, there is not enough time to implement frequency dependant T-line. A simpler fitted PI section model is implemented instead.

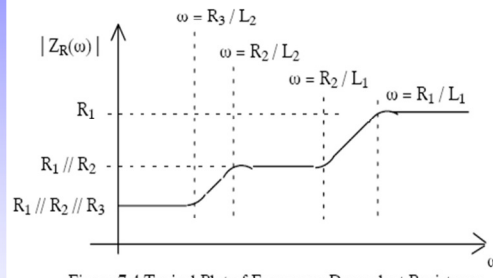
New Simulation Models

29

Frequency Dependent PI Section Model

- Fitting the frequency dependent characteristic of resistor-

$$Z_R(\omega) = \frac{R_1}{1 + \frac{R_1}{j\omega L_1}} \frac{R_2}{1 + \frac{R_2}{j\omega L_2}} \frac{R_3}{1 + \frac{R_3}{j\omega L_2}}$$



Real time digital simulation for the power industry

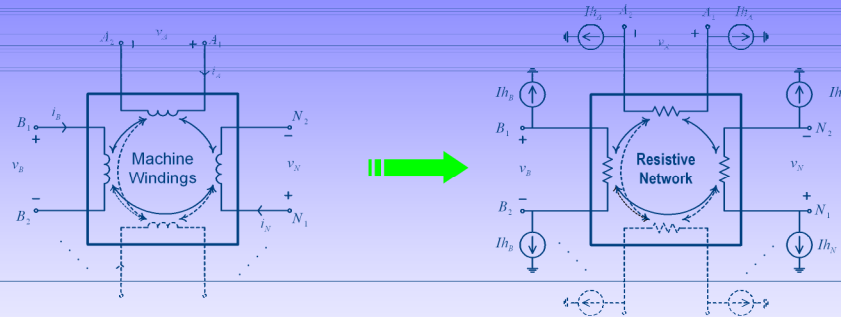
RTDS
Technologies

A typical frequency dependent resistance curve is fitted with R_1 , R_2 , R_3 and L_1 , L_2 .

New Simulation Models

30

Embedded Synchronous Machine Model on GPC/PB5:



- Elements of the equivalent conductance matrix are evaluated and added to the admittance matrix of the network in every time-step.
- History term current sources are computed and injected in every time-step.



Real time digital simulation for the power industry

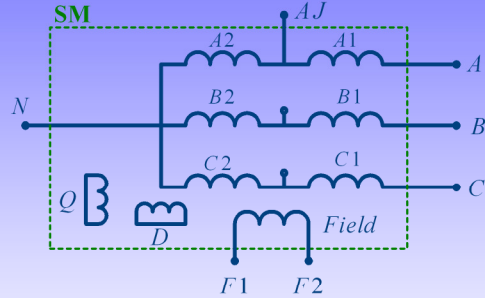
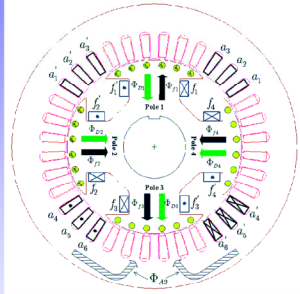
RTDS
Technologies

The conductance matrix of a machine is a function of time. To simplify the solutions, an interface approach is taken by most EMTP type simulation programs such as EMTDC and RTDS. An interface introduces an one time step delay between the machine and the rest of the network. The new model eliminate the interface and the conductance matrix is computed and sent to the network solution every time step resulting in a more robust and accurate machine model.

