Small Wind Turbine Based Packet Energy System with Battery Storage

Presenter: Md Shakhawat Hossain
Supervisor: Dr. Tariq Iqbal
Faculty of Engineering & Applied Science
Memorial University of Newfoundland

6th June, 2014

Outline

- Background of packet energy system
- Design and implementation of a grid connected energy storage system to profit from net-metering and variable rate electricity
- Design and implementation of a wind energy based packet energy system
- Analysis of simulation and experimental results
- Conclusions
- Future works

Background

- CanWEA believes that 20% of Canada's electricity demand can be satisfied from the wind energy by 2025.
- Wind energy can also cut Canada's annual greenhouse gas emissions by 17 Megatons.
- Wind projects have very short construction periods and can be deployed quickly with many benefits delivered to local communities.

What is Energy Packet Network (EPN) ?

- "Energy packet networks (EPNs)" has been suggested by Dr. Erol Gelenbe [1].
- EPN offers smart management of energy flow. Here, energy flows like a packet in the internet rather than the continuous instantaneous flow of current towards points of energy consumption.
- An energy packet can be described as a pulse of power which lasts for a certain time. So, the unit of the energy packet is kWh. The duration of the energy packet is determined by the grid according to the requirement.
- The flow of energy in energy packet network is controlled by a Smart Energy Dispatching Center which is basically a computer control center.
- EPN tries to optimize the energy flows by making the best use of available renewable energy sources and existing pricing policies.

Related Works

- A new type of power system is proposed named "Digital Grid" in [2] . Here, a wide-area synchronized power system is subdivided into smaller or medium sized cells. It can help to prevent wide area blackout.

- Plug-in vehicle charging has been proposed using charge packets which are analogous to discrete data packets used in communication system [3]. Here, packetized charging breaks the required charge time into many small intervals or packets.

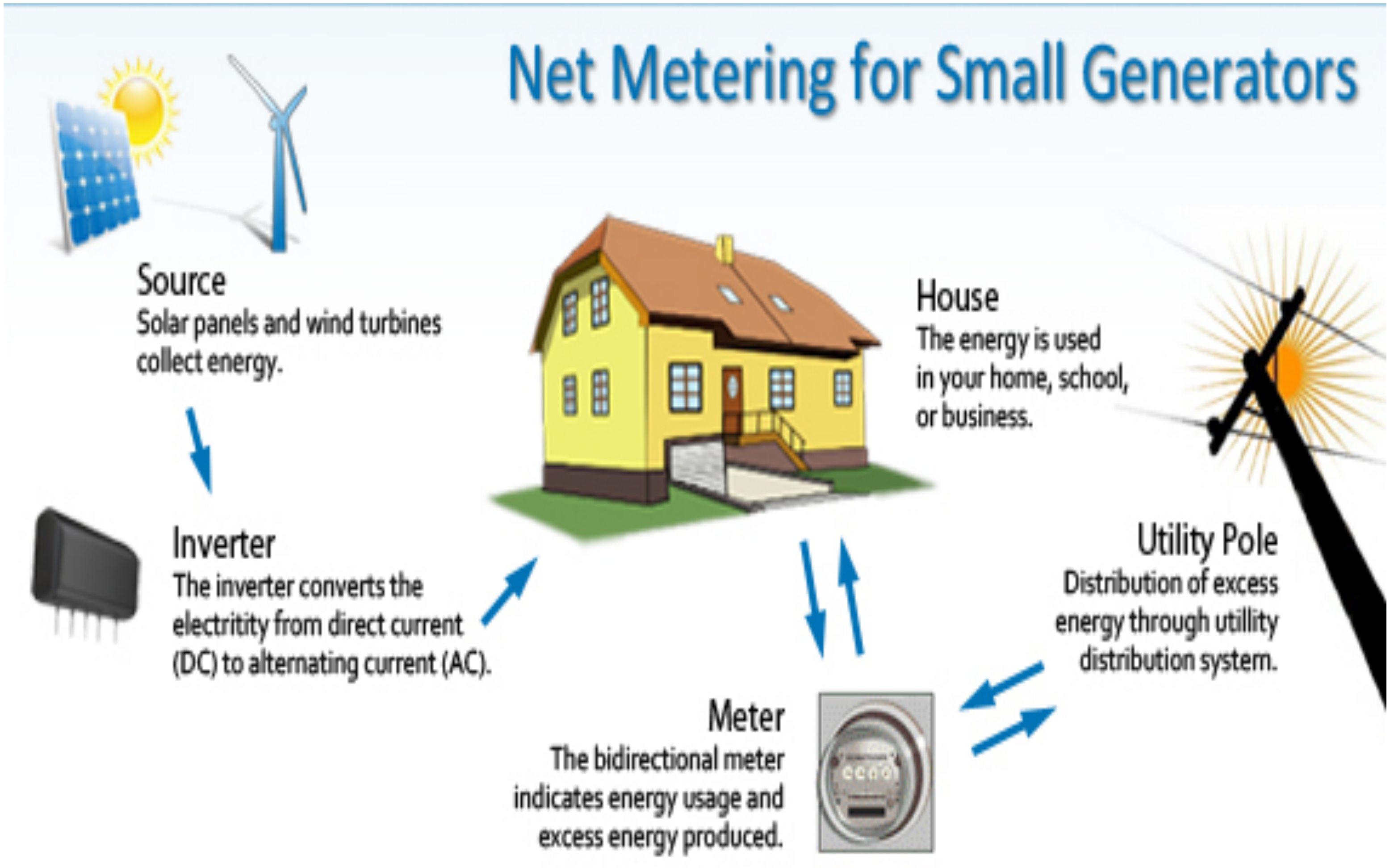
- An electric power system with intelligent power switches (IPS) based on the internet and micro-grid has been proposed in [4]. Packetized energy is transferred from power sources to loads through IPS.

- An internet-based energy provisioning concept has been proposed in [5]. Customers can order and request future power demands through a system called Online Purchase Electricity Now (OPEN)

EPN will play a vital role in future grid. Internet concepts are being used in smart grid to make it more reliable, secured and cost effective

Design and implementation of a grid connected energy storage system to profit from net-metering and variable rate electricity

What is Net-Metering ?



Understanding Net-Meter Digital Displays

Program Number

- Meter type that is associated with the net metering customer's account.
- Direction of electricity flow

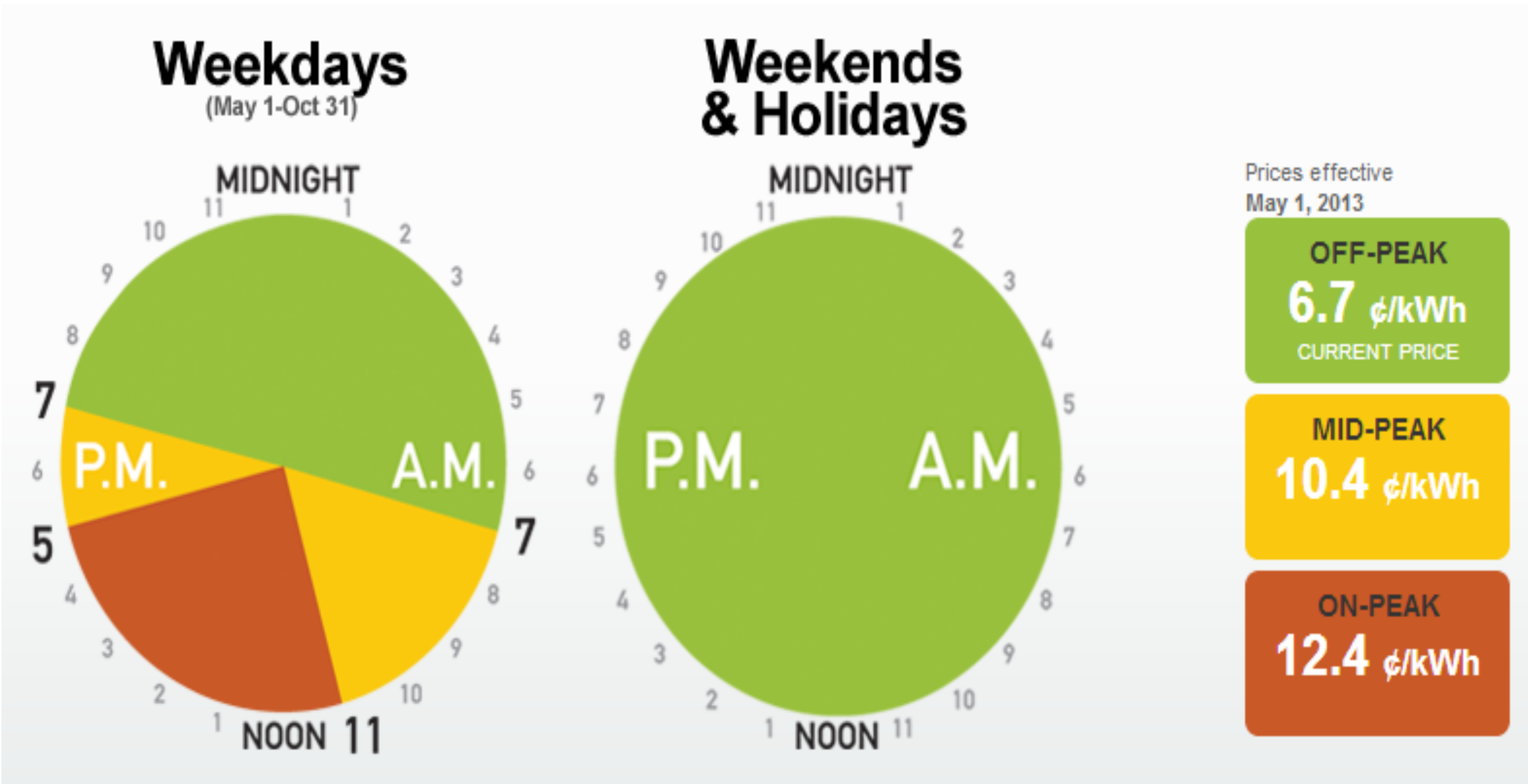
Billing Register

- Total kWh usage (net consumption and generation) registered by the meter

Segment Screen

- Every LCD segment that can possibly show up on the meter screen

Variable Rate Electricity



Objective: Store energy in batteries when it is cheaper and sell that back when it is pricy. Try to make money using the storage.

