Modeling, Design and Simulation of A Low Cost Supervisory Controller for Ramea Hybrid Power System

Jiuchuan Zhang
Faculty of Engineering and Applied Science
Memorial University

OUTLINE

- Introduction
- System Modeling
- Control Logic
- Case Studies
- Controller Design
- Conclusion
- Future Work

OBJECTIVE

- **Develop a simple low order dynamic model of Ramea Hybrid Power System**

- **Design and simulate a dynamic controller to maintain system stability**

- **Develop a simple low cost Supervisory Control and Data Acquisition (SCADA) system for Ramea Hybrid power system**

INTRODUCTION

What is Renewable Energy ?

Renewable energy (RE) comes from continually replenished resources and in the forms as: wind, water waves, tides, sunlight as well as geothermal heat.

Why we need Renewable Energy?

- Lower environmental impact than conventional energy technologies
- Limited deposit of fossil oil
- Provide more options for customers
- Provide a mean to have stable predictable energy prices

INTRODUCTION (CONT'D)

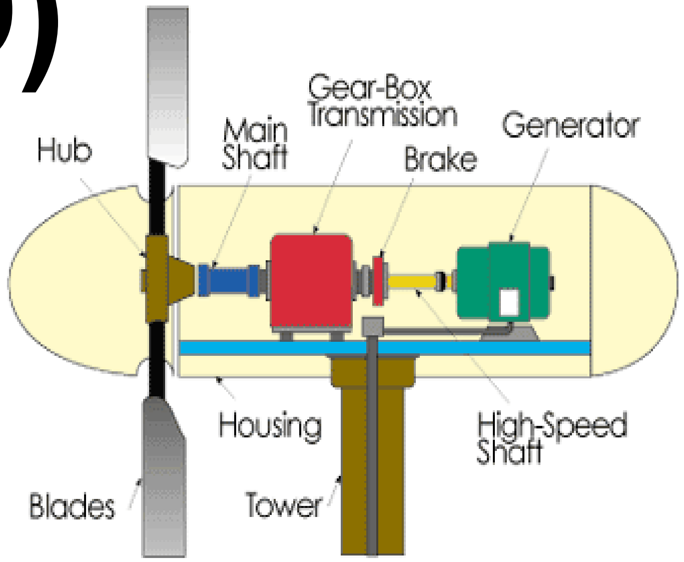


Figure 1. Basic Component of a Wind Turbine

Wind power

- Wind power is growing at the rate of 30% annually and is the one of the fastest growing energy source for generating electrical power

- One major advantage for wind power over conventional fuels is it produces neither harmful emissions nor any hazarded wastes

- Does not contribute to global warming and acid rain

- Does not lead to radioactive sources and risk like nuclear plants

INTRODUCTION (CONT'D)

- Ramea is a small island located 10km off south coast of Newfoundland.
- Population around 700
- Region annual mean wind speed 7.5 m/s and annual wind energy is 466.63 W/m^2
- Was chosen as a pilot site for Canada's wind-diesel demonstration project in 2004

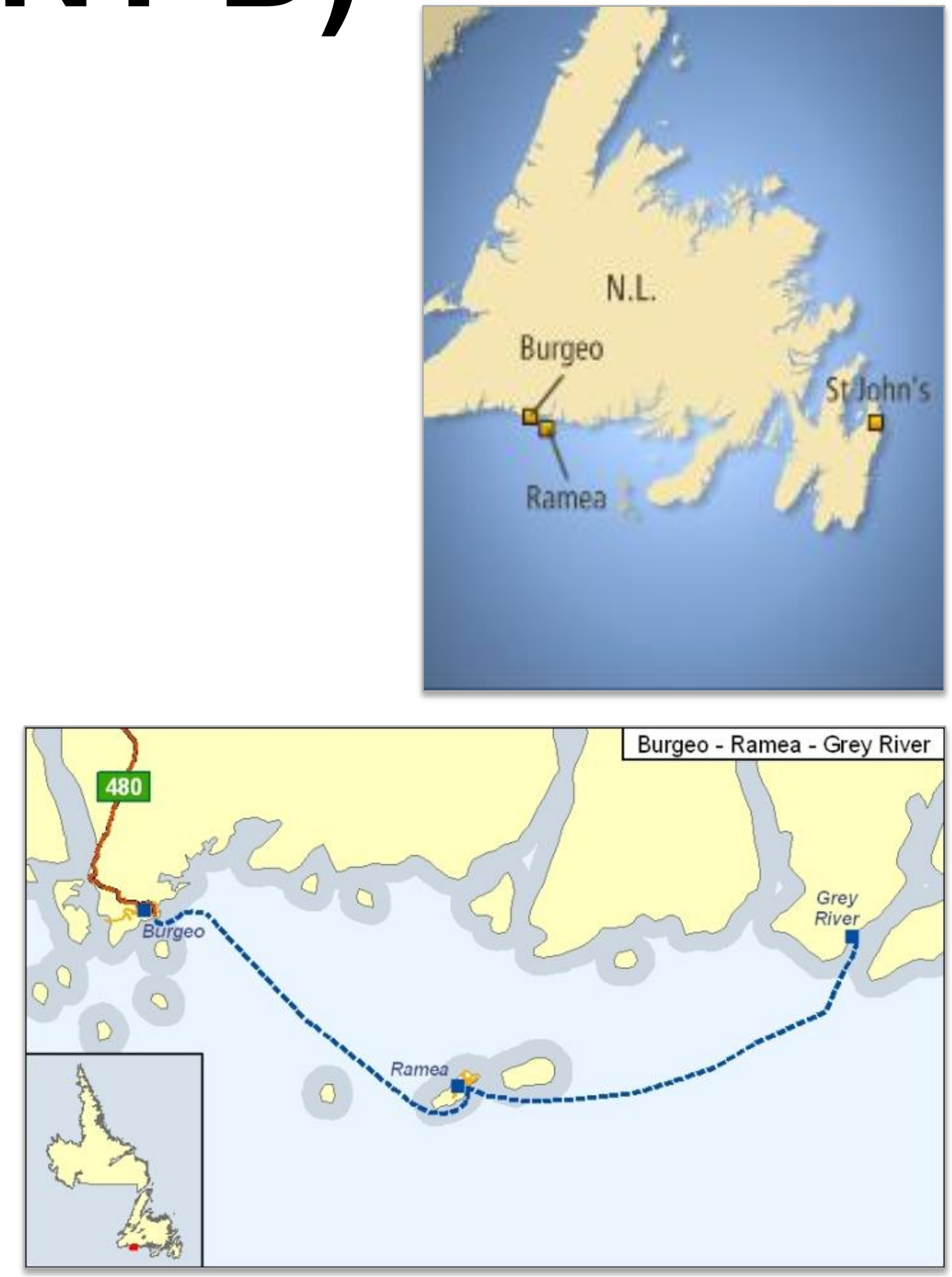


Figure 2. a) Ramea Island in Canada

Ramea Island

Figure 2. b) Wind Diesel System on Ramea Island in Canada

Figure 2. c) Ramea Community

Ramea Hybrid Power System

- Six 65 kW wind turbines
- Three 100 kW wind turbines
- 200 kW Electrolyzer
- 250 kW hydrogen generator
- Hydrogen storage tanks
- 925 kW diesel generators

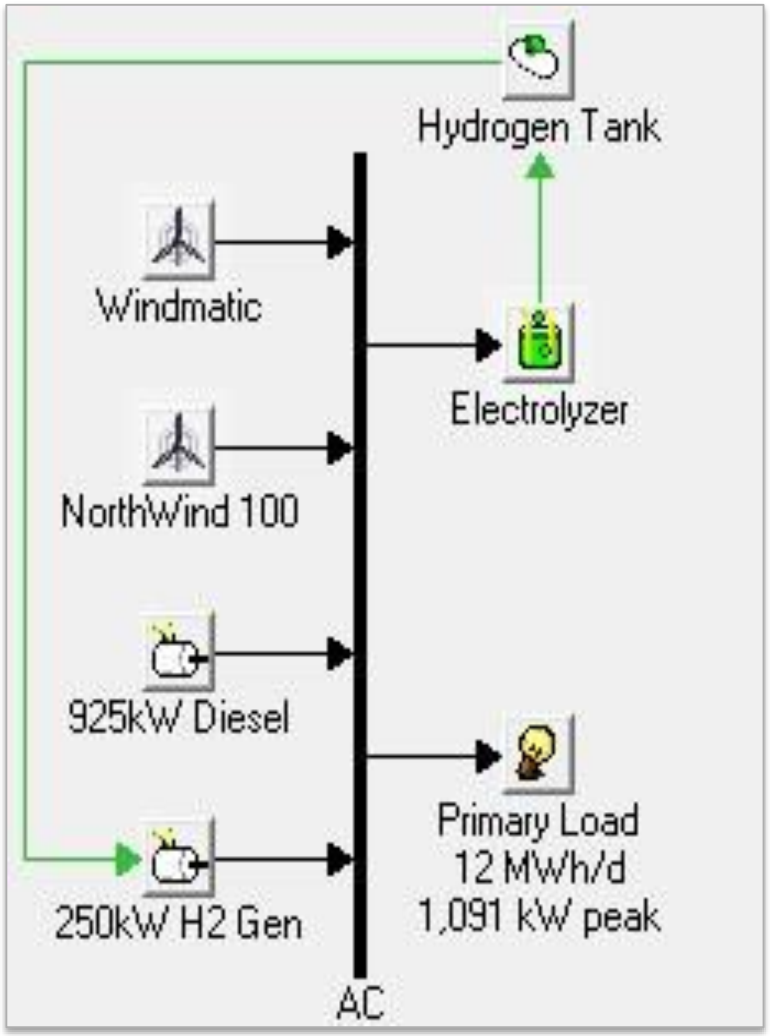


Figure 3. Ramea System in HOMER

Supervisory Control

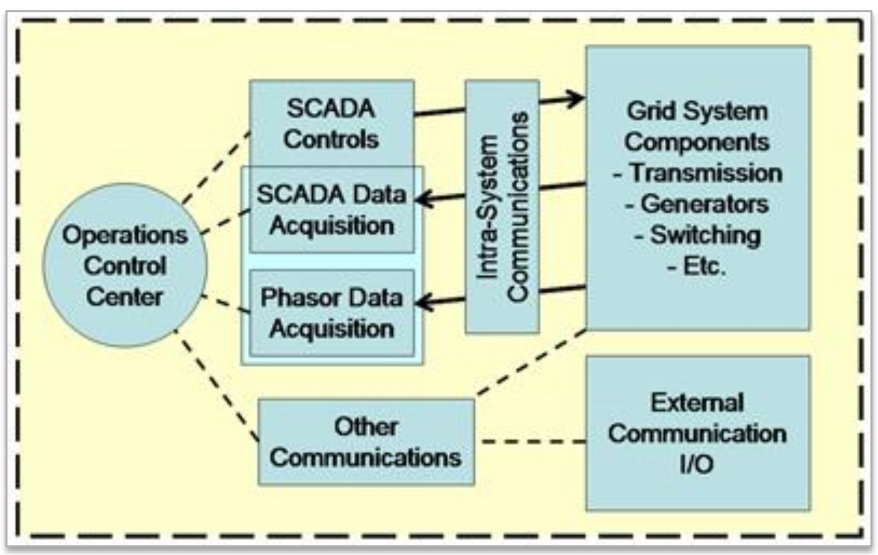


Figure 4. An example of SCADA system layout

- SCADA (Supervisory Control and Data Acquisition)
- RTU(Remote Terminal Unites) or PLCs Programmable Controller
- A simpler and less costly controller for small Renewable Energy systems is essential