New Simulation Models

31

Embed Synchronous Machine Model



Validating the Machine Model in Faulted Conditions:

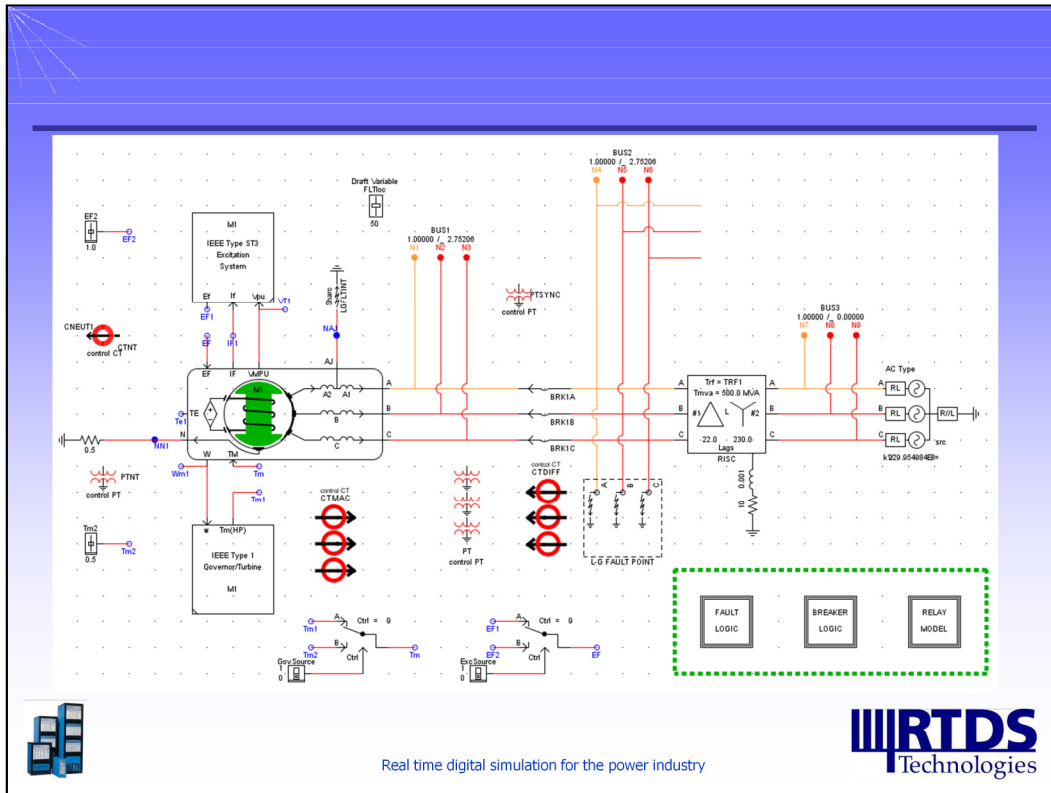
- External faults:
 - Solid three phase short circuit
 - Terminal-to-neutral short circuit
- Internal Fault:
 - A solid short circuit between node AJ and the neutral



Real time digital simulation for the power industry

RTDS
Technologies

The machine model is suitable for generator protection tests with both external and internal faults.



This is a test case for machine fault. A stator phase A to ground fault is applied. The generator protection relay will open the breakers when the fault is detected.

New Simulation Models

34

Some Renewable Energy Model

➤ *Wind power generation*

1. Induction Machine – direct connected
2. Double Fed Induction Machine – soft connected
3. Synchronous/PM Machine - Back-to-back DC connected

➤ *PV (Photovoltaic) generation system*

➤ *FC (Fuel Cell) generation system*



Real time digital simulation for the power industry

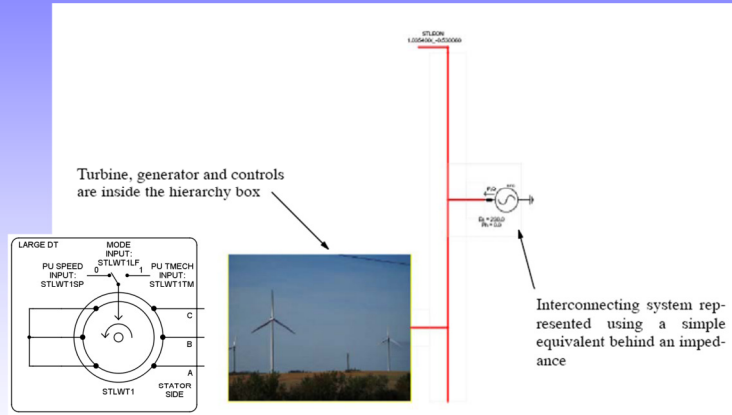
RTDS
Technologies

There are also new models for renewable energy.