Energy Storage System Design in Homer

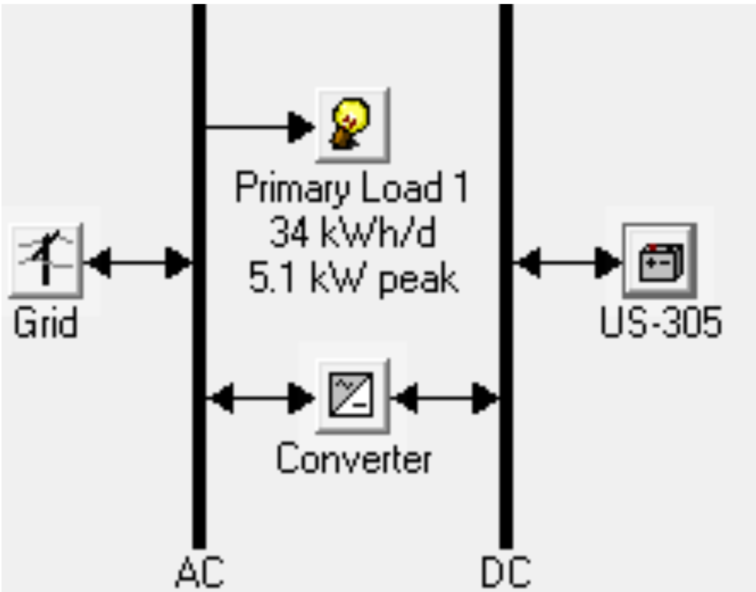


Figure 1

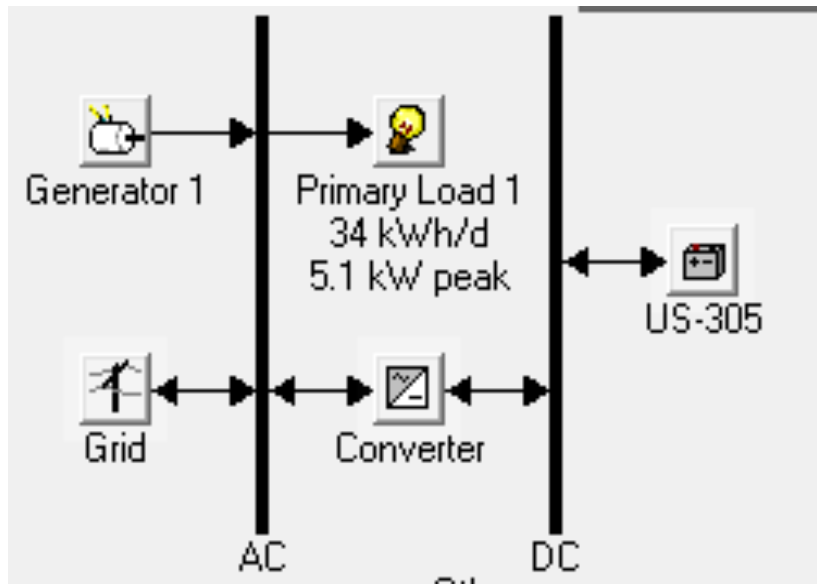
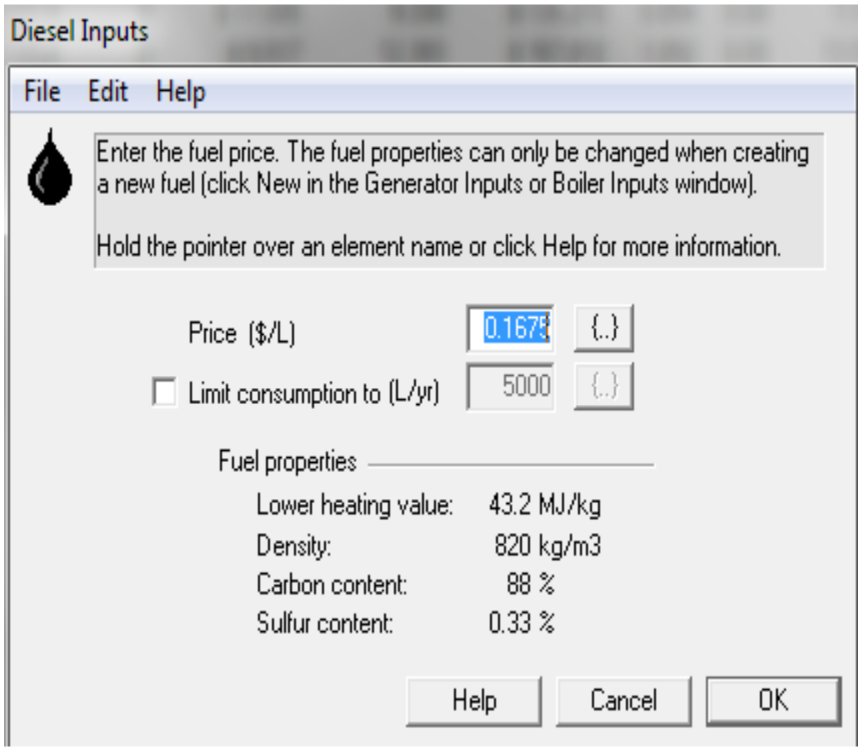


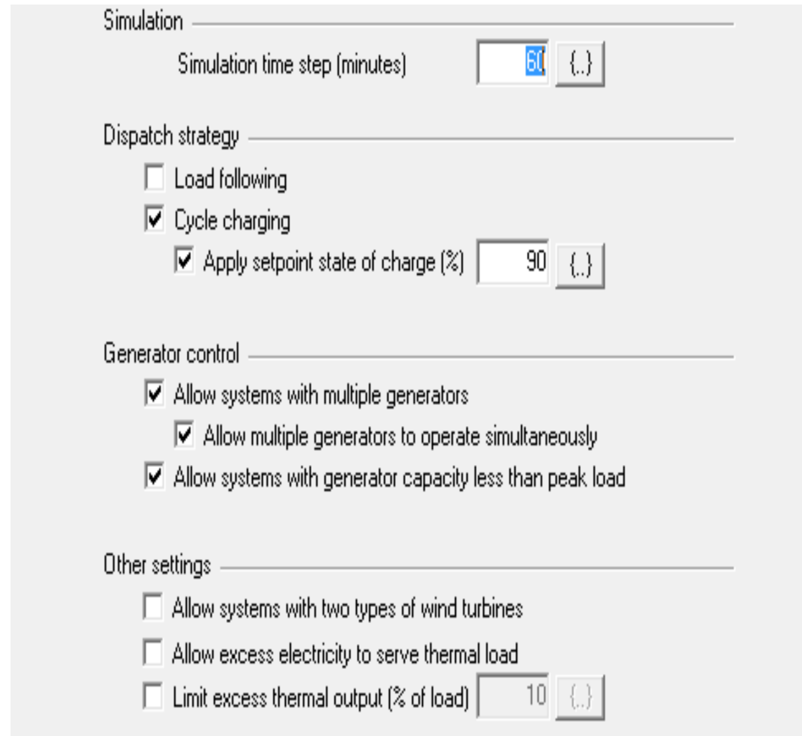
Figure 2

Grid Purchase is 0.

Homer does not model a bidirectional converter. A diesel generator is used to represent energy purchase from the grid.

Diesel inputs and System Control in Homer

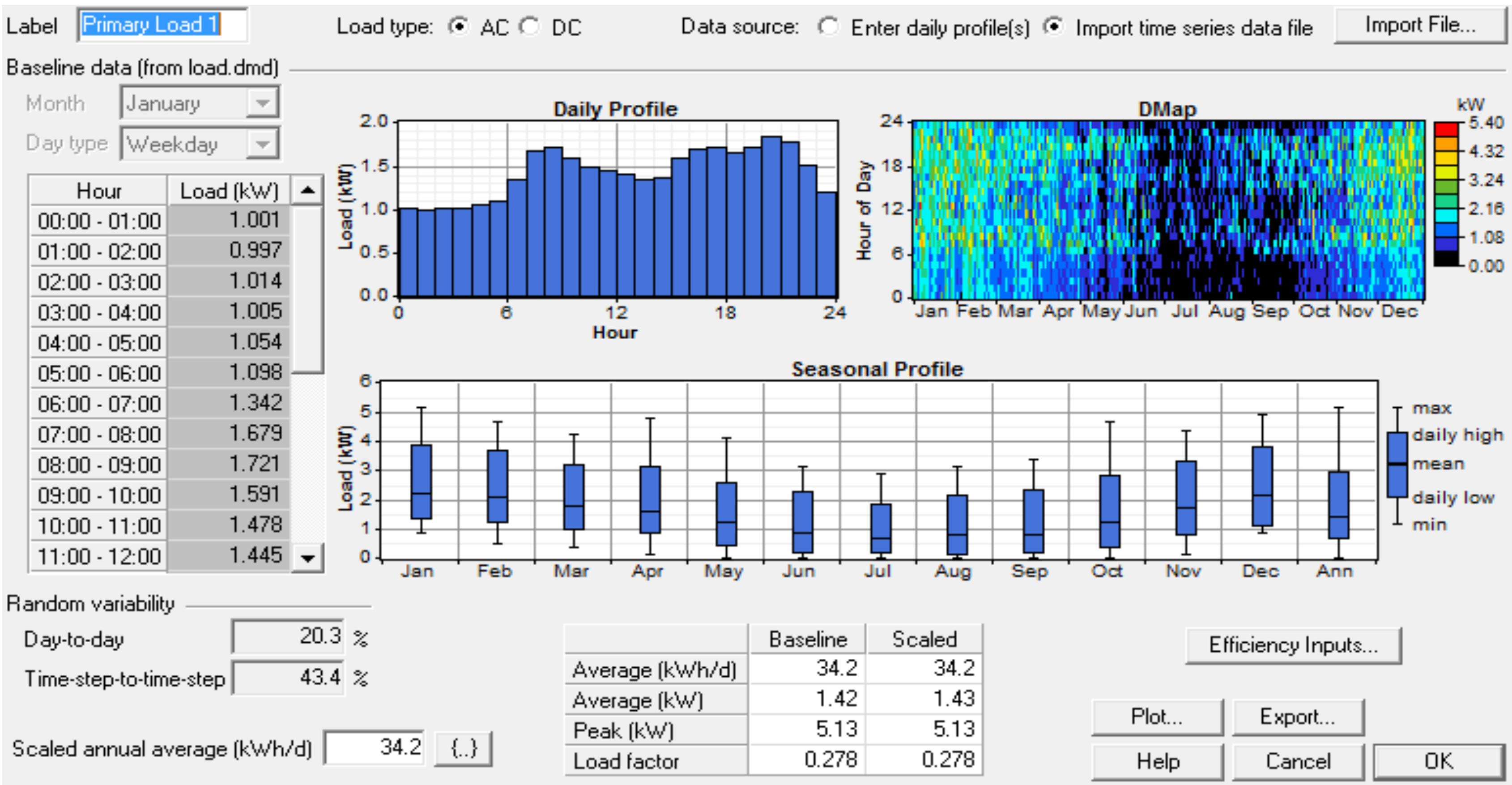




Diesel fuel cost is adjusted to represent electricity purchase from the grid.

Fuel price = 0.067($/kWh) / 0.4(L/kWh) = $0.1675 /L.

Typical Household Load



Actual logged data of a 3 bedroom house in St. John’s.

Converter and Battery Specifications in Homer

Converter Specification

- 11.4 KW bidirectional converter
- The capital cost and replacement cost is $ 4,022.
- Lifetime and efficiency of inverter output is set to 15 years and 85% respectively.

Battery Specification

- 6V, 305Ah USB US-305
- The capital cost and replacement cost is $ 234
- the O & M cost is $50 per year.
- 8 batteries is used per string to make 48V DC bus.

Results from Homer

Total household load served = 12,483 kWh/yr.
Energy from grid considering efficiency of battery and inverter =17,435 kWh/yr.

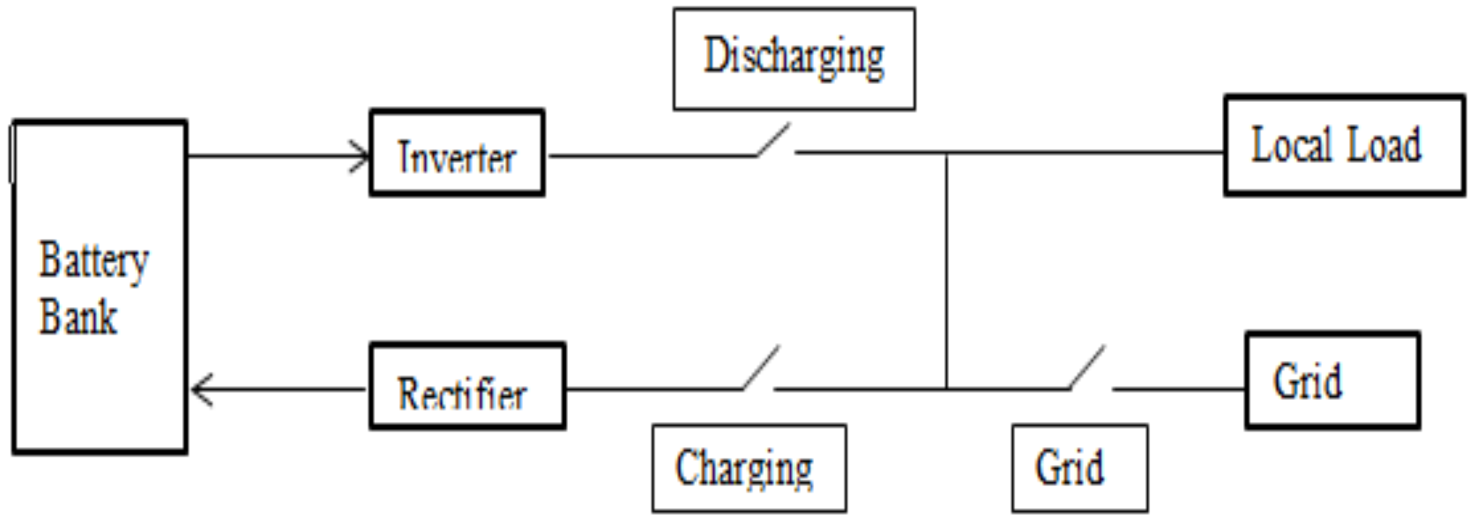
Electricity price during off peak = $0.067/kWh
Electricity price during on peak = $0.124/kWh

Total cost if energy is bought from grid during off peak= 17,435*0.067 = $1,168.15/yr.
Total cost if energy is bought from grid during on peak = 12,483*0.124 = $1,547.89/yr.

Profit=1,547.89 – 1,168.15 = $380/yr. (approx.)