SYSTEM MODELING

- Modeling of power system equipment and power electronics can be very complex
- Mathematical models are nonlinear and high order
- Result in long simulations time and require powerful computers
- In order to lower the complexity: real power and first order transfer functions are proposed and used in this work

SYSTEM MODELING (CONT'D)

- Example : takes around 10 minutes for a 5 second simulation in MATLAB/Simulink of a DC-DC buck converter

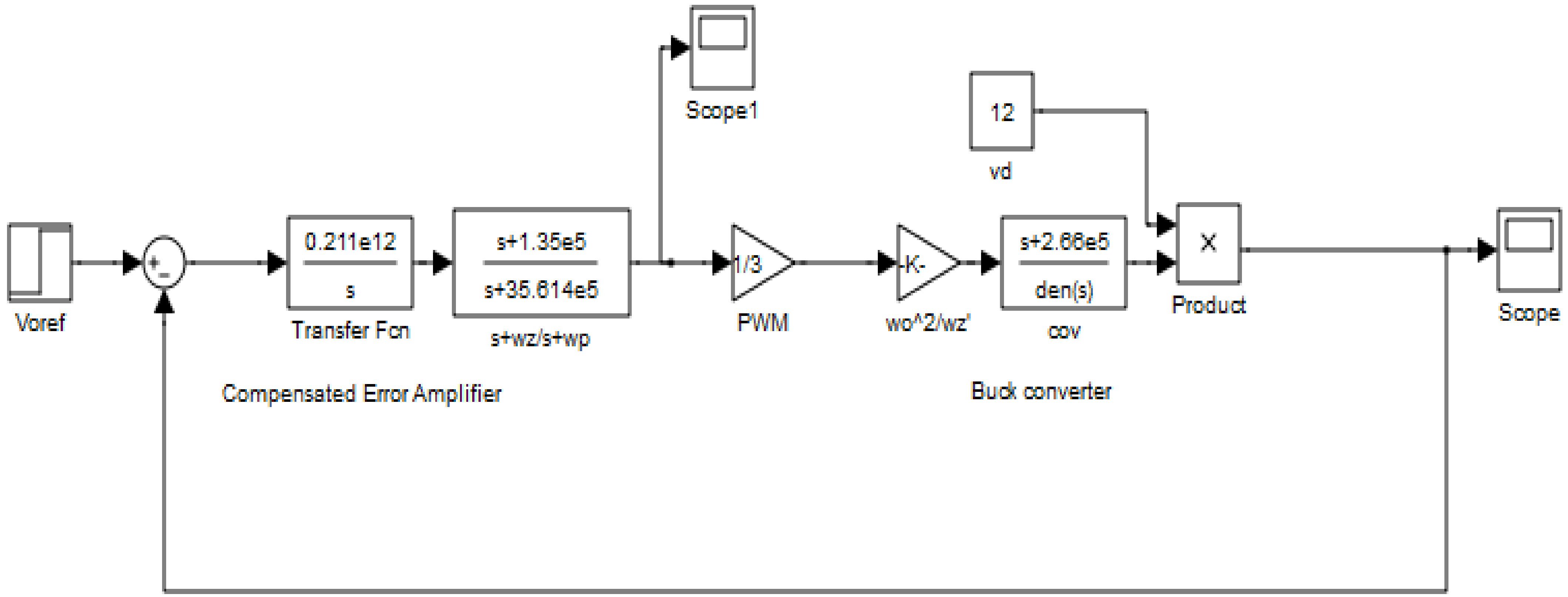


Figure 5. Simulink Block Diagram for a DC-DC Buck Converter

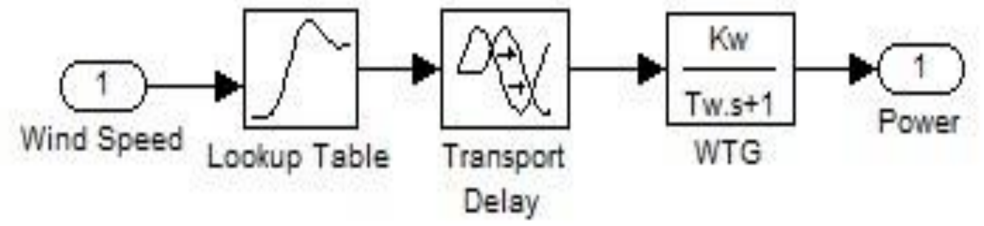
SYSTEM MODELING (CONT'D)

Wind-speed and Wind Turbine Model:

- **Output mechanical power of wind turbines :**

$$P_w = \frac{1}{2}\rho A_r C_p V_w^3$$

A simple wind turbine model can be represented



Wind-speed and Wind Turbine Model (cont'd):

- **First-order-lag expression for wind turbine :** $\frac{K}{H+Ts}$
- **Relationship between H and J :**

$$H = zJ\,\frac{\Omega_{gen}^2}{2Pn_{gb}^2} = zJ\,\frac{\left(\frac{f(1+S_G)2\pi}{n_{pp}}\right)^2}{2Pn_{gb}^2} \quad \textbf{also} \quad J = k_J M L^2$$

- **Power relate to rotor diameter:** $P \cong k_p D^{ap} = 310D^{2.01}$
- **Mass related to length:** $M \cong k_M L^{a_M} = 2.95L^{2.13}$
- **Rotor diameter related to blade length:** $D \cong rel_{DL} L = 2.08L$
- **Gearbox ratio related to rotor diameter:** $n_{gb} \cong k_{gb} D = 1.186D$

Wind-speed and Wind Turbine Model (cont'd):

- **Combine the above equations :**

$H \cong k_H D^{a_H} = 2.63 D^{0.12}$ **or** $H \cong 1.87\, P^{0.0597}$ **(where P is power)**

- **An equation to estimate resistant torque due to drag is :**

$$\mathrm{T} = T_{drag} = S_d\, \Omega$$

- **K is an adjustable parameter normally is :** *H*

- **Transfer function for 100 kW wind turbine is :**

$$\frac{1}{0.778s + 1}$$

- **And for 65 kW :**

$$\frac{1}{0.548s + 1}$$

Desiel Generator Model

- First order model
- Saturation governs the maximum output power
- Two parts: 30% minimum level and full operating model

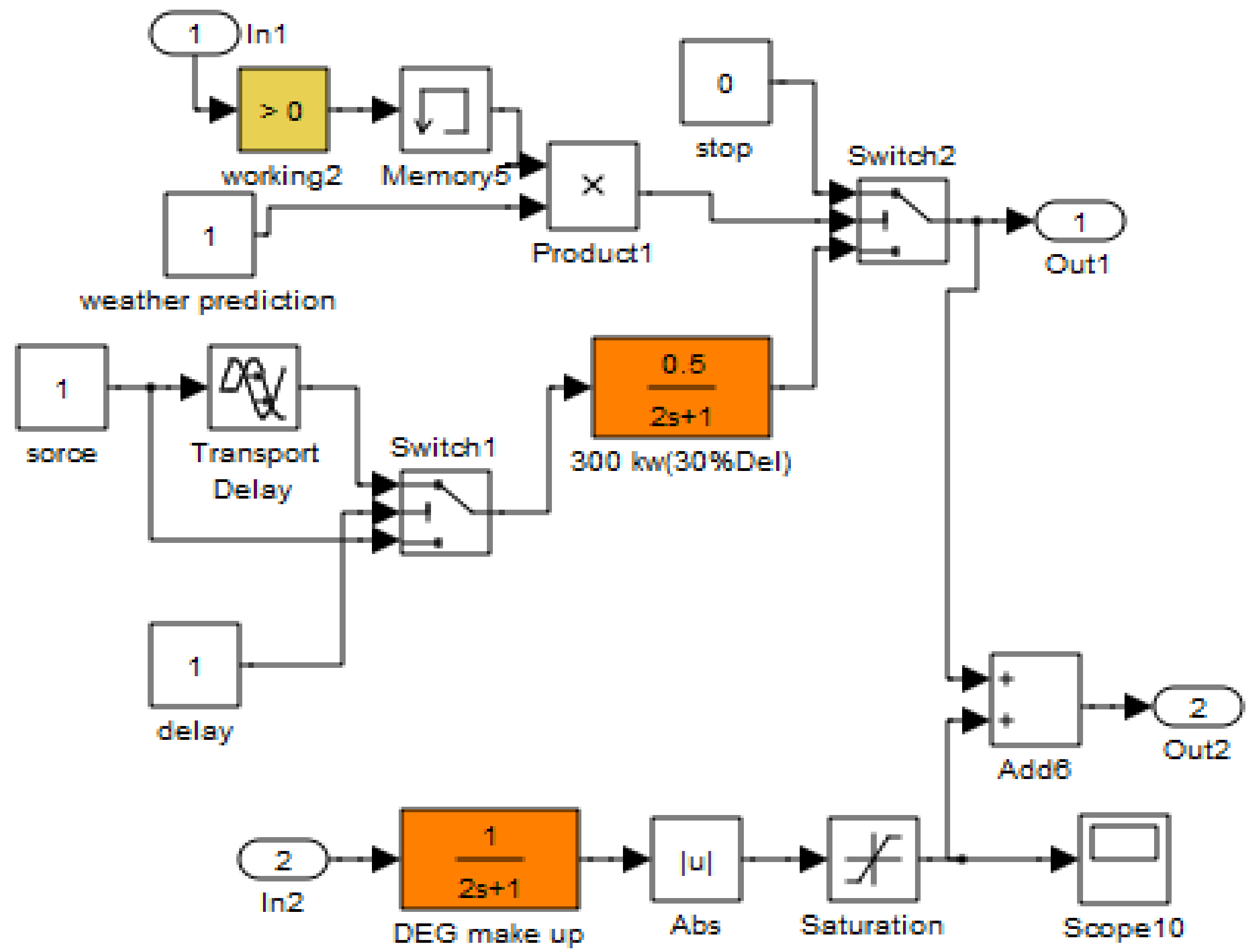
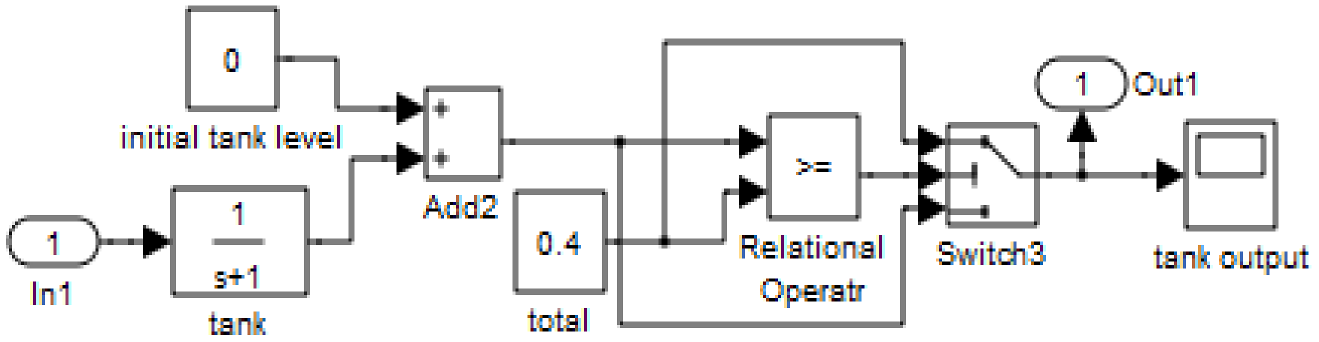


