Study of stand-alone and grid-connected setups of renewable energy systems for Newfoundland

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➢ Introduction

- Renewable energy systems are chiefly categorized as:

Type	Main issue
Small-scale stand-alone	Costly; based on DC bus
Large-scale grid-connected	Difficult to control

- **Purpose:** potential design improvements of renewable setups in Newfoundland

Small-scale

- Sizing of a Wind-PV-battery system
- Efficiency improvement: Snow detection on PVs

Large-scale systems

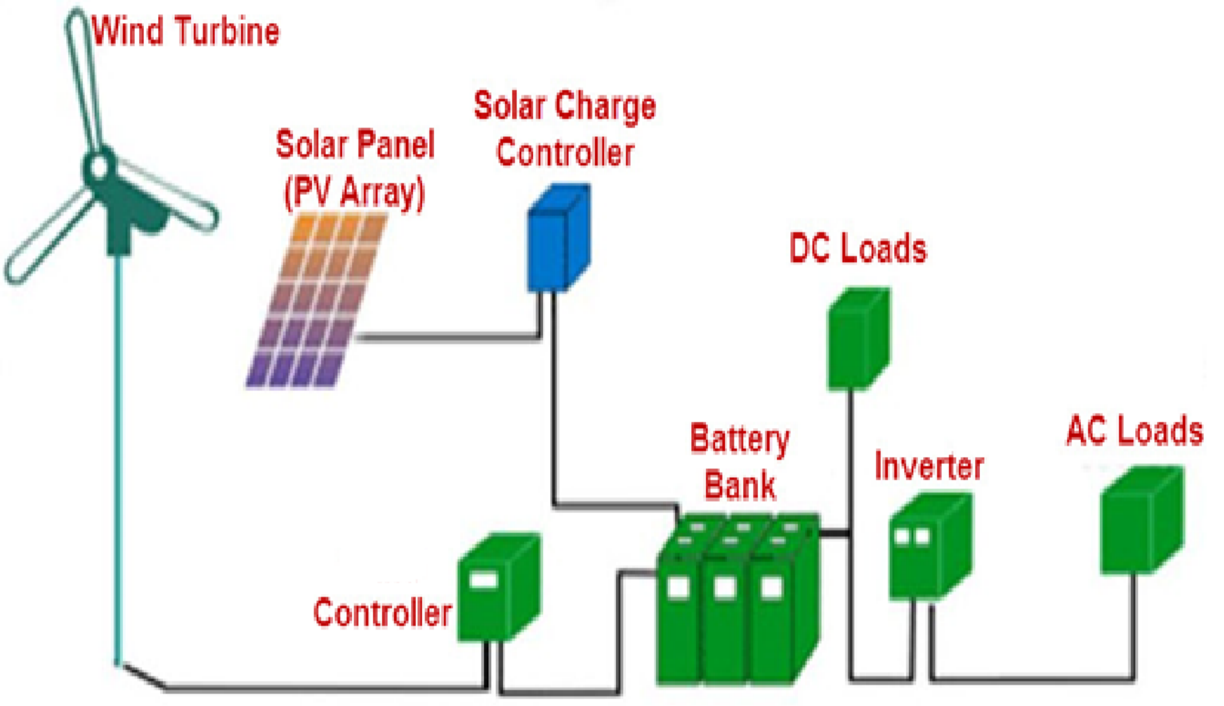
- Study of grid connection of large-scale wind power

Outline:

- ✓ System sizing of small-scale stand-alone system for Newfoundland
- ✓ Improving stand-alone systems: Snow detection on PVs
- ✓ Grid connection of large-scale wind power to the isolated grid of Newfoundland
- ✓ Conclusions
- ✓ Future work
- ✓ Publications

✓ System sizing of small-scale stand-alone system for Newfoundland:

- To overcome the intermittency of renewable power generators, proper design of a hybrid system is crucial
- Available software: Homer, iHoga



Hybrid renewable wind-PV-battery system

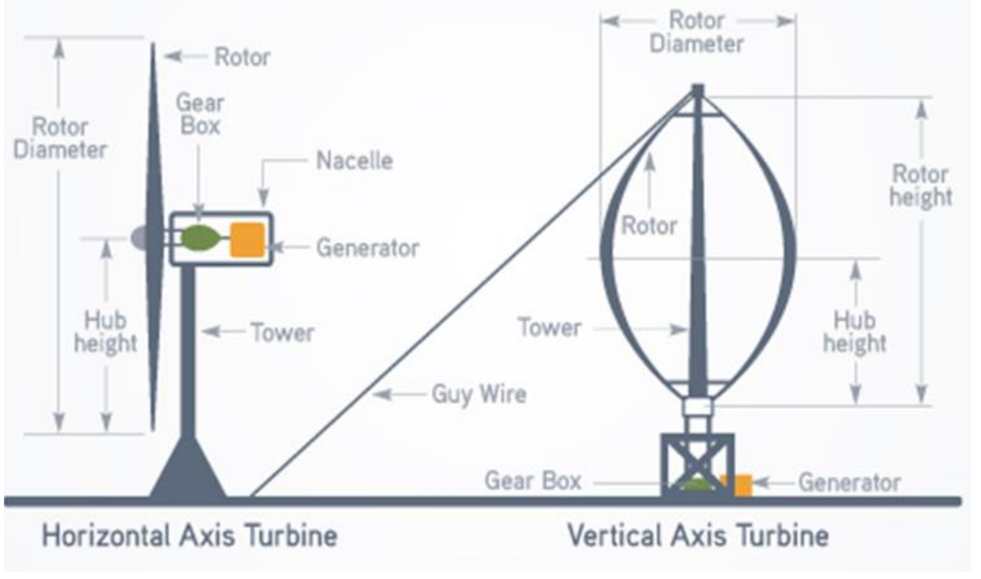
		Advantages	Disadvantages
Software tools	HOMER	User friendly.	Does not let user intuitively select appropriate system components.
	HOGA	Carried out by genetic algorithms.	Simulation is carried out using 1h intervals.

- Method used in this study is similar to Homer; In addition, it gives the owner the ability to reduce the initial cost
- This method considers 2% possibility of power shortage

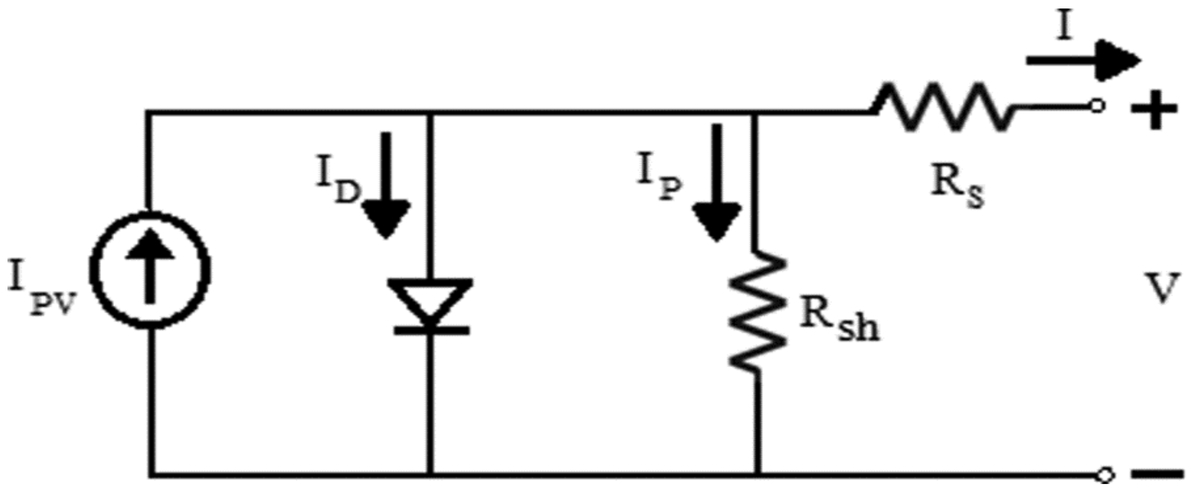
➢ System components

❑ Wind turbines

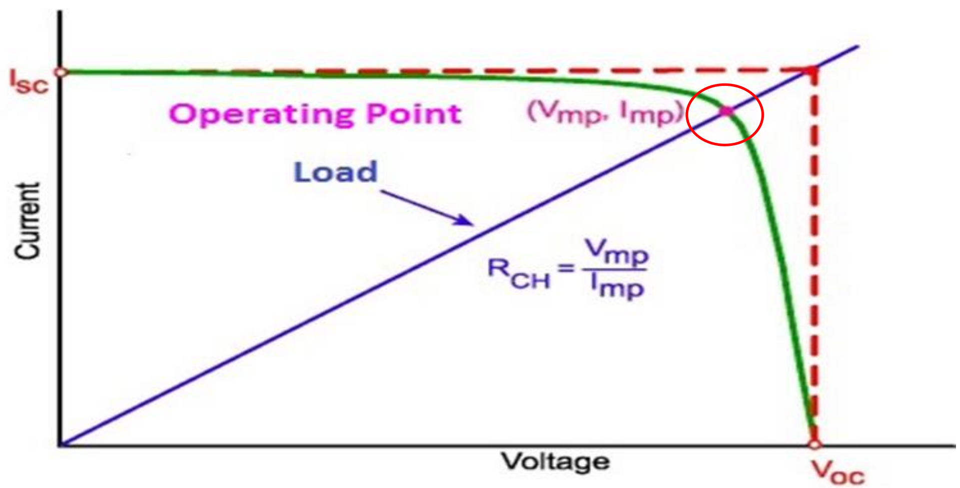
- Based on rotor axis orientation
  - a) Horizontal axis (HAWT)
  - b) Vertical axis (VAWT)
- Based on the size and energy production capacity
  - a) Small wind turbine (≤300kW)
  - b) Large wind turbine (>300kW)
- Based on rotor speed
  - a) Fixed speed
  - b) Variable speed



❑ Photovoltaic panels



Equivalent circuit of a PV module



Load matching of a PV panel with a given insolation; Match power using MPPT

➢ System sizing in Matlab

❑**Mathematical Model of components**

❑**LPSP** (investigates the reliability of hybrid systems)

The ratio of all energy deficits to the total load demand (LPSP=0 : load is always satisfied; LPSP=1 : load will never be satisfied)

❑**NLPS** (basic element for cost saving)