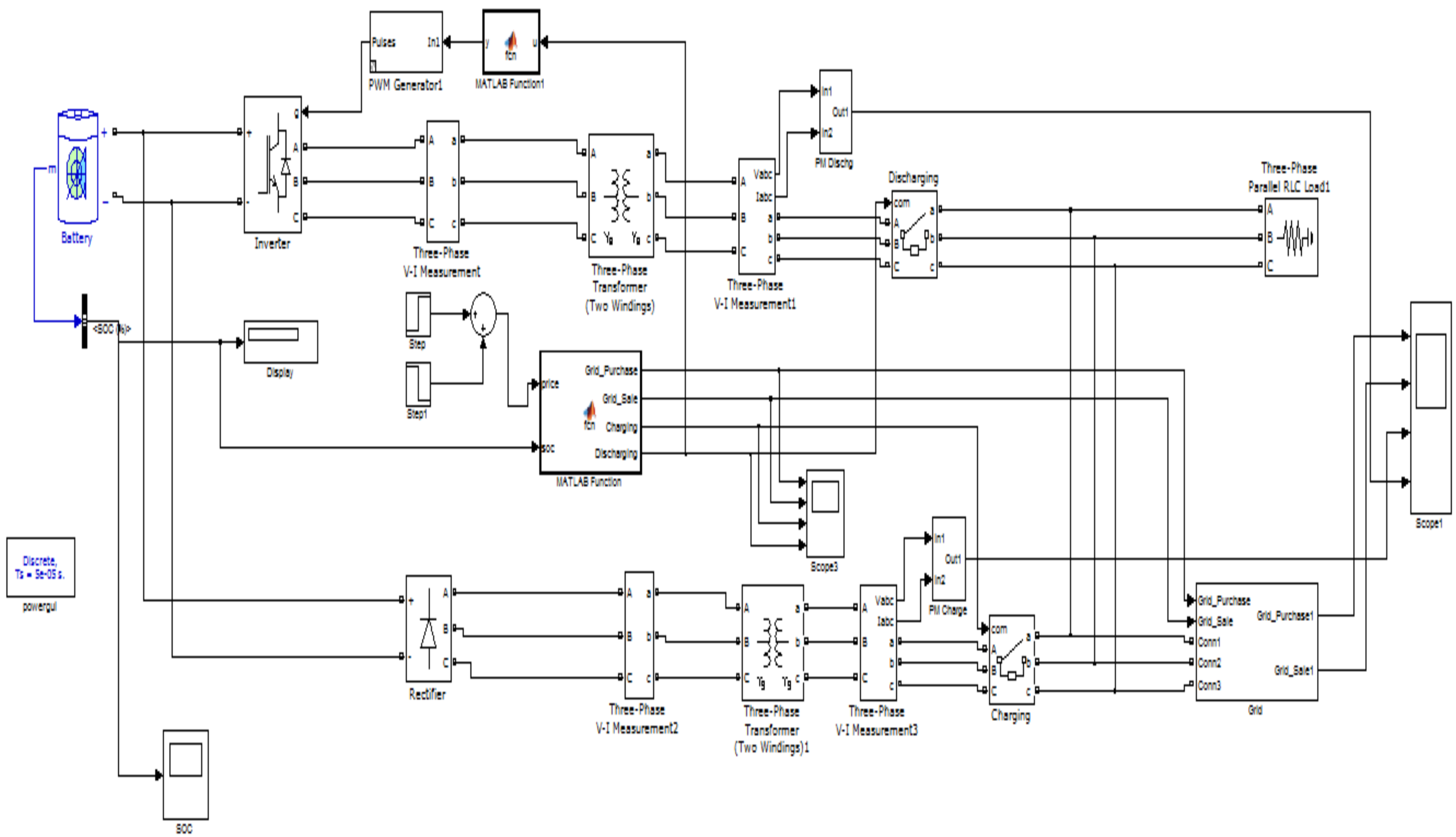
This indicates that profit could be generated using battery based energy storage system.

Design and Control of Battery Energy Storage System

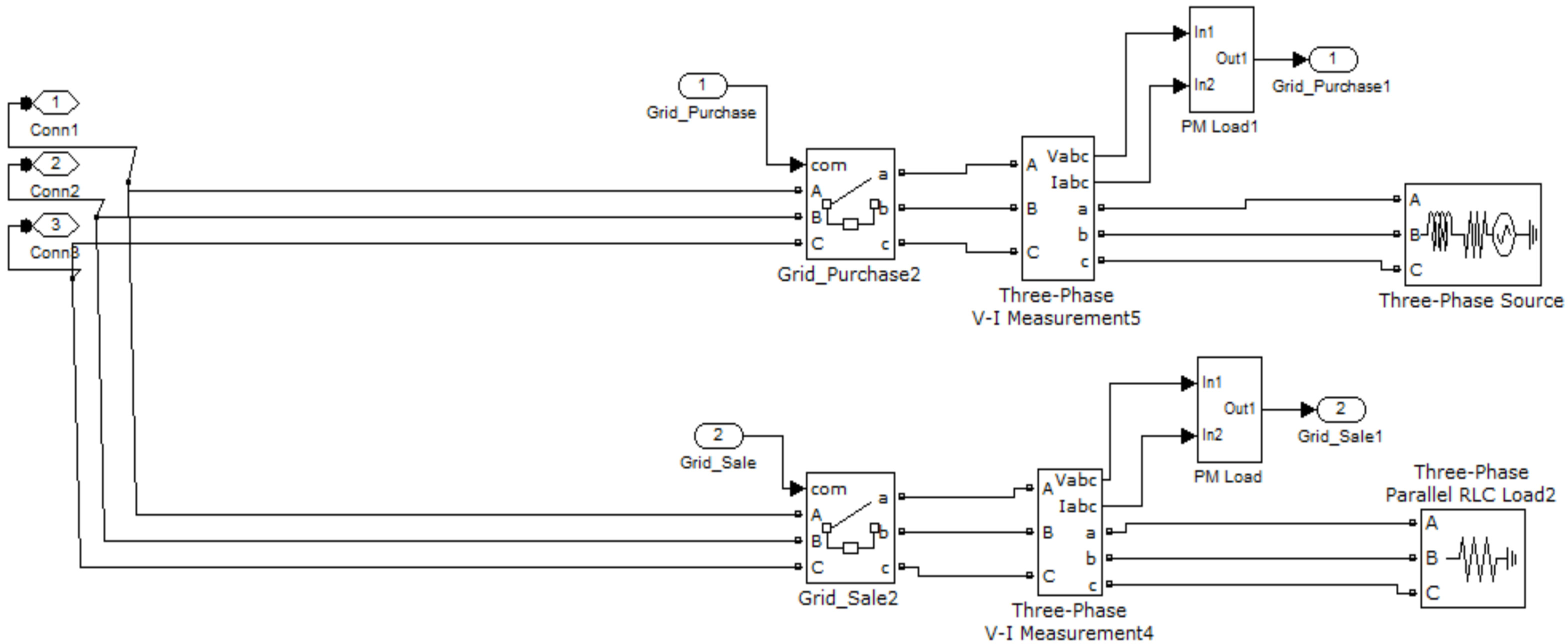


Switches are turned ON/OFF based on battery's state of charge (SOC) & electricity prices

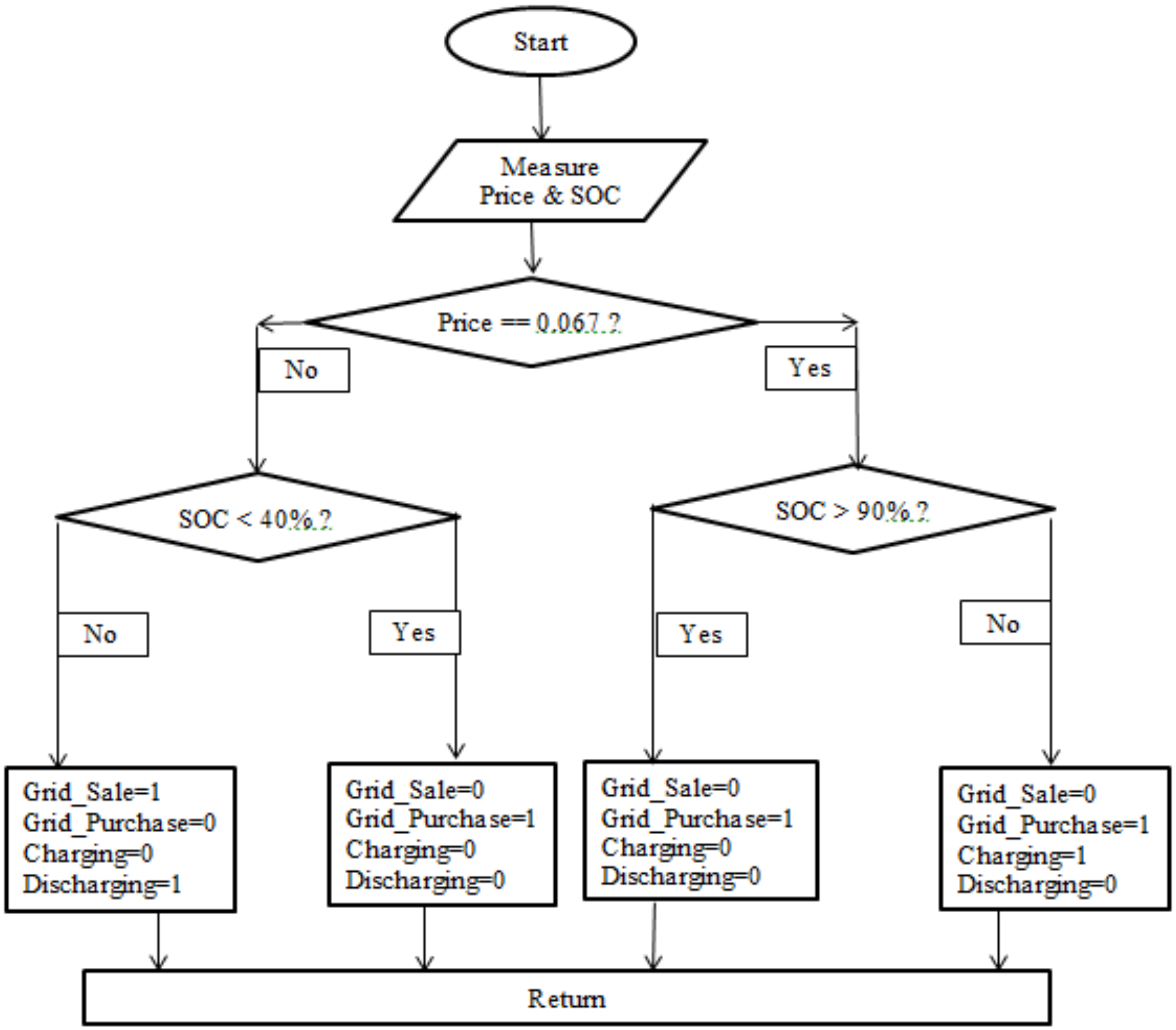
Battery Energy Storage System Modeling in Simulink/Matlab