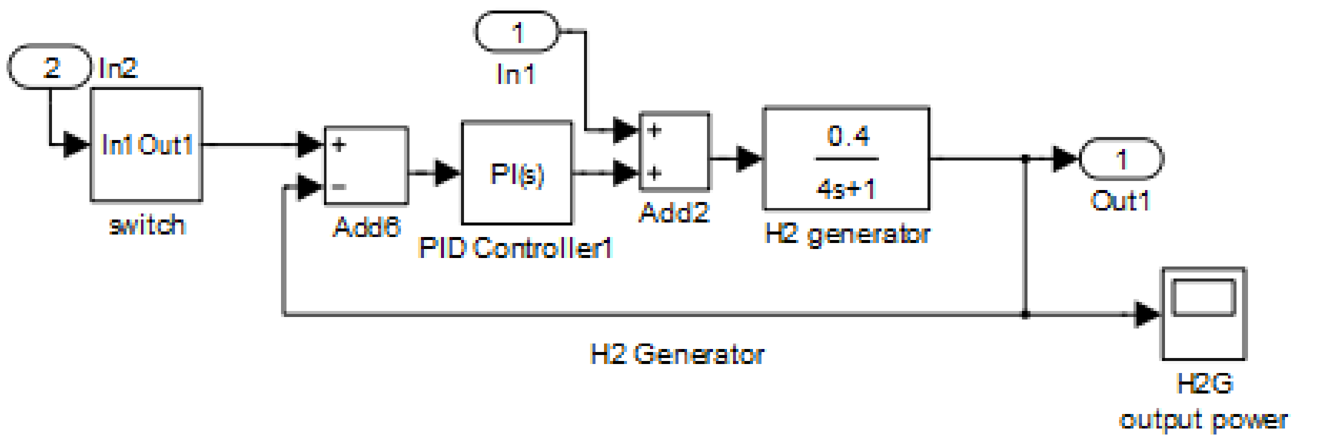
Figure 6. Block Diagram for DEG

Hydrogen Generator and Hydrogen Tanks Modeling

- Hydrogen tank model



- Hydrogen generator model



Ramea System Dynamic Model

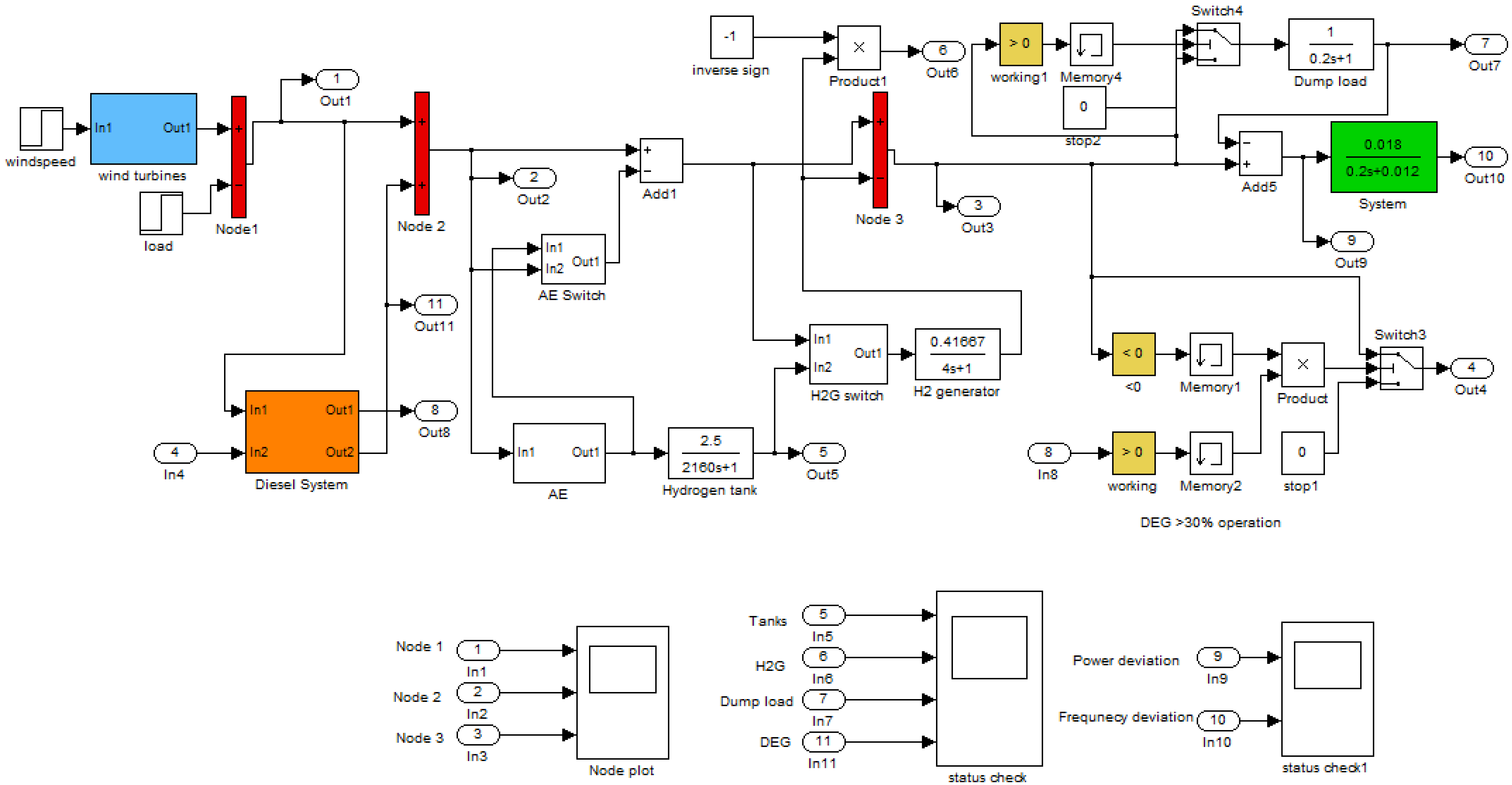


Figure 7. Ramea System Dynamic Model in MATLAB/Simulink

Frequency response model for the system

- The utility frequency is the frequency of the oscillations of alternating current (AC) in an electric power grid transmitted from power plants to the end-users
- “System” frequency is the mean frequency of all the online machines
- Frequency deviation of each individual machine must be strictly minimized to avoid mechanical damage to the generators and disruption of the entire system
- Frequency deviation needs to be controlled (within 1% range)

Frequency response model for the system (cont'd)

- **Overall Δ power and Δ frequency:**

$$\Delta P_T(t) - \Delta P_L(t) = 2H\frac{d\Delta f(t)}{dt} + D\Delta f(t)$$

- **Applying Laplace transform :**

$$\Delta P_T(s) - \Delta P_L(s) = 2Hs\Delta f(s) + D\Delta f(s)$$

- **Define power deviation :**$\Delta P = \Delta P_T(s) - \Delta P_L(s)$

  we can get : $\frac{\Delta \boldsymbol{f}}{\Delta \boldsymbol{P}} = \frac{1}{2H+D}$

- **Assume D is 0.012 (1% change in frequency will cause a 1.2 change in load) and H is 0.2**

CONTROL LOGIC

- Based on the priority of the equipment
- Priority : WTG-> DEG(30%) -> AE/H2G -> Dump load / DEG (above 30%)
- Main objective: maximize use of renewable energy
- Maintain system stable: net power is zero