Number of times power deficit happens in a year

- Low NLPS and low initial cost of the system are our optimization objectives

❑ Evaluation

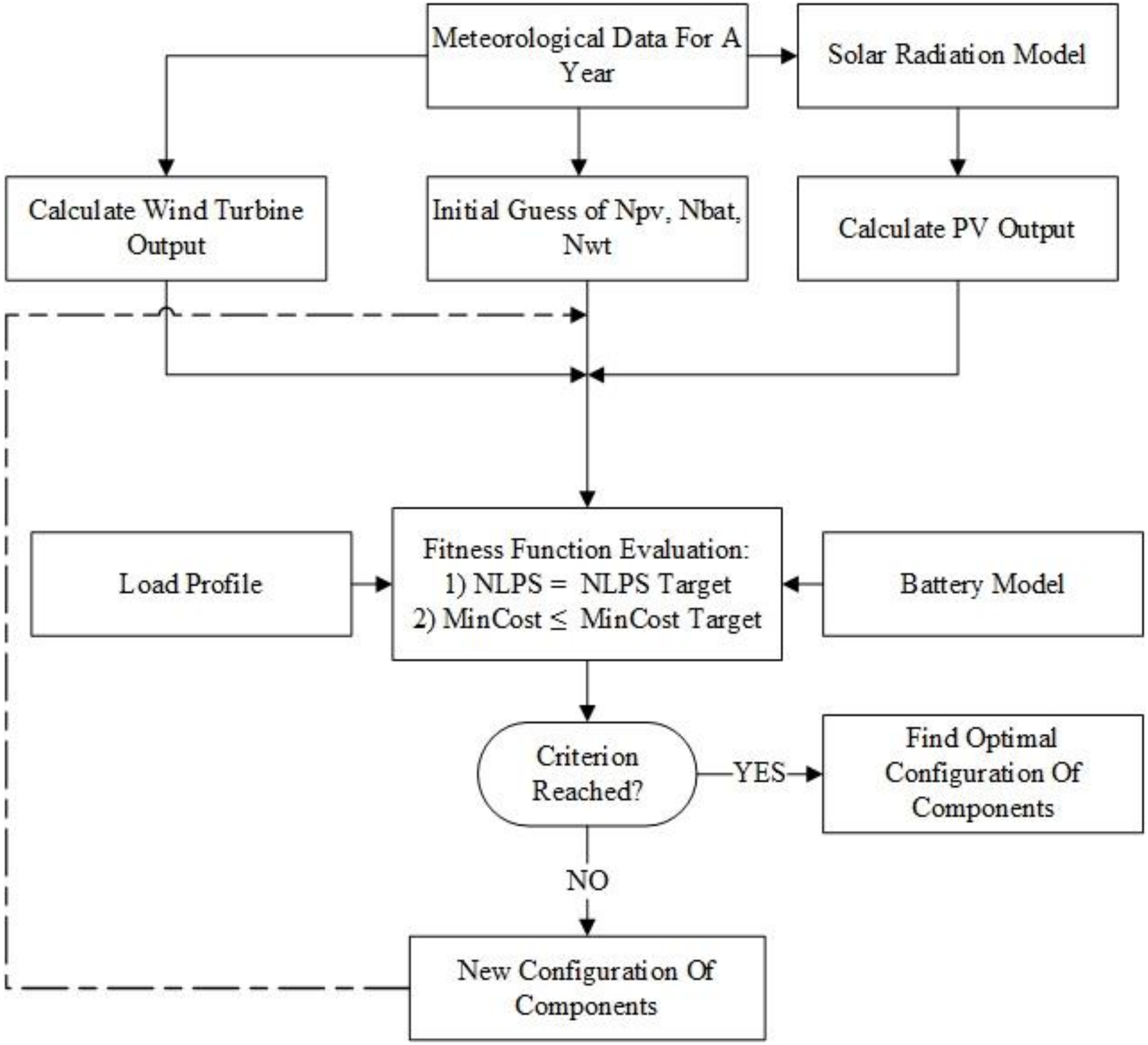
1) Energy generated by renewable sources at each time step is calculated

2) generated energy > load demand :   batteries will be charged

    generated energy < load demand :   batteries will be discharged

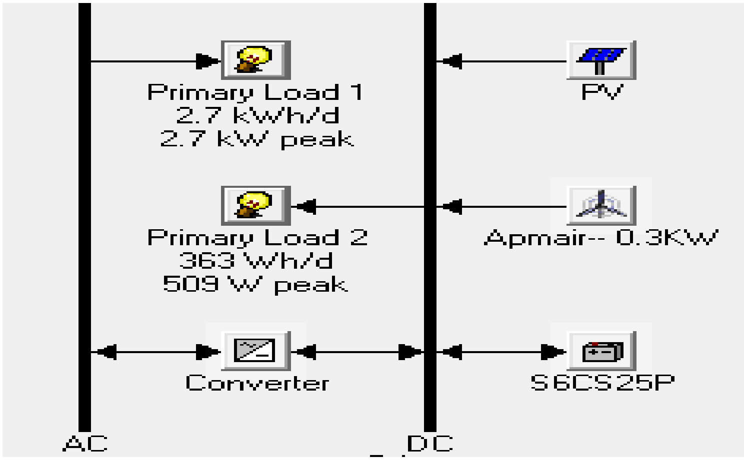
3) generated energy + energy stored in batteries = available energy

4) For hour t: available energy < load demand : deficit is called Loss of Power Supply (LPS)

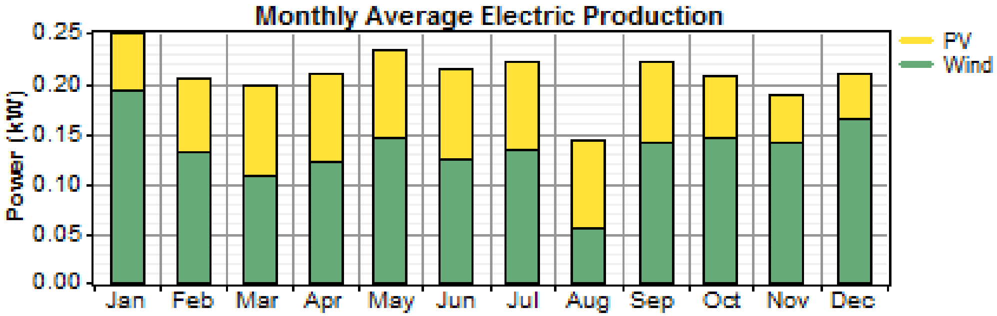


Algorithm for optimal sizing the system

➢ System sizing in Homer for a comparison



System schematics in Homer



Electricity production graph

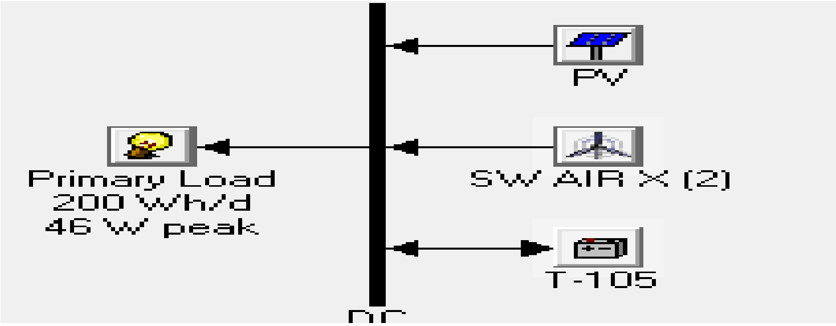
➢ Conclusion

	Developed Code (for NLPS=200)	Homer Software
# of PVs	5	6
# of wind turbines	1	2
# of batteries	10	14
Cost	15,520	22000

Comparison of results

- Considering NLPS= 2%, $ 6480 USD are saved (30% of investment money) if sizing is done using the proposed method

➢ Case study



System overview

	Developed Code (for NLPS=200)	Homer Software
# of PVs	0.1	0.05
# of wind turbines	0	1
# of batteries	2	2
Cost	1060	2520

- Considering NLPS=2%, $ 1460 USD are saved (42% of investment money)

✓ Improving off-grid systems: Snow detection on PVs

- Roughly 74% of PVs are installed in countries that experience some amount of snowfall

- St. John’s received more than three meters of snow during the winter of 2014.

- Snow losses from a PV system can be as high as 20% for a low profile system

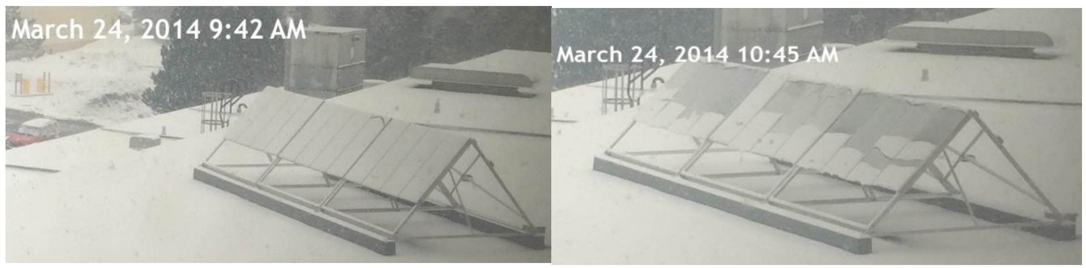
❑ Methods of snow detection:

- Satellite imaging
- Image processing
- Utilizing a wireless Zigbee microcontroller

Proposed method: A low cost method of snow detection on solar panels and sending alerts

➢ Snow shedding

Snow melting

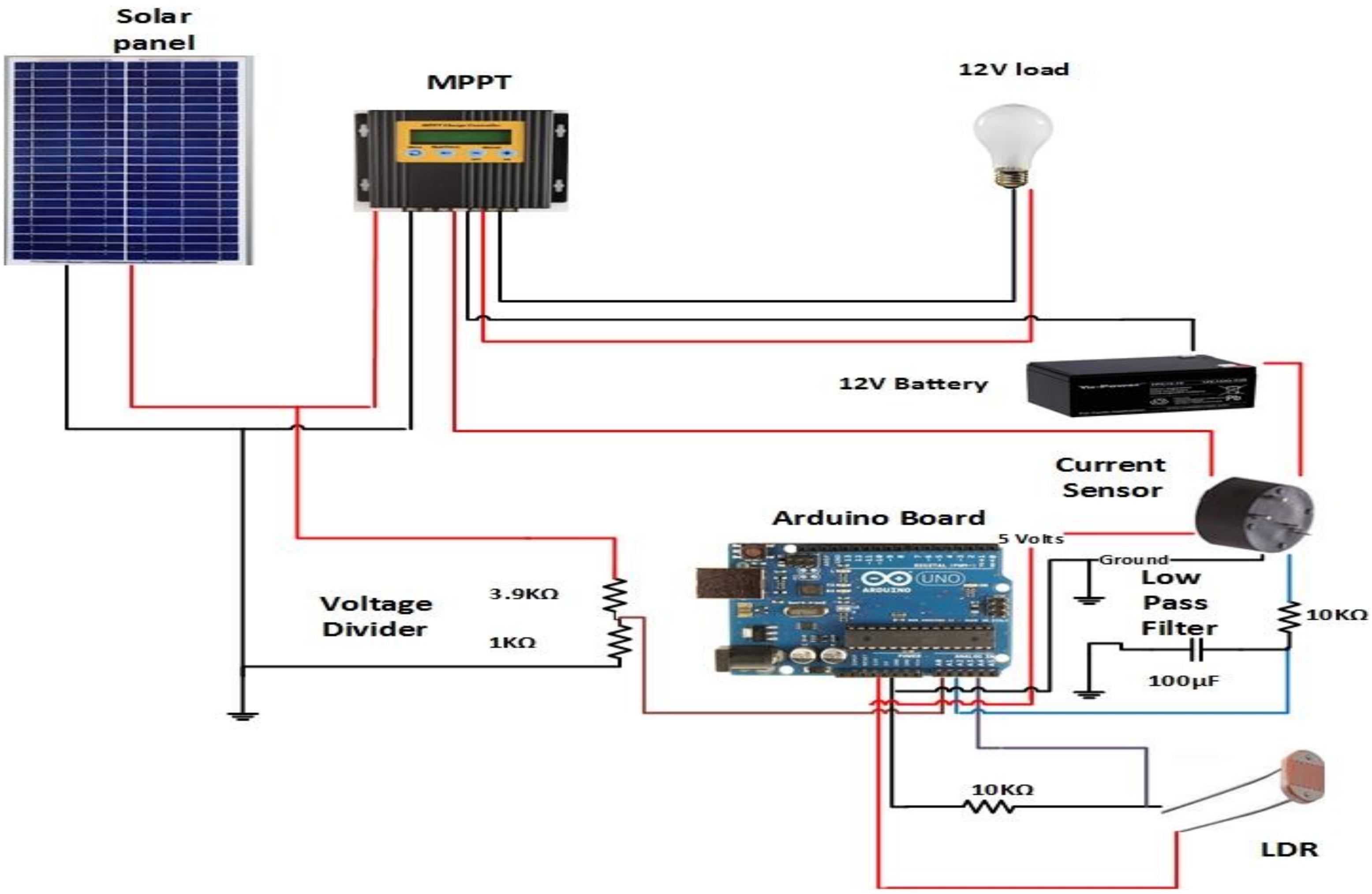


Sheet sliding

- Happens in the form of either melt on the surface of the modules or sheet sliding

