PSCAD MODEL OF A HOUSEHOLD DC-UNIT

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1. HOUSEHOLD DC-UNIT PSCAD MODEL

The objective of the model was to create a model for a household DC-unit which consists of production units, energy storage, DC-loads, and connection to AC distribution system. Model can be used as a base for further more specified development of the small-scale production. DC-voltage of 50V was chosen for the system using ~+-25V lines.

1.1. Brief introduction to PSCAD EMTD software

Transient simulations mean short time period simulations to find out what kind of equipment is and controls are need so that microgrid manages to supply electricity that fulfils the quality standards in different operating situations. PSCAD® is popular software used for transient modelling of electric systems. PSCAD® enables the user to schematically construct a circuit, run a simulation, analyze the results, and manage the data in a graphical environment.

1.2. Simulation of different components inside DC-unit

The model was divided into smaller simulation blocks that represent real life components. Different simulation blocks in the model are,

- DC unit, which includes:
  - Wind turbine
  - Battery system
  - Boost converters
  - Overcharge control for battery
- Inverter for AC-connection
- AC connection

Figure 1.1 represents layout of the model the whole system in PSCAD.

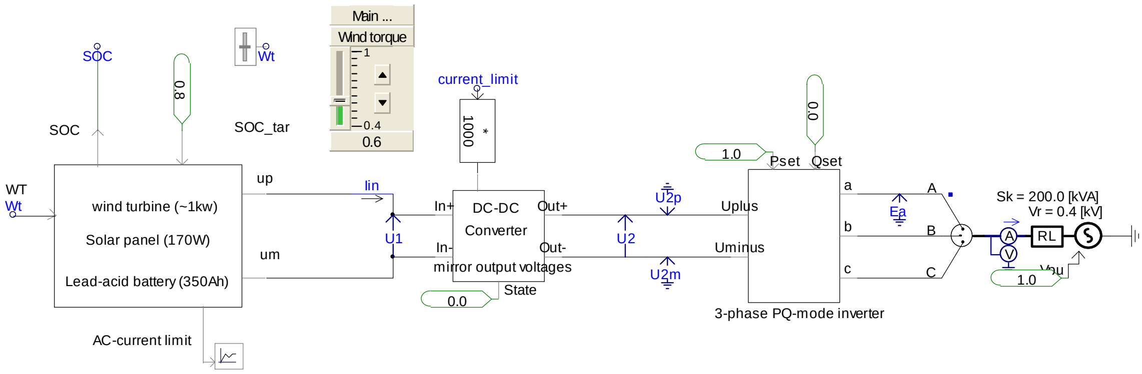

Figure 1.1. Layout of the whole model

Simulation blocks visible in the figure are DC-unit on the left, Boost converter for the inverter in the middle, and inverter and AC- connection on the right.

1.3. DC-unit simulation block

DC-unit modelling block is a basically a shell that holds production, storage and load simulation blocks inside. Inputs for the DC-unit are desired state of charge for battery, and wind torque related to nominal wind torque. DC-unit outputs negative and positive voltage nodes, current limit for grid connection, and current state of charge for the battery. Figure 1.2 represents circuit layout of simulation block for DC node.