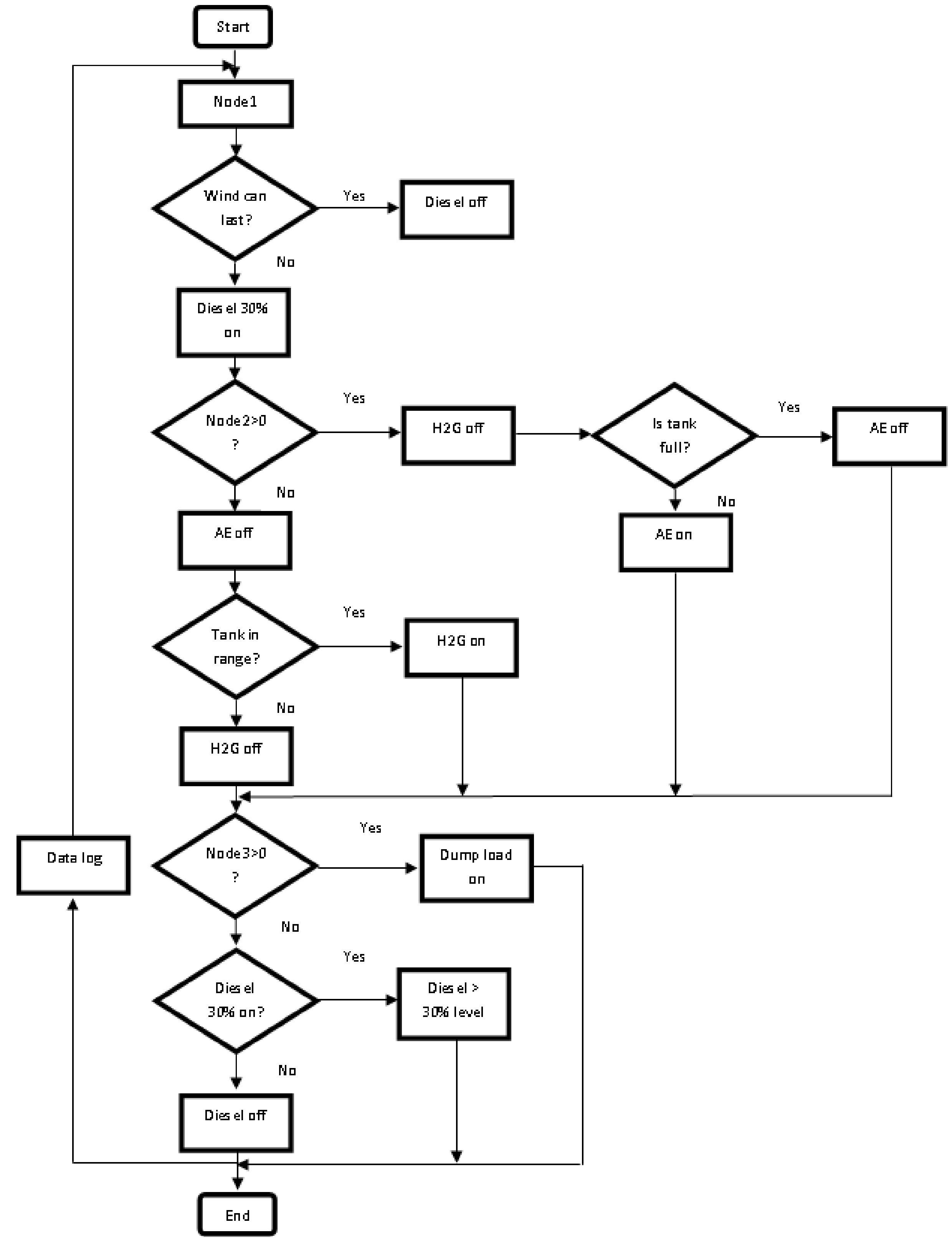


Figure 8 a) Flow Chart of System Control Logic

CONTROL LOGIC (CONT'D)

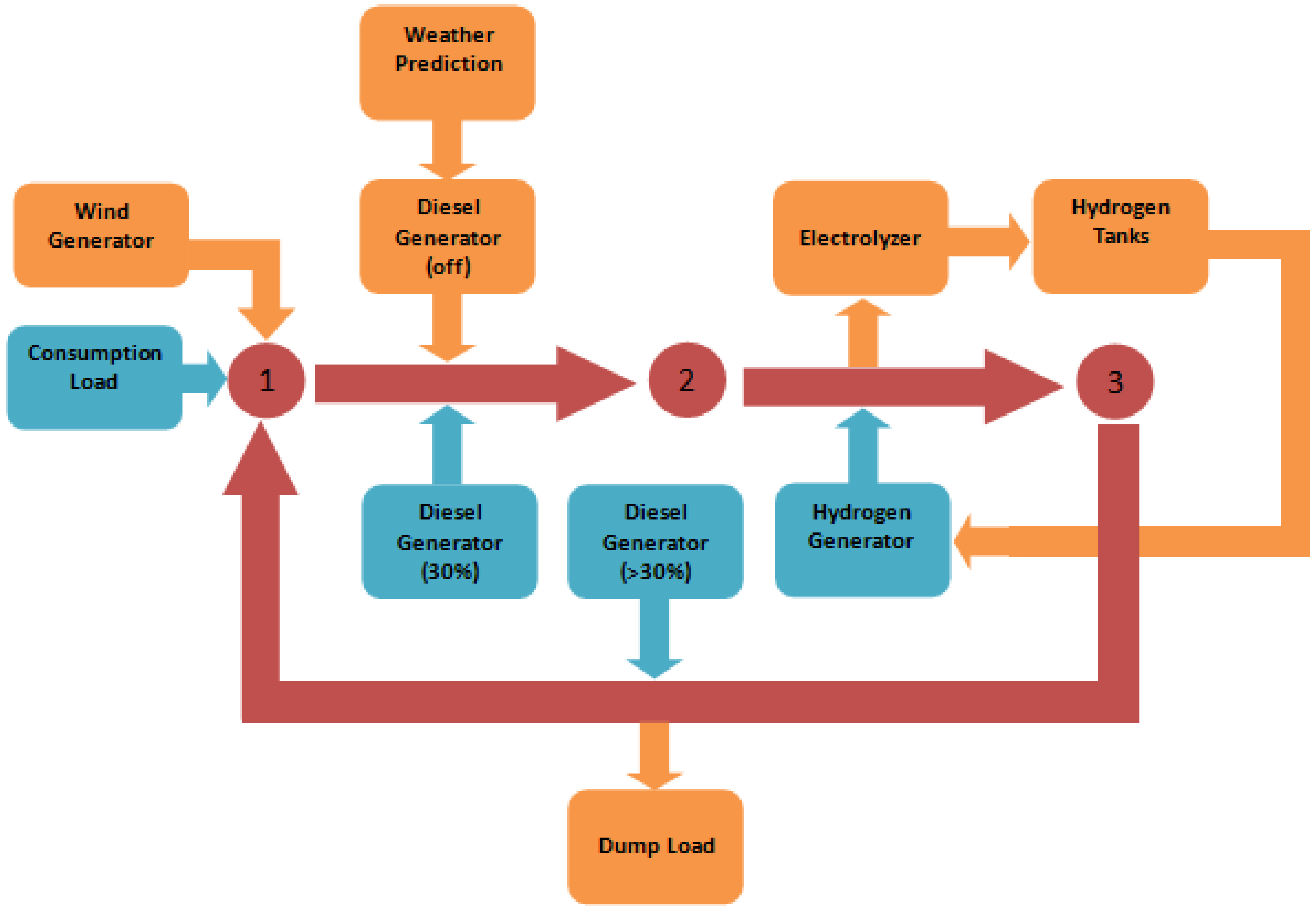


Figure 8 b) "Node" Diagram for System Control

CASE STUDIES

Five general case studies :

1. Load > (WTG+ H2G)
2. Load< (WTG+DEG min.)
3. Load< (WTG+H2G)
4. Load< WTG
5. WTG=0

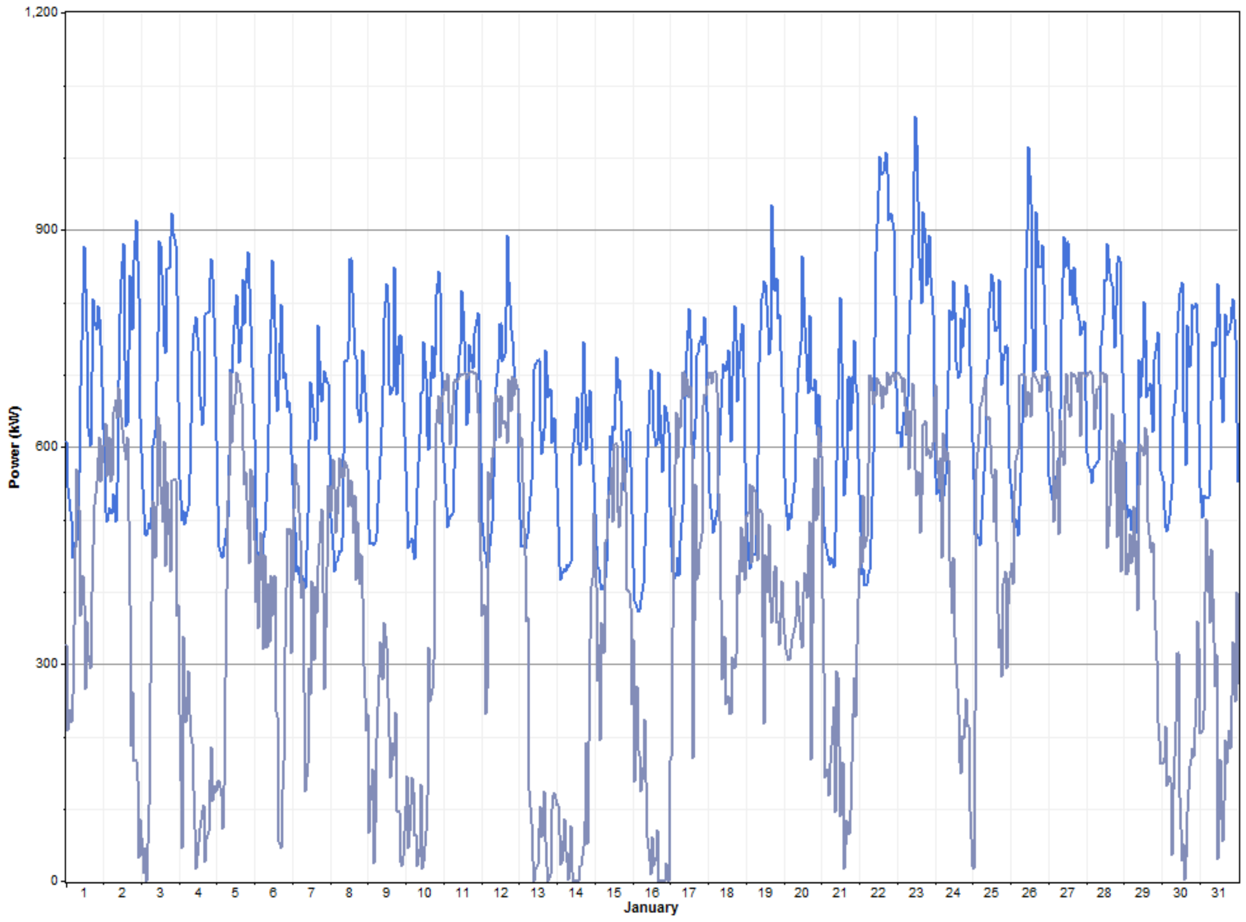


Figure 9. Hourly Load Data and Total Renewable Output Power from HOMER

Case Study (cont'd) :

Case 1: Load > (WTGs + H2G)

- Wind speed : 8 m/s
- Load change from 0.7 to 0.9 p.u. (1 p.u.= 600 kW) at t=1000 s
- Weather prediction is "0", diesel generator operates at 30% level

