"Optimal Sizing, Modeling, and Design of a Supervisory Controller of a Stand-Alone Hybrid Energy System"

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Outline

- Thesis objectives
- Introduction
- The system sizing
- Renewable resources
- Sizing results
- Modeling and simulation
- Experimental set-up
- Conclusion and future work

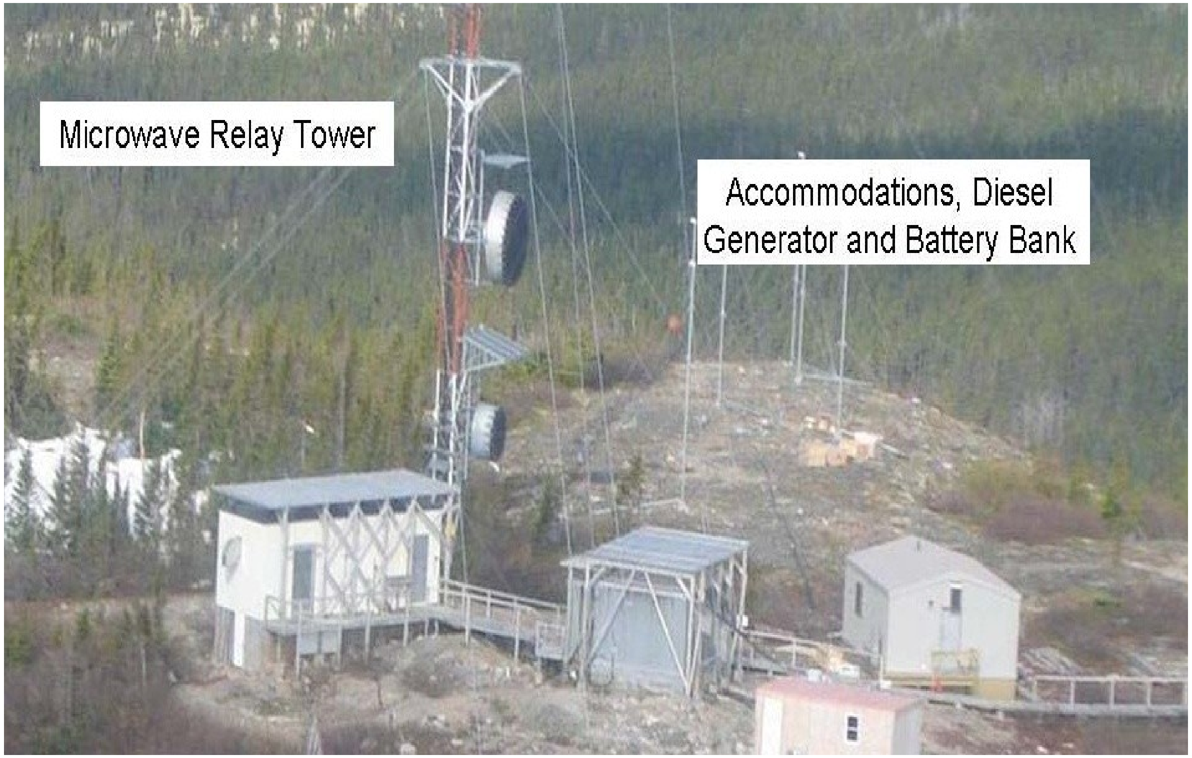
Thesis Objectives

- Sizing and profitability study for a stand-alone telecommunication site in Labrador, Canada.

- Modeling the system using Matlab/Simulink

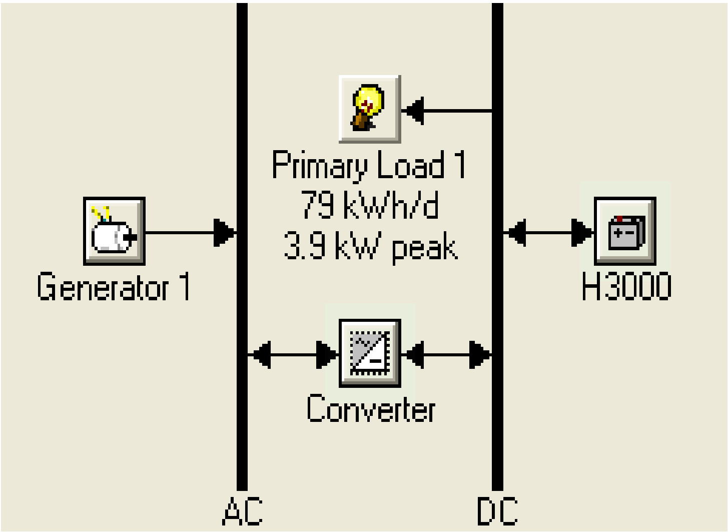
- Experimental testing of proposed supervisory controller