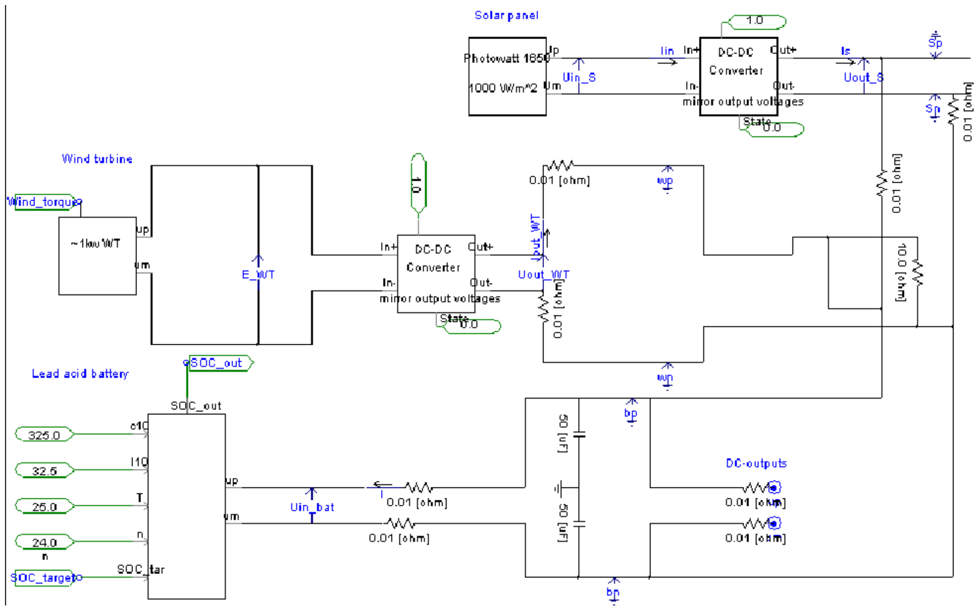

Figure 1.2. Circuit layout of simulation block DC-unit

1.3.1. Solar panel simulation

Panel chosen for simulations was older model of photowatt 1650 panel. Data for model was collected from [1]. The principle for the solar panel model is to use multiple diodes with resistances in parallel to mimic UI-curve for the panel. This method was introduced in [2]. Performance of panel reflects panel performance in standard operating conditions. Figure 1.3 represents PSCAD model of the solar panel.

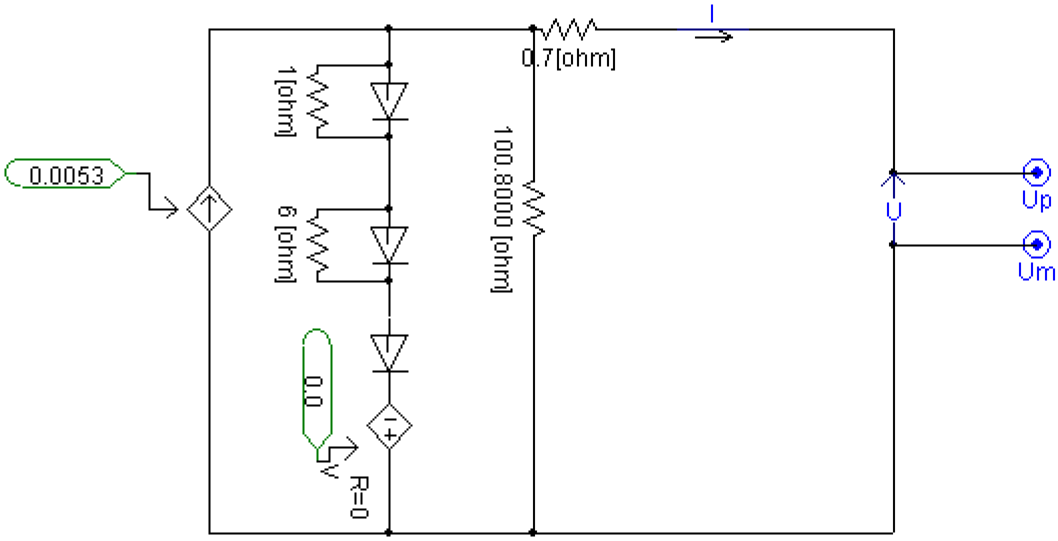

Figure 1.3. Solar panel model

1.3.2. Wind turbine model

Wind turbine was modelled using the permanent magnet generator model found in PSCAD-master library. The machine was parameterised so that nominal output power is 1kW. Rated line-to-line-voltage was set to 25 V and nominal electric frequency to 50 Hz. Rectification was done with diodes as it is with most of the small-scale wind generators nowadays.

Dynamics of the generator was modelled using equation:

$$Tw - T_e = J\frac{d\omega_r}{dt} + B\omega_r$$

Tw = Torque delivered by the wind turbine [Nm]

T_e =Electrical counter torque developed by the generator [Nm]

J =Inertia constant of the system [kg/m^2]

ω_r =mechanical rotating speed [rad/s]

B =factor of losses caused by friction

Figure 1.4 represents the simulation block of the wind turbine. Dynamic equation is presented under the circuit in the figure.