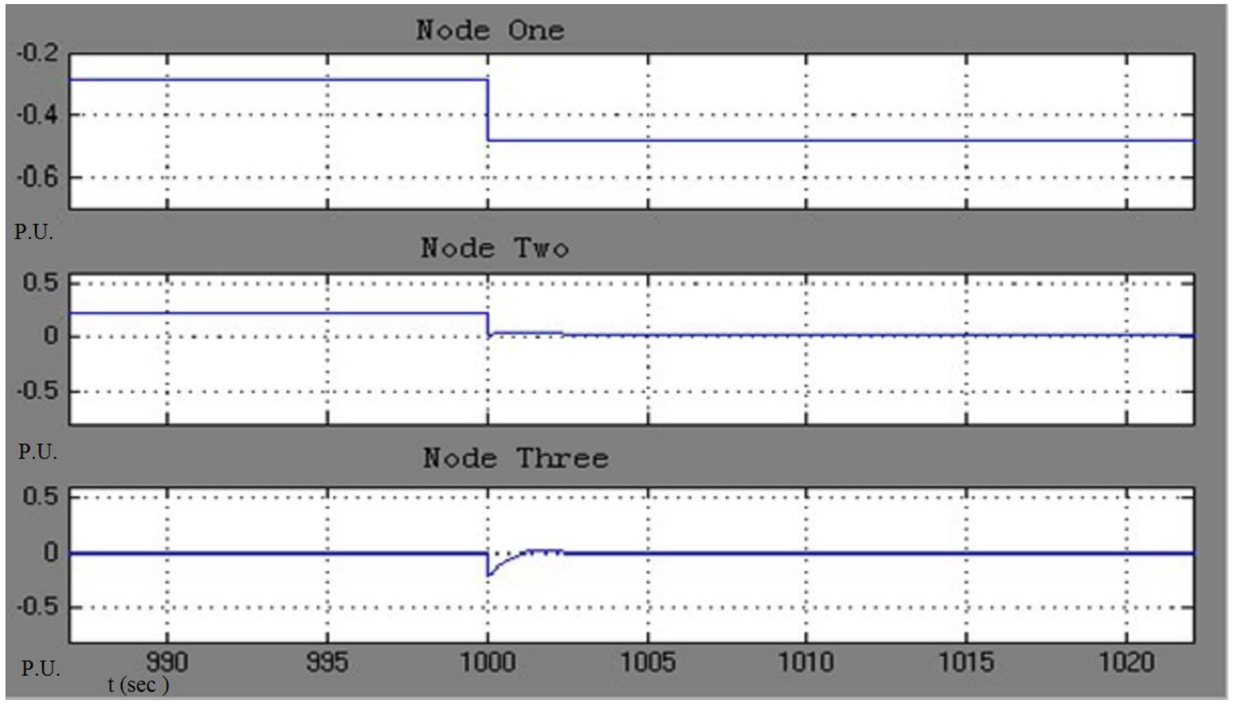


Figure 10. Node Plot for Case 1

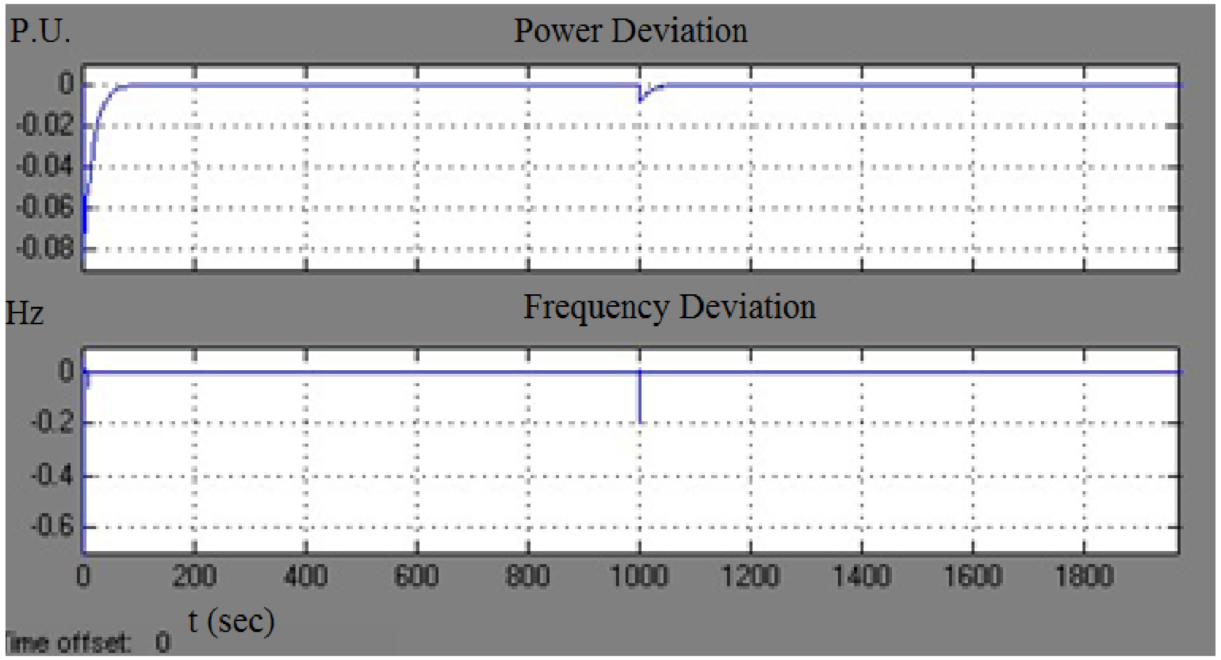


Figure 11. Frequency and Power Deviation

Case Study (cont'd) :

Case 2: Load < (WTGs + DEG mini.)

- Wind speed : 8 m/s to 8.5 m/s at t=2000 sec
- Load change from 0.5 to 0.7 p.u. at t=1000 sec
- Surplus power will trigger AE
- If AE reaches Maximum rating power, Dump load will be on

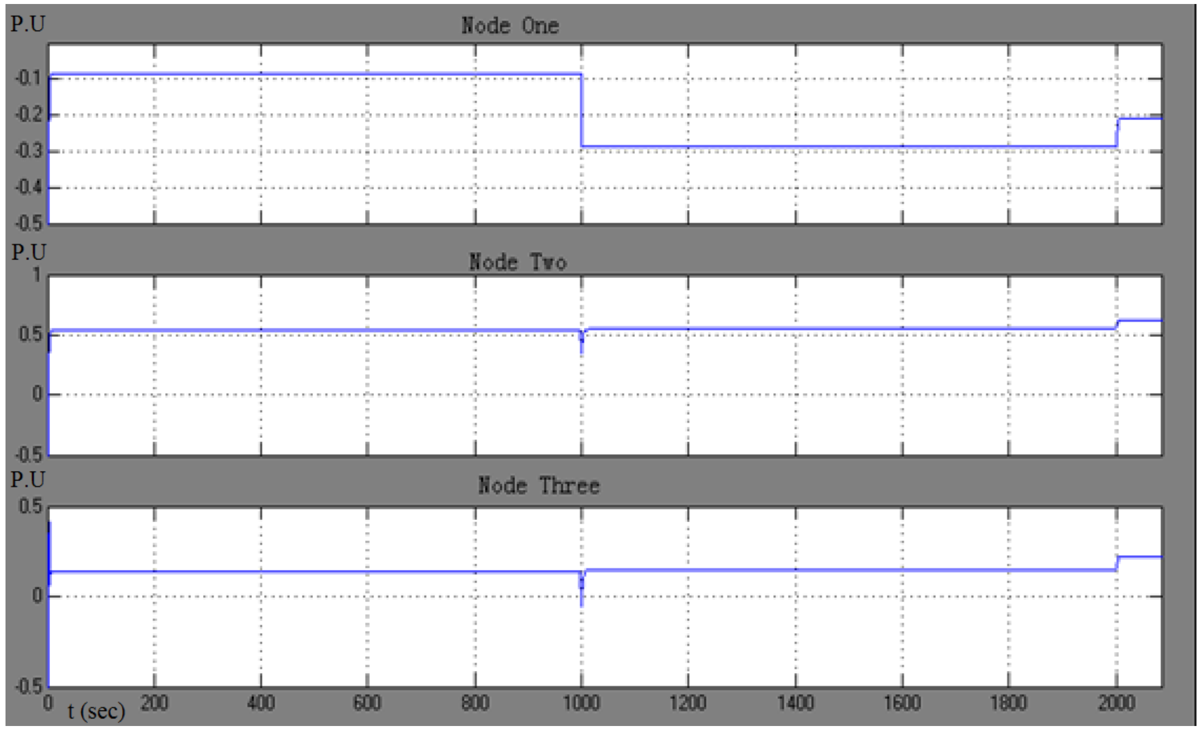


Figure 12. Node Plot for Case 2

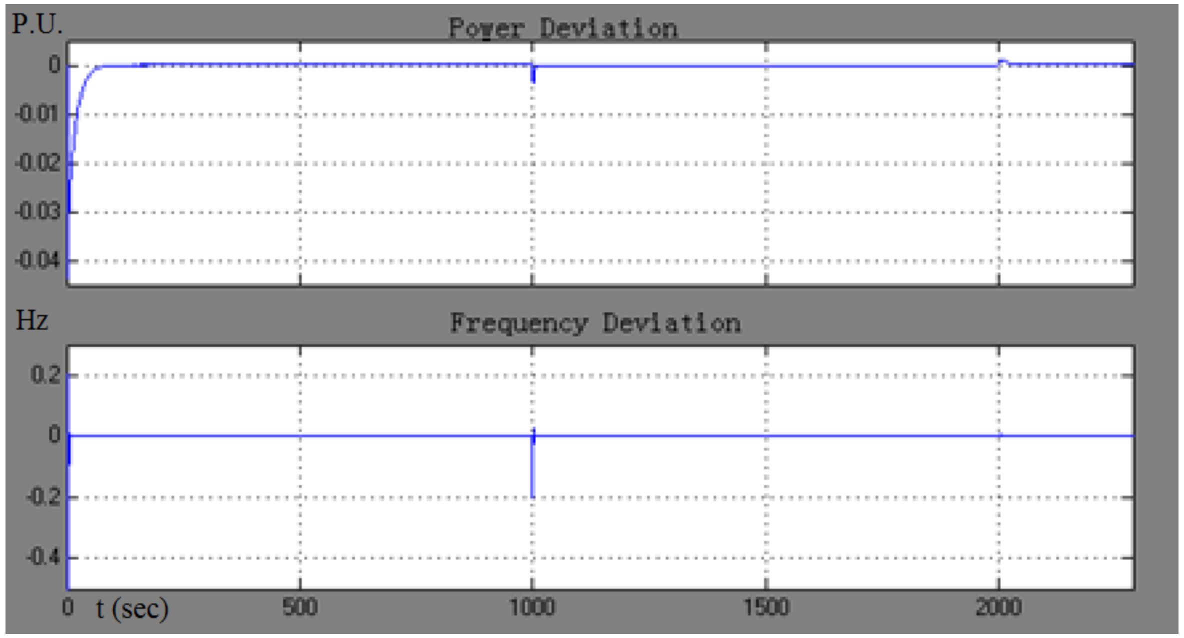


Figure 13. Power and Frequency Deviation

Case Study (cont'd) :