- Sheet sliding: Due to sunlight or rise of temperature (incidental radiation would penetrate the layer of snow)

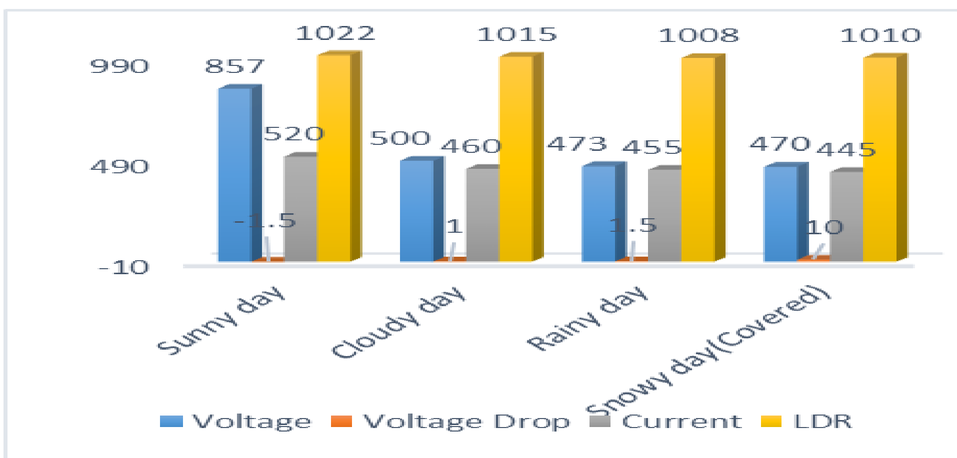
➢ Design of snow detection system



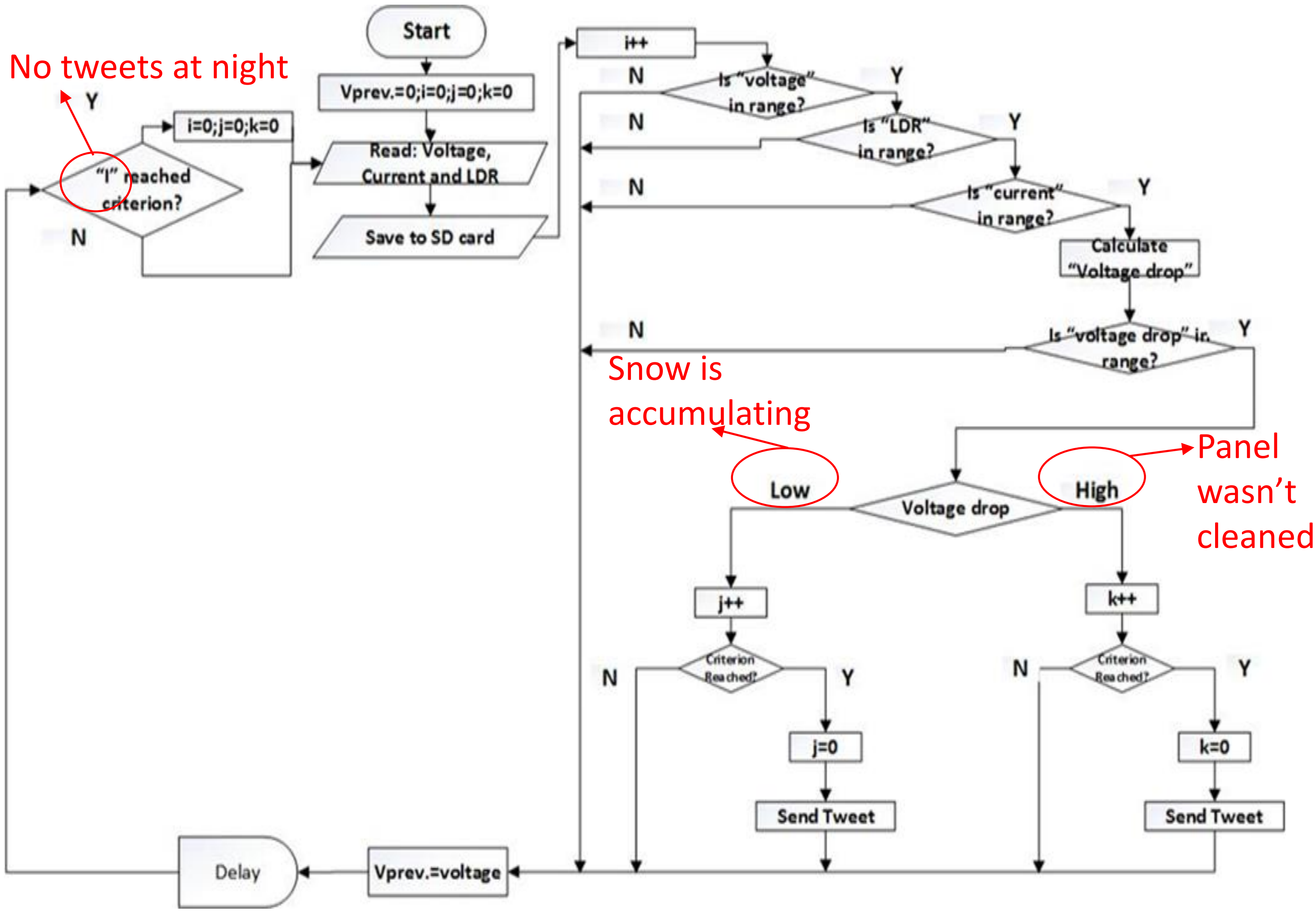
System circuit diagram

➢Alert algorithm

- V, I, and LDR are read from sensors; voltage drop is calculated by microcontroller at each time step (2 minutes)
- Five centimeters of snow on panels is a distinguishable feature affecting the PVs performance
- Key point: thick overcast of clouds is differentiated from snow by voltage drop value



Average of sensors readings during three months



Algorithm for snow detection

➢Arduino code and issues

- Arduino WiFi shield will not connect to WPA2 Enterprise encryption networks; So a WPA network was created
- Logging onto Twitter: Twitter authentication is a lengthy code (difficult to implement on the Arduino)
- Twitter authentication is implemented by connecting Arduino to a website to connect to the twitter server
- Two loops are defined as void loops: One is for sending the tweets and the other for writing sensor values on an SD card

➢ Experimental results

System setup

Snow on panels

Tweeted message

✓ Grid connection of large-scale wind power to the isolated grid of Newfoundland:

1. Uncontrollability of output power presents barrier (high estimates of auxiliary service costs)

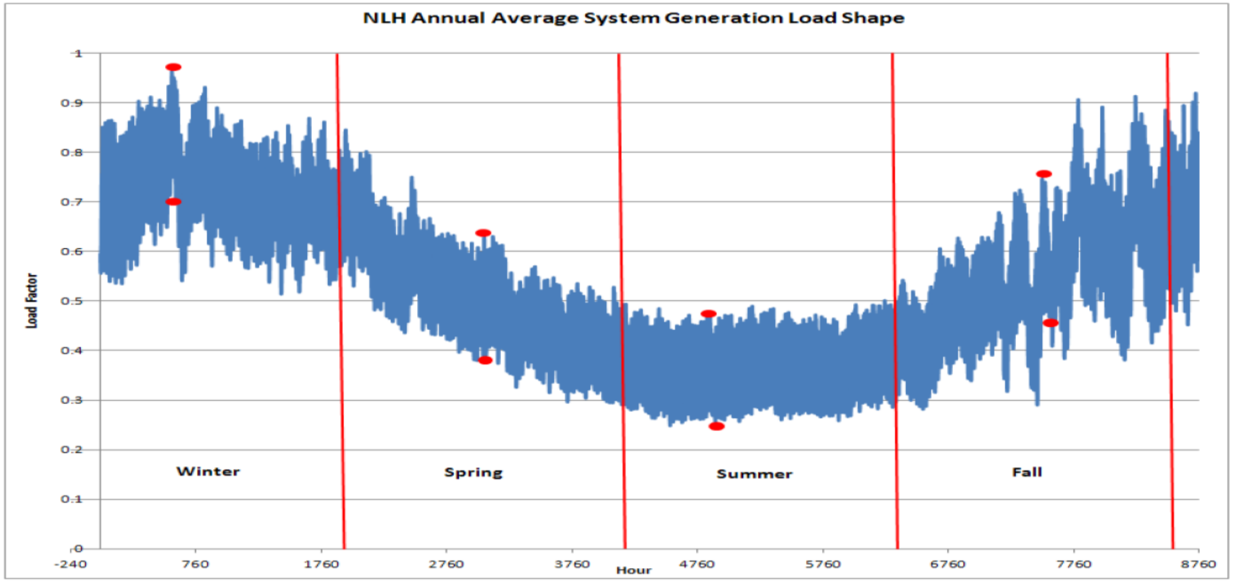
- This imposes integration costs relative to system characteristics and wind penetration level

2. Theory: wide geographical distribution of wind farms results in smoothing of overall output power, thereby reducing the impact of unpredictability of wind resources

➢ Study Parameters

- NLH's wind integration load flow analysis are used to conduct the simulations

❑ Demand load



2008-2011 NLH annual average system generation load shape ("Wind Integration Study- Isolated Island", Newfoundland Hydro)

❑Wind farms

No.	Plant	Region	Bus #	Point of Interconnection (POI)	
				Location	Bus #
1	Doyles WG1	Western	1001	Doyles 66kV	201
2	Doyles WG2	Western	1002	Doyles 66kV	201
3	Stephenville WG1	Western	1003	Stephenville 66kV	204
4	Stephenville WG2	Western	1004	Stephenville 66kV	204
5	Massey Drive WG1	Western	1005	Massey Drive 66kV	115
6	Peter's Barren WG1	GNP	1006	Peter's Barren 66kV	121
7	Bear Cove WG1	GNP	1007	Bear Cove 138kV	134
8	Buchans WG1	Central	1008	Buchans 66kV	151
9	Springdale WG1	Central	1009	Springdale 138kV	113
10	Cobb's Pond WG1	Central	1010	Cobb's Pond 66kV	316
11	St. Lawrence WG1	Burin Peninsula	1011	St. Lawrence 66kV	372
12	St. Lawrence WG2	Burin Peninsula	1012	St. Lawrence 66kV	372
13	Sunnyside WG1	Western Avalon	1013	Sunnyside 138kV	223
14	Sunnyside WG2	Western Avalon	1014	Sunnyside 138kV	223
15	Fermeuse WG1	Eastern Avalon	1015	Goulds 66kV	457
16	Bay Bulls WG1	Eastern Avalon	1016	Goulds 66kV	457
17	Goulds WG1	Eastern Avalon	1017	Goulds 66kV	457
18	Kelligrews WG1	Eastern Avalon	1018	Kelligrews 66kV	348
19	Bay Roberts WG1	Eastern Avalon	1019	Bay Roberts 66kV	309
20	Heart's Content WG1	Eastern Avalon	1020	Heart's Content 66kV	501