Grid Model in Matlab/Simulink

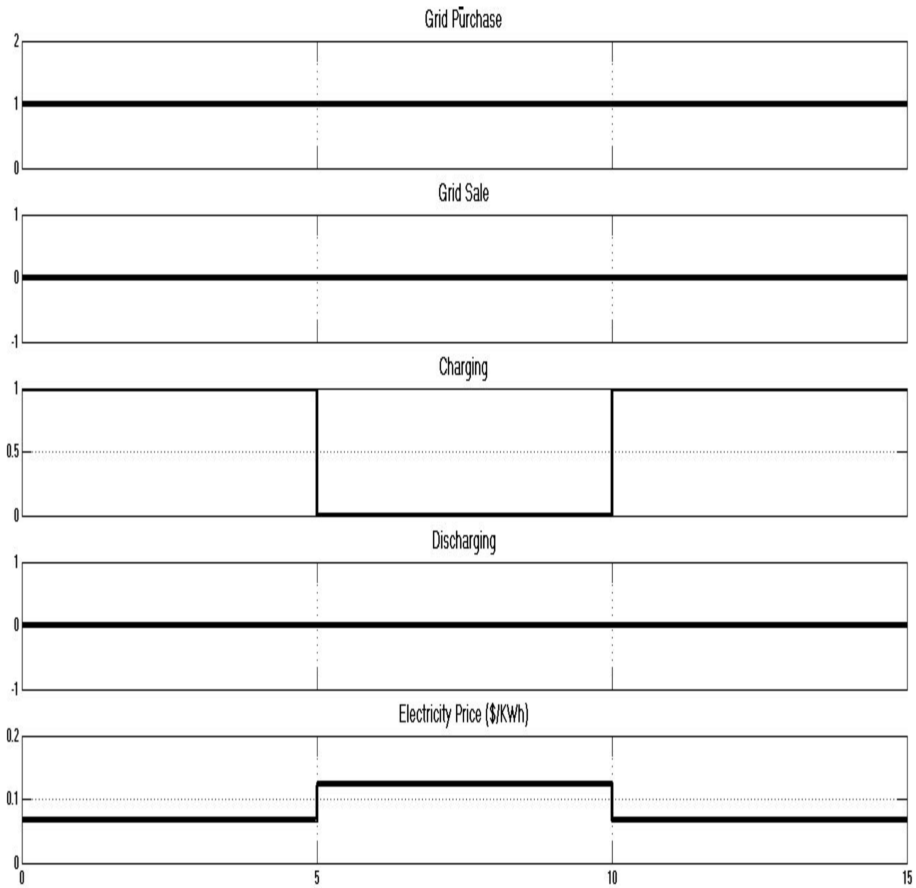


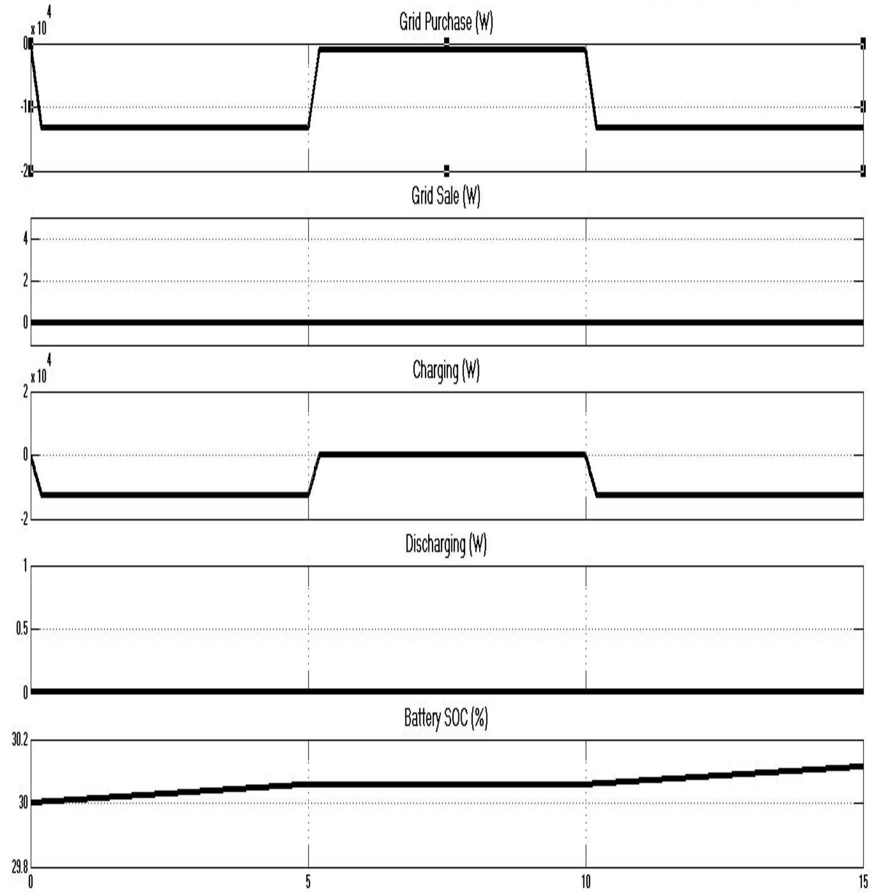
Flow Chart of Battery Energy Storage System Control



Simulation Results

Case 1: when SOC = 30% (Simulation time 3 min 10 seconds)

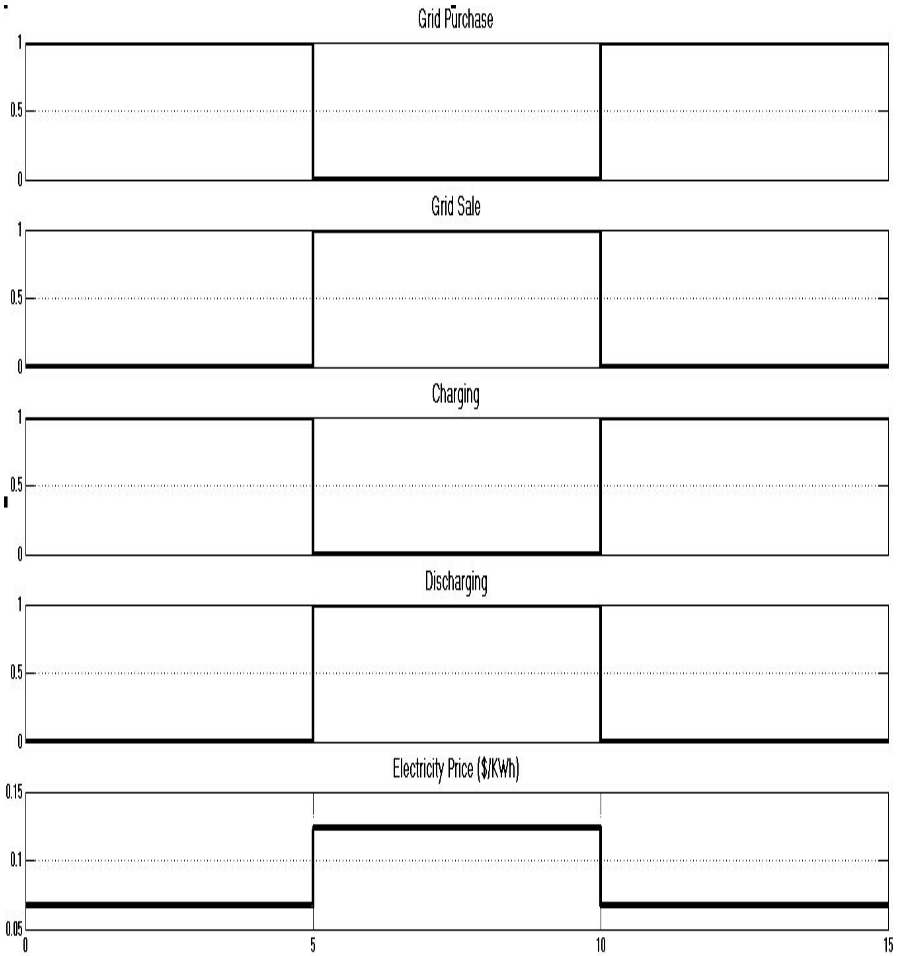


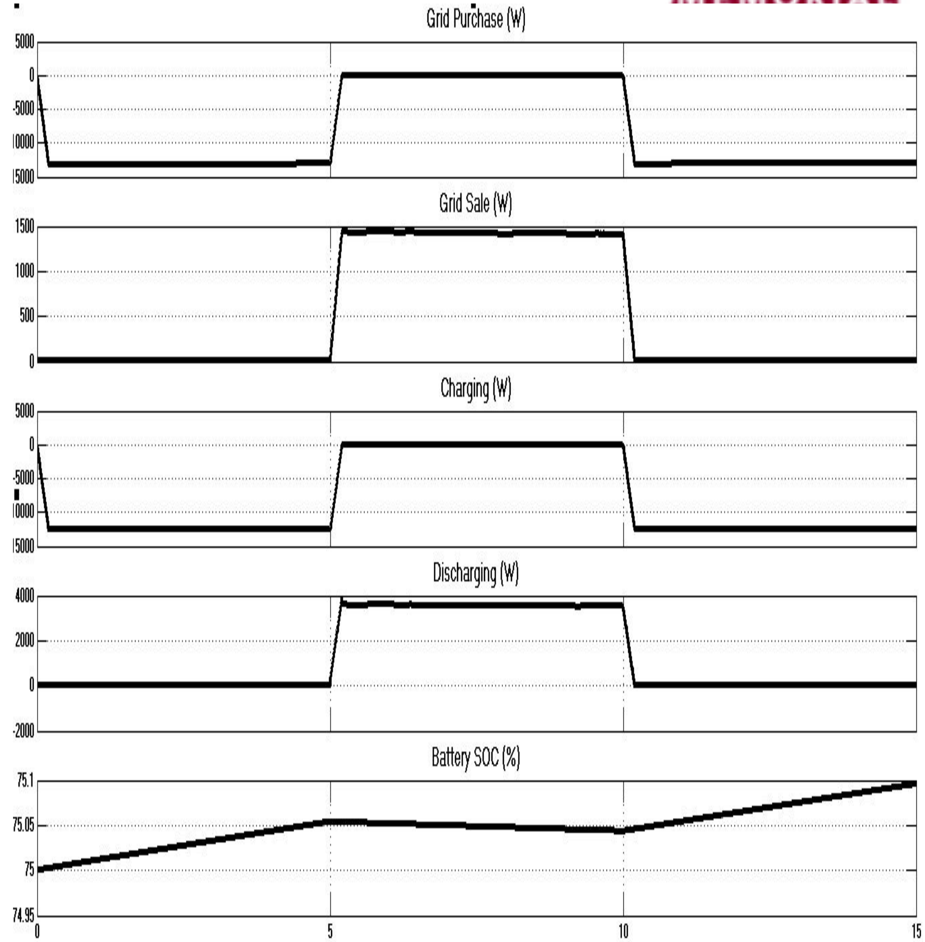


Control Values:

During Low Price	During high Price
Grid_Purchase=1	Grid_Purchase=1
Grid_Sale=0	Grid_Sale=0
Charging=1	Charging=0
Discharging=0	Discharging=0

Case 2: when SOC = 75%



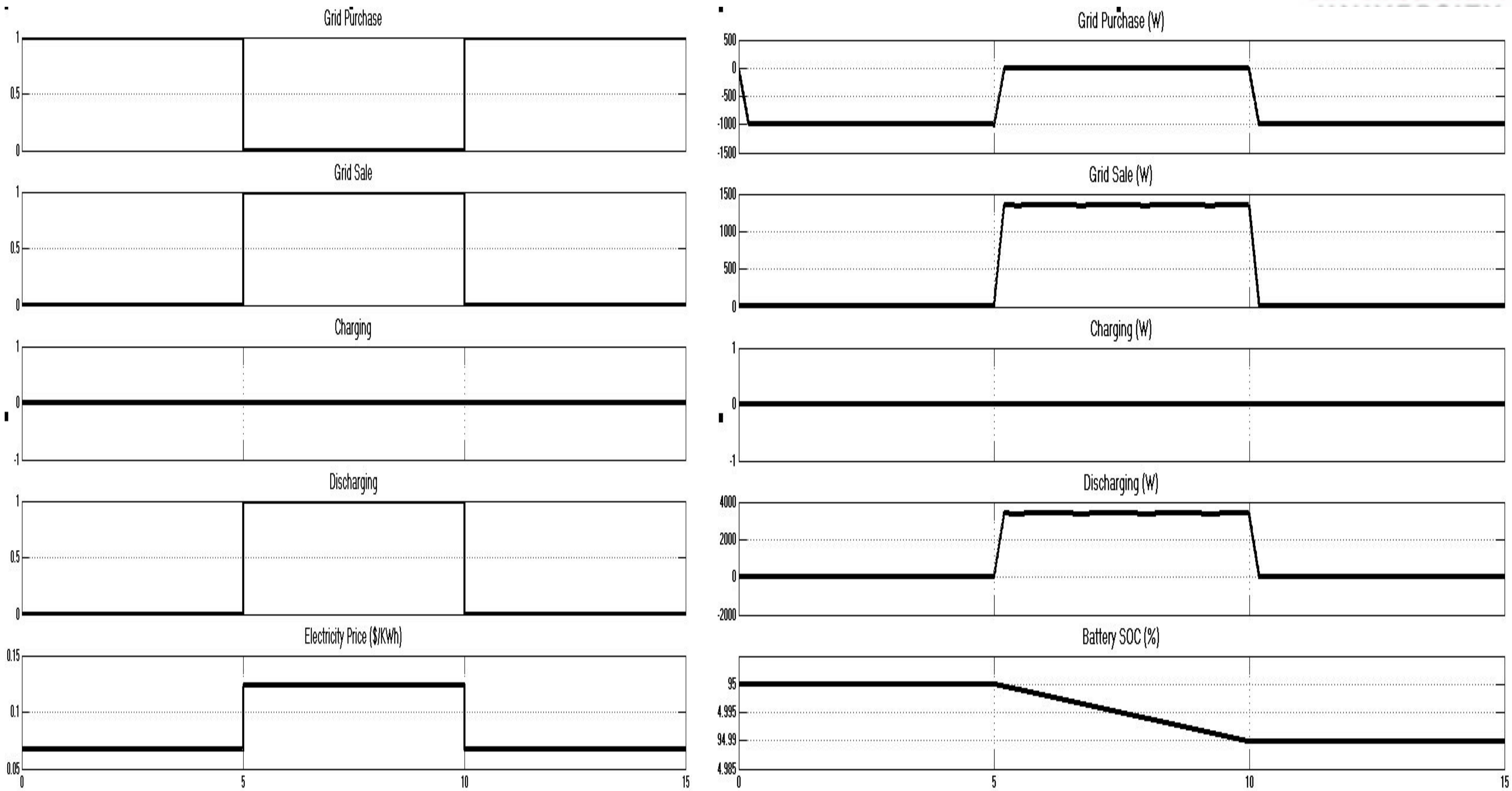


Control Values:

During Low Price
Grid_Purchase=1
Grid_Sale=0
Charging=1
Discharging=0

During high Price
Grid_Purchase=0
Grid_Sale=1
Charging=0
Discharging=1

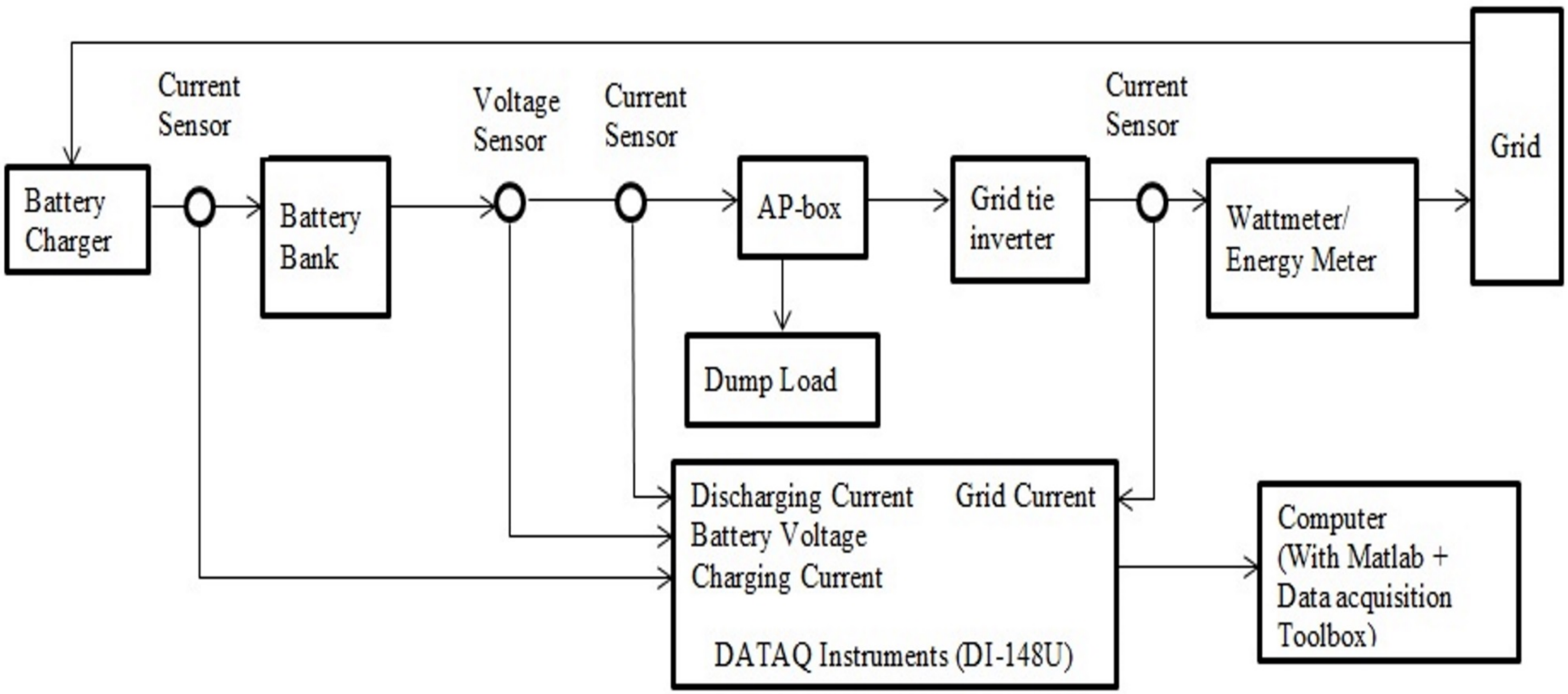
Case 3: when SOC = 95%



Control Values:

	During Low Price	During high Price
	Grid_Purchase=1	Grid_Purchase=0
	Grid_Sale=0	Grid_Sale=1
	Charging=0	Charging=0
	Discharging=0	Discharging=1

Block Diagram of Experimental Setup



Apparatus used in Experimental Setup

- Four 12V lead acid Batteries (maximum charging current is 2.1A)

- Grid Tie Inverter UWT-I-250 STARTER KIT
  - AP-box with 24 V AC/12 V DC Adaptor: connecting & safety box
  - Grid Tie Inverter
  - DUMPLOAD DL-2-100