Introduction

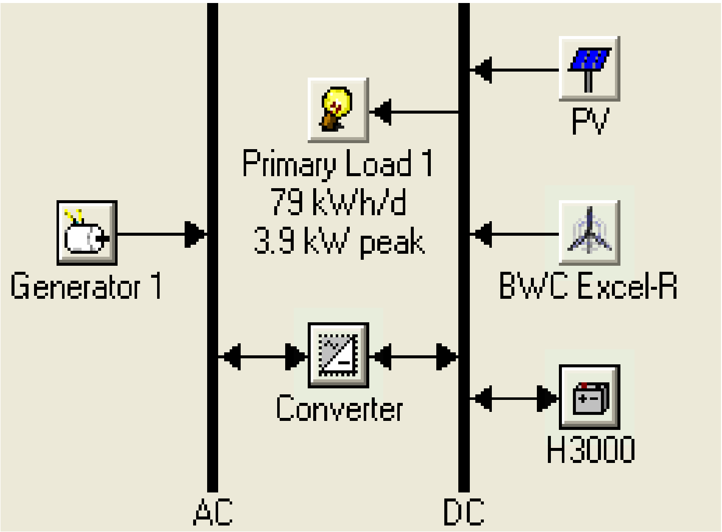


A photograph of Bell-Aliant's telecommunication site at Mulligan, Labrador

Sizing the hybrid system

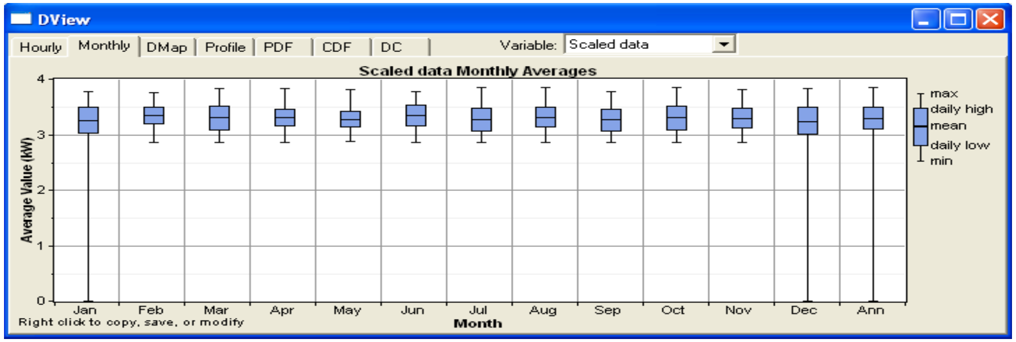


The existing power system

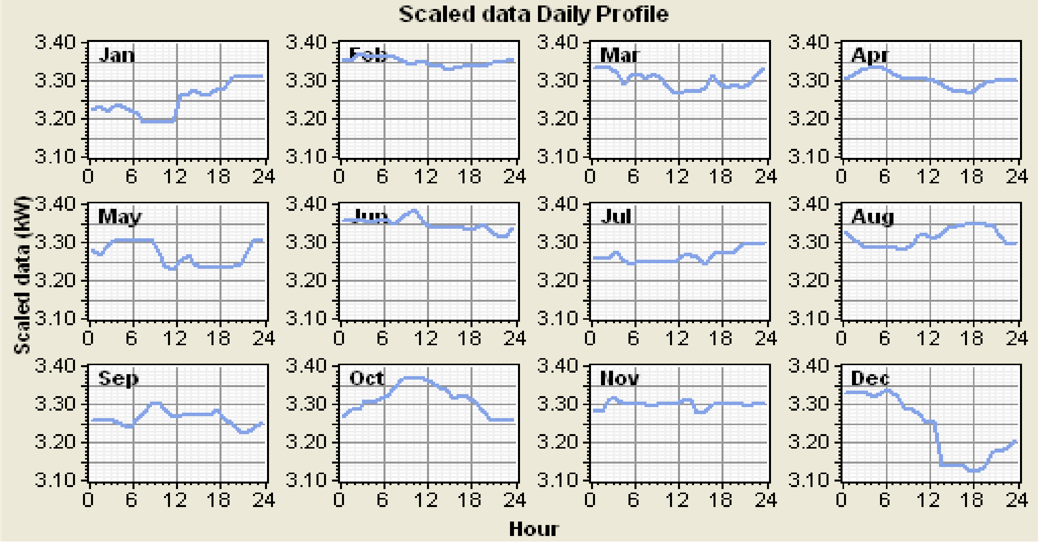


The proposed power system

Electrical load

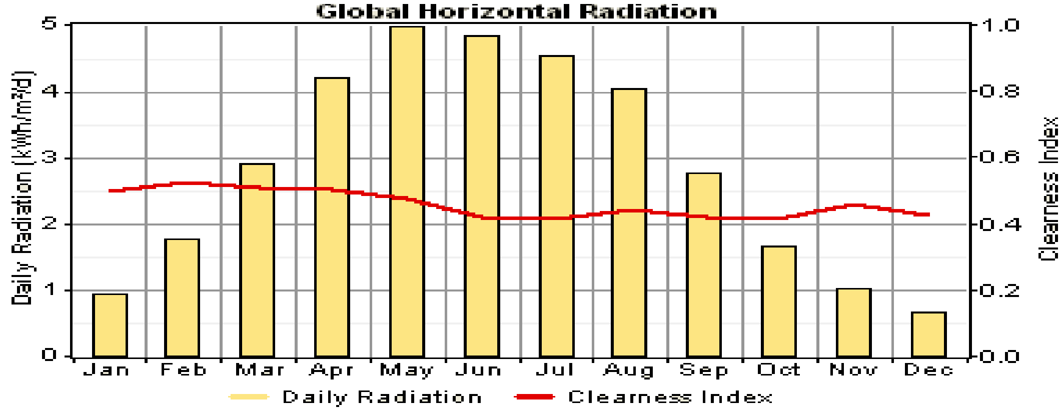


Monthly load profile of Mulligan site for a year

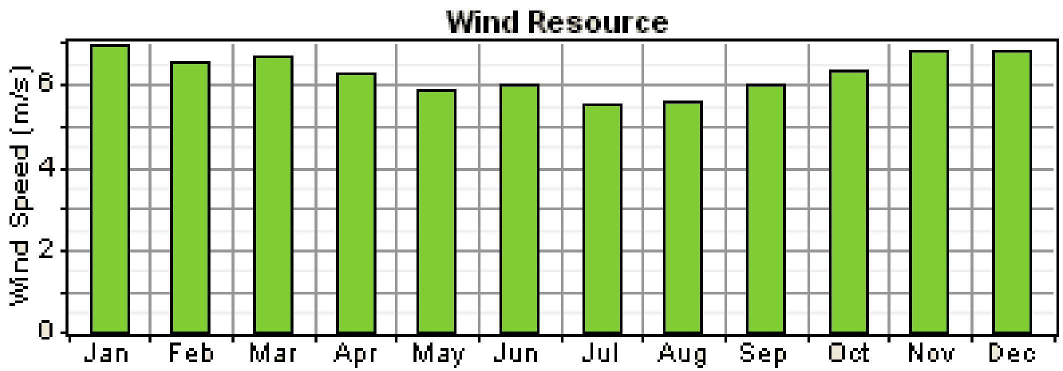


Daily load profile of Mulligan site for a year

Renewable resources

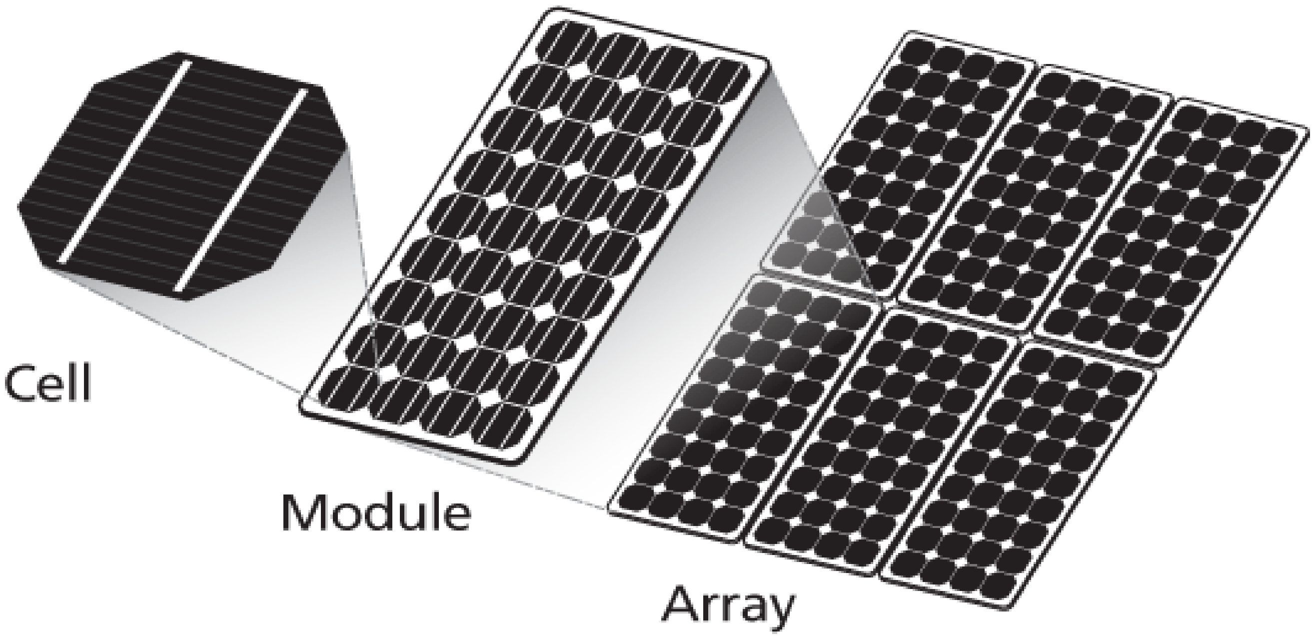


Monthly solar radiation produced by HOMER



The average monthly wind speed for a year

Basic concepts



PV cell, module and array

Sizing and Comparison Results

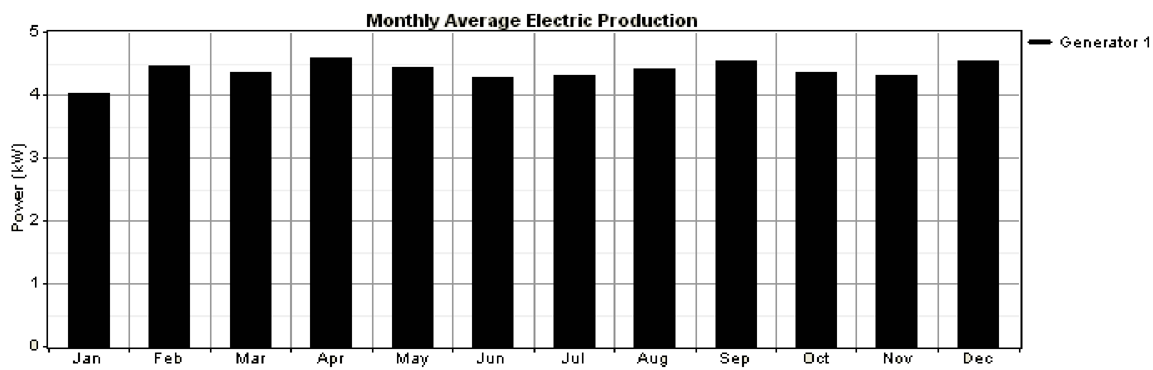
➢The existing system

Sensitivity Results | Optimization Results

Double click on a system below for simulation results.

			Label (kW)	H3000	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Label (hrs)
			25	48	25	$ 197,237	65,172	$ 823,072	2.973	0.00	12,672	1,536

Optimized result for the non-renewable energy system



Monthly average electric production for non-renewable energy system

➢The proposed system

Sensitivity Results | Optimization Results

Sensitivity variables

Primary Load 1 (kWh/d) 79.1 Global Solar (kWh/m²/d) 2.85 Wind Speed (m/s) 6.26 Diesel Price ($/L) 5

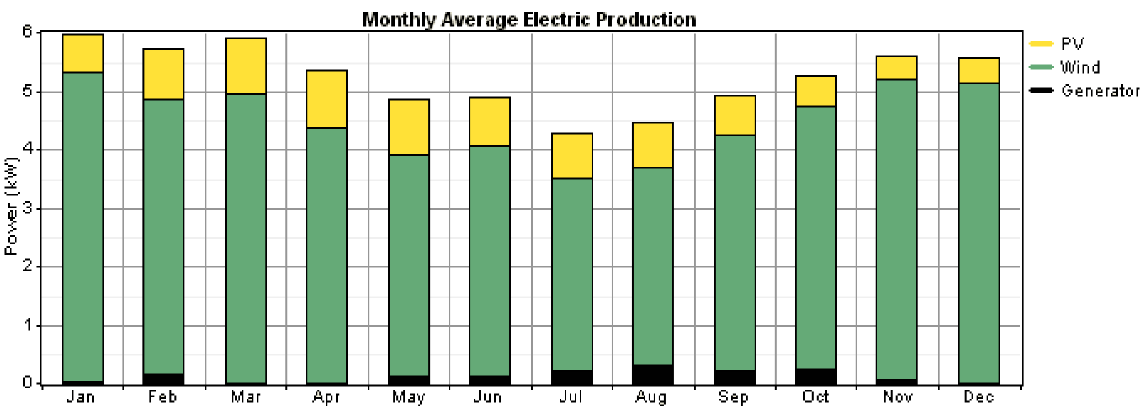
Double click on a system below for simulation results.

PV (kW)	XLR	Label (kW)	H3000	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Label (hrs)
5.60	2	25	24	7	$ 968,420	4,158	$ 1,011,514	3.385	0.98	335	145
	3	25	24	7	$ 974,051	4,135	$ 1,016,906	3.403	0.98	349	151

Optimized result for the renewable energy system

Production	kWh/yr	%
PV array	6,403	14
Wind turbines	38,325	84
Generator 1	1,088	2
Total	45,815	100

Energy production for proposed system from HOMER software



Monthly average electric production for renewable energy system

Quantity	kWh/yr	%
Excess electricity	15,323	33.4
Unmet electric load	0.00	0.0
Capacity shortage	0.00	0.0

Quantity	Value
Renewable fraction	0.976

Excess energy for proposed system from HOMER software

➢Comparison: Based on the coat and fuel consumption

	Existing system	Proposed system
Intial capital cost ($)	$197,237	$968,420
Total NPC ($)	$823,072	$1,011,514
Fuel Consumption in a year (L)	12,672L	335L
Fuel consumption in 20 years (L)	253,440L	6,700L
Total cost in 20 years ($)	$2,090,272	$1,045,014

➢ Comparison: Based on emissions

Pollutant	Emissions (kg/yr)
Carbon dioxide	33,370
Carbon monoxide	82.4
Unburned hydrocarbons	9.12
Particulate matter	6.21
Sulfur dioxide	67
Nitrogen oxides	735

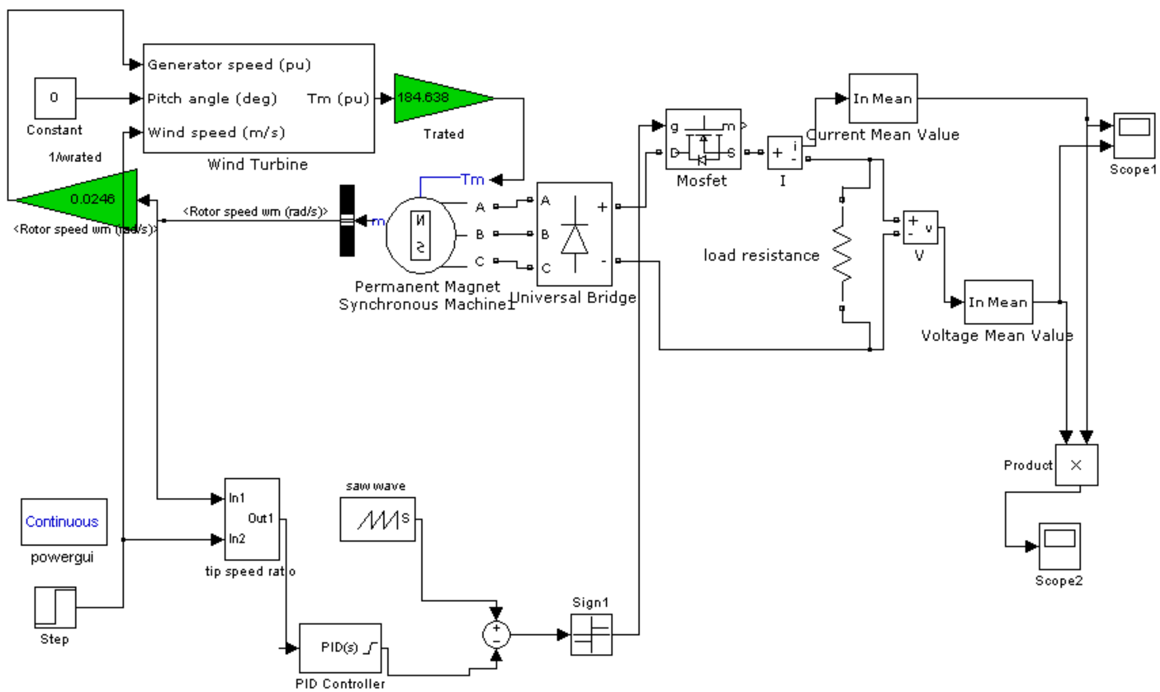
Emission values in the existing system produced from HOMER tool

Pollutant	Emissions (kg/yr)
Carbon dioxide	883
Carbon monoxide	2.18
Unburned hydrocarbons	0.241
Particulate matter	0.164
Sulfur dioxide	1.77
Nitrogen oxides	19.4