Assumed list of distributed wind plants for the base year 2020

❑NLH study results

Year	Extreme Light Load			Peak Load		
	Wind Generation Level (MW)	Wind Penetration Level (%)	System Inertia (MW.s)	Wind Generation Level (MW)	Wind Penetration Level (%)	System Inertia (MW.s)
2020	225	36.8	3340	500	28.5	7197

NLH power system study results for year 2020

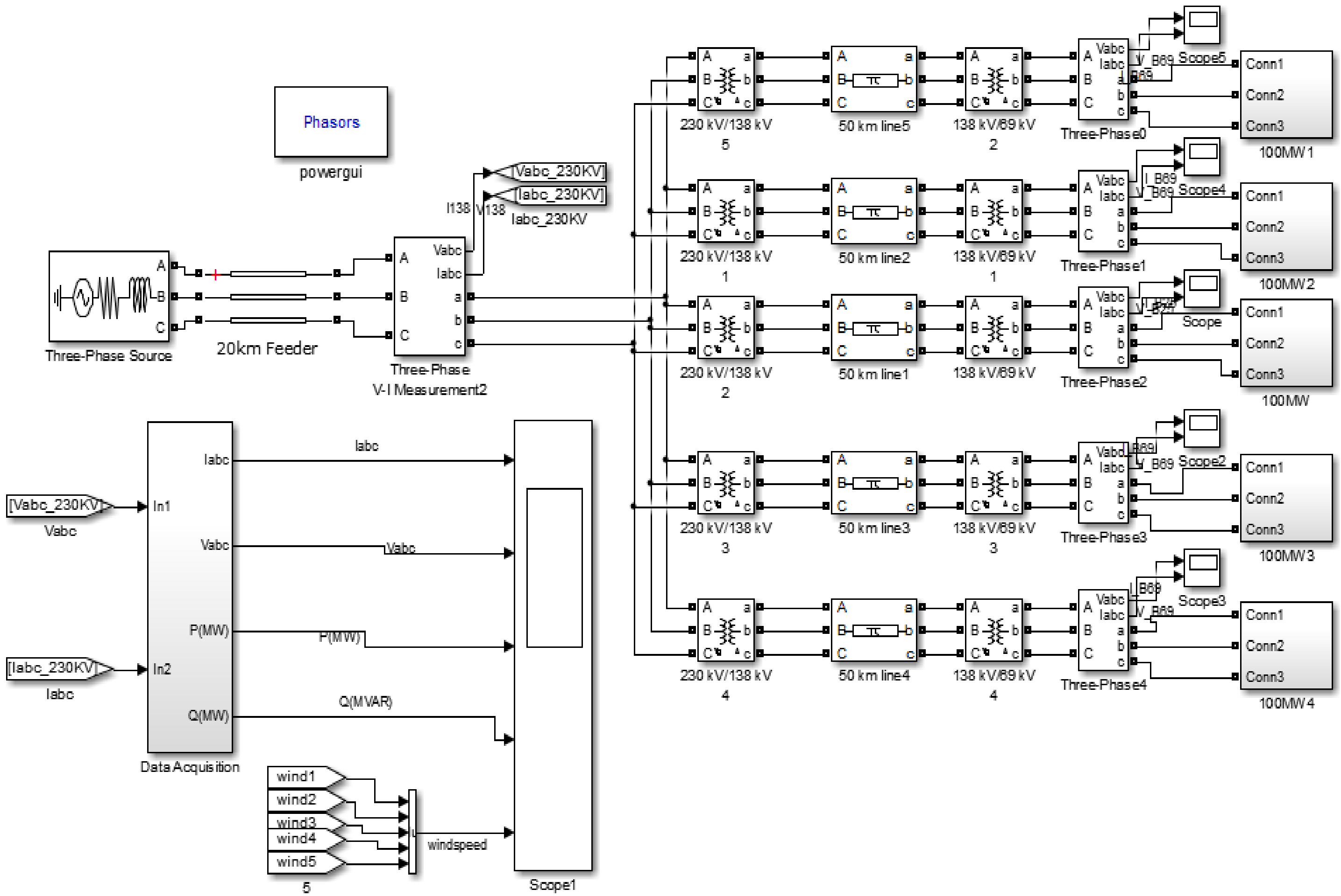
➢ Power system operating criteria

1. **Stability Criteria**
   A. Over Frequency Setting: 61.2 Hz for 0.2 seconds
   B. Under Frequency Setting: 56.4 Hz for 0.2 seconds.

2. **Voltage Criteria**
   A. Normal conditions: maintained between 95% and 105% of nominal
   B. During contingency events : permitted to vary between 90% and 110% of nominal

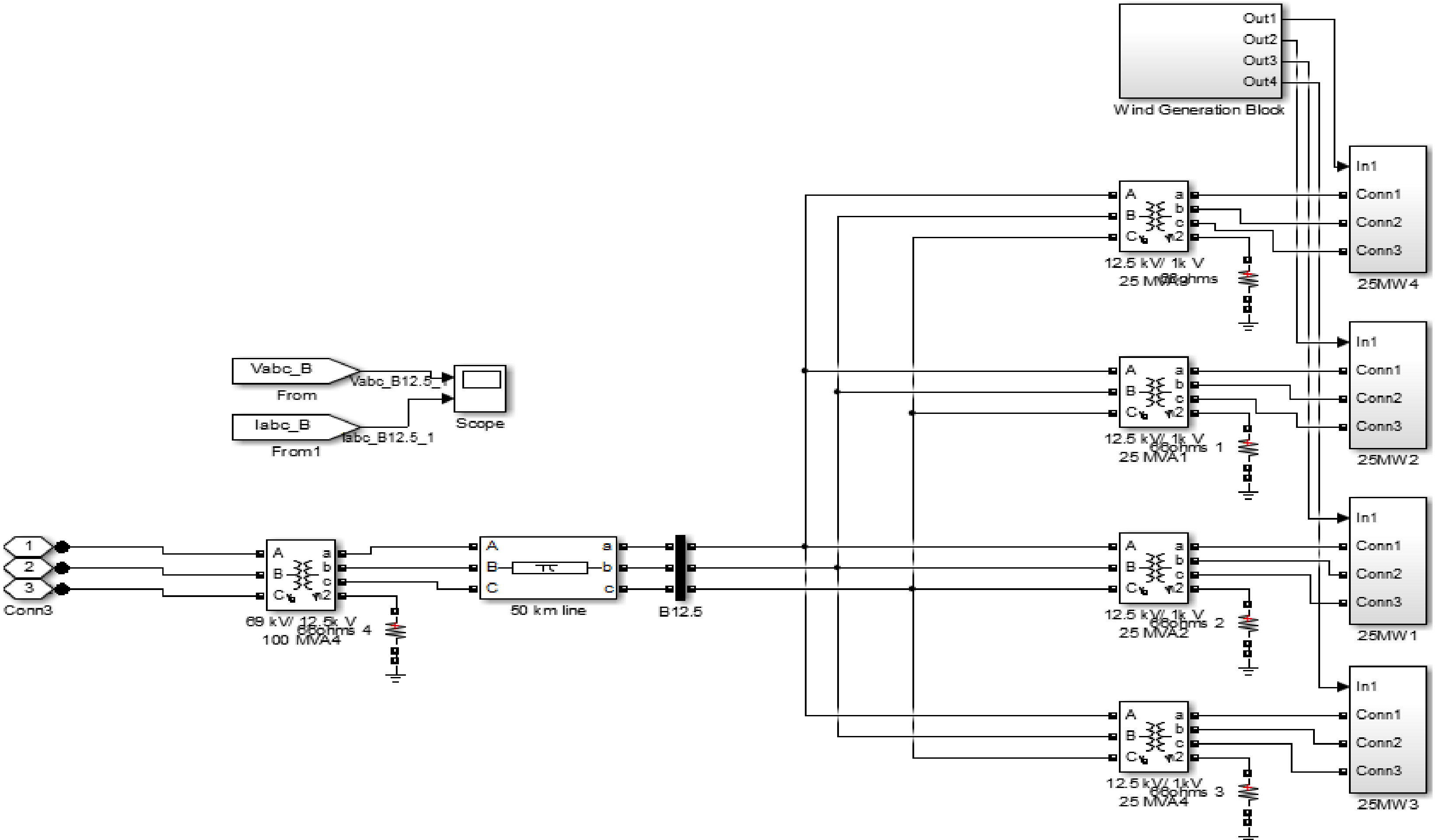
➢ Simulink model

- Implemented in ‘Phasor’ simulation method
- 500MW wind capacity of Newfoundland, comprised of five 100MW wind farms



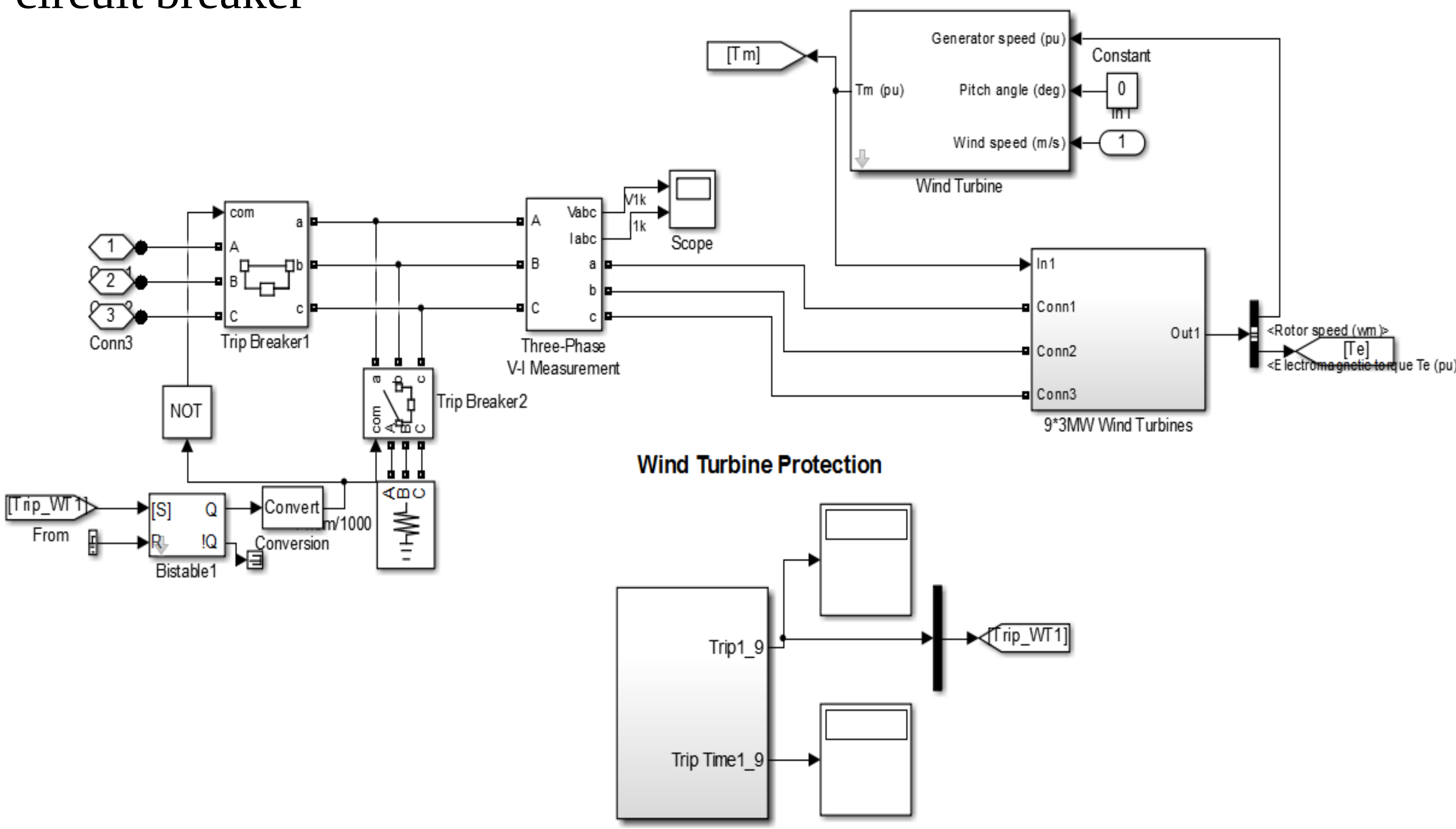
Modeling of five 100 MW capacity of wind farms in Newfoundland