New Simulation Models

35

Wind power generation simulation: Variable speed induction machine type



Simulation case for the **Wind farm at St. Leon, Manitoba**, including
Vestas V82 (formerly known as NEC Micon NM82) turbines rated at 1.65 MW



Real time digital simulation for the power industry

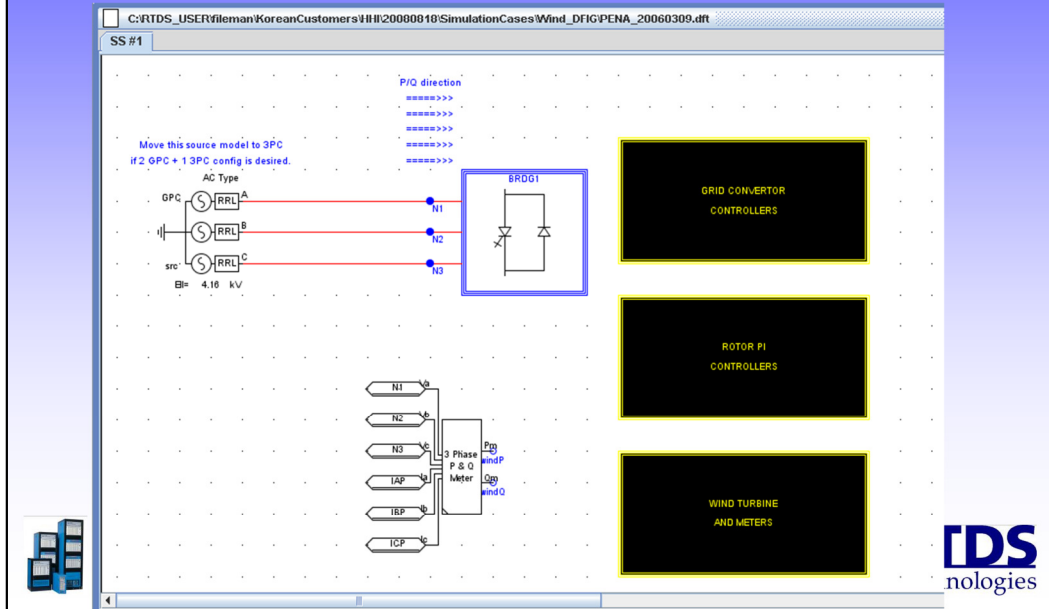


This is a simulation case for the wind farm at St. Leon, Manitoba. It is an induction machine type system rated at 1.65 MW.

New Simulation Models

36

Wind power simulation: DFIG (Doubly Fed Induction Generator) type



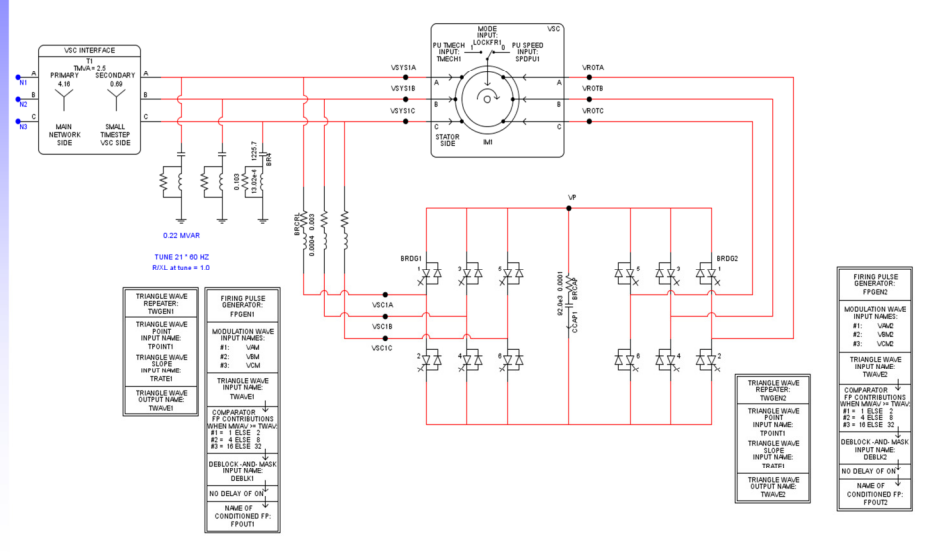
Here we have the doubly fed induction generator connected to a wind turbine.