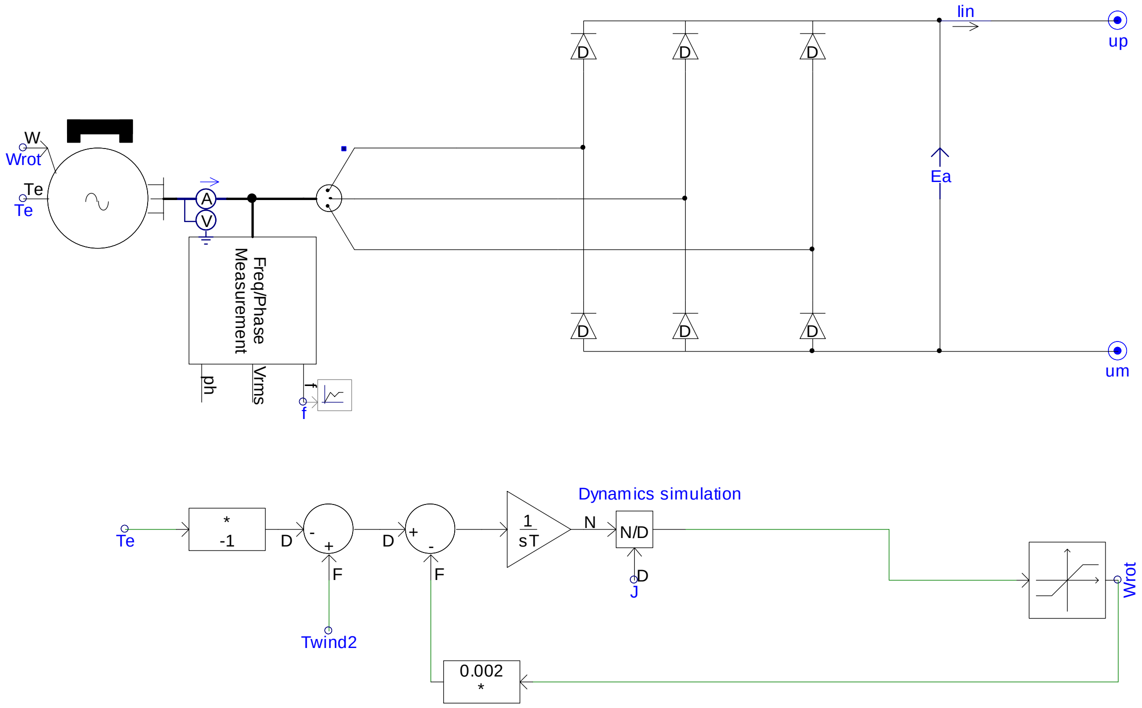

Figure 1.4. Wind turbine simulation block

Other parameters for the model are presented in figure 1.5

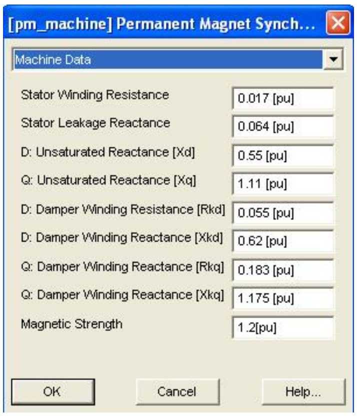

Figure 1.5. Other generator parameters

At start of simulation, torque 1.4 times nominal was used to speed up the turbine to chosen power and speed.

1.3.3. Boost converters with simple MPP trackers

Boost converters were modelled so that negative and positive input voltages are raised to -25 and +25 V respectively. Circuit layout was modified from buck-boost converter. Note that both IGBTs are controlled with same signal. Individual controls would be needed if loads could be connected also between earth and lines as system now controls voltages correctly, if loads are connected between lines. Figure 1.6 represents circuit layout of the converter, figure 1.7 calculation of gate signal, and 1.8 maximum power point (MPP) tracking system.