- Voltage sensor: voltage divider circuit

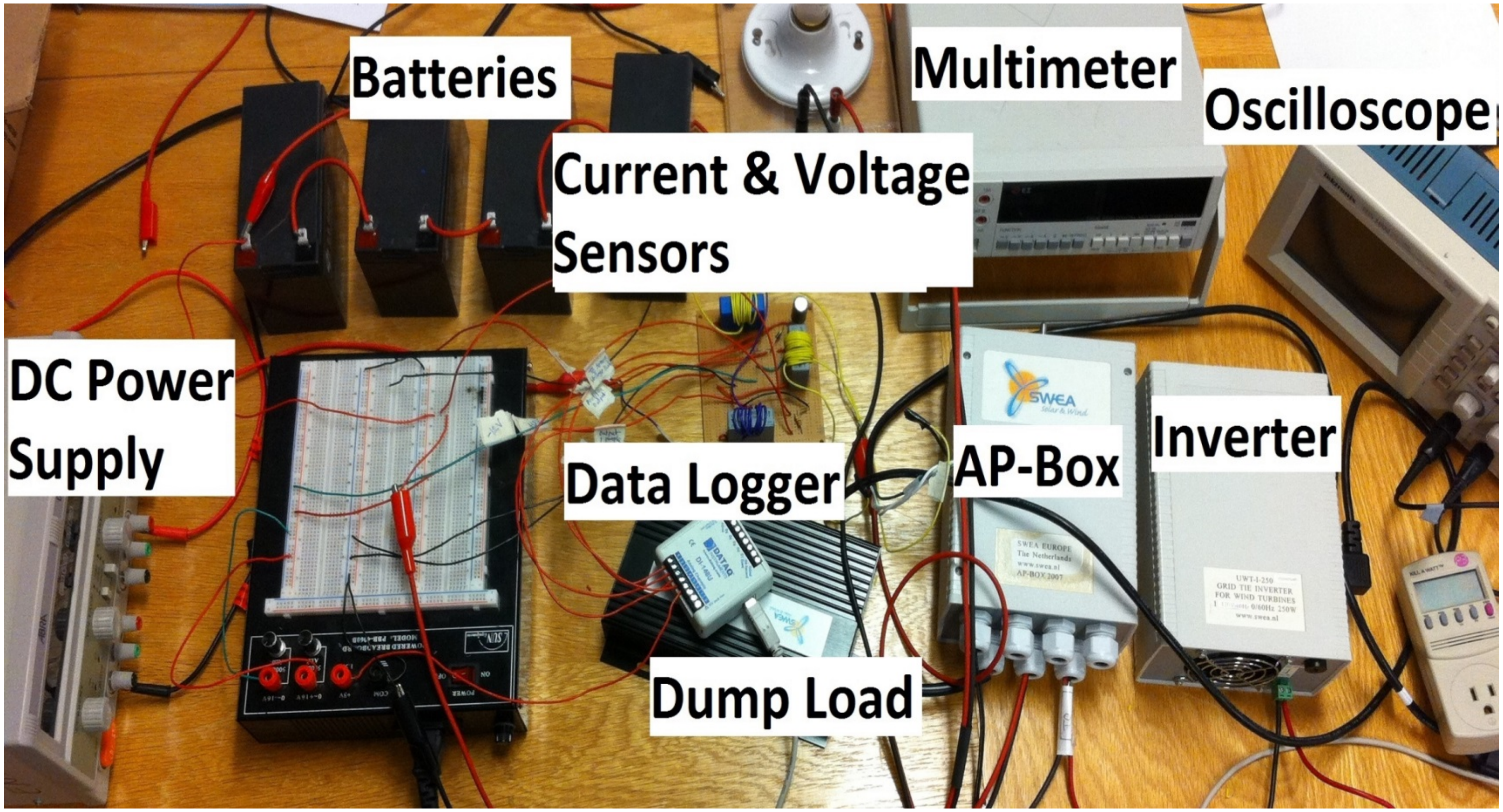
- Current Sensors: LA 55-P & CLN-50

  Primary and Secondary nominal current (rms) is 50A and 50mA

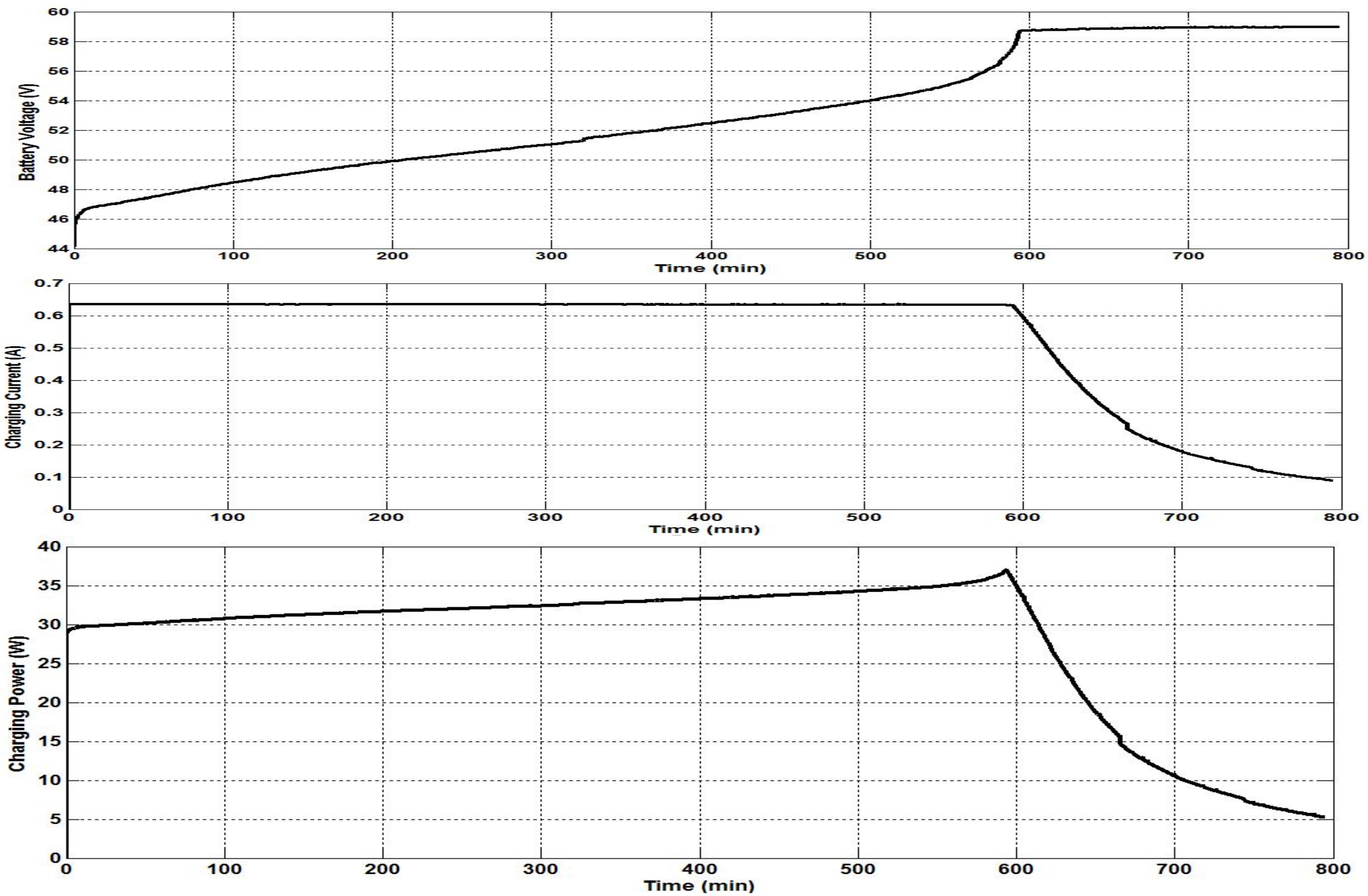
  The conversion ratio is 1:1000

- DI-148U (manufactured by Dataq Instruments) for data acquisition

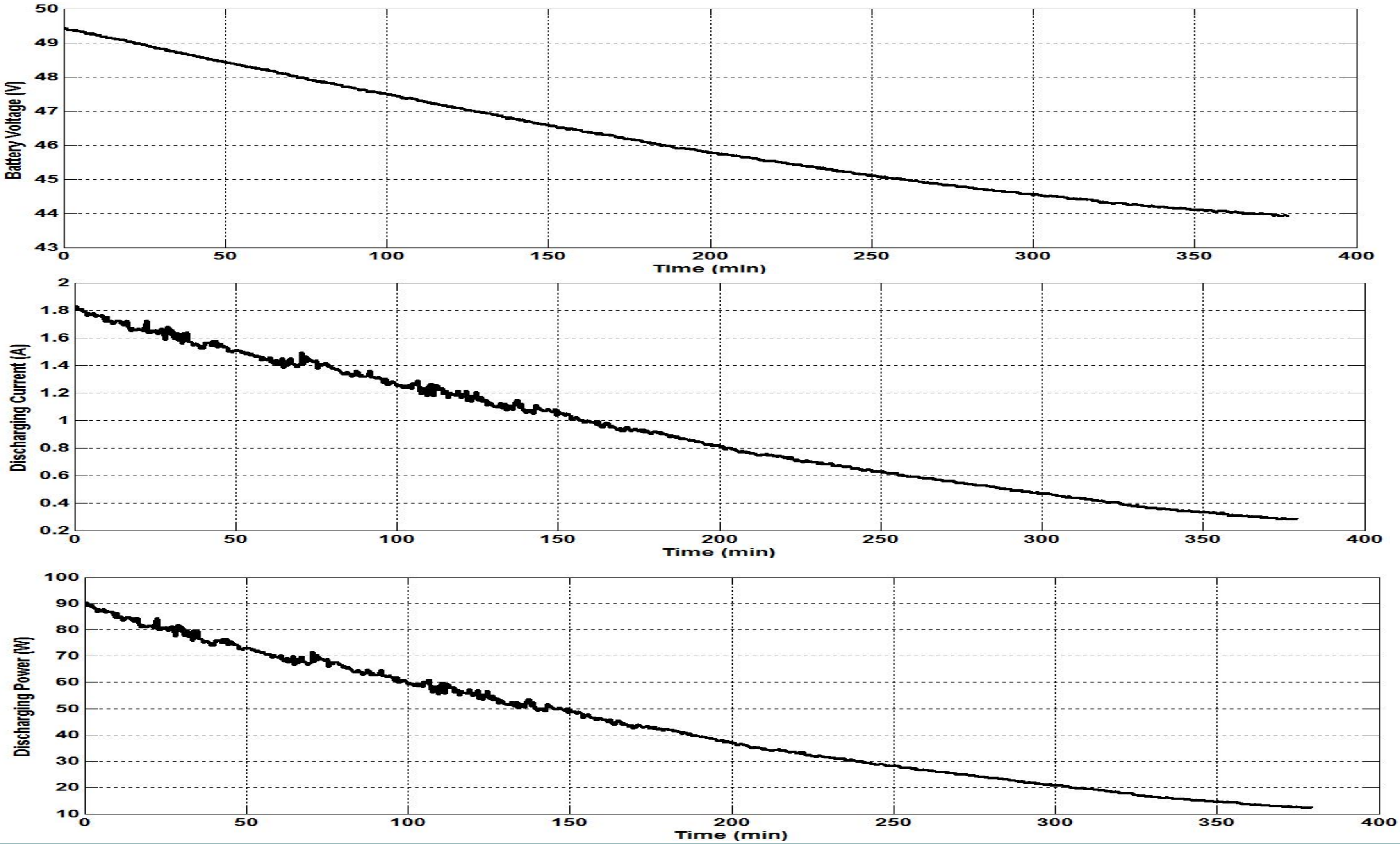
Experimental Setup in Laboratory



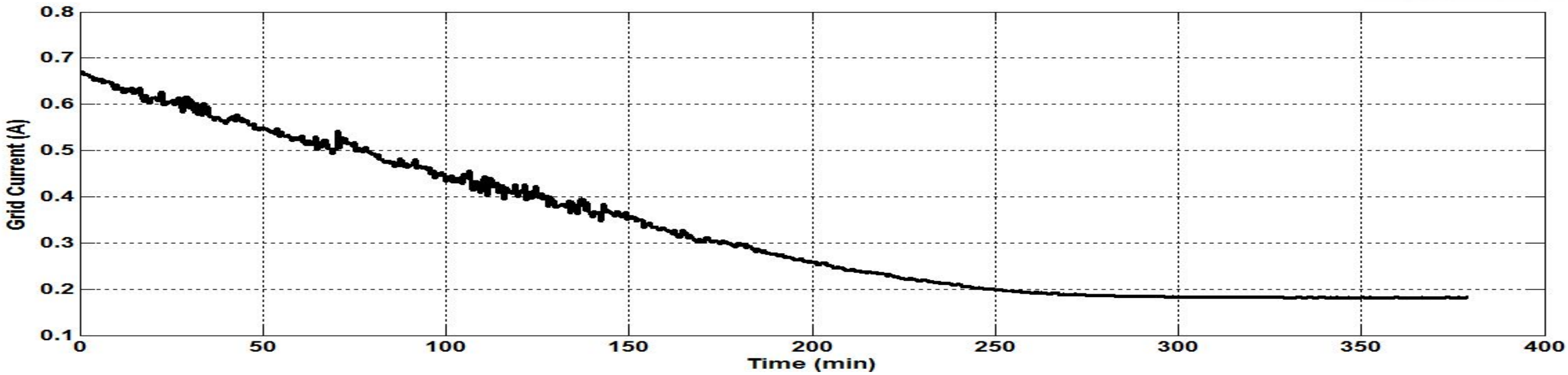
Battery Voltage, Current & Power During Charging Cycle

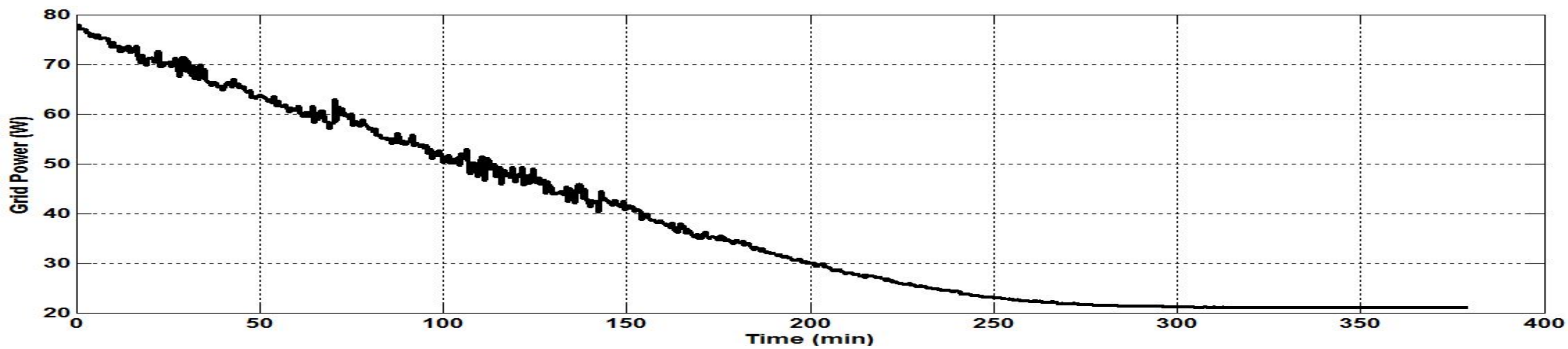


Battery Voltage, Current & Power During Discharging Cycle



Output Current and Power of the Inverter





It is assumed that grid voltage is fixed.

Experimental Results and Analysis

Total charging energy = 370.2885 Wh
Total discharging energy = 272.5765 Wh
Battery efficiency = 272.5765/370.2885=73.6%
Inverter efficiency = 85%
Overall efficiency = 62.6%

From the actual logged data of a 3 bedroom house in St. John's, total household load is 12,483 kWh/yr.

Energy needed to buy from grid 12,483/0.626= 19,941 kWh/yr. to serve household load

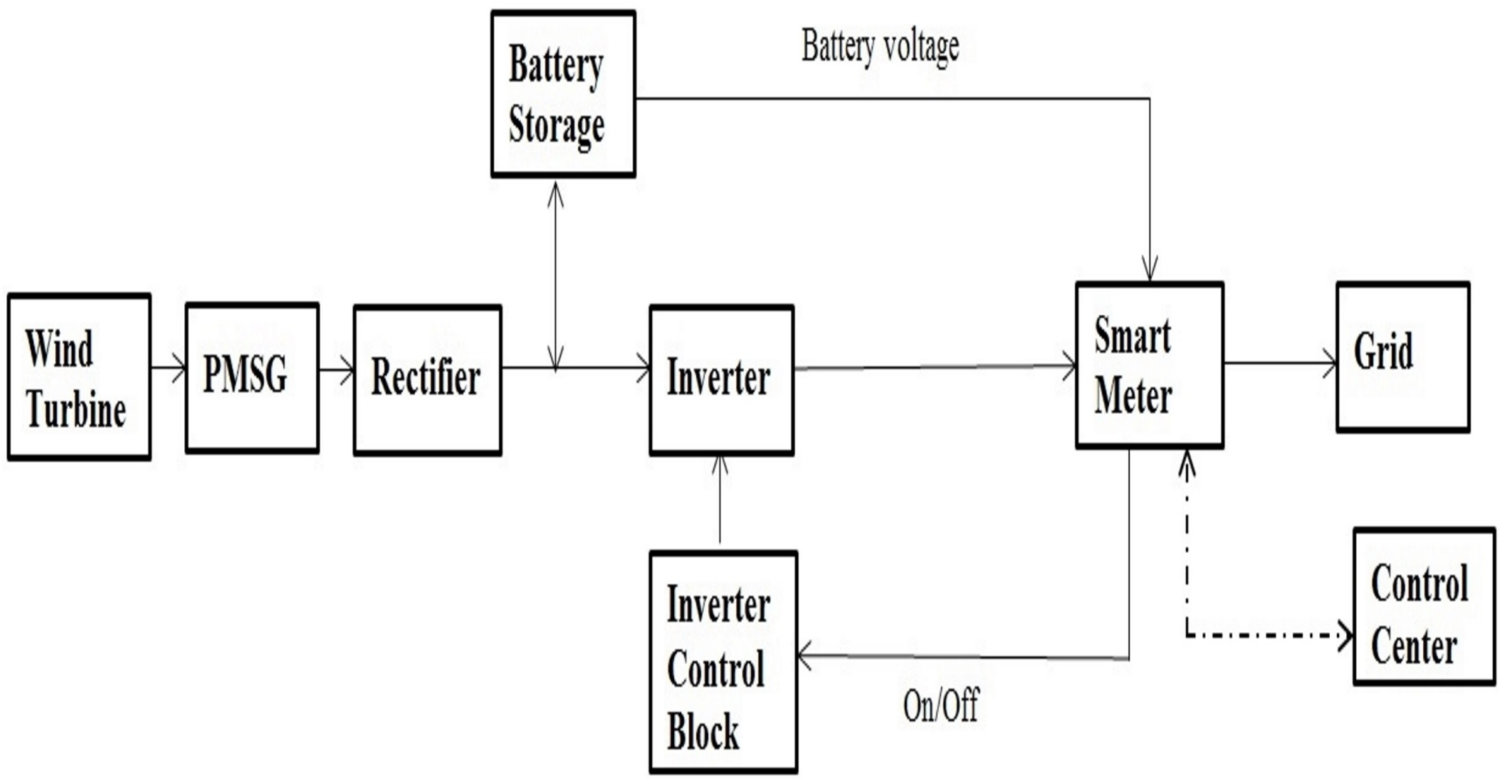
Profit = 12,483*0.124 – 19,941*0.067 = $212/yr. (approx.)

Energy price ratio for Ontario Energy Board (OEB) is 0.124/0.067=1.85 while it is 0.301/0.195=1.54 for SDG& E.

This indicates that profit could be generated if we have an efficient energy storage system.

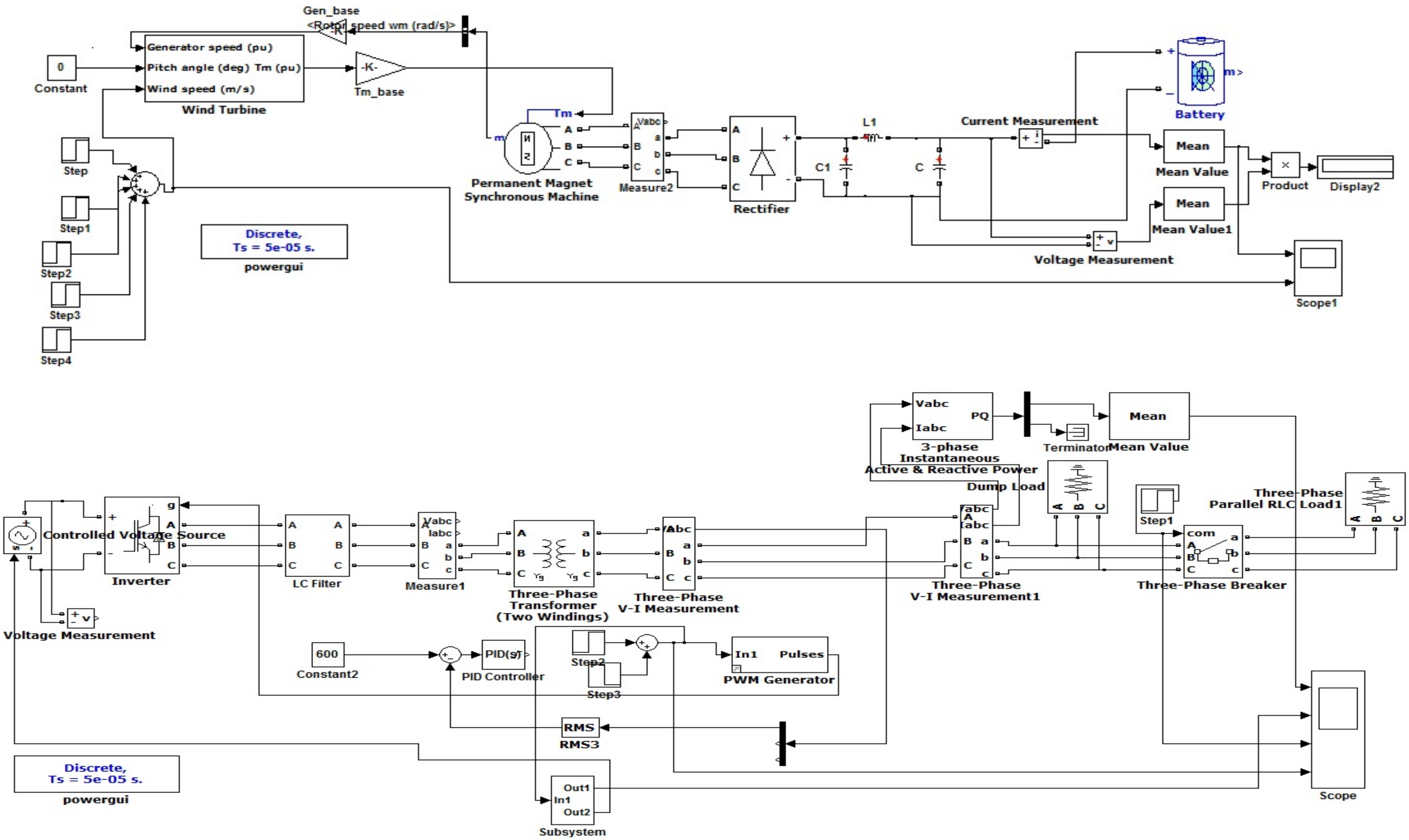
Small Wind Turbine Based Packet Energy System

Small Wind Turbine with Battery Storage



Smart meter will send the battery storage status information to the smart energy dispatch center. After getting the energy storage status, the control center randomly selects an energy system depending on the energy demand and energy production.