Emission values in the proposed system produced from HOMER tool

Modeling and simulation

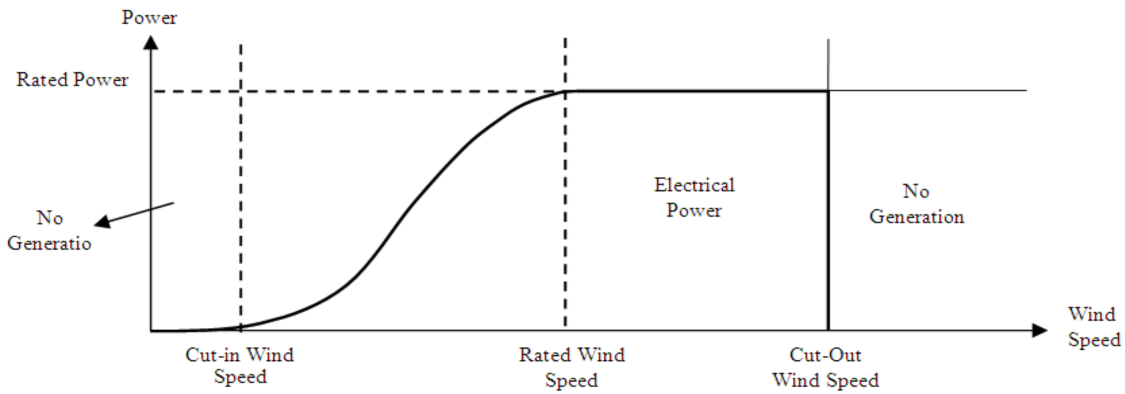
➢ Wind Turbine



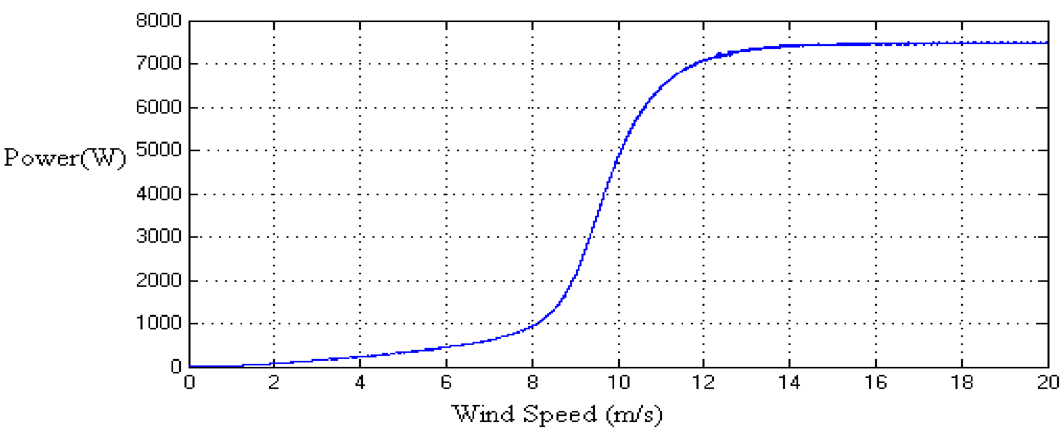
$$\lambda = \frac{\omega R}{v}$$

Simulink model for the wind energy conversion system

➢ Wind Turbine (cont)

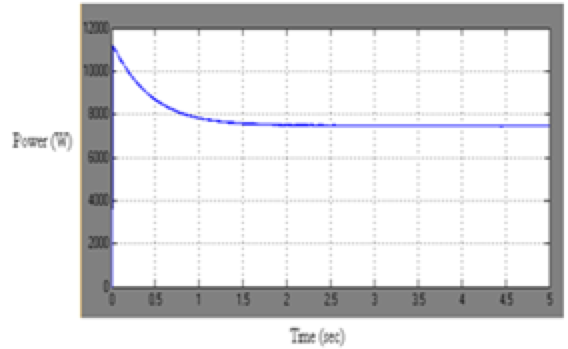


A typical wind turbine power curve

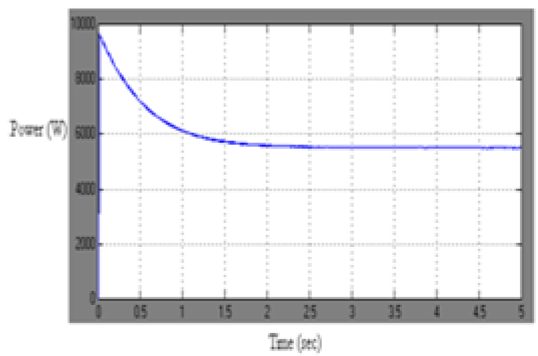


Wind turbine power curve

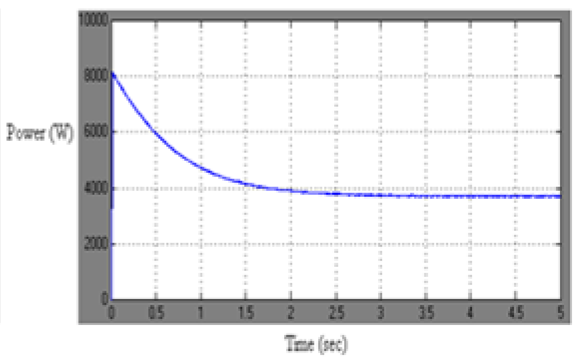
➢ Wind Turbine (cont)



Wind Speed= 12(m/sec), Power =7500W



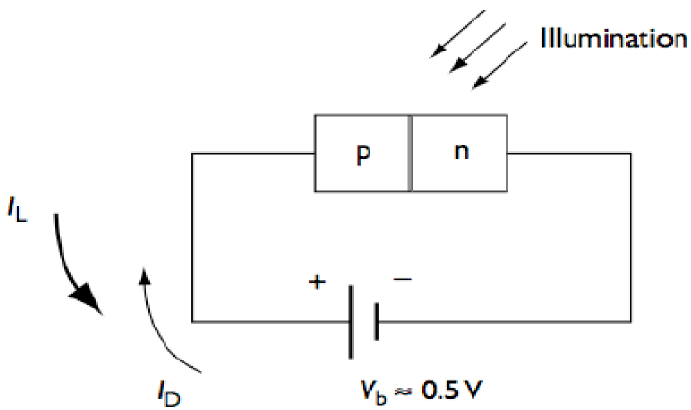
Wind Speed= 10(m/sec), Power =5500W



Wind Speed= 8(m/sec), Power =3700W

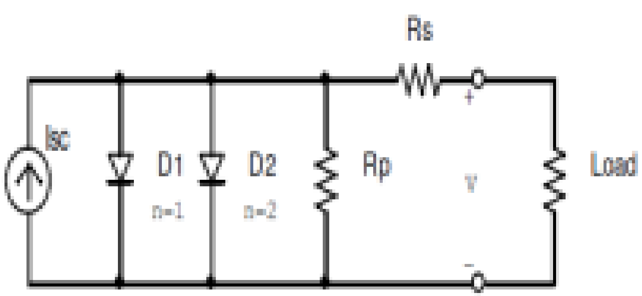
The effect of wind speed

➢ Photovoltaic System



$$I_D = I_0\{\exp[eV_b/(kT)] - 1\}$$

$$I = I_0[\exp(eV_b/kT) - 1] - I_L$$



$$I = I_{sc} - I_{01}\left[e^{q\left(\frac{V+I.R_S}{kT}\right)} - 1\right] - I_{02}\left[e^{q\left(\frac{V+I.R_S}{2kT}\right)} - 1\right] - \left(\frac{V+I.R_S}{R_p}\right)$$

➢ Photovoltaic System (cont)

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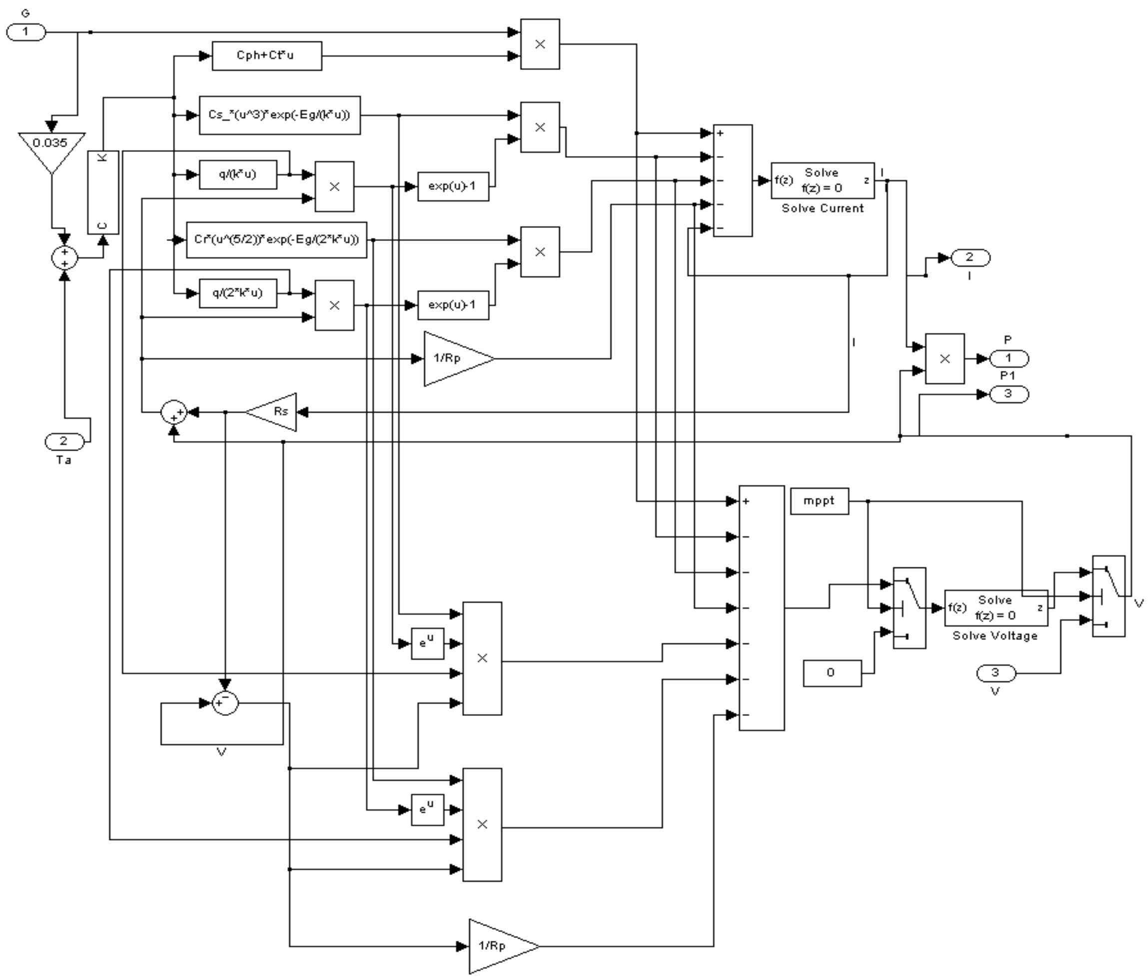
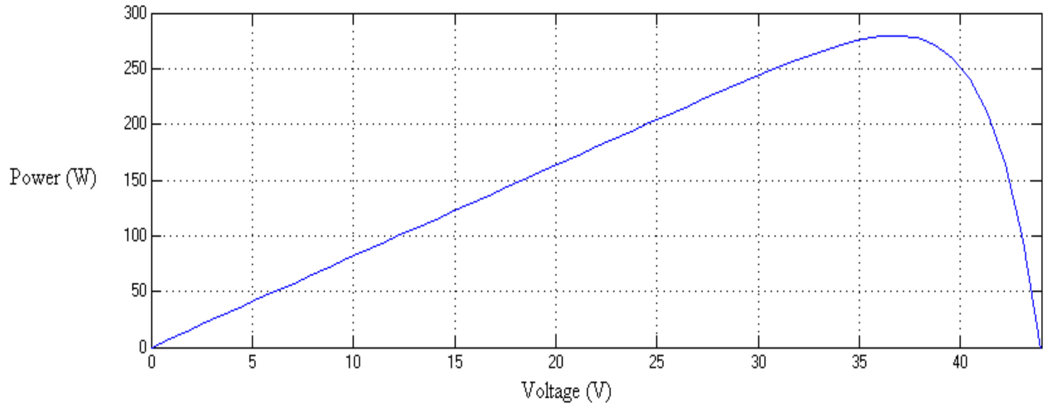
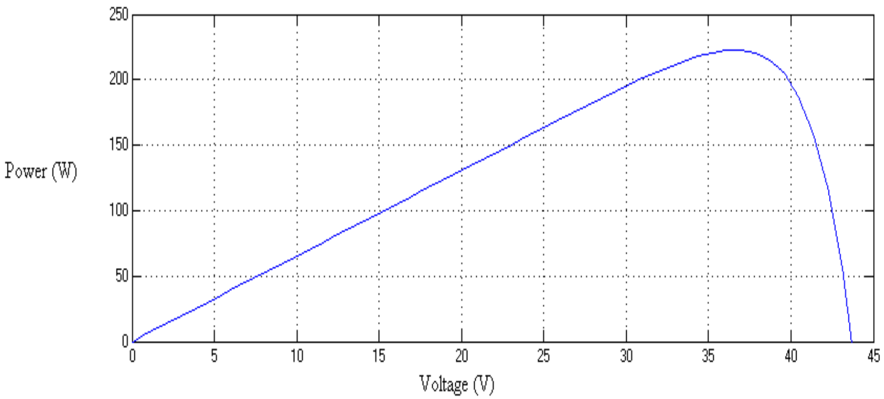