Case 3: Load < (WTGs + H2G)

- Wind speed : 8 m/s to 8.5 m/s at t=2000 sec
- Load change from 0.5 to 0.7 p.u. at t=1000 sec
- DEG min. depends on weather prediction
- H2G supply enough power to maintain system stability

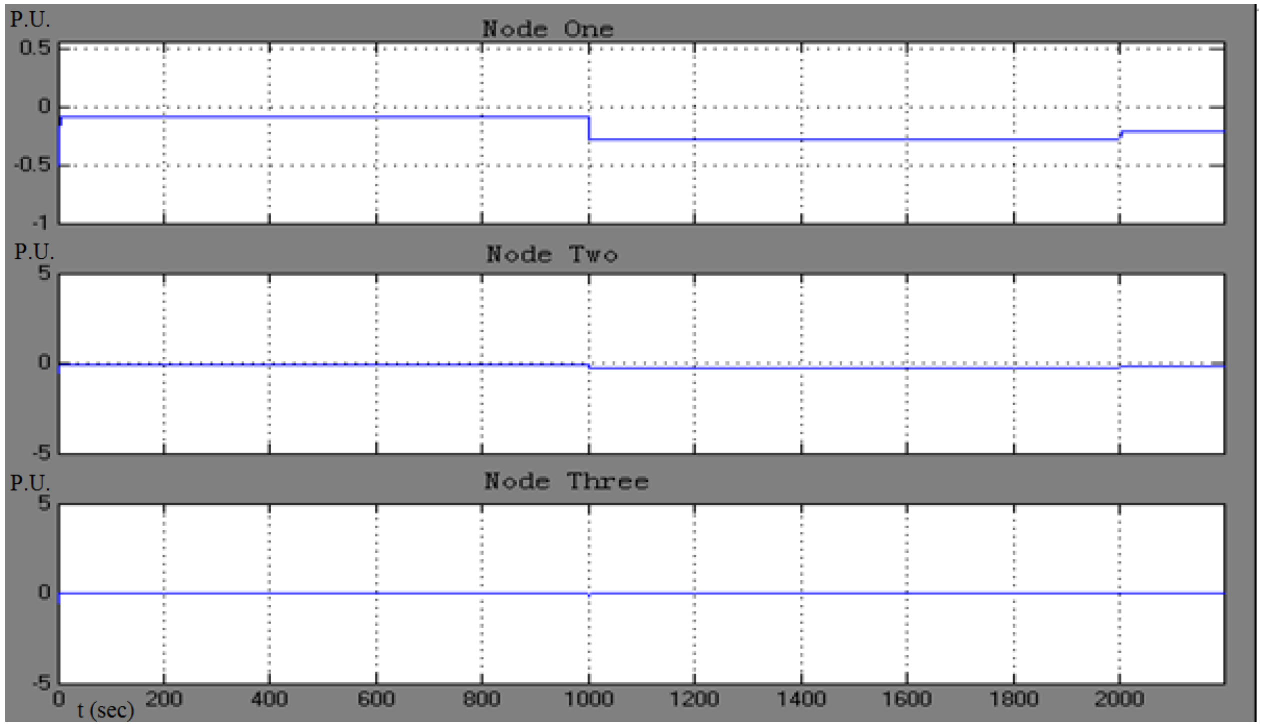


Figure 14. Node Plot for Case 3

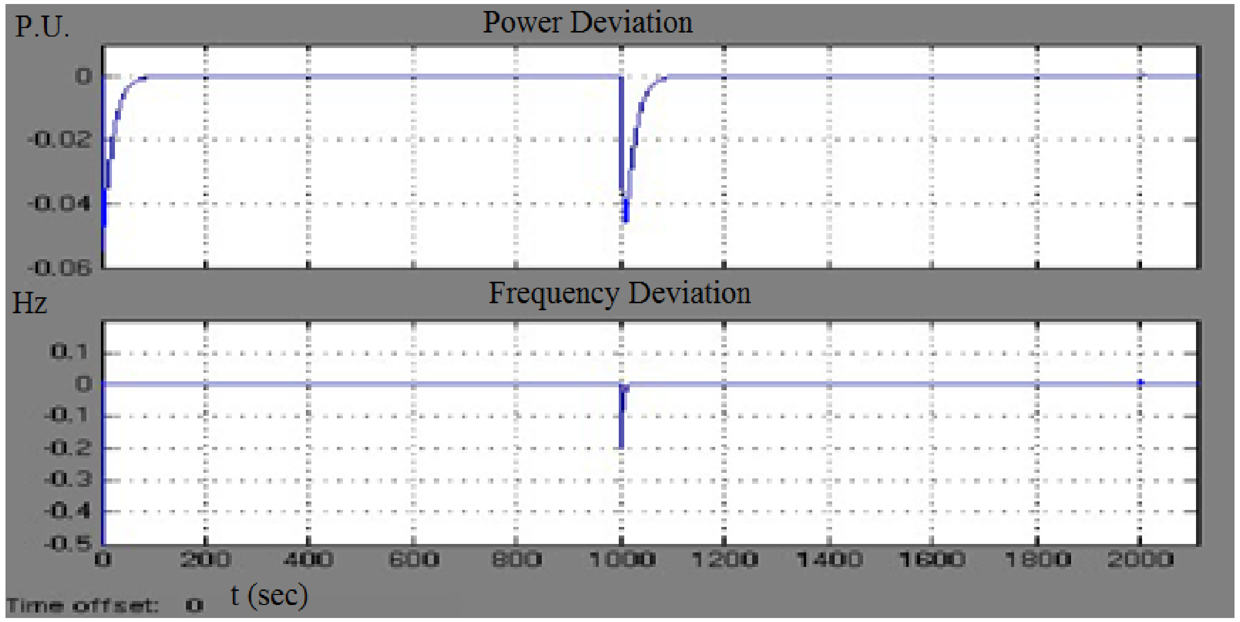


Figure 15. Power and Frequency Deviation

Case Study (cont'd) :

Case 4: Load < WTGs

- Wind speed : 8 m/s to 8.5 m/s at t=2000 sec
- Load change from 0.1 to 0.3 p.u. at t=1000 sec
- H2G is off
- DEG depends on weather prediction
- Surplus power consumed by AE
- No dump load needed