- Each 100MW wind farm has unique weather patterns, including four 25MW DFIG wind farms

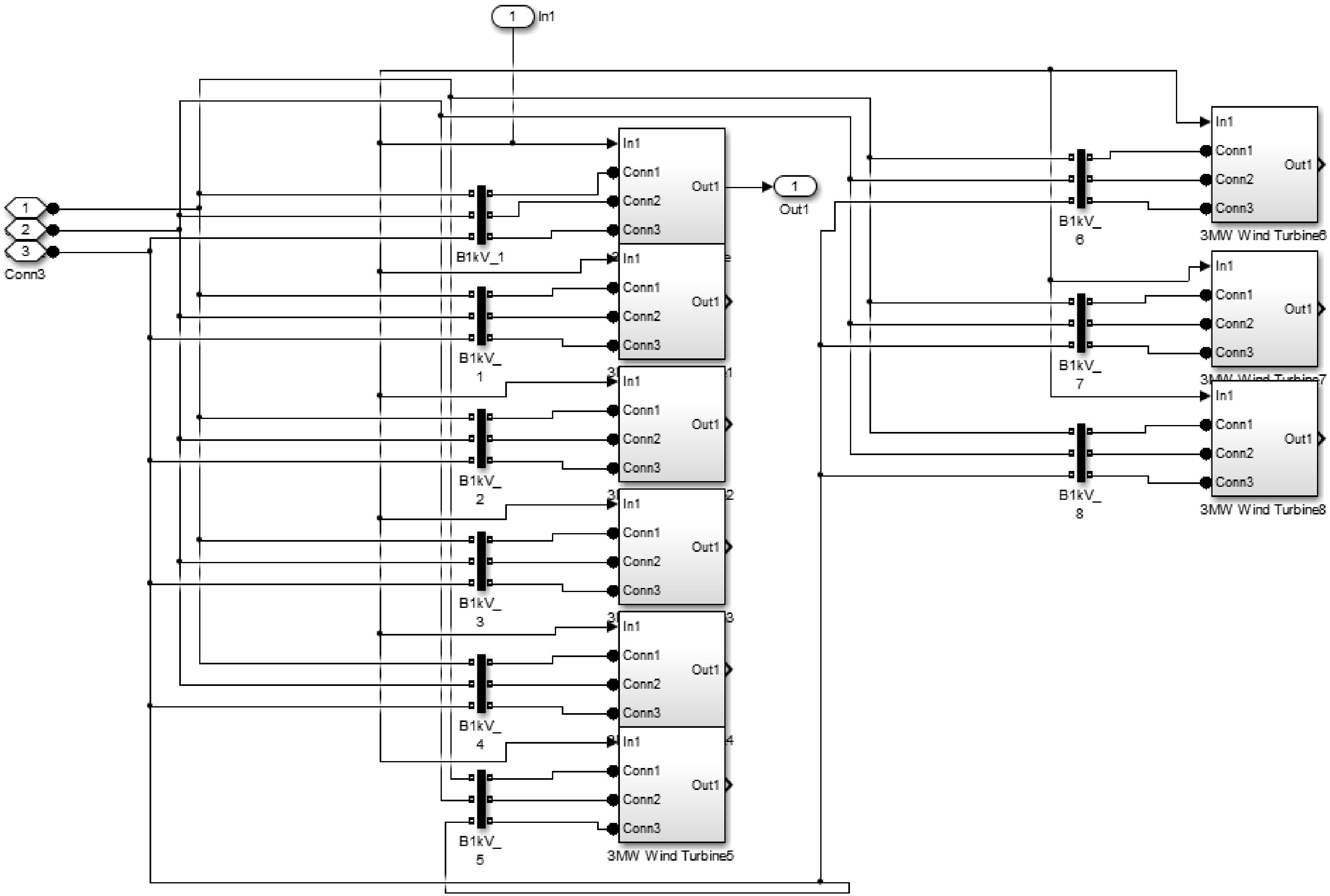


Modeling of each 100 MW capacity wind farm made of four 25 MW wind farms

- Each 25MW wind farm is composed of 9, 3MW wind turbine
- A trip command, sent from the protection block, will be actuated by a circuit breaker



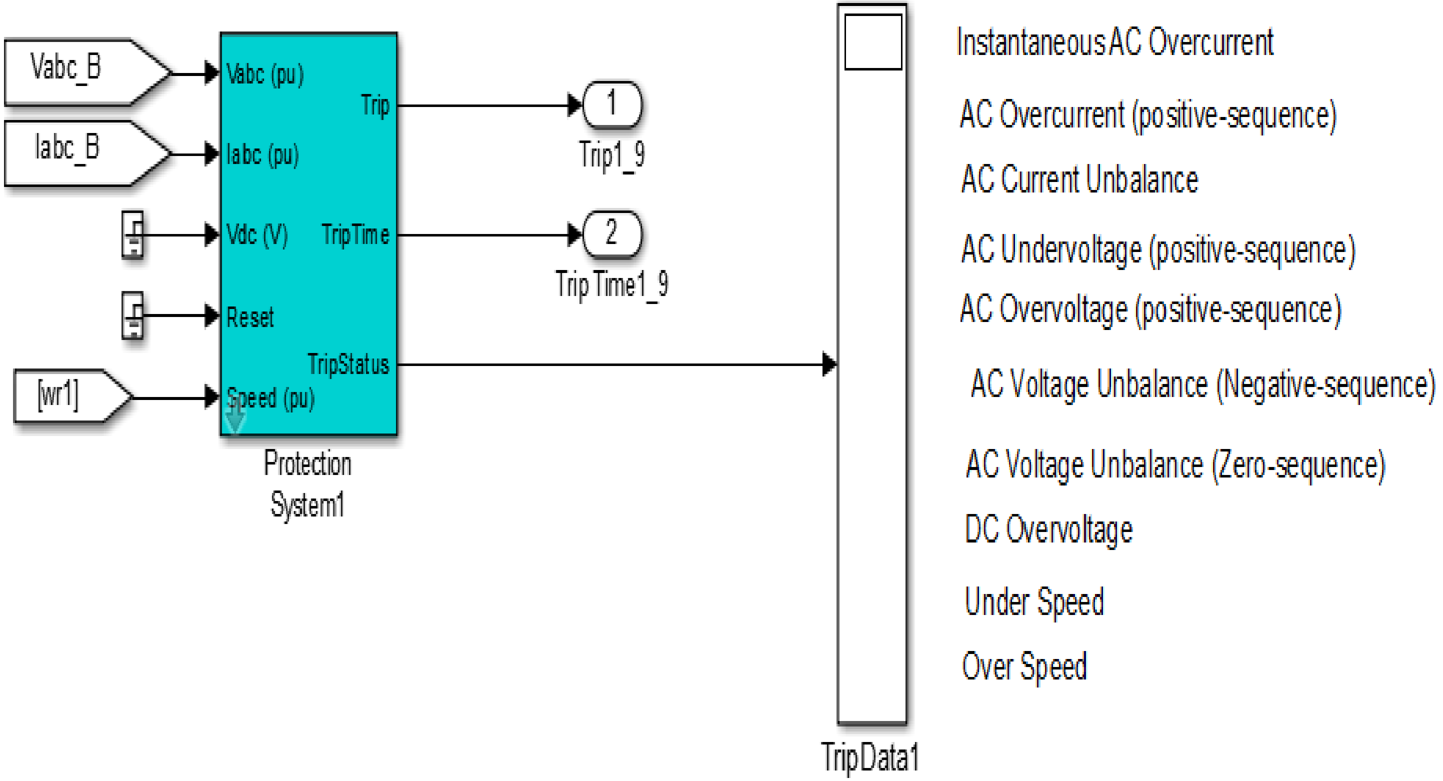
A 25 MW wind farm grid connection



Details of a 25MW wind farm model in Simulink (9*3MW)

Fundamental frequency	60
Instantaneous AC overcurrent (p.u)	10
Maximum AC current (p.u)	0.4
AC under/over voltage (p.u)	0.75/1.1
Maximum voltage unbalance (p.u)	0.05
Under/over speed (p.u)	0.3/1.5

Protection system parameters



Wind turbine protection

➢ Simulation and analyses

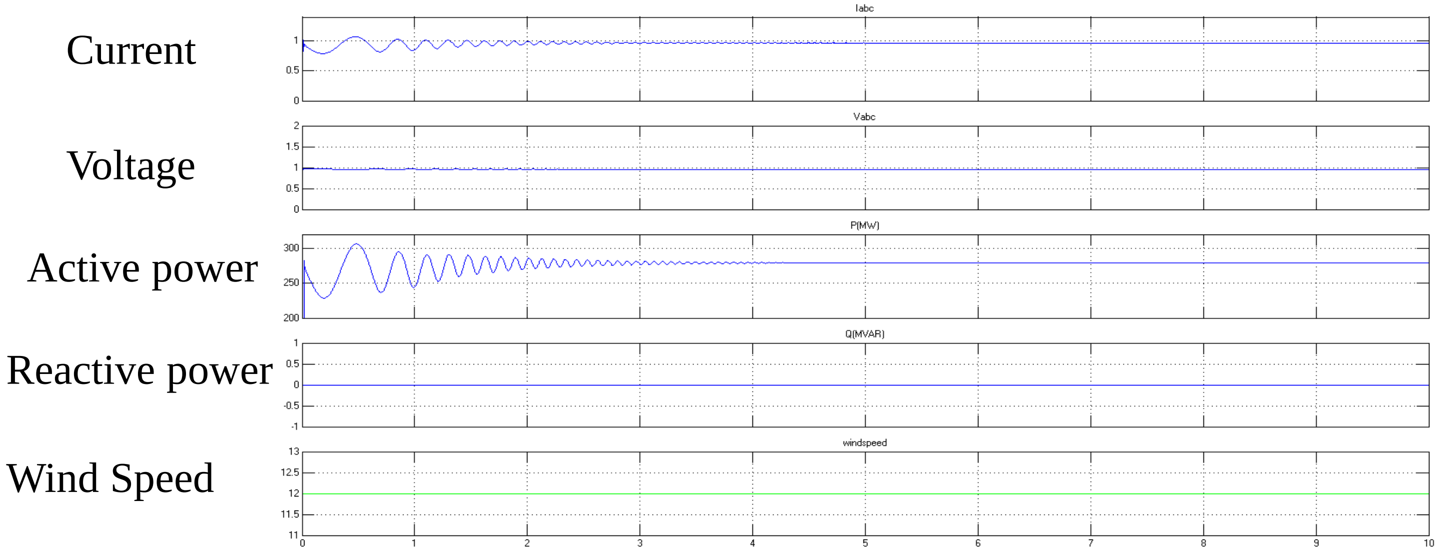
❑ Voltage regulation

- For maximum wind penetration of 500 MW, steady state voltage and current load flow values show no voltage concerns with distributed generation throughout the island