Subsystem model of the solar cell

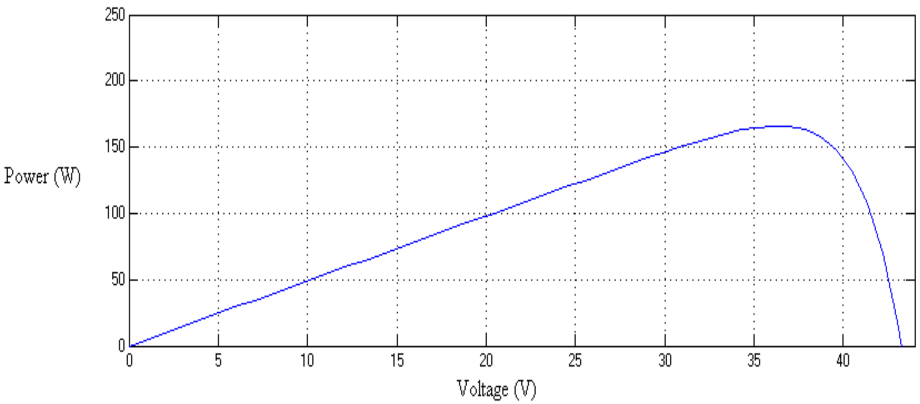
➢ Photovoltaic System (cont)



P-V output characteristics with 1000(W/m²)

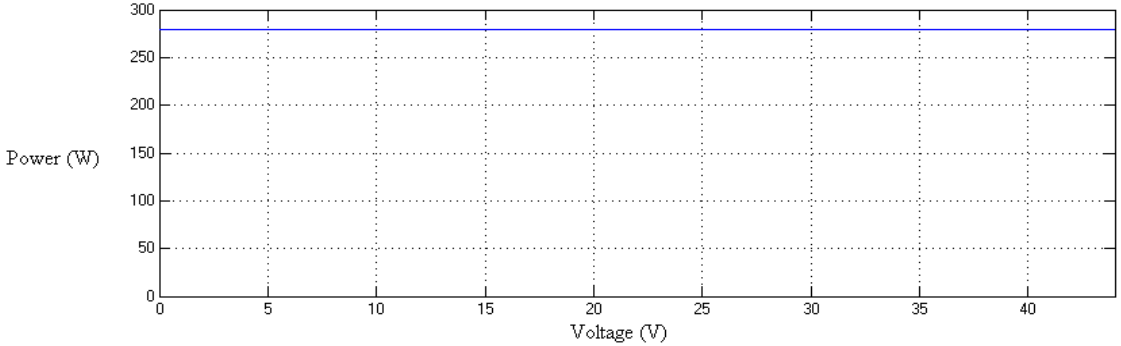


P-V output characteristics with 800(W/m²)

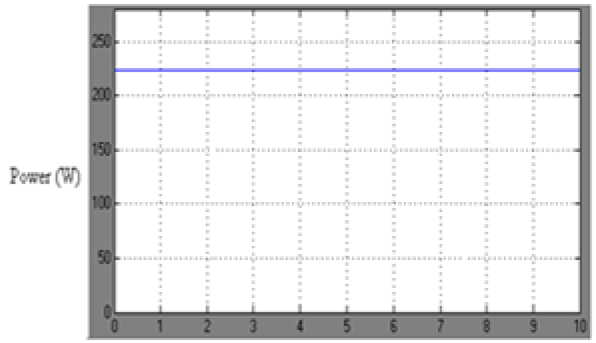


P-V output characteristics with 600(W/m²)

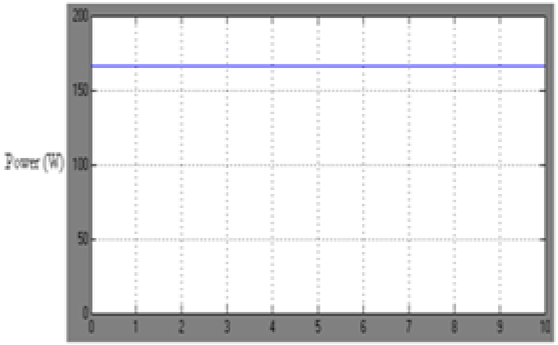
➢ Photovoltaic System (cont)