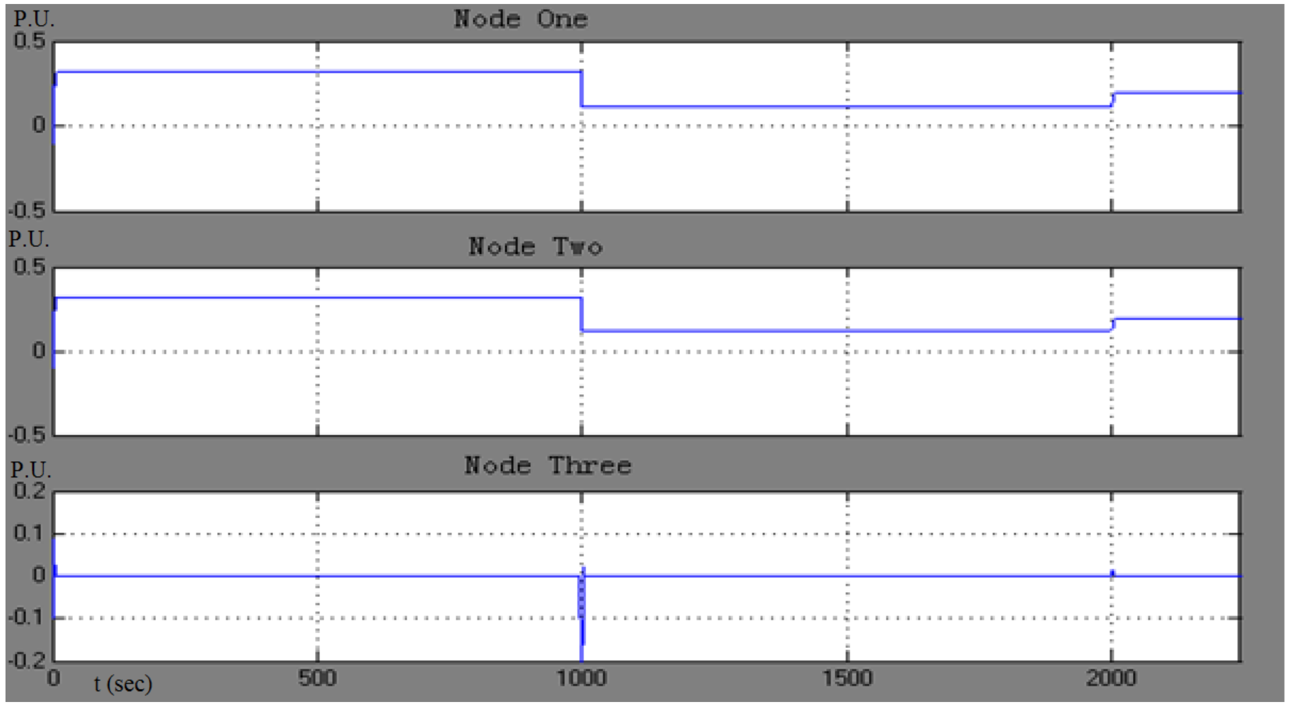


Figure 16. Node Plot for Case 4

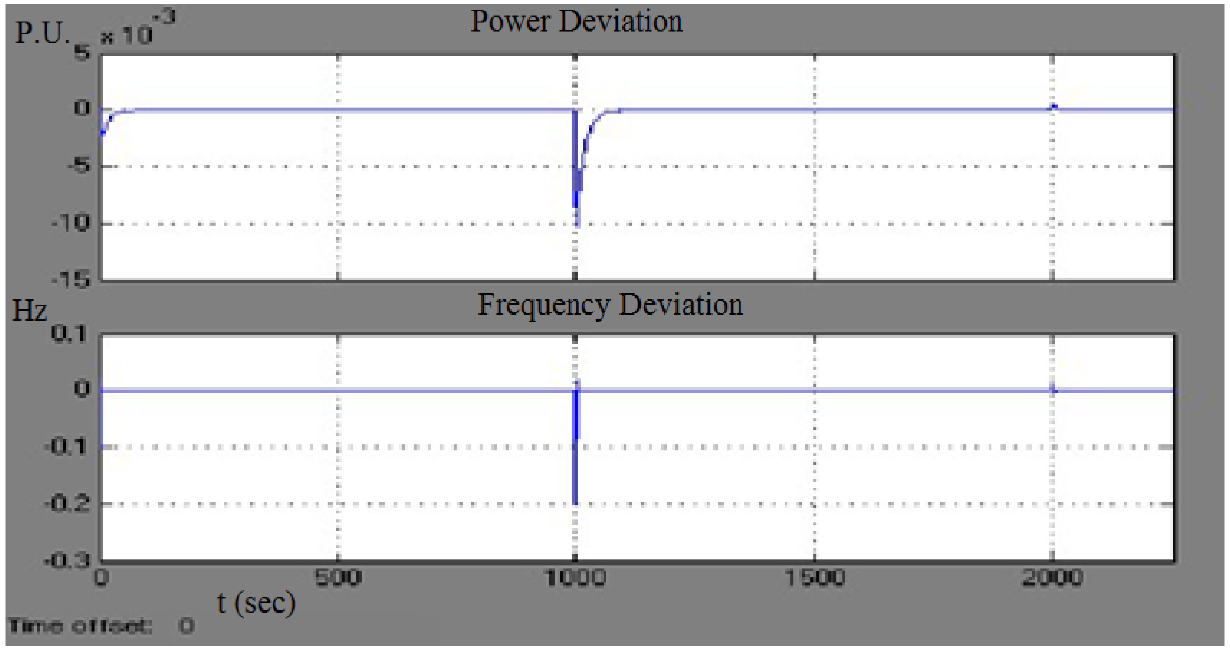


Figure 17. Power and Frequency Deviation

Case Study (cont'd) :

Case 5: WTG=0

- Load change from 0.4 to 0.1 p.u. at t=1000 sec
- DEG at 30% minimum level first
- For power shortage, check H2G first
- For power surplus , check AE and then dump load
- N3<0 implies DEG need to be operate avove 30% level

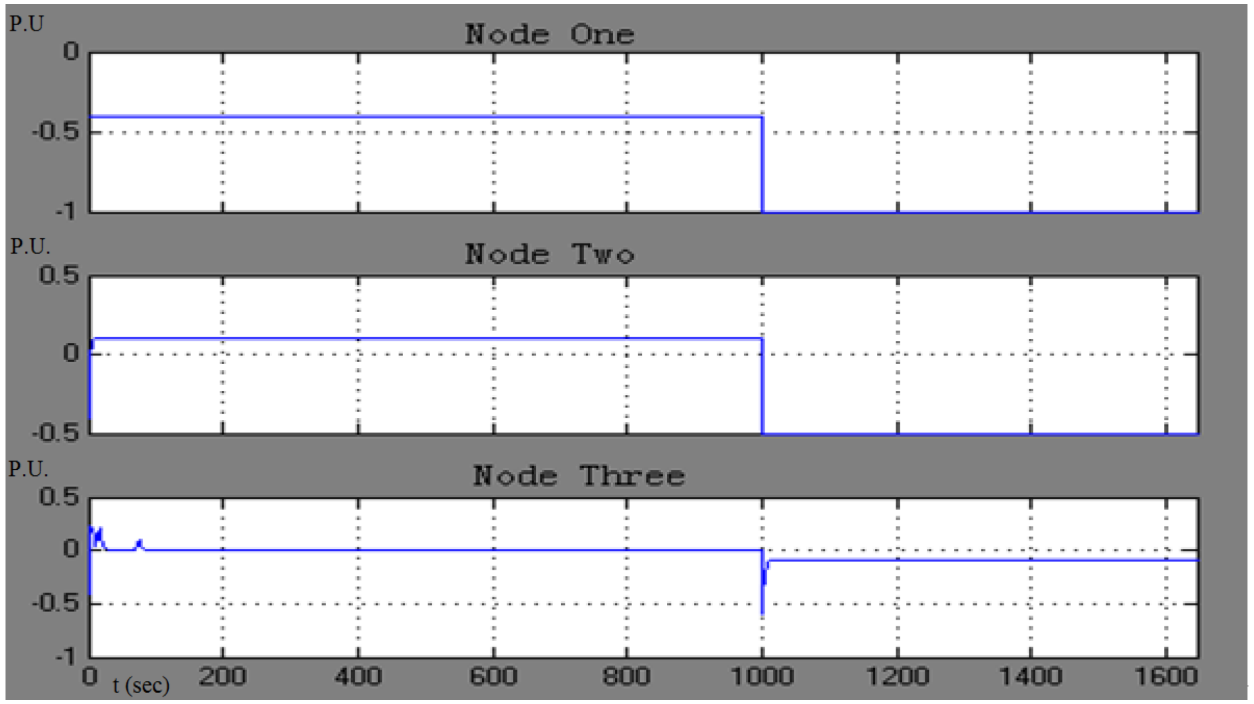


Figure 18. Node Plot for Case 4

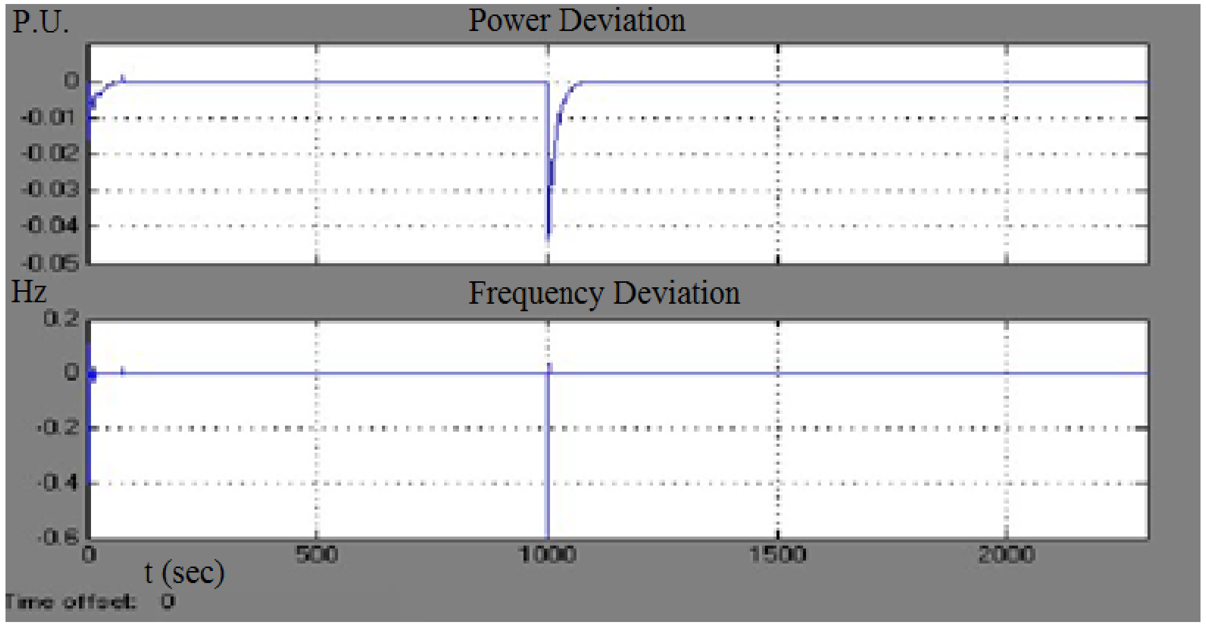


Figure 19. Power and Frequency Deviation

CONTROLLER DESIGN

- Lack of lab testing equipment such as DEG and WTG
- Test the control logic through a low voltage electrical circuit
- Output of each equipment can be represented by a low DC voltage (0-5V)
- Microcontroller PIC18F4550
- EasyPIC 3 is selected to program the PIC18F4550
- Programming in Mikrobasic

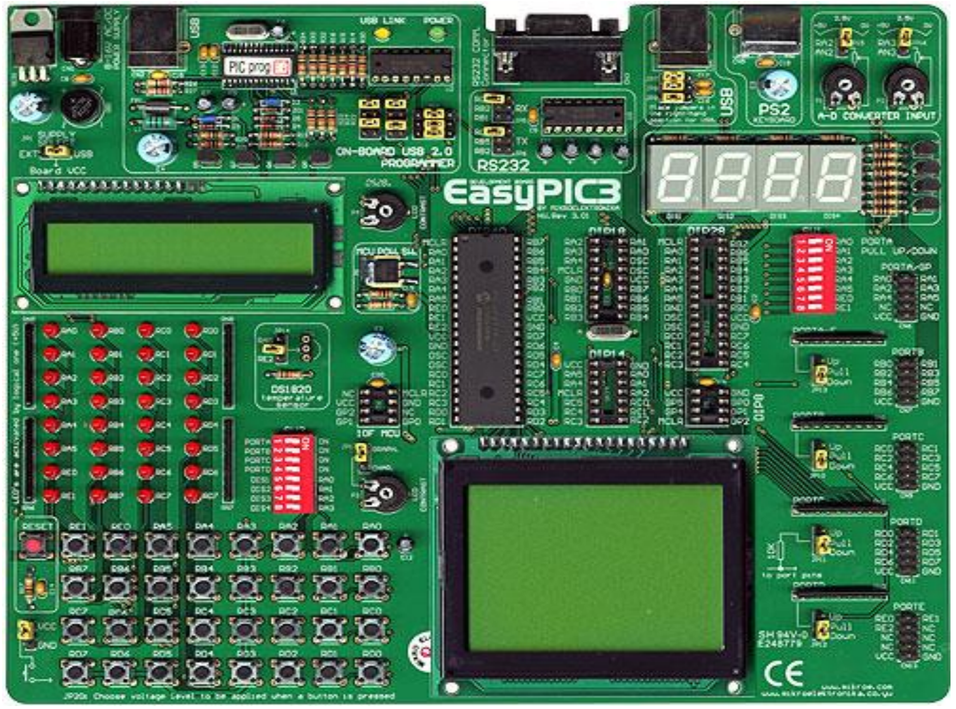


Figure 20. EasyPIC 3 Layout

CONTROLLER DESIGN (CONT'D)

- Controller based on PIC18F4550
- Two inputs (WTGs and Load) -> Two potentiometers
- System equipments status -> LEDs (on/ off)
- System parameters values are shown on a Graphic-LCD (GLCD)
- Data is stored on a MicroSD card
- Data will be plotted and imported to an excel file by a simple MATLAB code