New Simulation Models

37

Wind power generation simulation: DFIG type

Small time simulation part – Two bridges (2-level) and IM were modeled:



This is what inside the small time step box: an interface transformer, filters, a DFIG and two 2-level bridges converting AC to DC and then to AC of the power grid side.

New Simulation Models

35

Wind power generation simulation: DFIG type

- Based on “*Doubly fed induction generator using back-to-back PWM converters and its application to variable speed wind-energy generation*” by R. Pena et al.
 - Detailed/Realistic parameters were given.
- Control Strategy
 - Grid side bridge: P/Q decoupled control
 - P on d-axis: Controls the bridge cap voltage
 - Q on q-axis: Controls grid side Q flow
 - Rotor side bridge: Vector control
 - Torque order is on Q-axis
 - Basic MPPT (Maximum power point tracking)

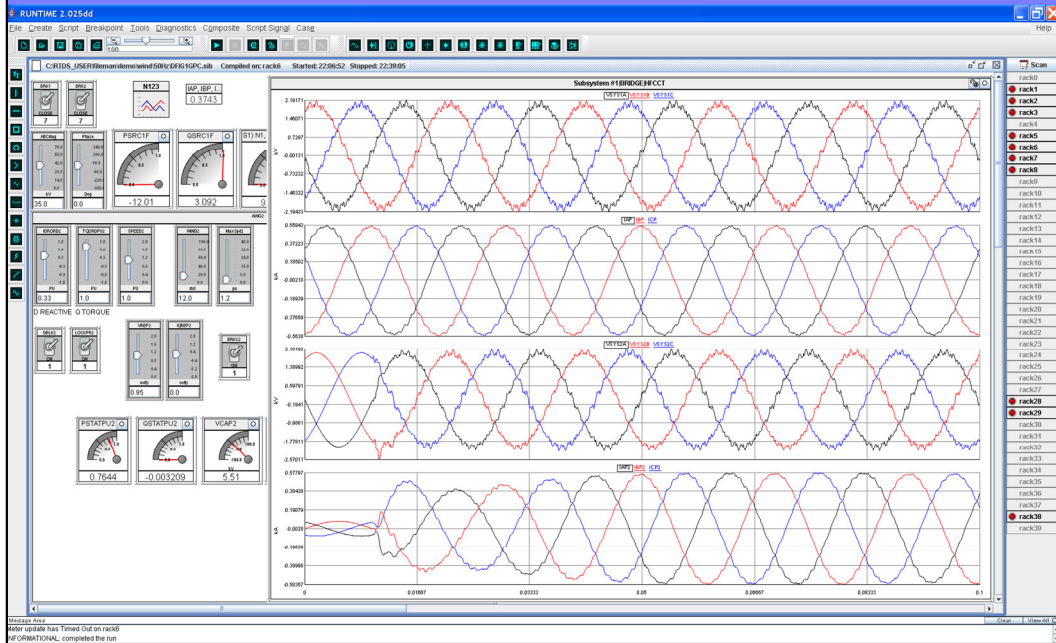


Real time digital simulation for the power industry

RTDS
Technologies

The controllers are based on this paper. P and Q can be controlled separately.