P-V output characteristics with MPPT technique

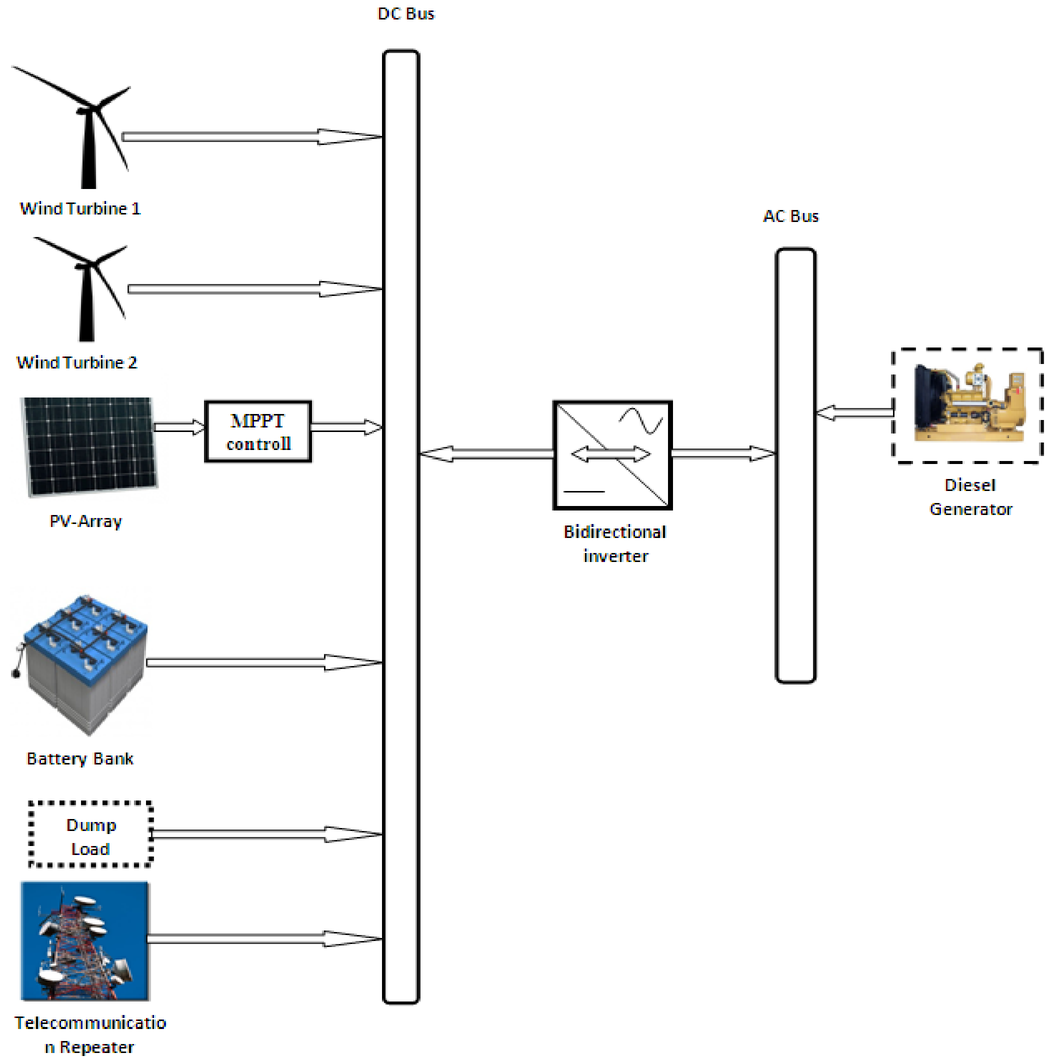


solar irradiance=800W/m2; P=225W

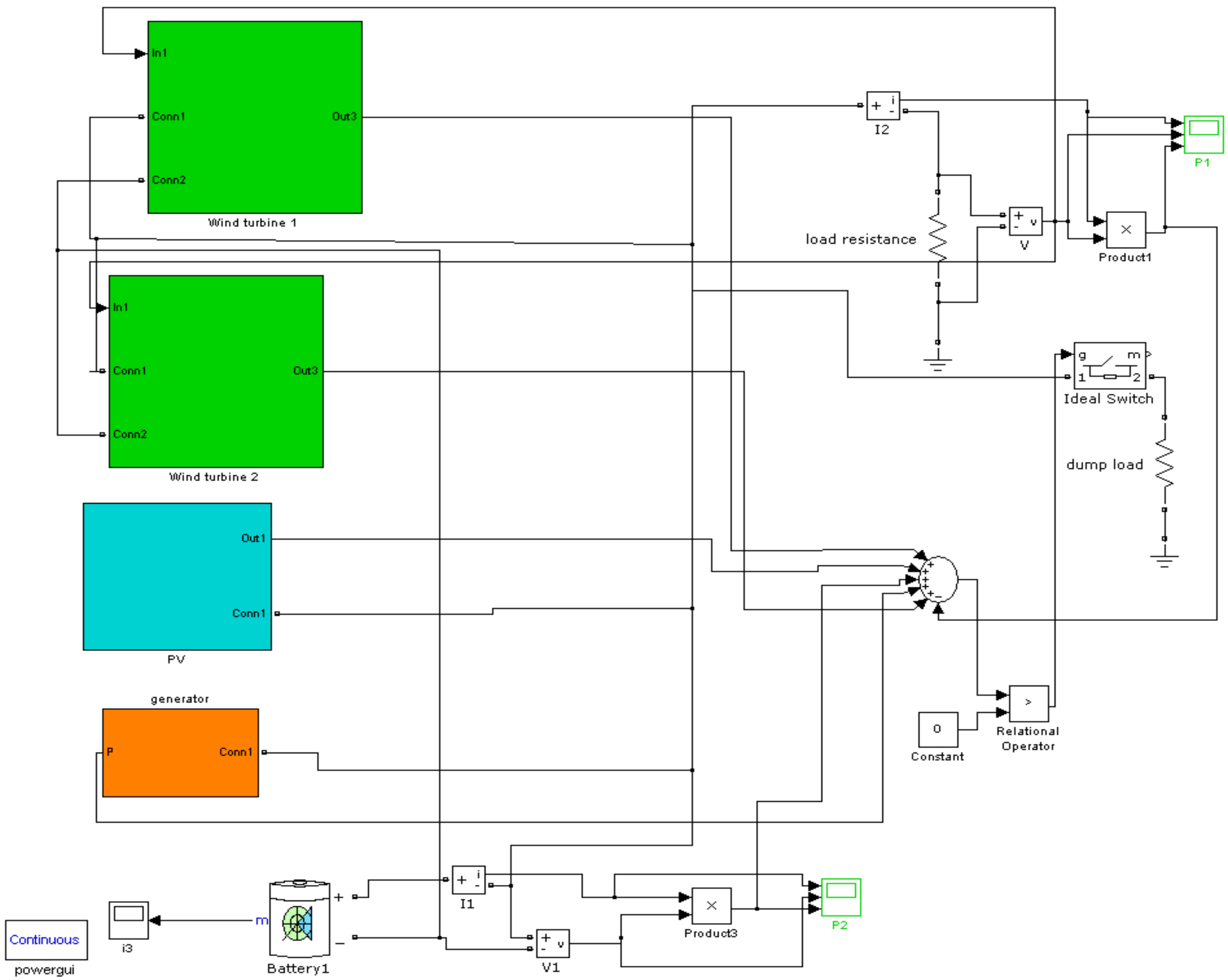


solar irradiance=600W/m2; P=170W

The effect of solar irradiance

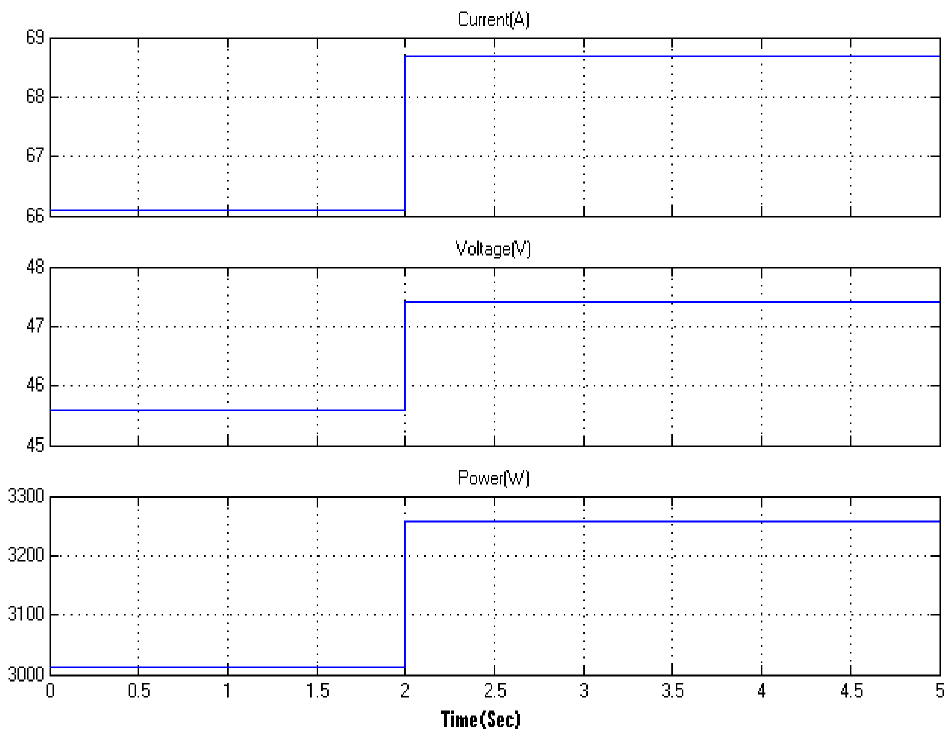


System configuration of the proposed alternative hybrid energy system

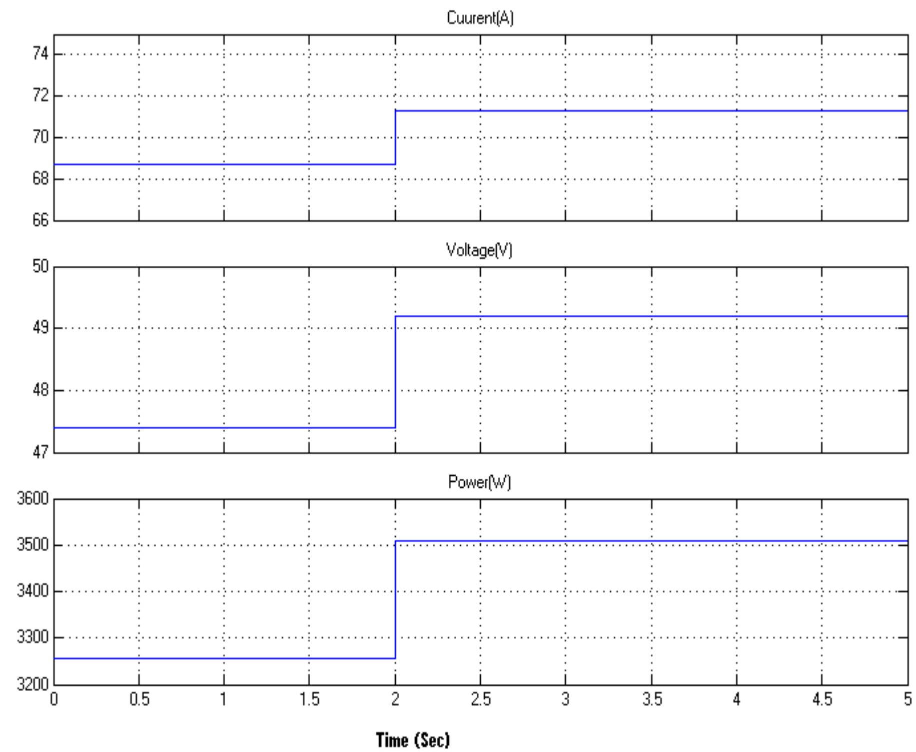


Simulink model for the whole hybrid power system

➢Case 1: Step change in wind speed

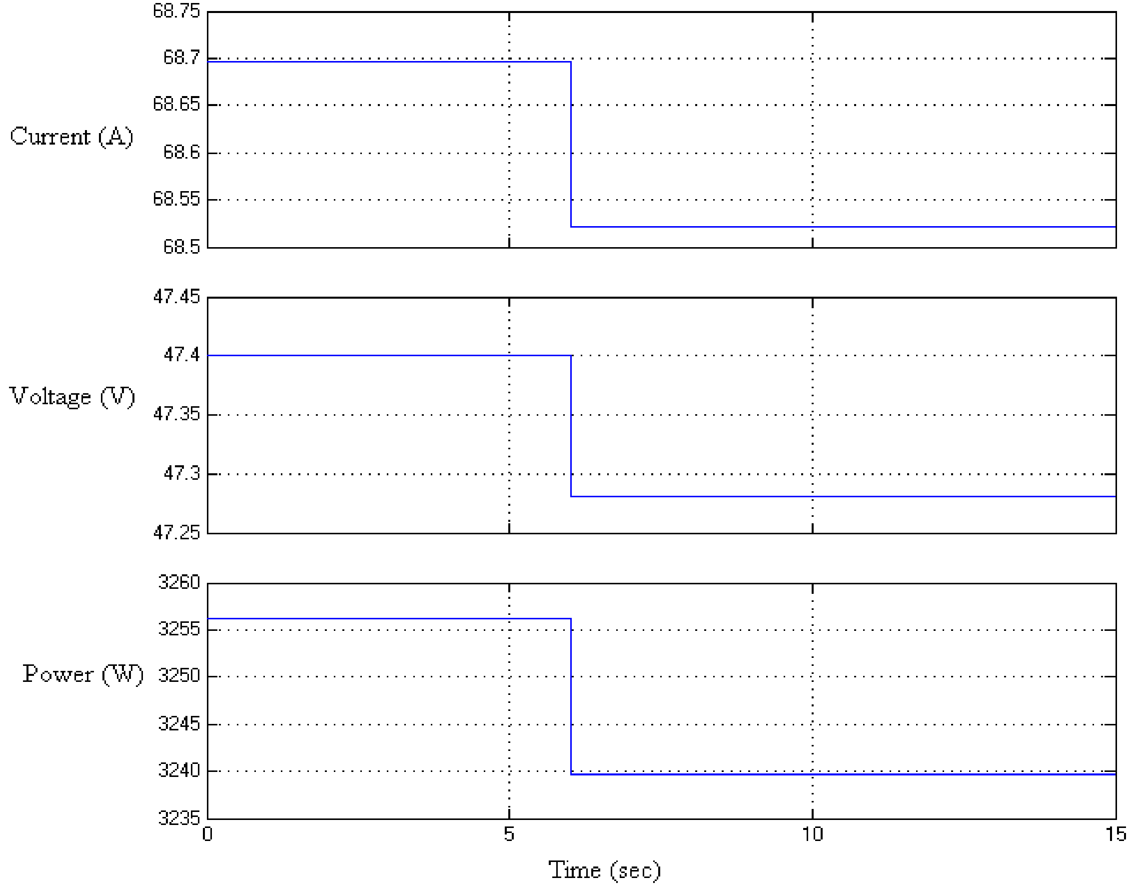


Current, voltage, and power of the system 10m/s to 12m/s wind speed



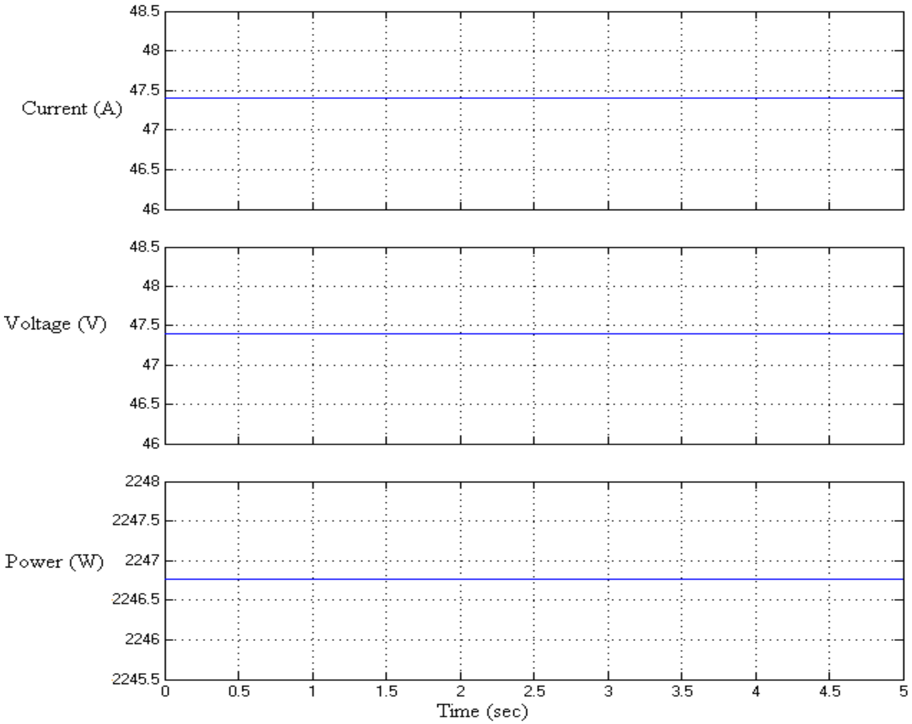
Current, voltage, and power of the system12m/s to 14m/s wind speed