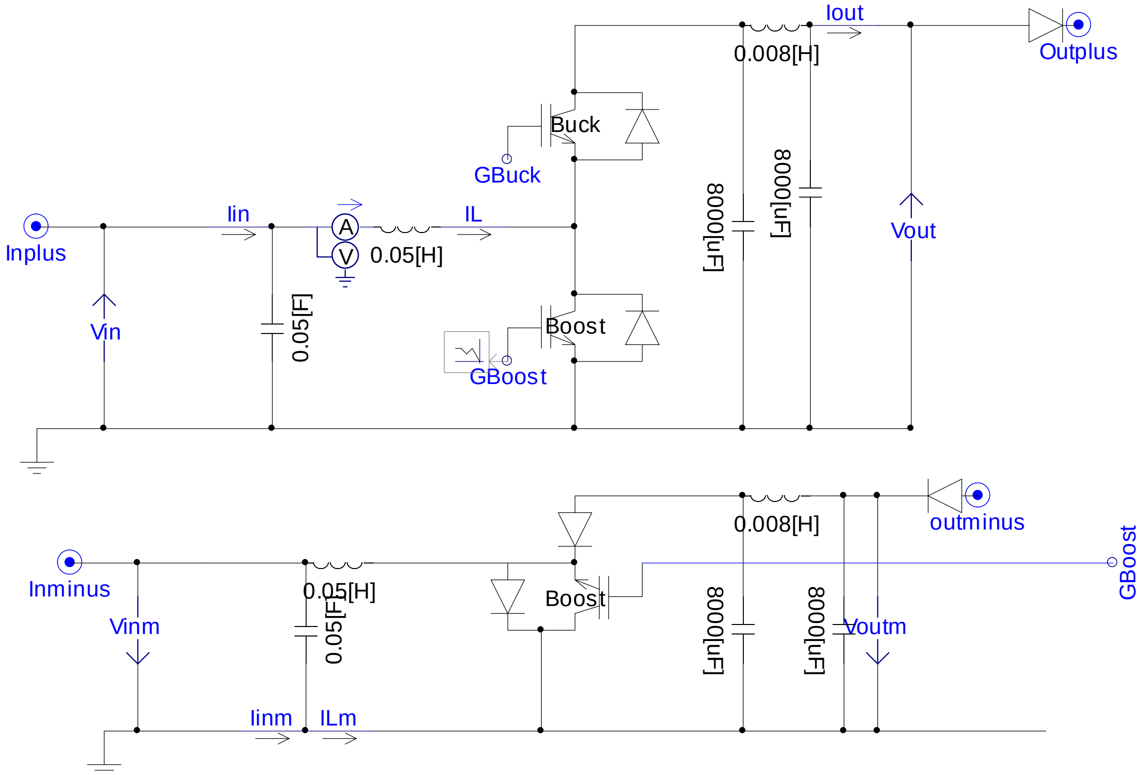

Figure 1.6. Circuit layout for boost converter

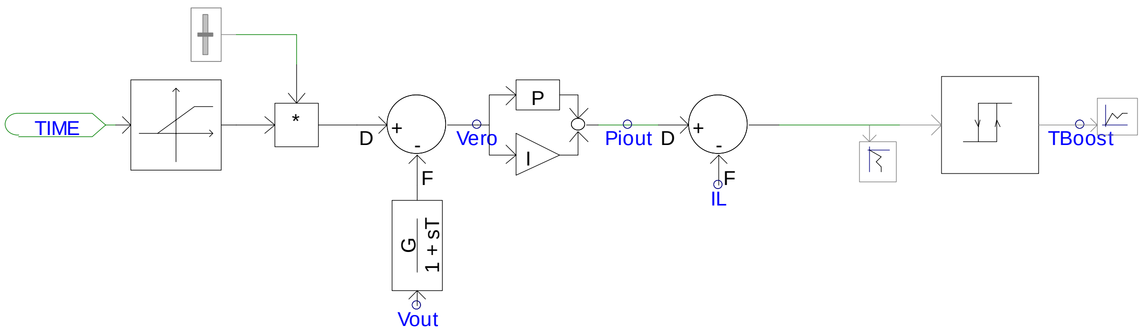

Figure 1.7. Boost converter control signal calculation

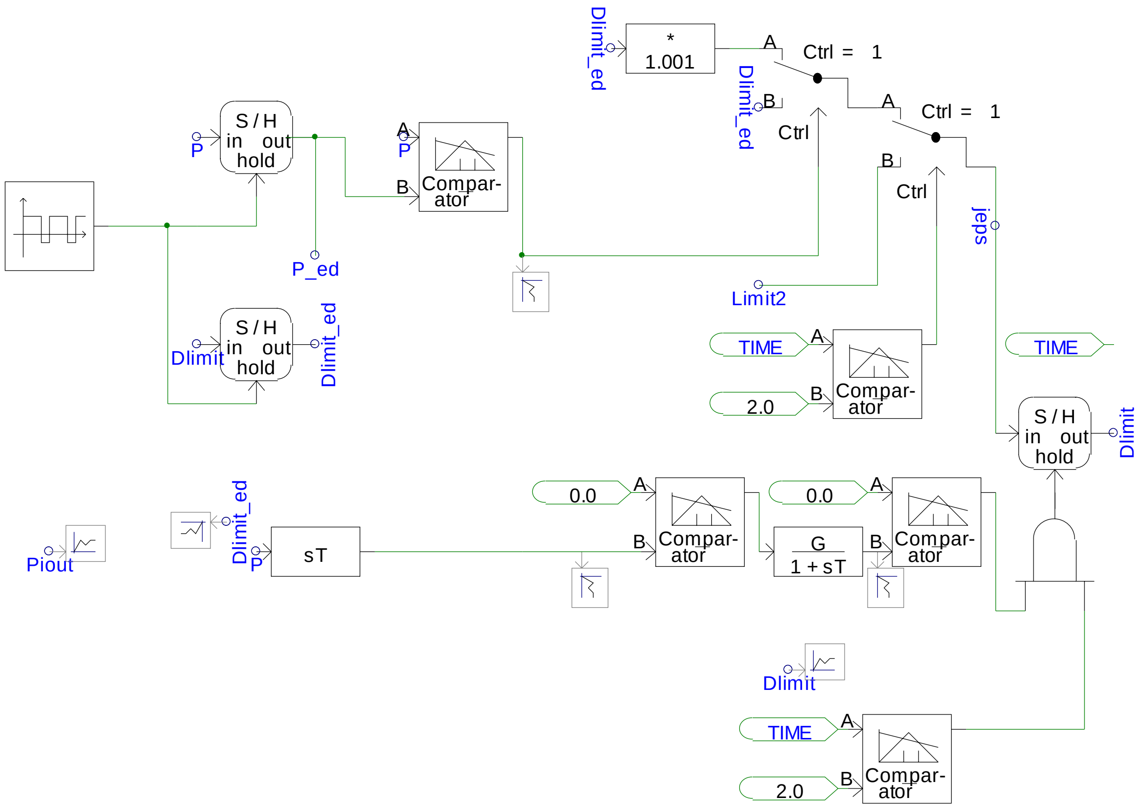

Figure 1.8. MPP-tracking system

The MPP-tracker operates at 40Hz trying to increase current limit of the boost converter in 0,1% increments until maximum power is achieved. Current limit is set to PI-controller in figure 1.7. Similar boost converter is used for wind turbine and solar power plant with slightly different parameters.

1.3.4. Battery unit model

Lead acid battery was chosen as energy storage for this model. Model is based on CIEMAT model which is used in simulation in [3]. The model has different output voltage equations for discharge, charge, and overcharge situation and are calculated according to figure 1.9. Reference product for the model is STECO Saphir 3600, which has model parameters validated in [3].

$$V_{bat\_d} = n_b \cdot [1{,}965 + 0{,}12 \cdot EDC] - n_b \cdot \frac{|I_{bat}|}{C_{10}} \cdot \left(\frac{4}{1 + |I_{bat}|^{1.3}} + \frac{0{,}27}{EDC^{1.5}} + 0{,}02 \right) \cdot (1 - 0{,}007 \cdot \Delta T)$$

$$V_{bat\_c} = n_b \cdot [2 + 0{,}16 \cdot EDC] + n_b \cdot \frac{I_{bat}}{C_{10}} \cdot \left(\frac{6}{1 + I_{bat}^{\,0{,}86}} + \frac{0{,}48}{(1 - EDC)^{1{,}2}} + 0{,}036 \right) \cdot (1 - 0{,}025 \cdot \Delta T) \qquad (4)$$

$$V_{bat\_oc} = n_b \cdot V_g + n_b \cdot (V_{ec} - V_g) \cdot \left[1 - \exp\left(\frac{t - t_g}{\tau_g} \right) \right]$$