Simulink diagram of a grid connected small wind turbine



Simulink block parameters used in grid connected small wind turbine system

Simulation Block	Parameter	Value
Wind Turbine	Output Power	7.5 kW
	Pitch Angle	0 Deg.
Permanent Magnet Synchronous Machine	Number of Pole	24
Battery	Battery type	Lead-acid
	Nominal Voltage	6×8 V
	Rated Capacity	305×2 Ah
	Internal Resisteance	0.00019672×8/2
	Initial State of Charge (%)	80
Inverter	Power Electronic Device	IGBT/Diodes
PWM Generator	Carrier Frequency	1080 Hz
	Frequency of output voltage	60Hz
Rectifier	Power Electronic Device	Diodes
Transformer	Rating	10 KVA, 60 Hz
Grid	Voltage (p-p)	600 Vrms
Powergui	Sample Time	5×10^{-5} *sec.*

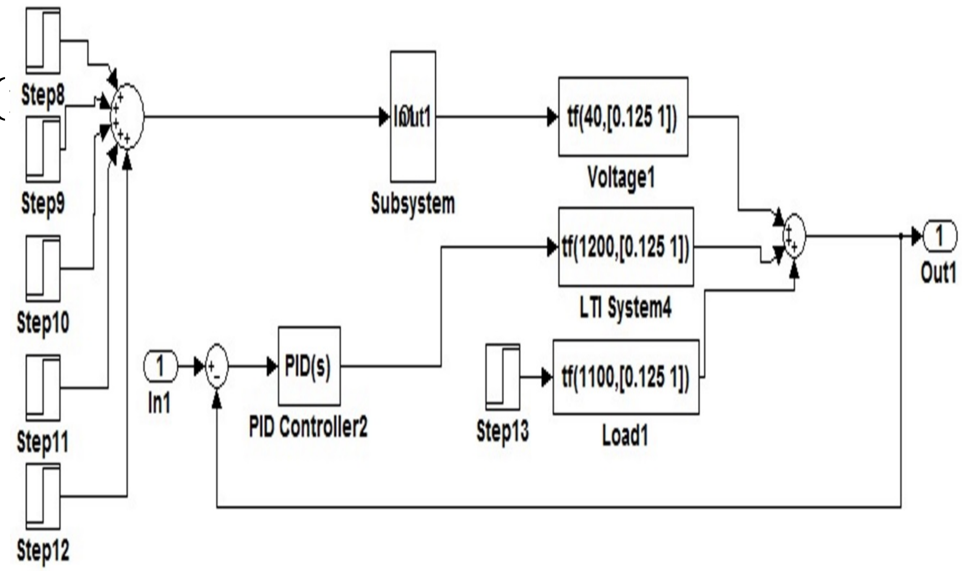
Modeling of wind energy based packet energy system

$$I_b(s)/W_s(s) = 8/0.72s+1$$

$$P_{out}(s)/V_b(s) = 40/0.125s+1$$

$$P_{out}(s)/C_{load}(s) = 1100/0.125s+1$$

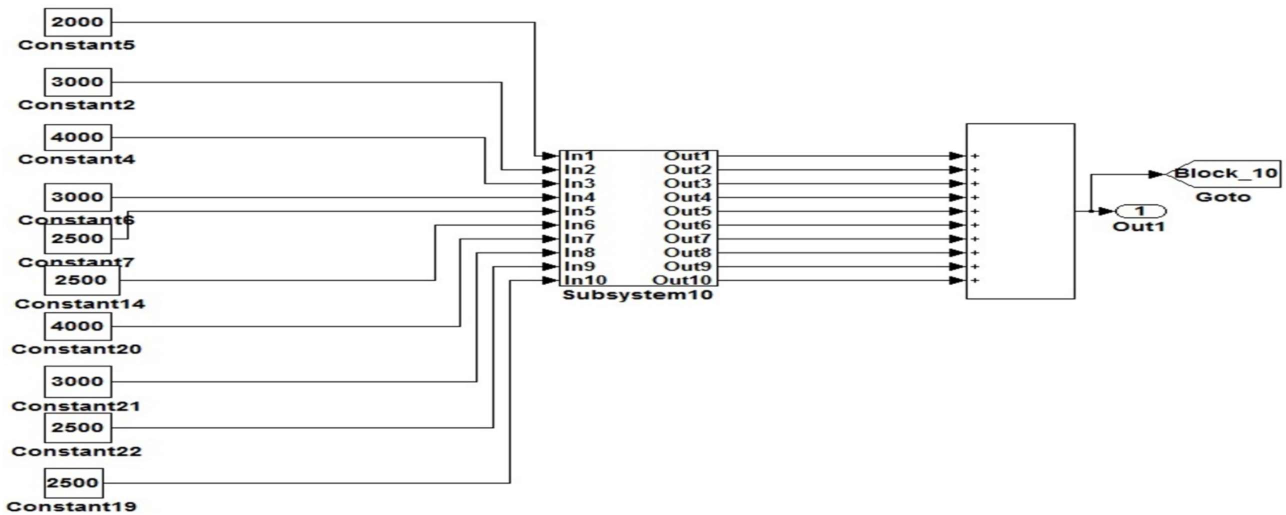
$$P_{out}(s)/C_{PWM}(s) = 1200/0.125s+1 \quad (4)$$



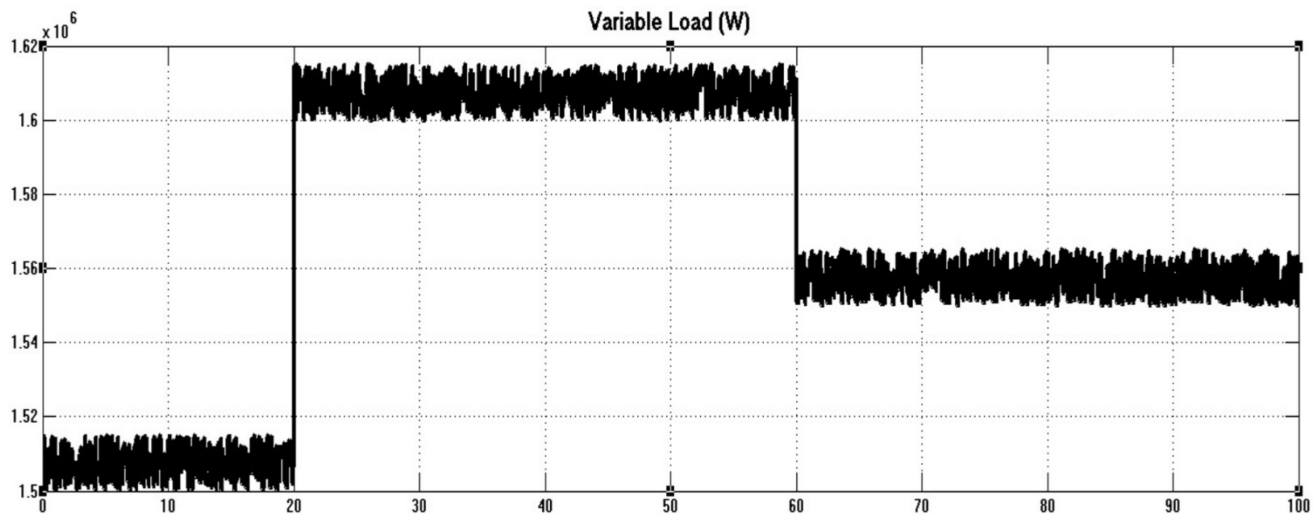
This diagram represents one block in the packet energy system

W_s - Wind speed
P_{out} - Output power of the inverter
V_b - Battery voltage
C_{load} - Change of load
C_{PWM} - Change in PWM

Modeling of wind energy based packet energy system (cont'd)

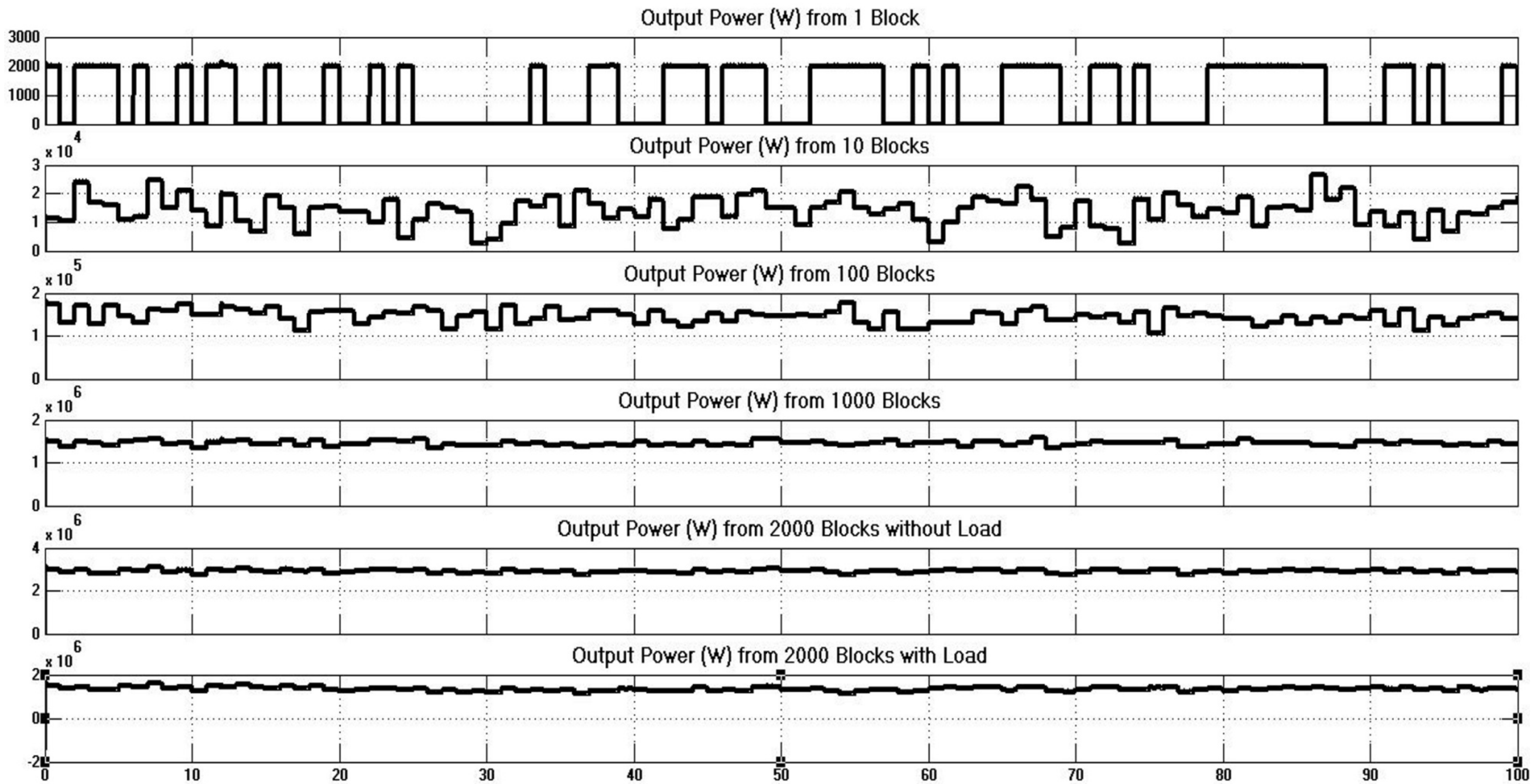


10 blocks have been added with different reference power.