➢Case 2: Step change in solar irradiation

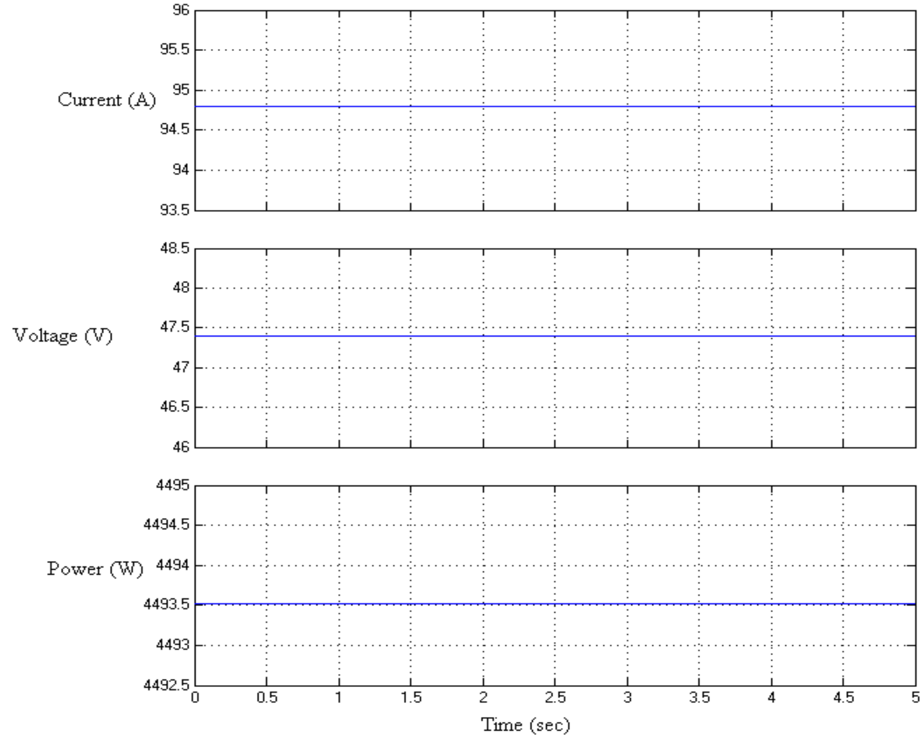


Current, voltage, and output power of the system 1000W/m² to 800W/m² solar irradiance

➢Case 3: Change in load

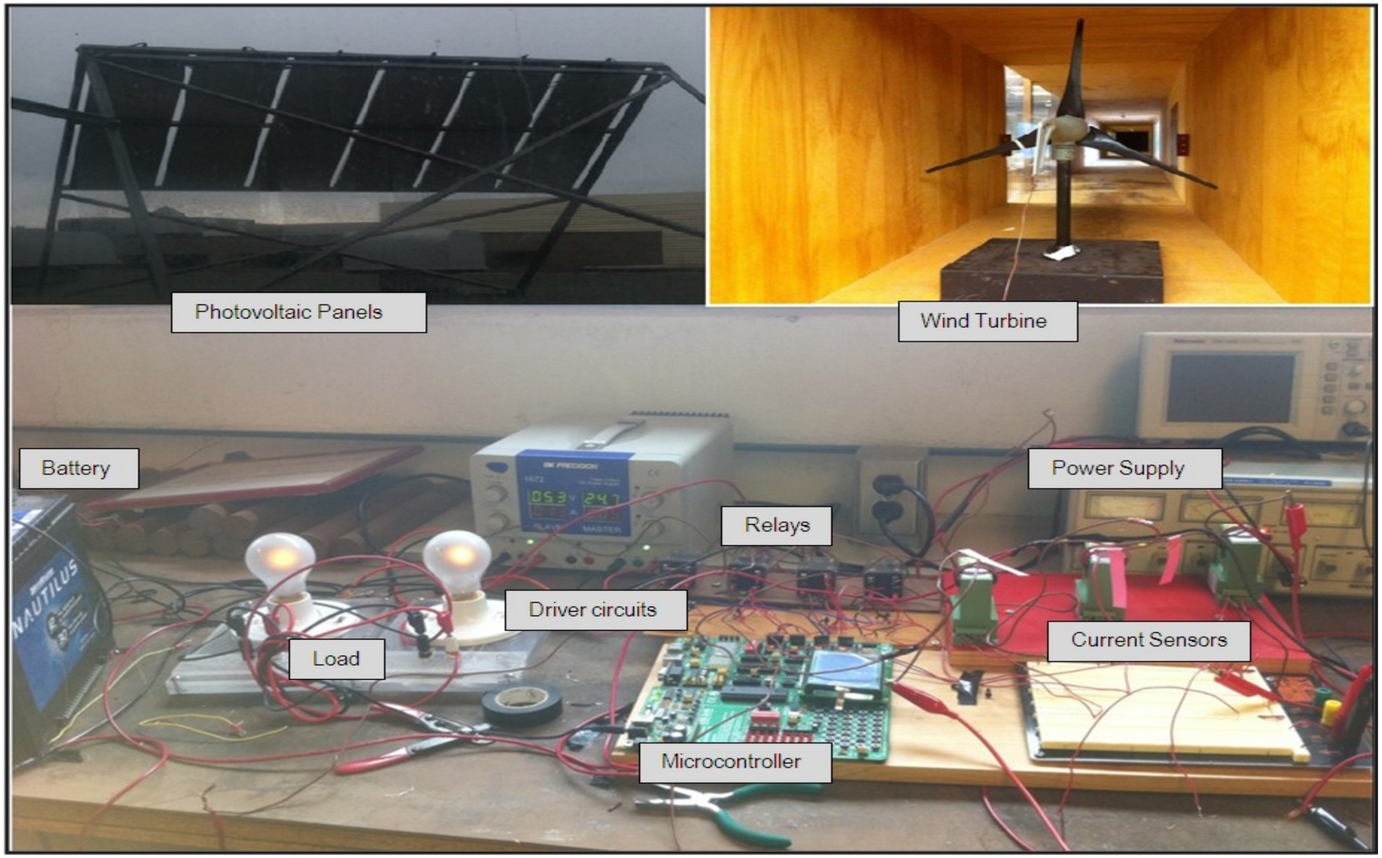


The system output when the load is increased



The system output when the load is decreased

Experimental set-up



The experimental setup in the lab with various components

Experimental set-up (cont)

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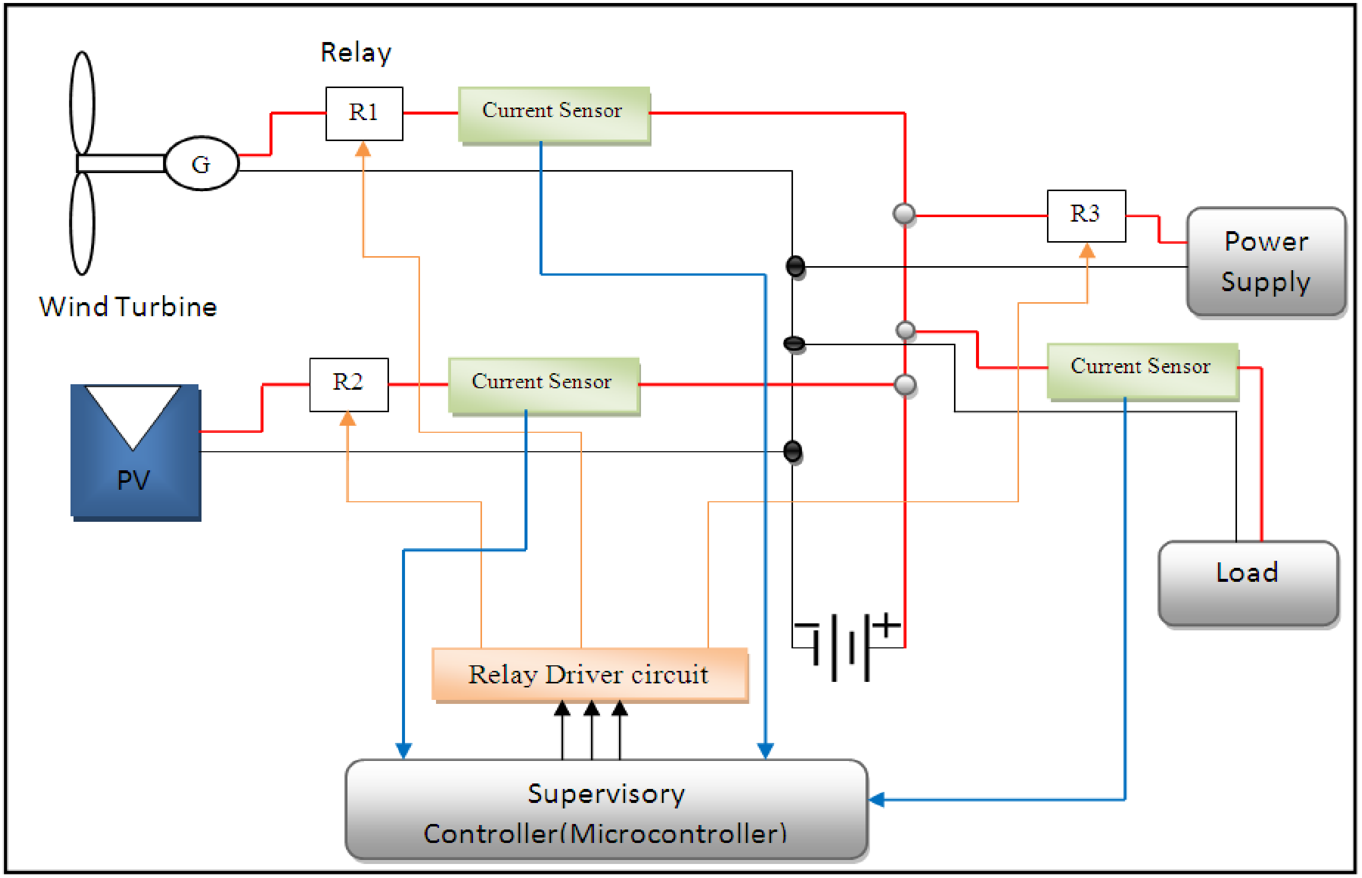

Schematic diagram of the experiment setup

Experimental set-up (cont)

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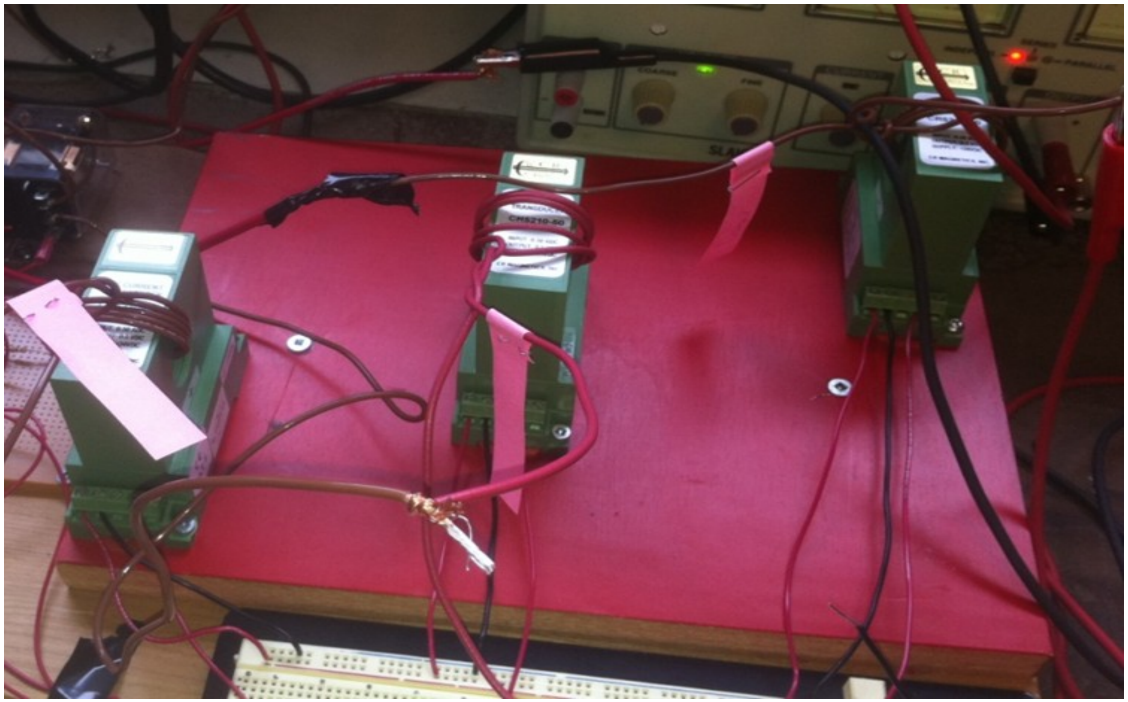
Wind speed measurements