Figure 1.9. Voltage equations in battery model. d=discharge, c=charge and oc= overcharge. [3].

Equation 1.10 represents calculation of state of charge by subtracting discharged charge Q_d . C_{bat} in equation 1.10 is instantaneous capacity which is calculated by equation 1.11.

$$EDC = 1 - \frac{Q_d}{C_{bat}}$$

Equation 1.10. State of charge calculation [3].

$$\frac{C_{bat}}{C_{10}} = \frac{1.67}{1 + 0.67 \cdot (\frac{I_{bat}}{I_{10}})^{0.9}} \cdot (1 + 0.005 \cdot \Delta T)$$

Equation 1.11. Calculation of instantaneous capacity

$$\begin{cases} V_{ec} = \left[2{,}45 + 2{,}011 \cdot \ln\left(1 + \frac{I_{bat}}{C_{10}} \right) \right] \cdot (1 - 0{,}002 \cdot \Delta T) \\ V_g = \left[2{,}24 + 1{,}97 \cdot \ln\left(1 + \frac{I_{bat}}{C_{10}} \right) \right] \cdot (1 - 0{,}002 \cdot \Delta T) \\ \tau_g = \dfrac{1{,}73}{1 + 852 \cdot \left(\frac{I_{bat}}{C_{10}} \right)^{1{,}67}} \end{cases}$$

Figure 1.12. Voltage components to overcharge equation

The Battery does not need a DC/DC-converter as voltage level of the system is in normal region for the battery. Battery unit has also an overcharge controller which gives a current reference boost converter connected to inverter. If state of charge of the battery is at desired maximum e.g. 80%, current reference is moved from zero to match current measured incoming to battery. Figure 1.13 represents the simulation of the overcharge protector.