Wind power generation simulation: DFIG Example



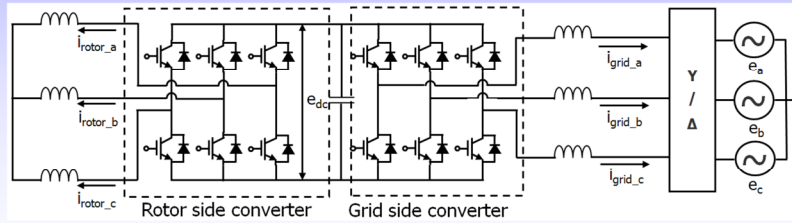
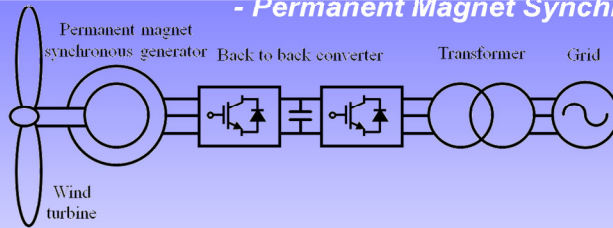
This is the RunTime screen shot. The meters are steady state values. There are actually identical two DFIGs in the system. The first two plots are transformer secondary voltages and primary currents of the first DFIG in steady state. The last two plots are transformer secondary voltages and primary currents of the second DFIG when it is being deblocked.

New Simulation Models

40

Wind power generation simulation: PMSG type

- Permanent Magnet Synchronous Generator



G.-H. Kim, Y.-J. Kim, M. Park et al., "RTDS-based real time simulations of grid-connected wind turbine generator systems," *In Applied Power Electronics Conference and Exposition (APEC), 2010 Twenty-Fifth Annual IEEE*, pp. 2085-2090.



Real time digital simulation for the power industry

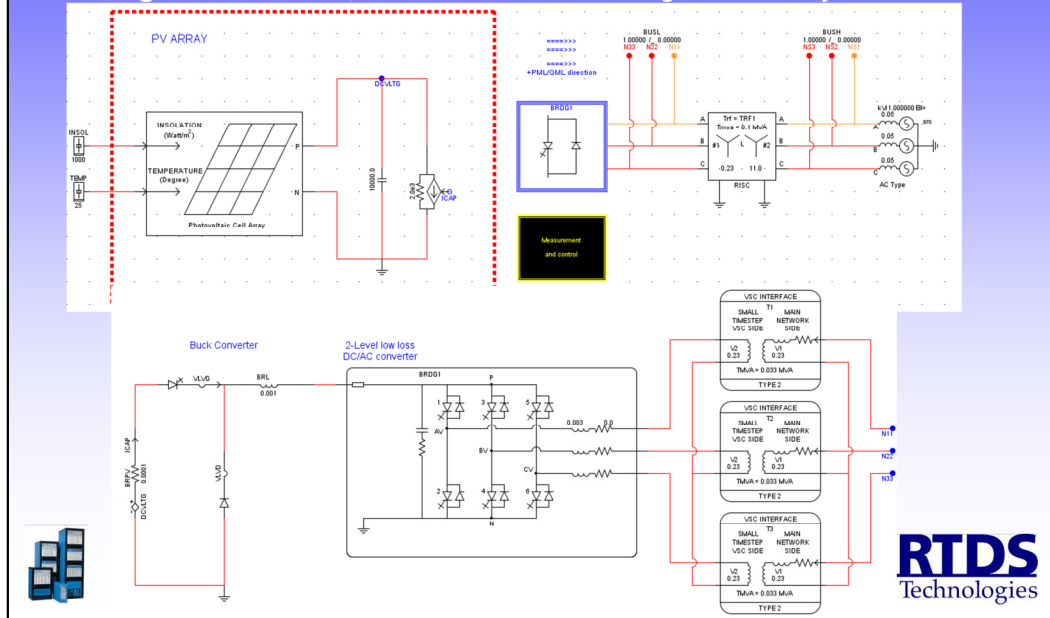


We also have a permanent magnet type of synchronous generator for wind power. A rotor side converter converts AC into DC and a grid side converter then converts the DC to AC connecting to the power grid.