Wind speed at the middle of the tunnel (m/s)	Blades rotational speed (rpm)	Wind speed where the wind turbine is in the tunnel (m/s)
7.9	185	4.78
10	971	6
12	1157	7.26
14	1446	8.5

Experimental set-up (cont)



CR5210 current transducers

Experimental set-up (cont)

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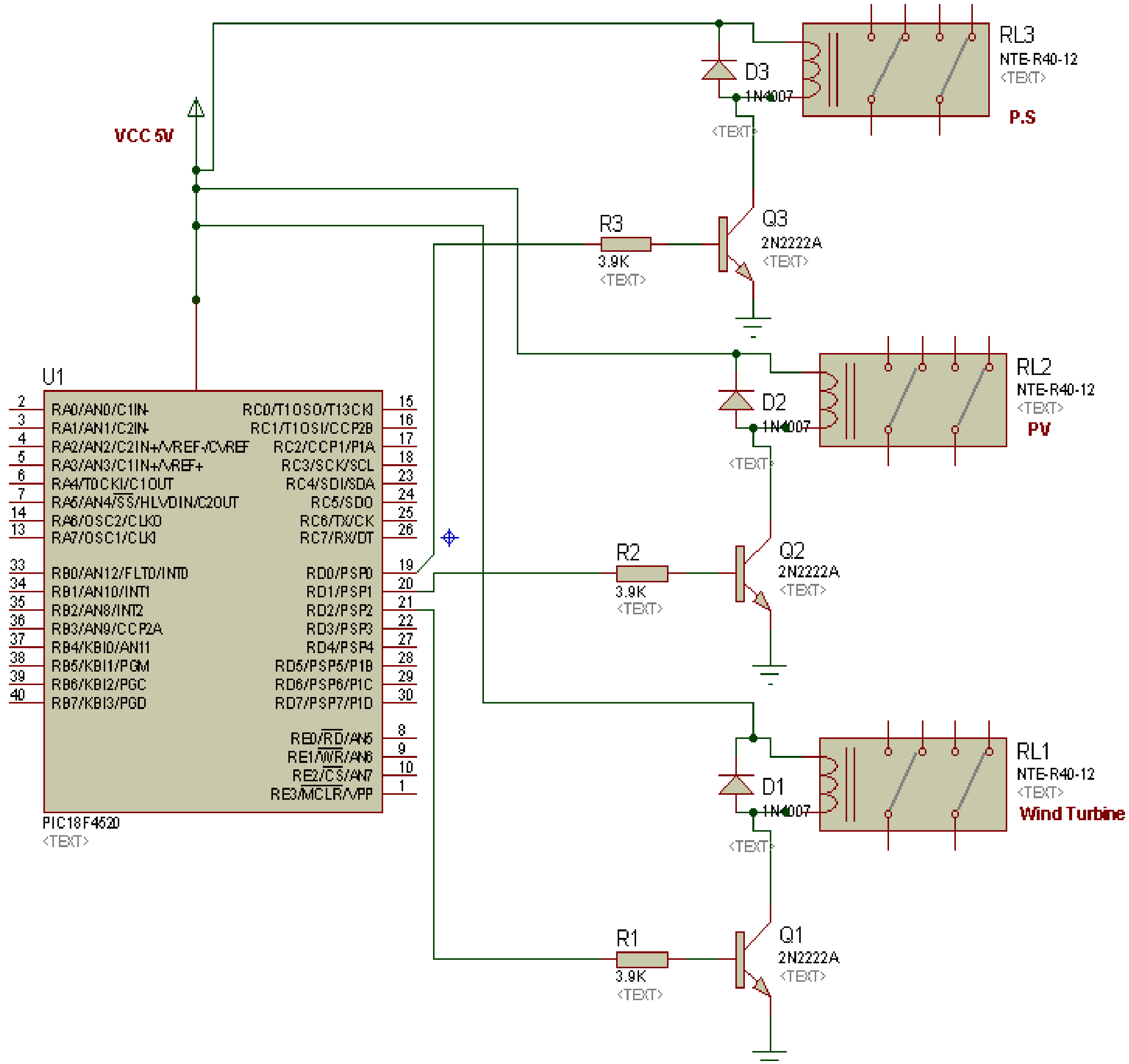

Relay driver circuits

Experiment Results

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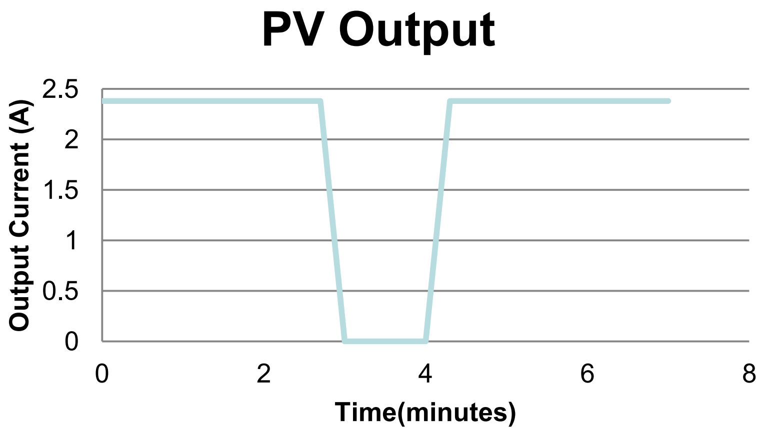
➢Case 1: Sunny day

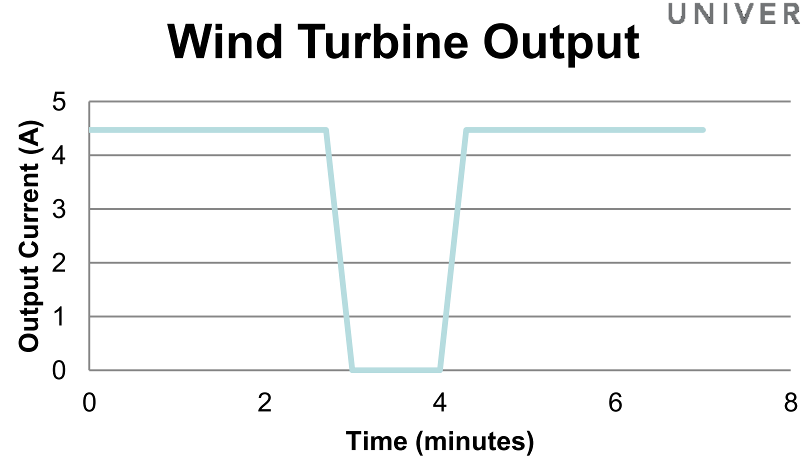
Experiment results in first 7 minutes

Time (minutes)	Battery Voltage (V)	Load Current (A)	PV Current (A)	Wind Current (A)	Diesel generator
1-3	12.16 v	7.72	2.38	4.47 (4.41-4.60)	off
3-4	12.14 discharging	7.69	0	0	on
4-7	12.16 v	7.72	2.38	4.47 (4.41-4.60)	off

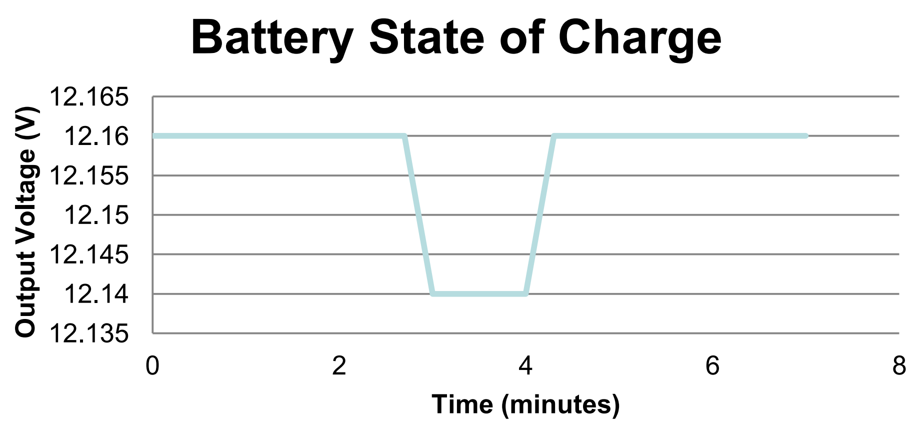
Experiment Results (cont)



PV output current in first 7 minutes

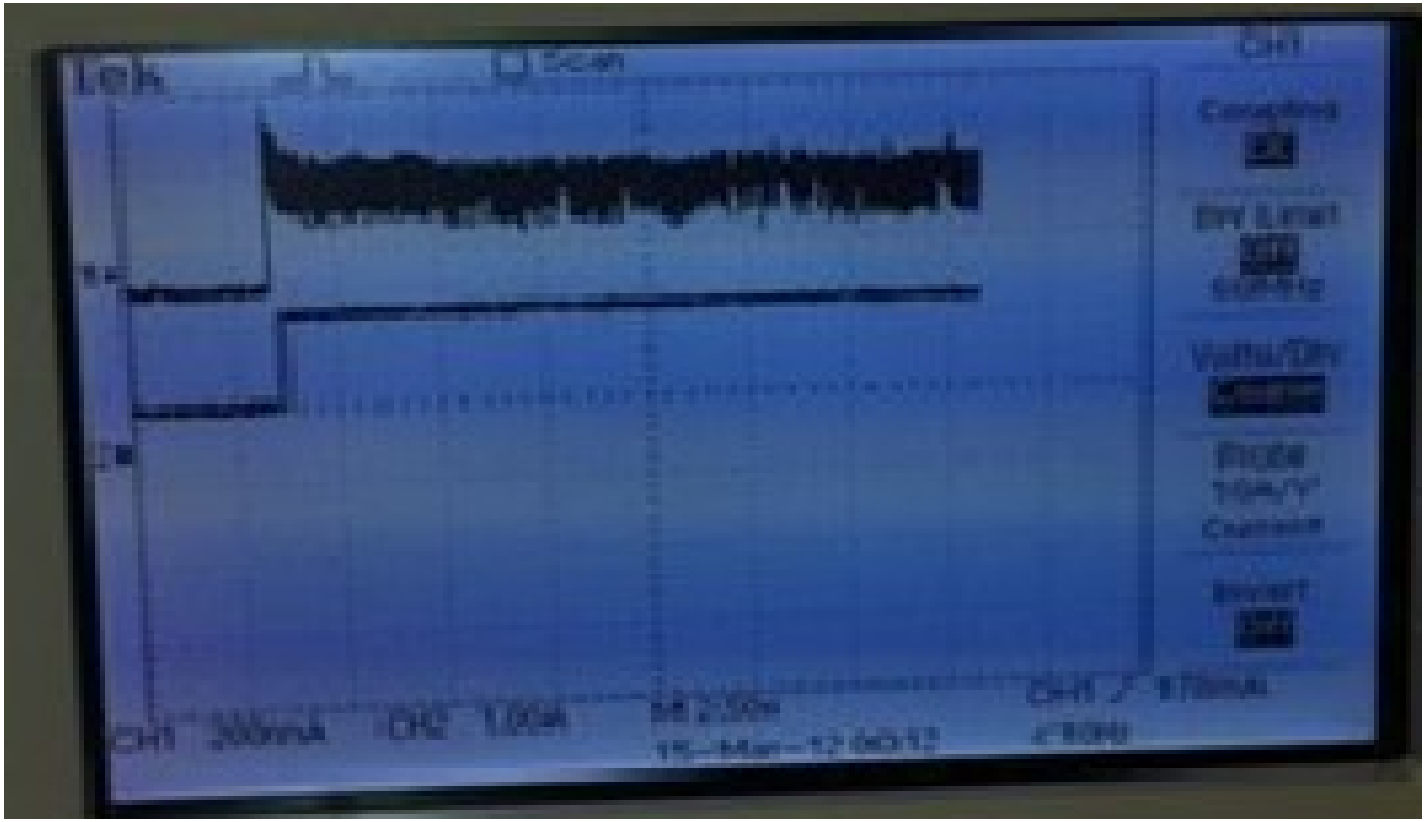


Wind current power in first 7 minutes



Battery state of charge in first 7 minutes

Experiment Results (cont)