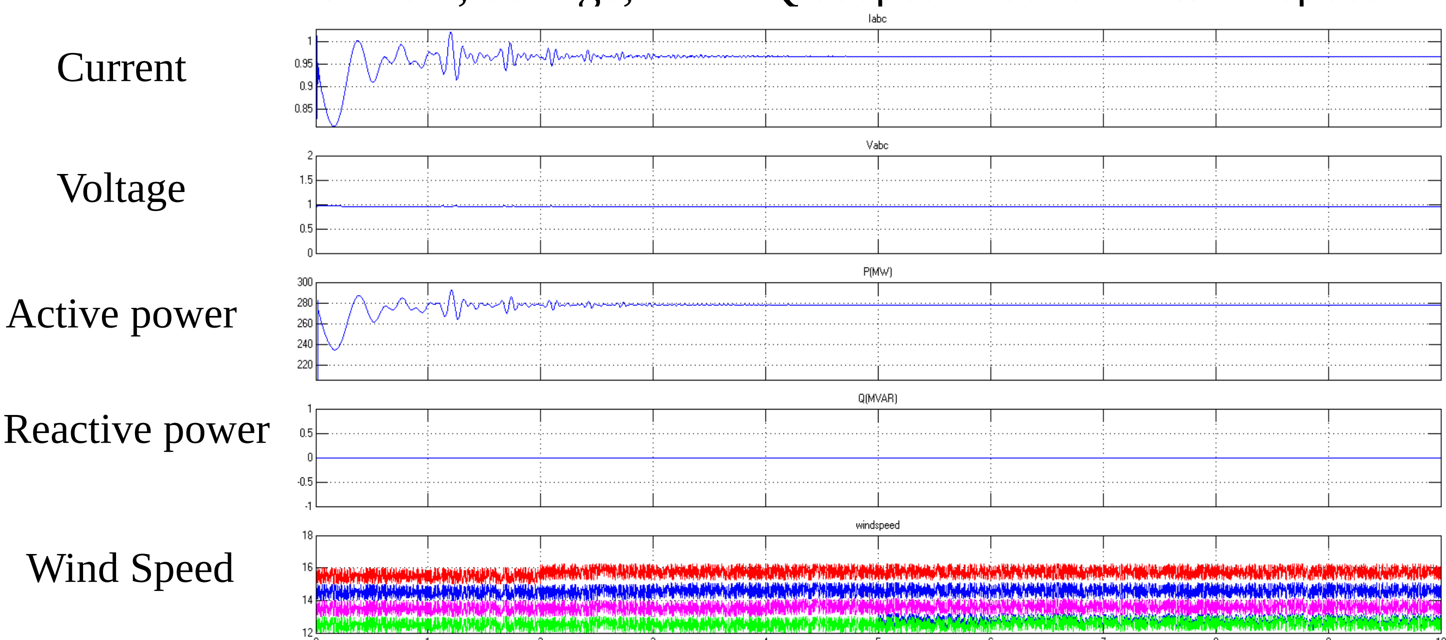
❑ Transient stability

1. Response to a constant 12m/s wind speed

2. Response to different wind speeds for each wind farm



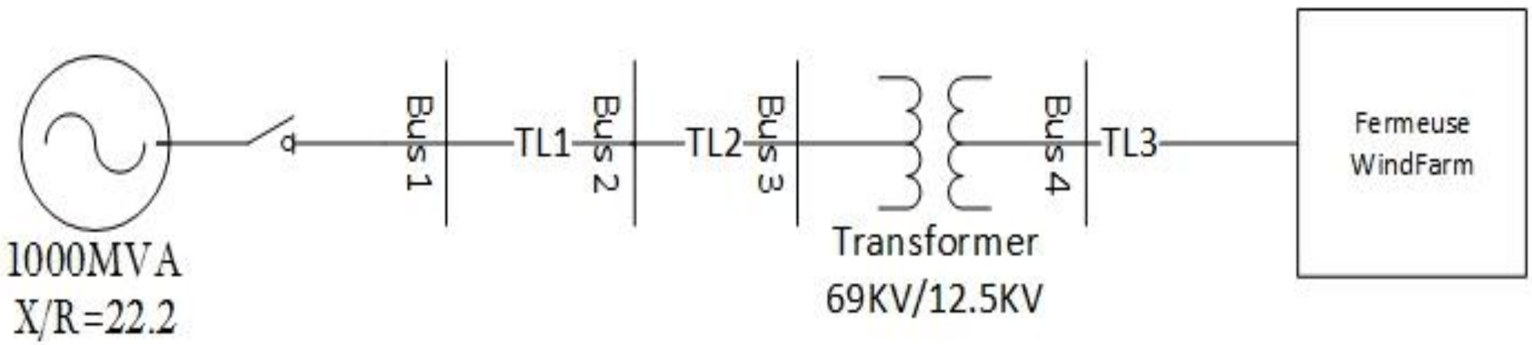
Current, voltage, P and Q scopes at constant wind speed



Current, voltage, P and Q scopes at variable wind speeds

➢ **Case study: The impact of Fermeuse wind farm on the Newfoundland grid**

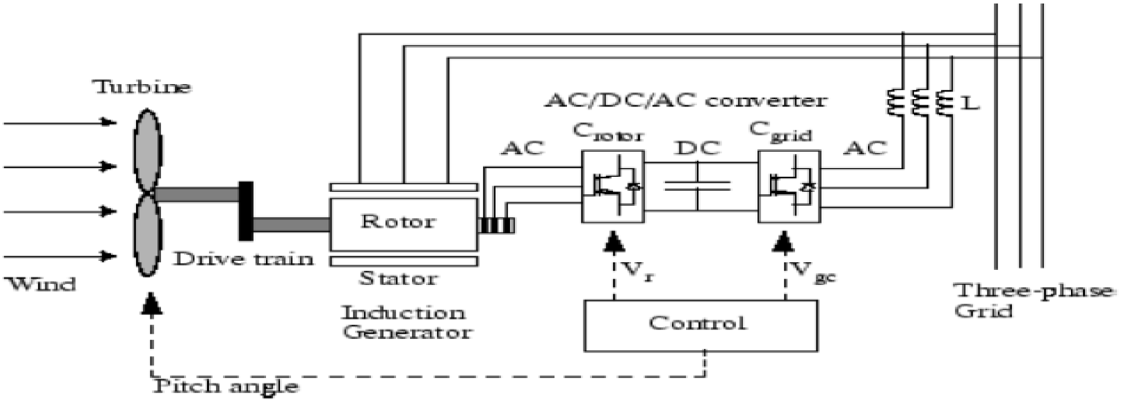
❑ **Single line diagram**



Fermeuse wind farm grid connection single line diagram

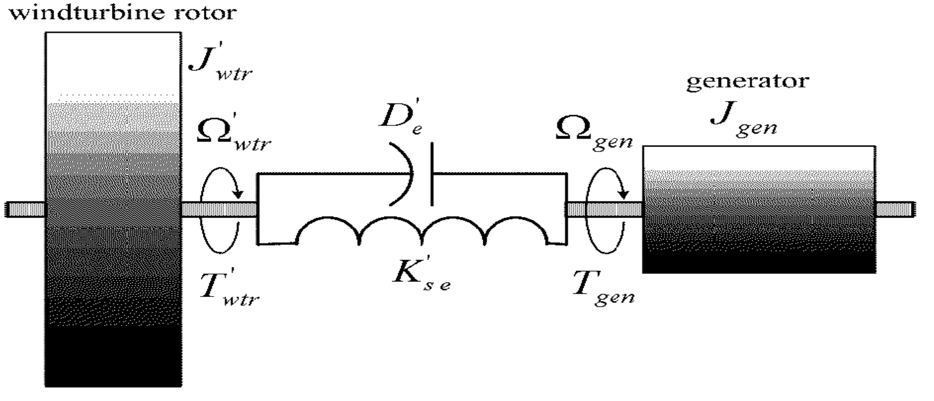
❑ System Components

1. Wind power generation system



Variable speed DFIG generator

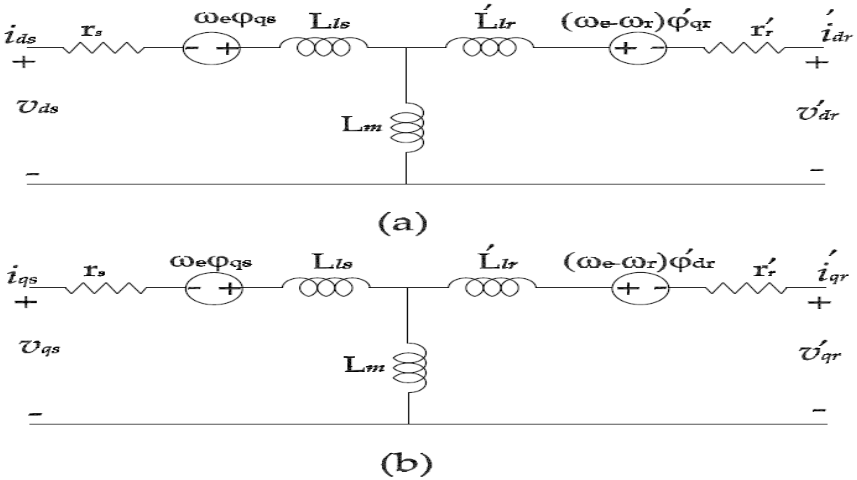
2. Two-mass model of drivetrain



Equivalent diagram of drive train

3. Generator

- Mathematical transformation called abc-to-dq0 transform



Equivalent circuit in synchronously rotating reference frame: (a) d-axis; (b) q-axis