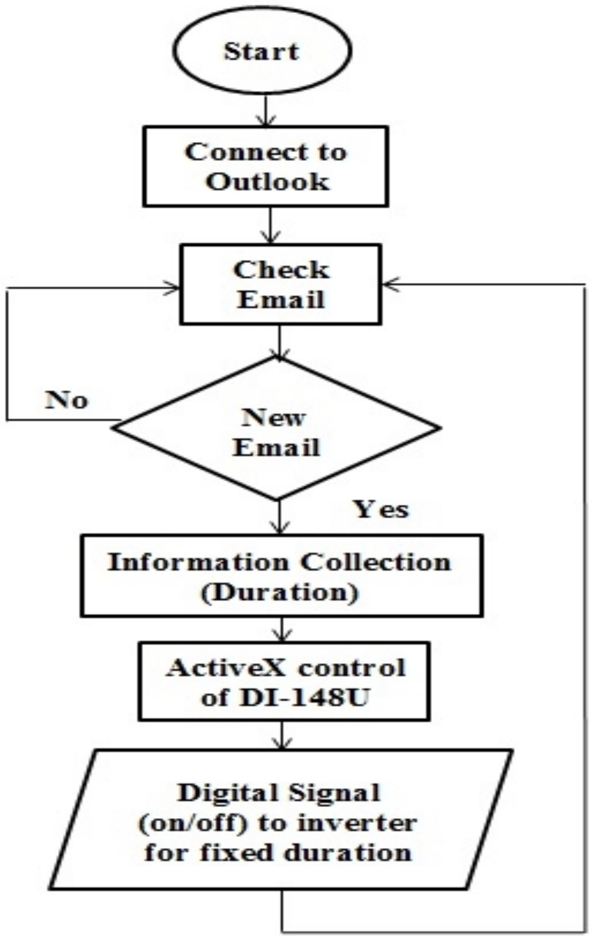
Large variable load with the presence of random fluctuations has been used in the system.

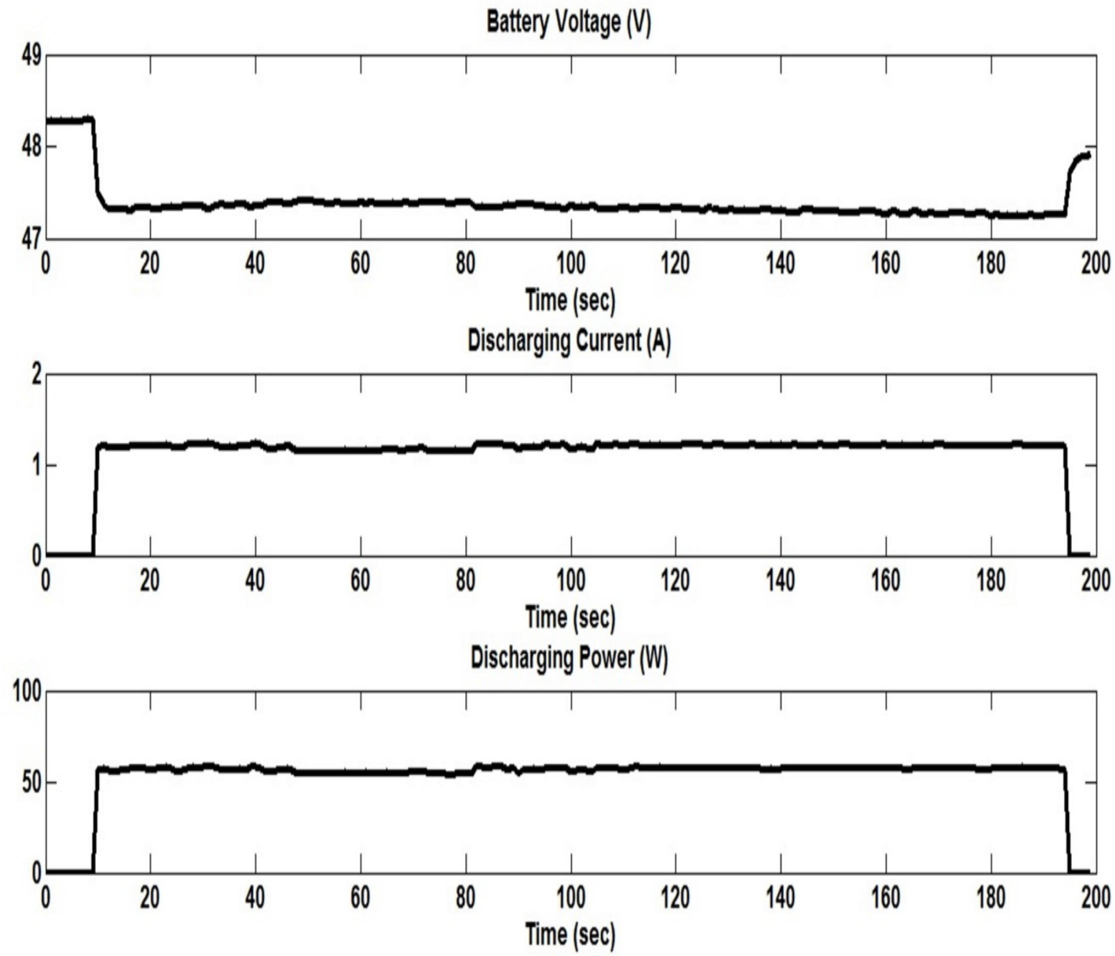
Simulation results of wind energy based packet energy system



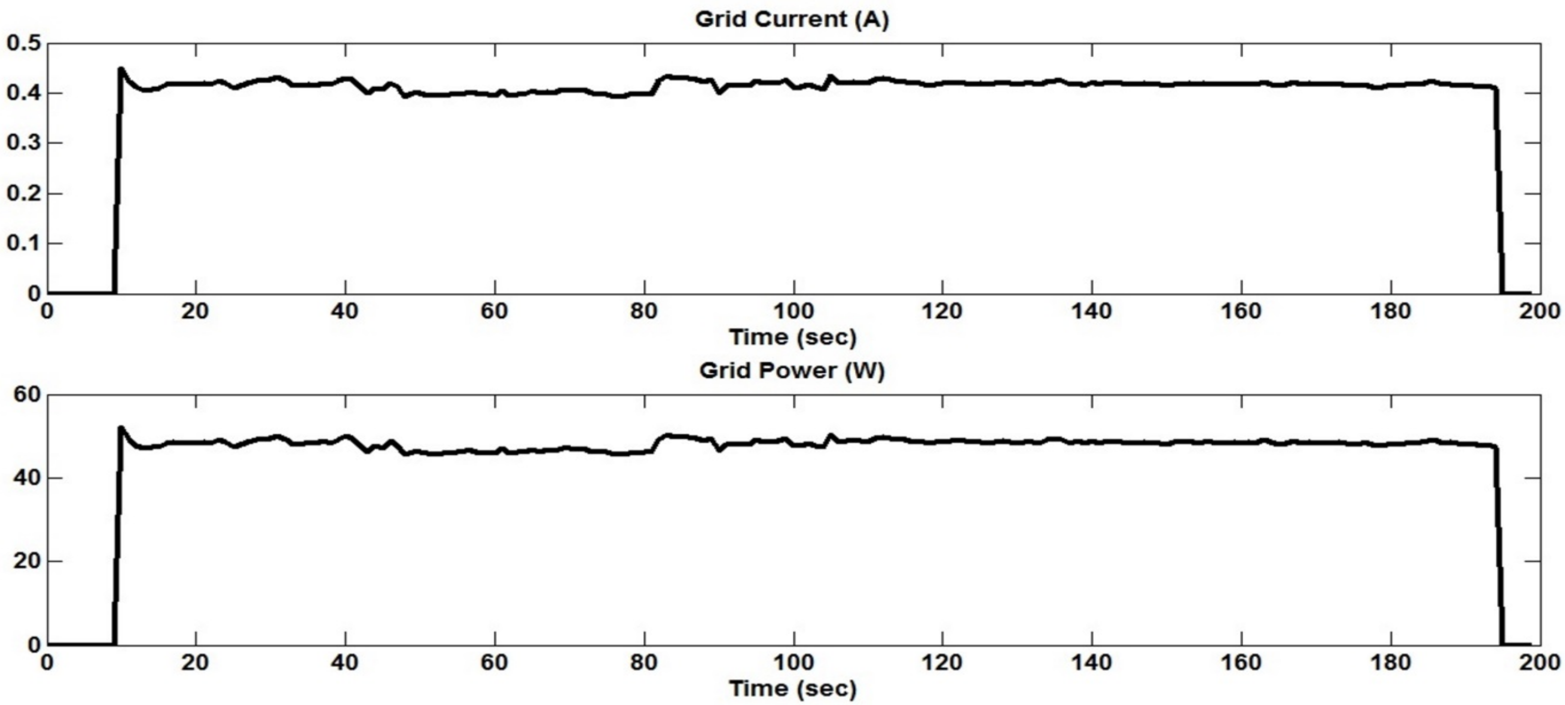
It could be concluded that random sources and random load fluctuations still leads to an almost steady output.

Flowchart to control inverter on/off using Matlab and experimental results





Grid current and output power of the inverter



Here, the inverter is turned on for 3 minutes. From the experimental results, it can be said that the implemented system can supply energy packets of variable duration as determined by the energy dispatch center.

Conclusions

- Grid connected battery based energy storage system has been designed in Homer & Matlab/Simulink to profit from net-metering and variable rate electricity.
- A small prototype of the grid connected battery storage system has been implemented in the laboratory.
- Small wind turbine based packet energy system has been modeled in Matlab/ Simulink and implemented in the laboratory.
- Control scheme has been proposed and simulated in Matlab/Simulink.

The outcomes of the analysis are listed below:

- Simple calculation shows that the grid connected battery storage system will make money to offset it's cost.
- The proposed control algorithm is able to manage the battery storage system without any dynamic issues.
- A microcontroller can be used as a supervisory controller. A battery based energy storage system can be implemented using this kind of low cost supervisory controller to profit from net-metering and variability of electricity price.
- A designed packet energy network system, consisting of thousands of smaller packet energy system, is able to provide stable power.
- With the help of energy packet network, smart energy dispatch centers can take the full advantage of renewable energy sources.
- Experimental results show that it is possible to make such an energy packet system in the existing grid. The proposed packet energy network could be implemented using already available commercial technology.

Future Work

- Lithium-ion batteries and a high efficiency charger can be used to increase the efficiency of the packet energy system.
- A bidirectional inverter can be used to analyze the effect of the battery based energy storage system in real life situations.
- The designed model can be developed further by using higher order transfer function to investigate the effect of the packet energy system.
- Only wind turbine has been used to model the energy packet network. PV modules can also be integrated to the energy packet network model.
- The designed prototype is not connected to the wind turbine, but wind turbine and PV modules can be connected to the battery storage to demonstrate the whole energy packet network system with variable load.
- A detailed economic analysis can also be done.

References

[1] E. Gelenbe, "Energy packet networks: smart electricity storage to meet surges in demand," in Proceedings of the 5th International ICST Conference on Simulation Tools and Techniques. ICST (Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering), 2012, pp. 1–7.

[2] R. Abe, H. Taoka, and D. McQuilkin, "Digital grid: communicative electrical grids of the future," Smart Grid, IEEE Transactions on, vol. 2, no. 2, pp. 399–410, 2011.

[3] P. Rezaei, J. Frolik, and P. Hines, "Packetized plug-in electric vehicle charge management," Smart Grid, IEEE Transactions on, vol. 5, pp. 642–650, 2014.

[4] T. Takuno, M. Koyama, and T. Hikihara, "In-home power distribution systems by circuit switching and power packet dispatching," in Smart Grid Communications (SmartGridComm), 2010 First IEEE International Conference on. IEEE, 2010, pp. 427–430.

[5] T. Jin and M. Mechehoul, "Ordering electricity via internet and its potentials for smart grid systems," Smart Grid, IEEE Transactions on, vol. 1, no. 3, pp. 302–310, 2010.

Acknowledgements

- Dr. Tariq Iqbal
- Natural Sciences and Engineering Research Council of Canada (NSERC)
- School of Graduate Studies (SGS) of Memorial University of Newfoundland
- Faculty of Engineering and Applied Science
- Mr. Greg O'leary & Mr. Glenn St. Croix
- My family & friends

Publications

- Md Shakhawat Hossain, M.T. Iqbal,“Design of an Energy Storage System to Profit from Net-Metering and Variable Rate Electricity”, presented in The 22nd Annual IEEE Newfoundland Electrical and Computer Engineering Conference (NECEC), 2013.
- Md Shakhawat Hossain and M. T. Iqbal, “Grid connected energy storage system to profit from net-metering and variable rate electricity,” presented in 27th Annual IEEE Canadian Conference on Electrical and Computer Engineering (CCECE), 2014.
- Md Shakhawat Hossain, M.T. Iqbal, “Wind Energy Based Packet Energy System” accepted in International Journal of Energy Science.

Thank You

Questions?