Scope display of wind turbine and PV Output

Experiment Results (cont)

➢Case 2: Wind speed is zero

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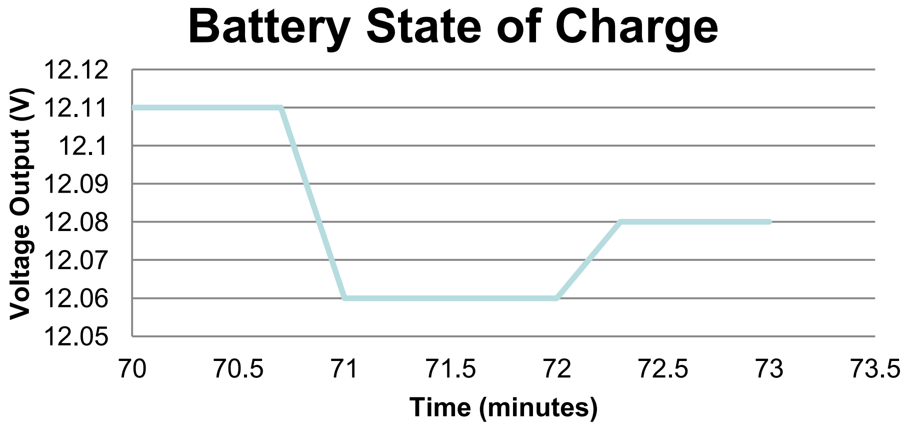
Experiment results when there is no wind

Time (minutes)	Battery Voltage (V)	Load Current (A)	PV Current (A)	Wind Current (A)	Diesel generator
70-71	12.11 v	7.65	2.41	0	off
71-72	12.06 discharging	7.65	0	0	on
72-73	12.08 v	7.65	2.41	0	off



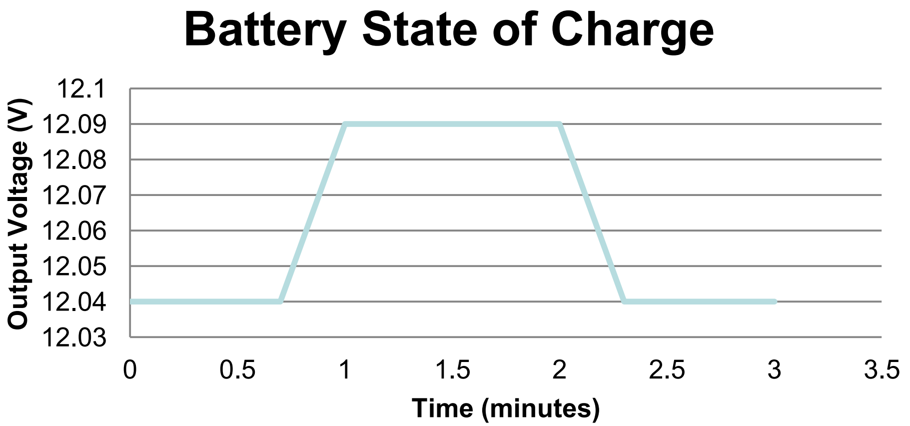
Battery state of charge when there is no wind

Experiment Results (cont)

➢Case 3: Cloudy day

Experiment results on a cloudy day

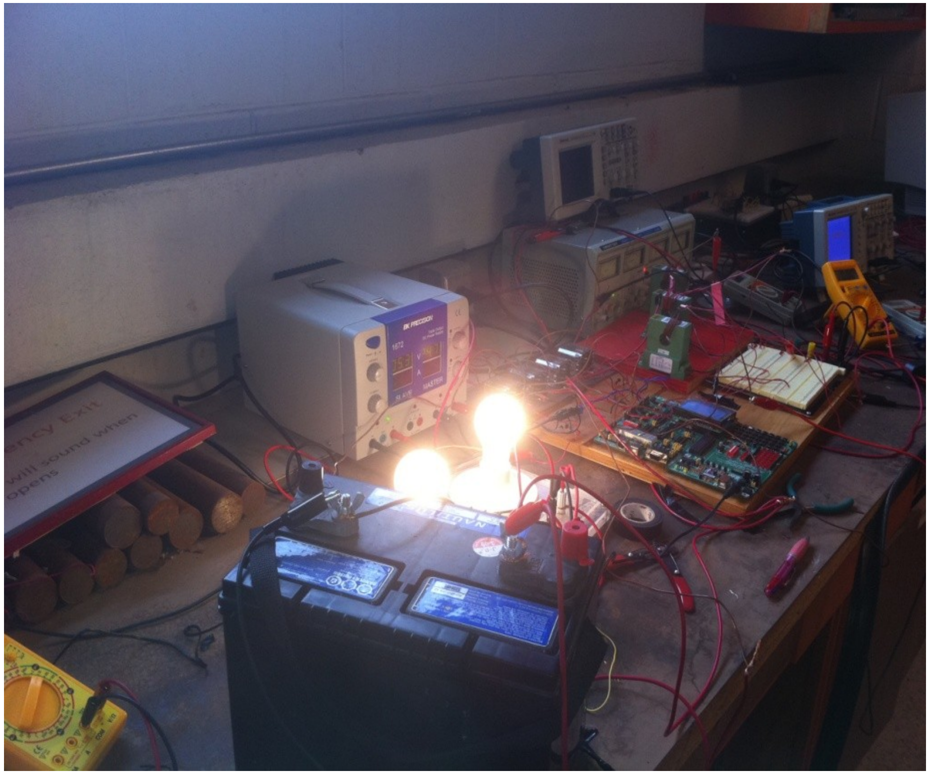
Time (minutes)	Battery Voltage (V)	Load Current (A)	PV Current (A)	Wind Current (A)	Diesel generator
1-2	12.03 V	7.65	0	4.47 (4.41-4.60)	off
2-3	12.09	7.69	0	0	on
3-4	12.03 V	7.72	0	4.47 (4.41-4.60)	off



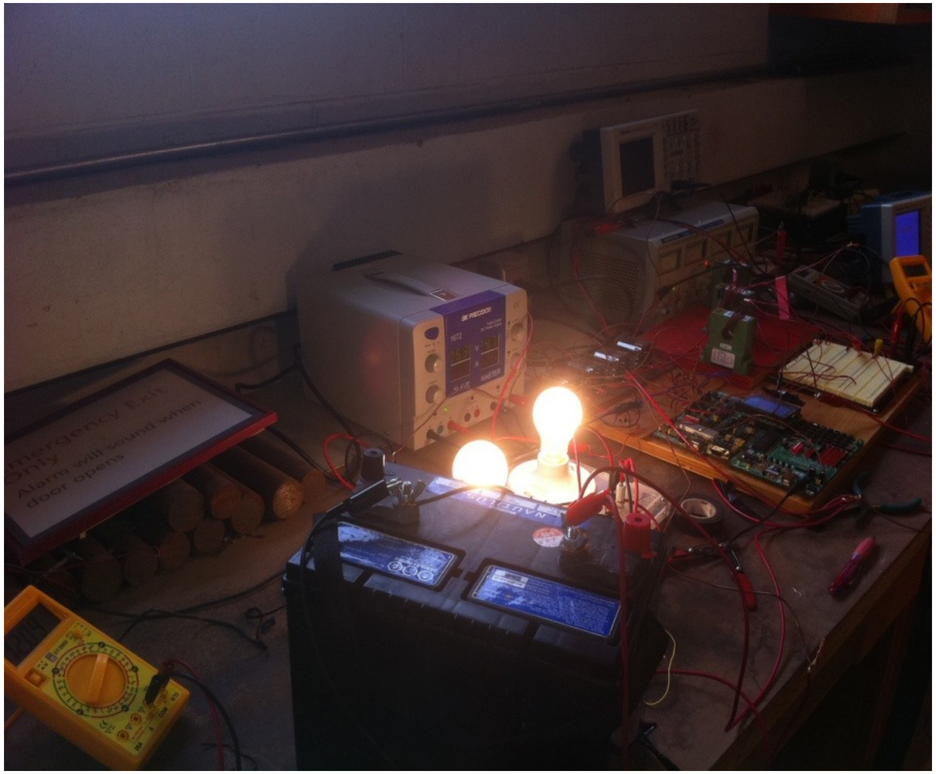
Battery state of charge

Experiment Results (cont)

- Experiment Results with Battery Connected and Disconnected



The load brightness when the renewable systems and battery are connected



The load brightness when only the renewable systems are connected

Conclusion

•HOMER software is used to determine the best optimal sizing and a pre-feasibility study of the system and sensitivity analysis is done when designing the system.

•A comparison between the existing and the proposed systems has been made based on system cost and emissions.

•System components have been modeled in Matlab/Simulink individually first and then a combination system has been modeled.

•Different scenarios have been considered for wind and solar subsystems and for the load as well.

•Wind turbine and solar panel data have been studied, and training in how they work has been done with the lab manager.

•A real time on/off supervisory controller has been proposed and implemented for a small scale system.

Future works

•Simulation for longer time.

•Additional controllers are highly recommended for some power components.

• It should be implemented for the same scale system.

•Grid connection can be considered in both dynamic modeling and for the experiment setup.

Acknowledgment

MEMORIAL UNIVERSITY

- **Dr. Tariq Iqbal**
- **Dr. George Mann**
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- Memorial University of Newfoundland

Publications

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•El Badawe, M.; Iqbal, T.; M, George.;, "Optimization and a modeling of a stand-alone wind/PV hybrid energy system" presented at *the 25th IEEE Conference on Electrical and Computer Engineering, (CCECE 12),* Montreal, Canada, April 29th – May 2, 2012.

•El Badawe, M.; Iqbal, T.; M, George.;, "Optimization and a comparison between renewable and non-renewable energy system for a telecommunication site" presented at *the 25th IEEE Conference on Electrical and Computer Engineering, (CCECE 12),* Montreal, Canada, April 29th – May 2, 2012.

•El Badawe, M.; Iqbal, T.; M, George.;, "Design and dynamic modeling of a hybrid street light system" presented at *IEEE 21, NECEC conference*, St.John's, NF, 2011.

•El Badawe, M.; Iqbal, T.; M, George.;, "Optimal sizing and modeling of a hybrid energy system for a remote telecommunication facility" presented at *IEEE 21, NECEC conference,* St.John's, NF, 2011.

Thanks for your Attention