New Simulation Models

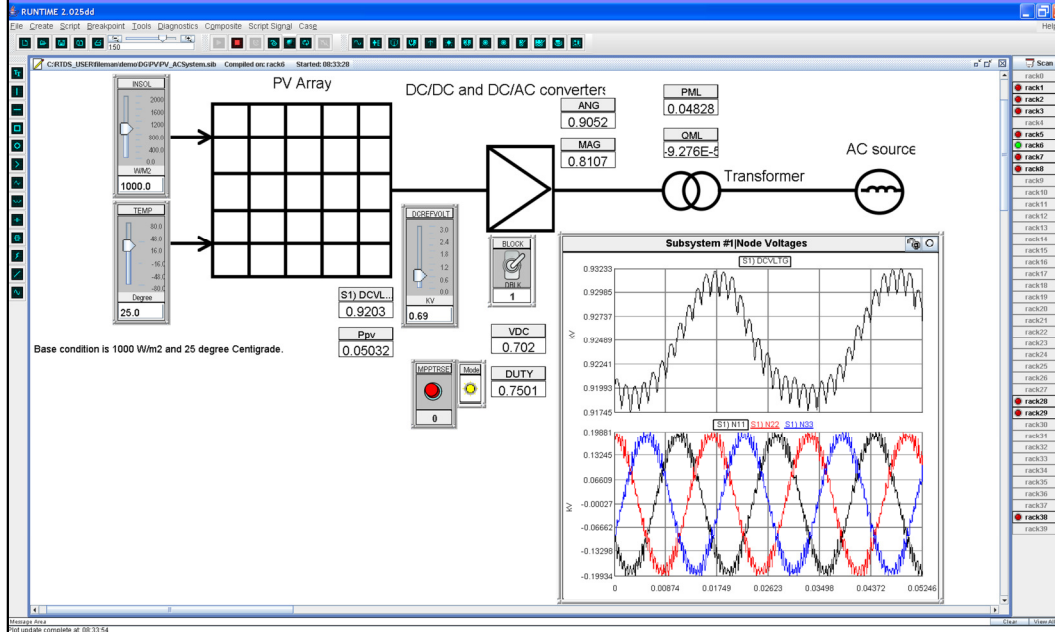
41

Micro grid simulation, AC interconnected PV generation system:



Here is a simulation case with Photovoltaic cells. We have the insolation level and temperature as inputs. The PV cell is connected to a Buck converter and a 2-level DC/AC converter feeding into the power network.

PV Example Case



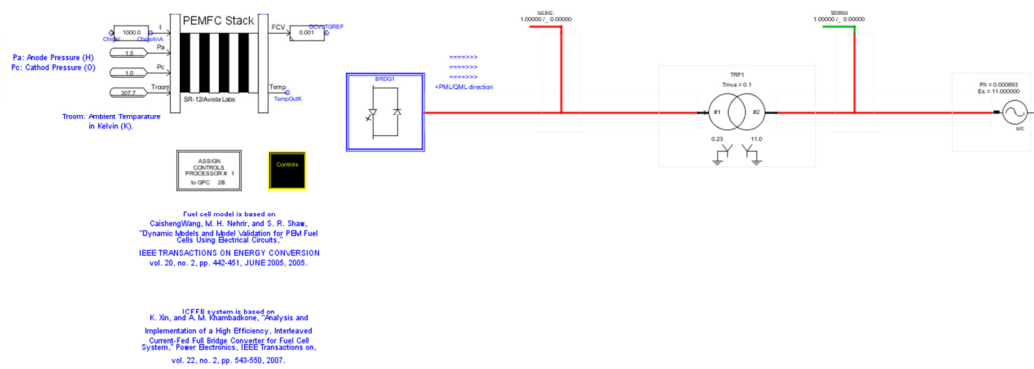
This is the RunTime screen shot. The system is in steady state. The first plot is the capacitor voltage and the second plot is the voltages at BusL.

New Simulation Models

43

Micro grid simulation:

AC interconnected FC (Fuel Cell) generation system:



PEMFC : Proton Exchange Membrane Fuel Cell, or
Polymer Electrolyte Membrane Fuel Cell

Real time digital simulation for the power industry



The last model is a fuel cell. The DC voltage is converted into AC by a converter.



Thank You!

Questions ?



Real time digital simulation for the power industry

RTDS
Technologies

Thanks very much for your attention. If you have any questions, please contact me by email.