Figure 21. Outputs from GLCD

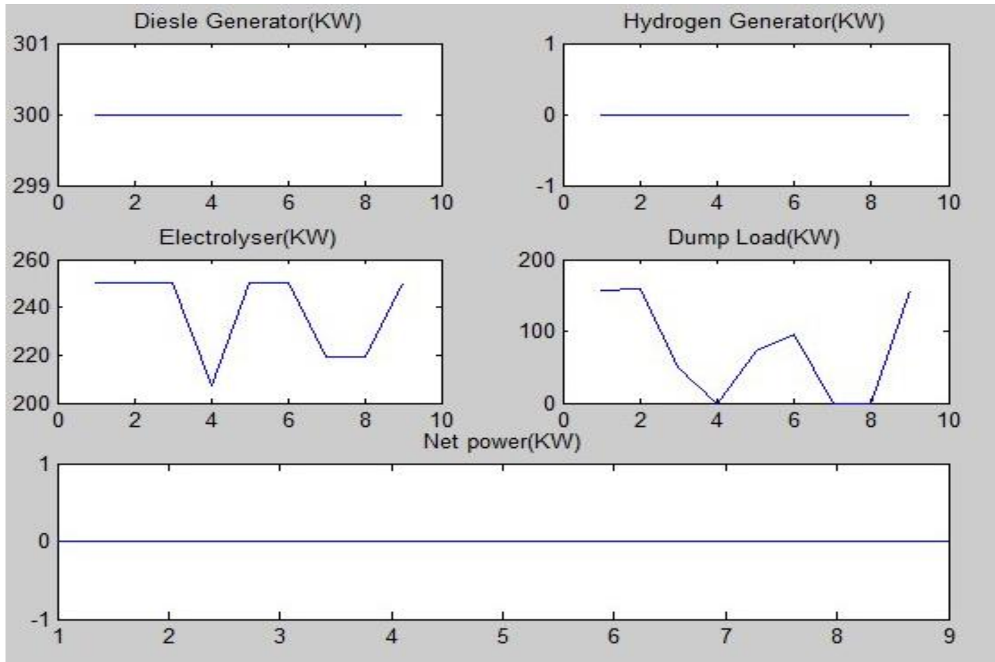


Figure 22. MATLAB Diagram fro 9 Data Points

Data log system

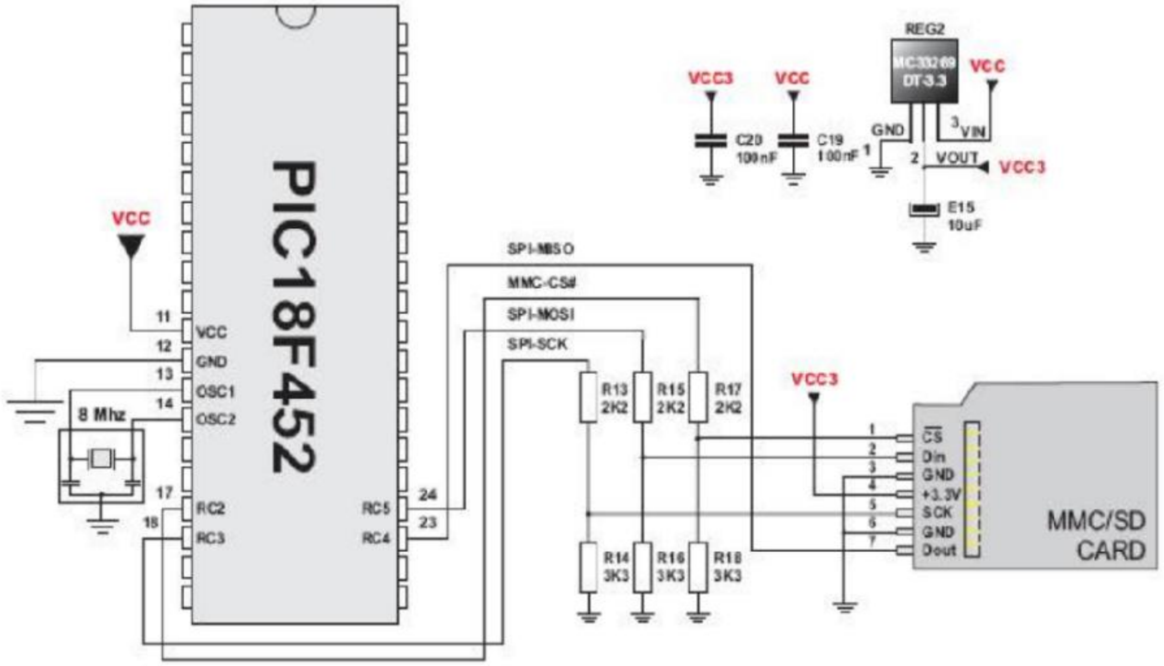


Figure 23. SD card Connection Layout

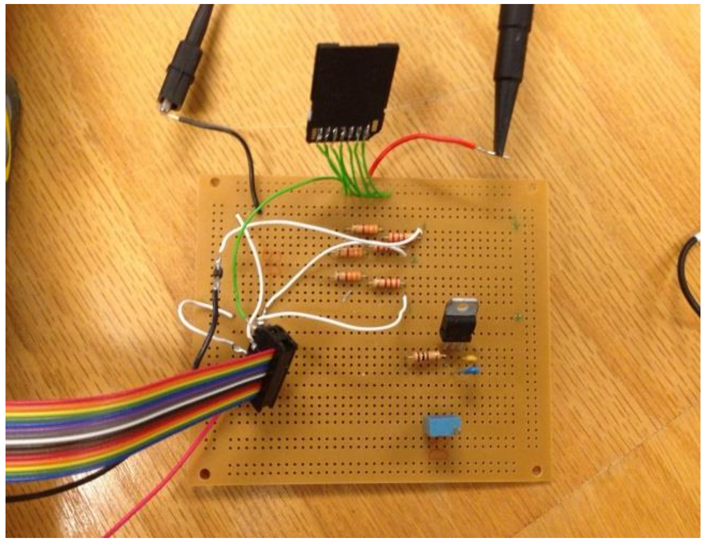


Figure 24. Circuit for Interacting MicroSD Card

EasyPIC3 Testing Results

- Two analog input: WTGs and Load Commutation
- Three factors: Weather prediction, tank levels(working range), and tank full/ not full
- Testing can be performed by varying the values of the inputs and the three factors
- A total of 27 groups of testing results

Tests Setting(KW)				Result(KW)				
Weather LATD.4	Tank full LATD.5	Tank usable LATD.3	WTG-Load (net)	DEG 30% LATC.0	DEG >30% LATC.1	AE LATC.2	H2G LATC.6	Dump load LATD.2
0	0	0	-52	300	0	249	0	0
0	0	0	-10	300	0	250	0	40
0	0	0	74	300	0	250	0	124
0	0	0	-369	371		0	0	0
0	0	1	54	300	0	250	0	104
0	0	1	-87	300	0	213	0	0
0	0	1	-365	300	0	0	65	0
0	0	1	122	300	0	250	0	172
0	0	1	-1023	773		0	250	0
1	0	0	378	0	0	250	0	128
1	0	0	147	0	0	147	0	0
1	0	0	-363	0	0	0	0	0
1	0	0	-	-	-	-	-	-
0	1	0	138	300	0	0	0	438
0	1	0	-52	300	0	0	0	249
0	1	0	-	-	-	-	-	-
0	1	0	-	-	-	-	-	-
0	1	1	-369	300	0	0	69	0
0	1	1	-102	300	0	0	0	198
0	1	1	108	300	0	0	0	408
0	1	1	-16	300	0	0	0	284
1	0	1	-15	0	0	0	16	0
1	0	1	-390	0	0	0	250	0
1	0	1	35	0	0	35	0	0
1	0	1	390	0	0	250	0	140
1	1	1	390	0	0	0	0	390
1	1	1	-48	0	0	0	48	0
1	1	1	-359	0	0	0	250	0
1	1	0	-359	0	0	0	0	0
1	1	0	80	0	0	0	0	80

EasyPIC3 Testing Results (cont'd)

- Values for the three factors : " 0 0 0 "
- "WTG – Load" is 52 kW
- Based on the control logic for this case, DEG 30 % (300kW) will be added to the system first
- Surplus power is 300-52 = 248 kW, which is less than the AE ratted power, this indicates AE can consume all the surplus power
- The simulation results in steady state are:

DEG 30%	DEG>30%	AE	H2G	Dump Load
300	0	249	0	0

CONCLUSION

- Developed a low order dynamic model of Ramea hybrid power system based on MATLAB/Simulink
- A10 minutes simulation could be done in few second based on the low order model
- Control logic developed based on the priority of the equipments
- Five case studies to analyze the system
- Controller design based on a PIC18F4550 microcontroller and data stored on a MicroSD card
- A need to get actual system parameters for a more accurate system modeling (NL Hydro does not provide those informations)

FUTURE WORK

- Study the impact of reactive power on the system stability
- Dynamic system modeling parameters are taken from other similar systems. Once Ramea power system data (such as load damping coefficient and inertia coefficient) is available, model parameters need to be recalculated and new simulations need to be performed
- For high power model simulations or real power system with actual power system equipment, code can be different
- Multiple micro-SD cards need to be studied and implemented on the circuit to prevent data loss during data accusation period. Wireless communication is also desirable.

ACKNOWLEDGEMENT

- Dr. Tariq Iqbal
- IEEE Newfoundland and Labrador Section & Newfoundland Electrical and Computer Engineering Conference (NECEC)
- Wind Energy Strategic Network (WESNet)
- School of Graduate Studies, Memorial University
- Thank you all

PUBLICATIONS

- Jiuchuan Zhang, M. T. Iqbal , “A Simple Frequency Control Approach for Ramea Wind Diesel Hydrogen Hybrid Power System”, presented at *21st IEEE, NECEC, 2012*
- Jiuchuan Zhang, M.T. Iqbal, “Design of a Supervisory Controller for Ramea Wind Diesel Hybrid Power System”, presented at WESNet *Student Poster Session and competition*, October 18, 2012, Toronto, Canada
- Jiuchuan Zhang, M.T. Iqbal, “A Low Cost Simple Supervisory Controller Design for Ramea Hybrid Power System”, presented at *22nd IEEE NECEC,* 2013
- Jiuchuan Zhang, M.T. Iqbal, “A Simple Low Cost Supervisory Controller for Ramea Hybrid Power System”, presented at WESNet *Student Poster Session and competition*, October 7, 2013, Toronto, Canada


ANY
questions?