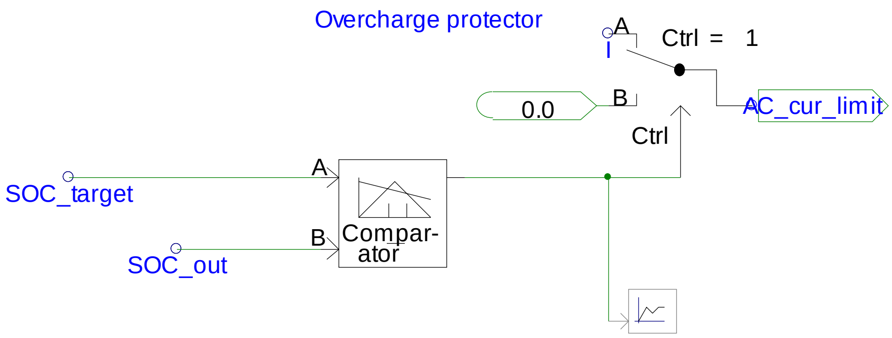

Figure 1.13. Overcharge protector.

1.4. Inverter model

Simulated inverter is 3-phase IGBT inverter that operates in PQ-mode (current source). A boost converter connected between DC-unit and inverter. Boost converter is given a current limit by the overcharge controller in battery system.

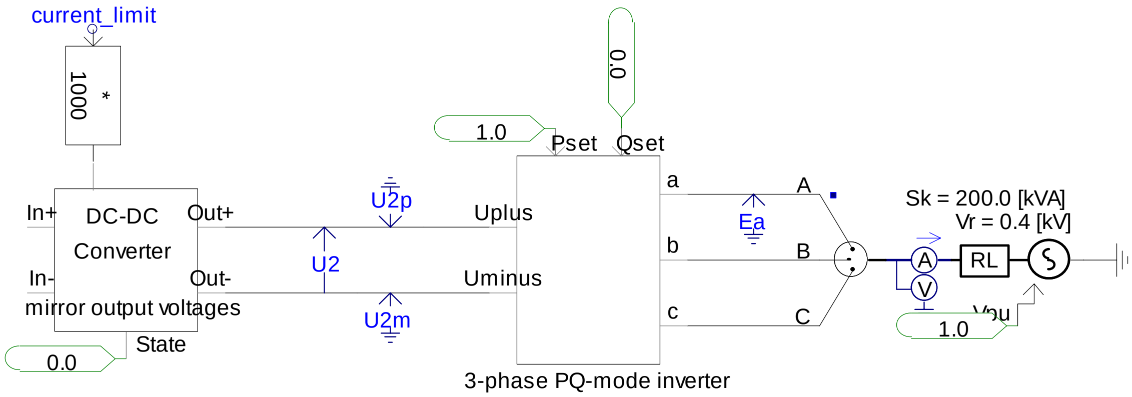

Figure 1.14. AC-connection simulation.

Pset input for the inverter is the maximum active power that can be supplied to AC grid. Qset is the maximum reactive power. Current of the inverter is primarily limited by the DC/DC-converter but Pset acts as absolute maximum. DC/DC-boost converter is similar that was presented in chapter 1.3.3.

Circuit model of the inverter in presented in figure 1.15 and control of the inverter in figure 1.16 Inverter control is done using DQ vectors. Active power is controlled with D-component and reactive power with Q-component.