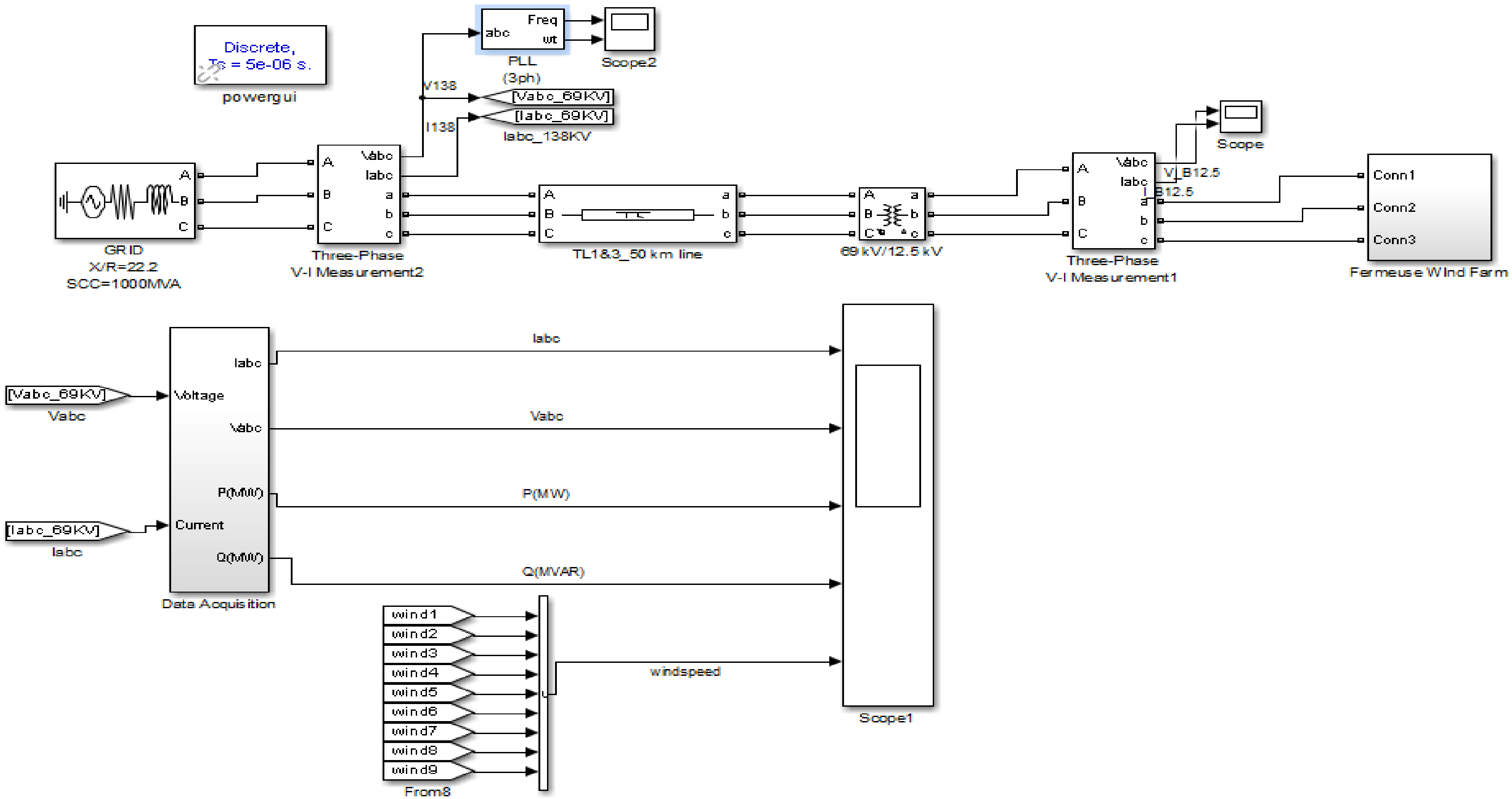
- Zero-sequence free equation ($i_0=0$): balanced conditions in the system

4. Converter

An AC-DC-AC pulse width modulation (PWM) converter is modeled by voltage source

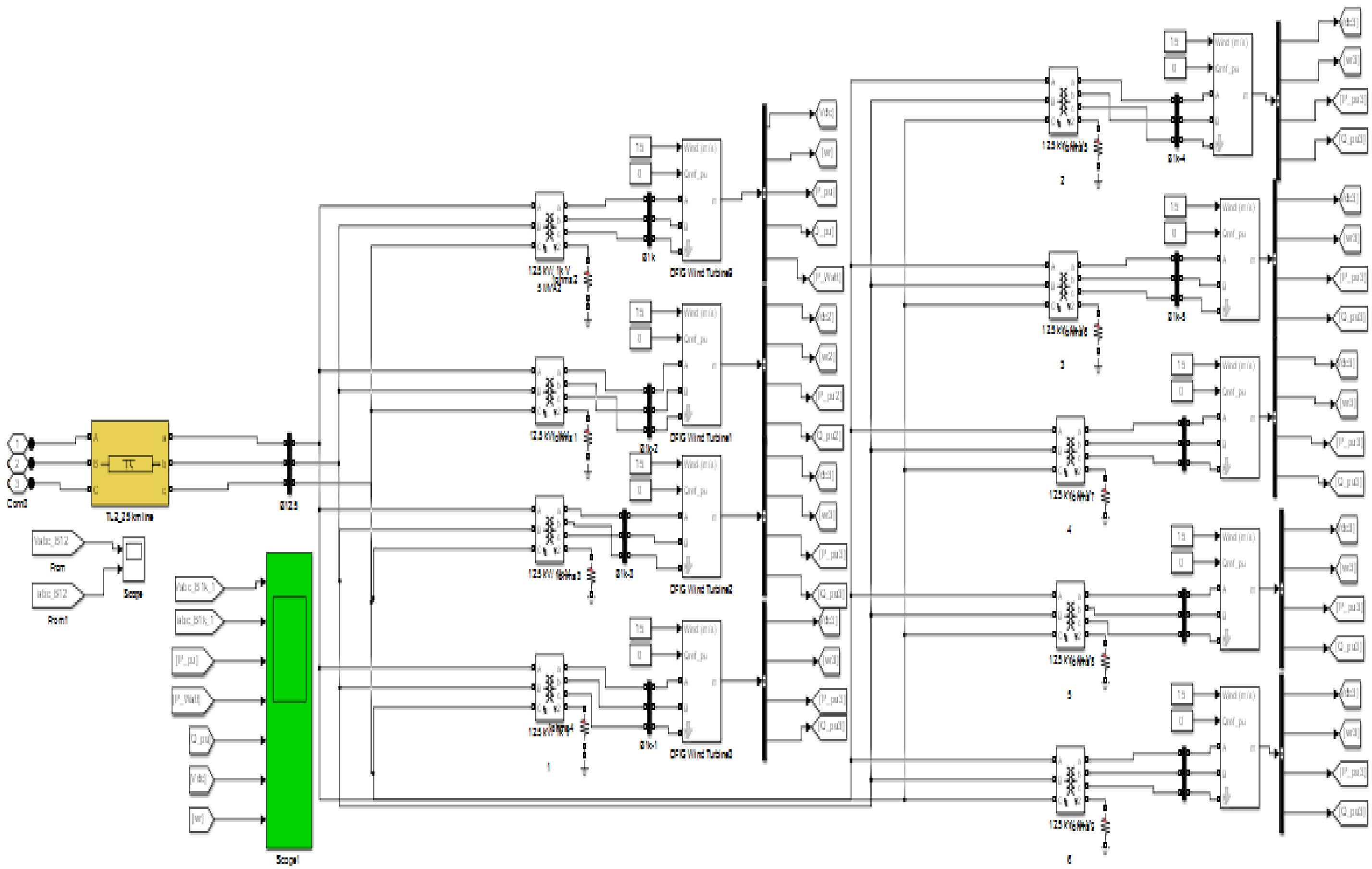
❑ Simulink model

- Implemented in 'Discrete' simulation method
- The level of voltage is adjusted, 12.5kV to 69kV, using a 40MVA transformer; Power connected to the utility grid through a transmission line
- A Phase Lock Loop (PLL) closed-loop control system is used to track frequency



Overall View of the Fermeuse wind farm model

- Each wind turbine is set to receive different wind speeds to represent the real situation
- No shadow effect
- Grid connection through one switch gear yard



Fermeuse wind farm detailed model(nine 3MW)

❑ Simulation results

Three different scenarios are considered to study transient stability:

(1) at constant wind speed

(2) at variable wind speeds

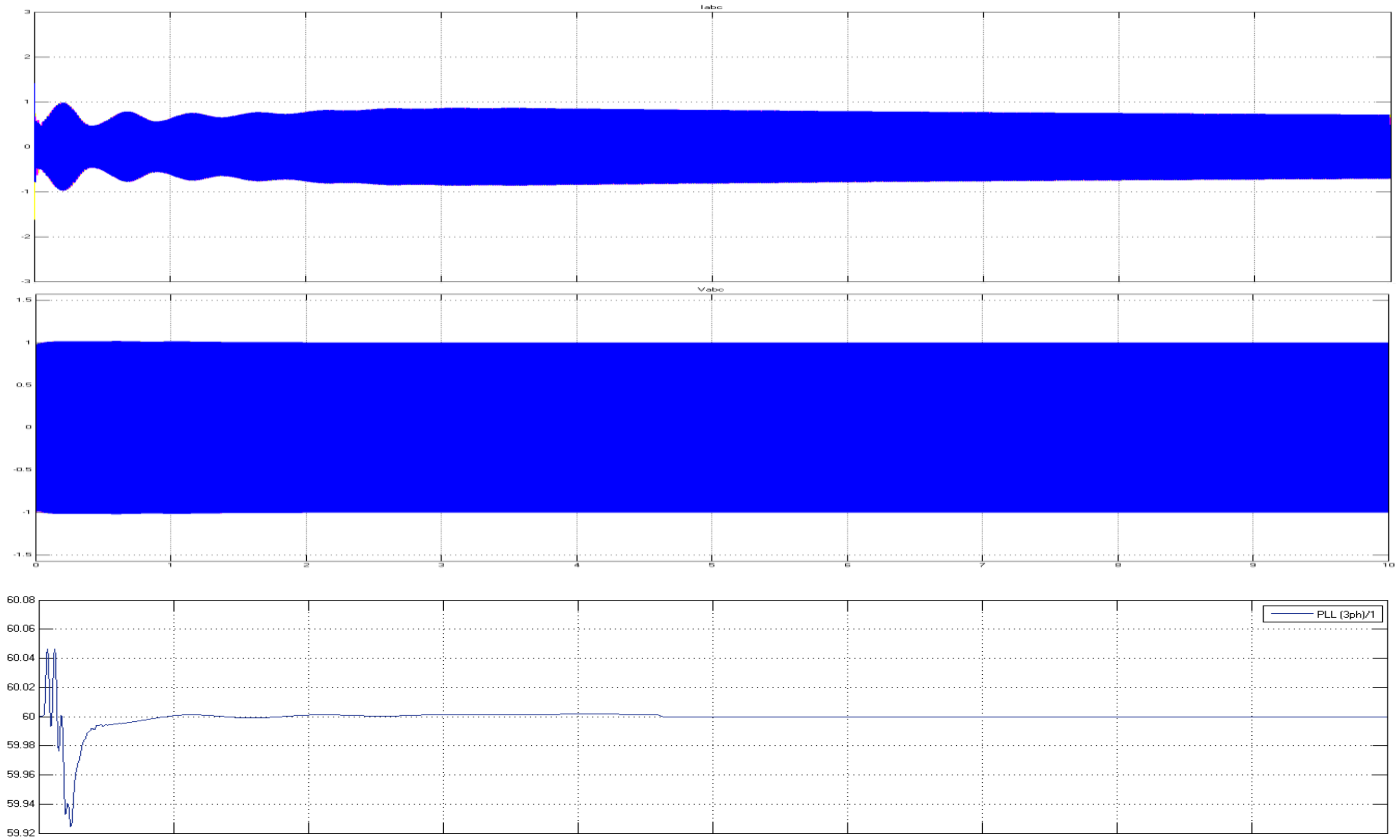
(3) the wind farm trips due to a fault (t=5s) and then reconnects to the grid (at t=15) simulated for 60 seconds