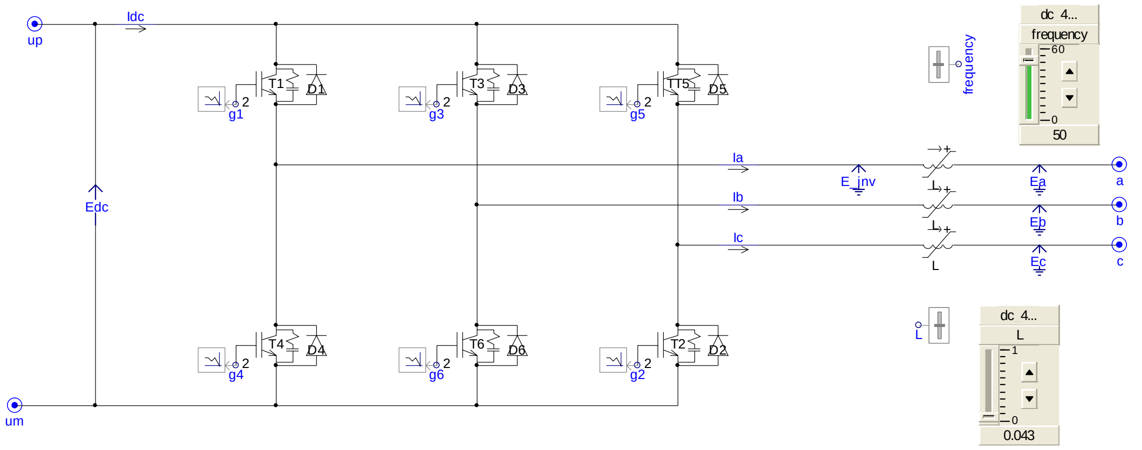

Figure 1.15. Inverter circuit model.

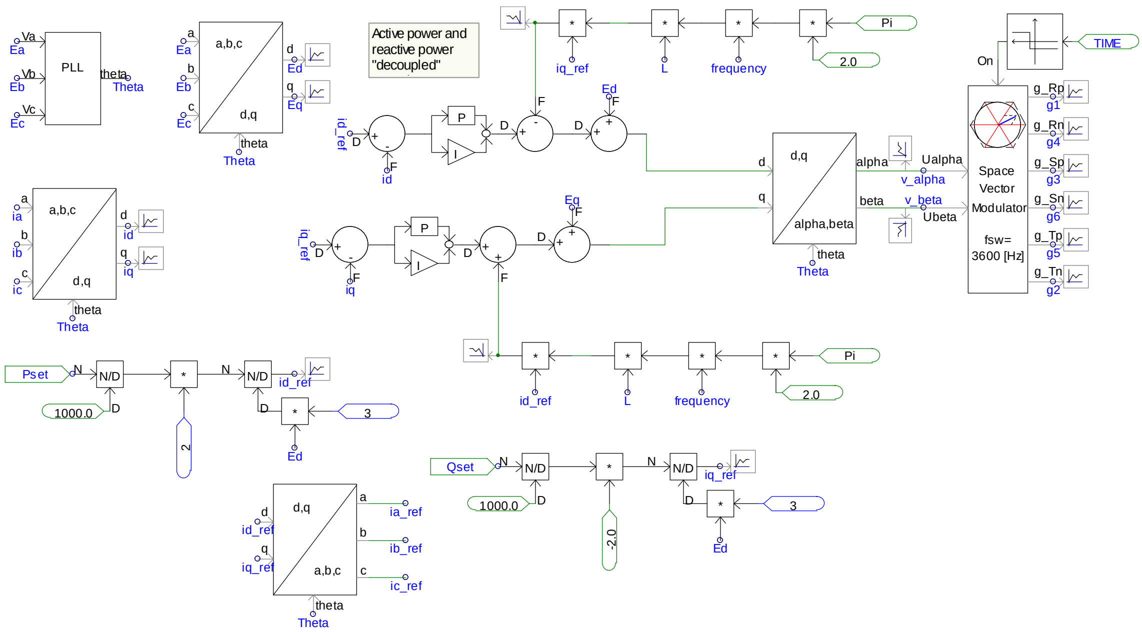

Figure 1.16. Inverter control model.

The modulator in inverter control system is space vector modulator developed in DENSY research program in 2005.

1.5. Grid model

Grid is simulated with VTT voltage source 1 component which can be set to certain fault level and R/X-ratio. Fault level was set to 200 kVA and R/X ratio to 2.01. 2.01 is same as RX-ratio of AXMK-4X185S ground cable.