(1) at constant wind speed

Current

Voltage

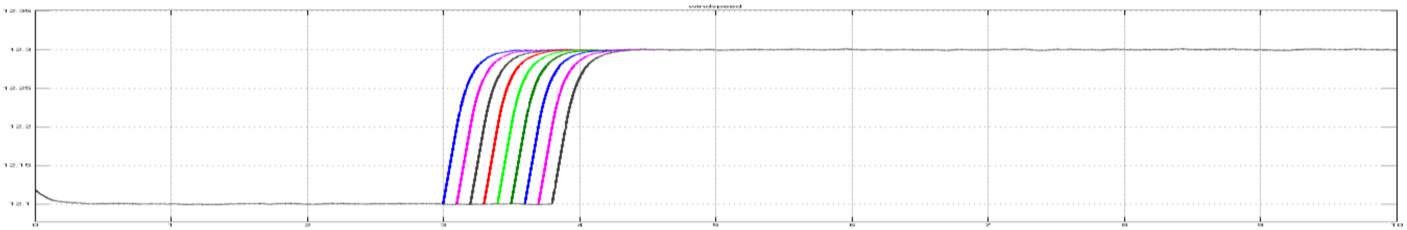
Frequency



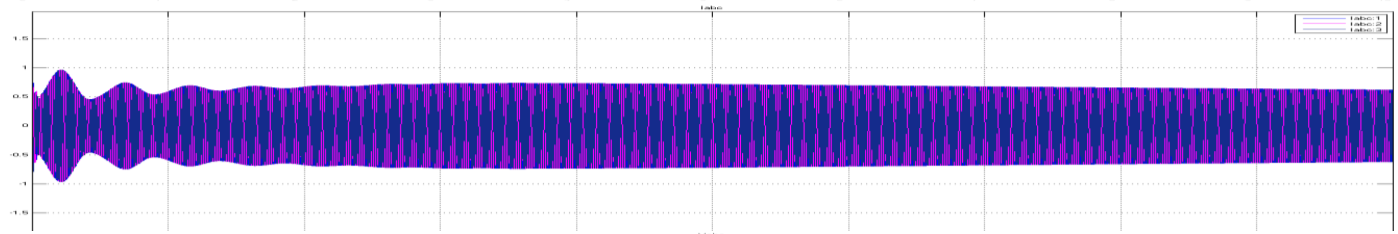
- Current fluctuation disappears after 2 seconds
- Frequency dip is less than 0.1 Hz
- Frequency fluctuations at the first 2 seconds are due to passing initial transient

(2) at variable wind speeds

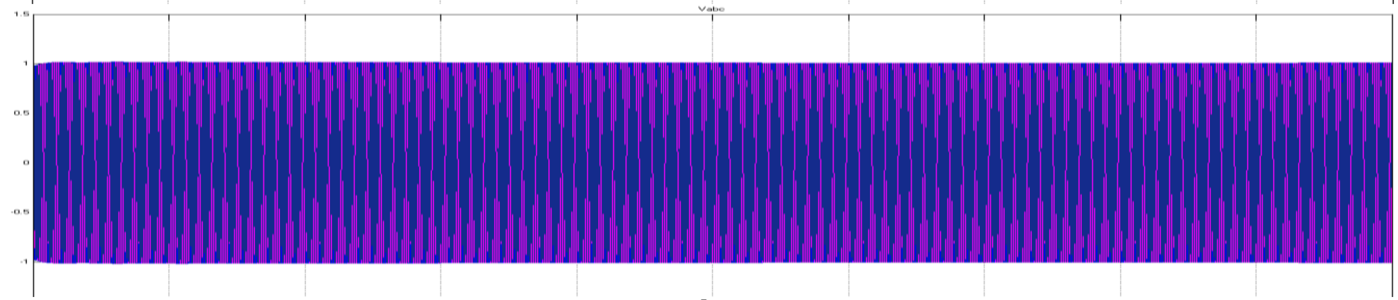
Wind speed



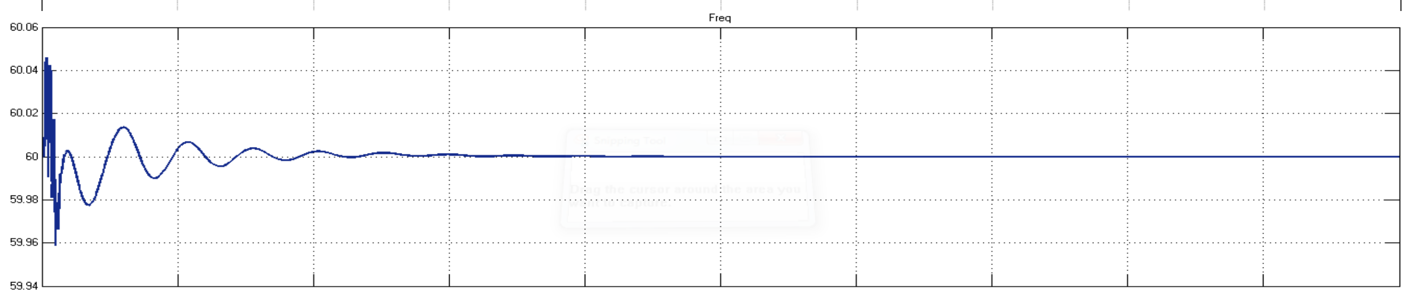
Current



Voltage

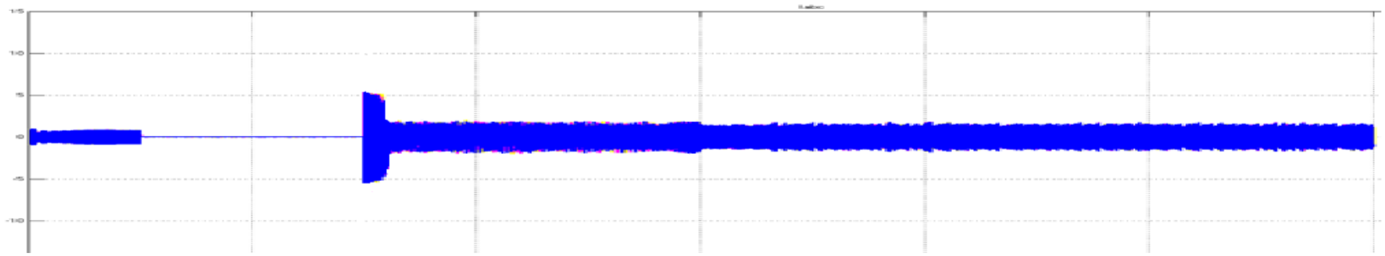


Frequency

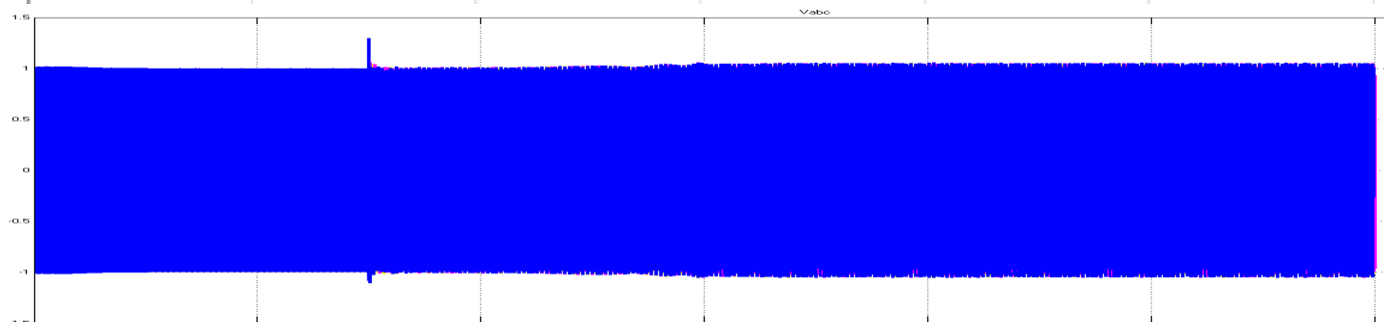


(3) The wind farm trips due to a fault and then reconnects to the grid.

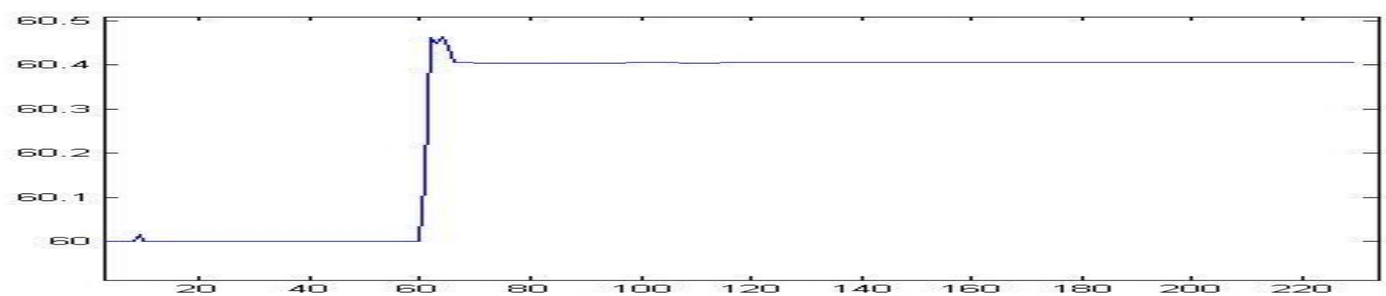
Current



Voltage



Frequency



- Instantaneous overcurrent is less than 10 per unit
- To eliminate fluctuations generated by PID regulator inside the PLL block and harmonics coming from the converters, findpeaks command of Matlab is used which detected 230 peaks in the frequency response

➢ Conclusion

- Small-scale renewable energy systems: the unique methodology for optimal sizing allows 2% lack of power supply in a year, resulting in a 30-40% reduction of the initial cost of the system

- To produce maximum energy from photovoltaic systems, a snow detection system was designed, built, and then tested capable of precisely identifying more than 5 cm of snow accumulation on solar panels and sending alerts

- Connection to the isolated grid of Newfoundland is analyzed by simulation of 500MW of wind capacity

- Simulation indicates that additional 500MW wind power will not have a significant effect

Conclusion cont.

- The impact of the Fermeuse wind farm on the isolated grid of Newfoundland was explored for three permissible scenarios

- Variable wind speeds cause very small fluctuations in the frequency and the current injected into the grid

- System trip and reconnection will result in a frequency variation of only 0.35 Hz and a voltage variation of less than 5%

➢ Future work

- For the hybrid wind-PV-battery system the following recommendation is suggested:

- Different types of long term and short term storage systems can be used

- To improve snow detection performance the following actions are recommended:

- Use of a pyranometer instead of LDR
- Investigation of a mathematical formulation relating climate data to sensors readings

- For grid connected wind farms the following recommendations are proposed:

- Study of harmonics generated by the power electronics of variable speed wind turbines
- Use of a static synchronous compensator (STATCOM) unit

Publications:

- Seyedali Meghdadi, Tariq Iqbal, “A Low Cost Method of Snow Detection on Solar Panels and Sending Alerts”, Journal of Clean Energy Technologies, Vol.3, No. 5, September 2014

- Seyedali Meghdadi, Tariq Iqbal, ”Impact of wind power integration to the island grid of Newfoundland and Labrador”, NECEC 2014

Acknowledgements

- I would like to express my sincere gratitude and appreciation to Dr. Tariq M. Iqbal for his priceless guidance, advice and financial support through the course of this work

- I also would like to thank Greg O’Leary and Glenn St. Croix for their support

Thank you!

Questions?