2. EXAMPLE SIMULATION

2.1. Setup

- Wind power production is set to 600 W
- Battery initial charge is 80%
- Target SOC for battery is set to 0.8
- Total domestic DC-load is set to 10Ω (about 260W)
- Solar panel operates at standard conditions

2.2. Simulation results

DC-line voltages are presented in figure 2.1

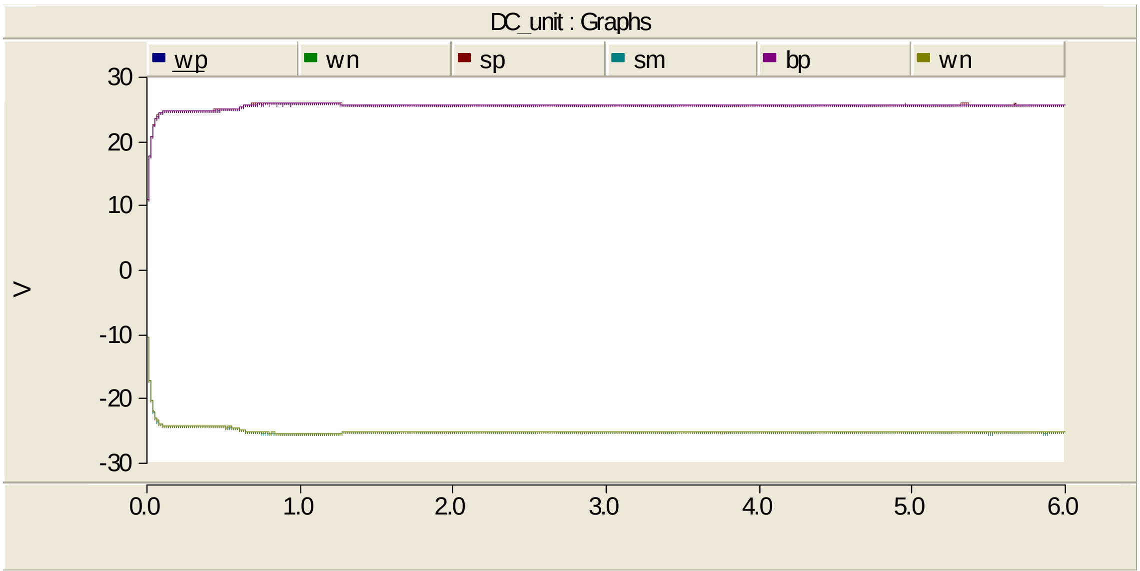

Figure 2.1. DC-unit line voltages.

At start of the simulation there is a current spike drawn from the battery to energize the DC- system and SOC of the battery declines under 0.8. The affect of current spike can be seen in figures 2.1 and 2.2. Battery starts to be charged as power of the production units increases. Power outputs of wind turbine and solar cell are presented in figures 2.3 and 2.4 respectively.

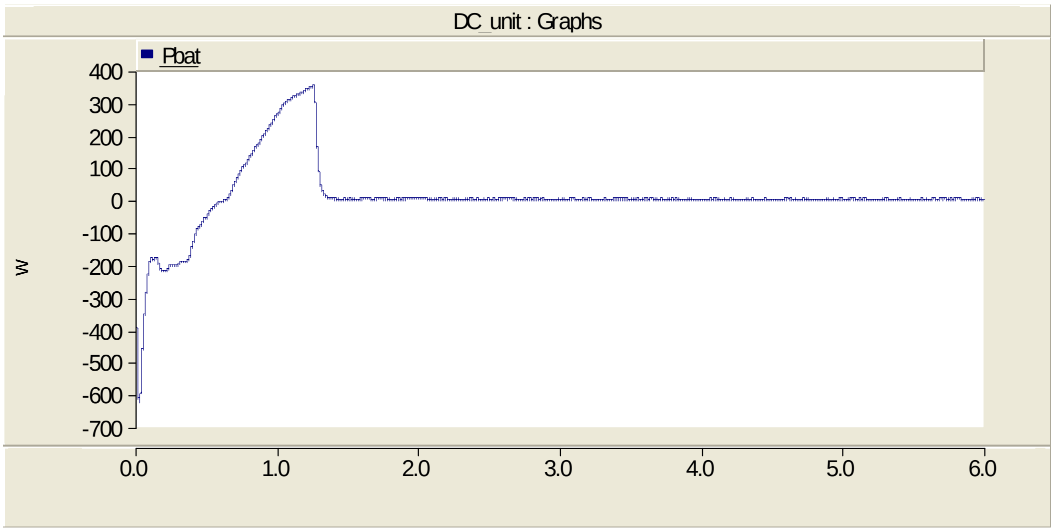

Figure 2.2. Battery charge power.

Wind power unit reaches it maximum output power in 2 seconds. Acceleration of turbine is helped by 1.4 times nominal wind torque at start.

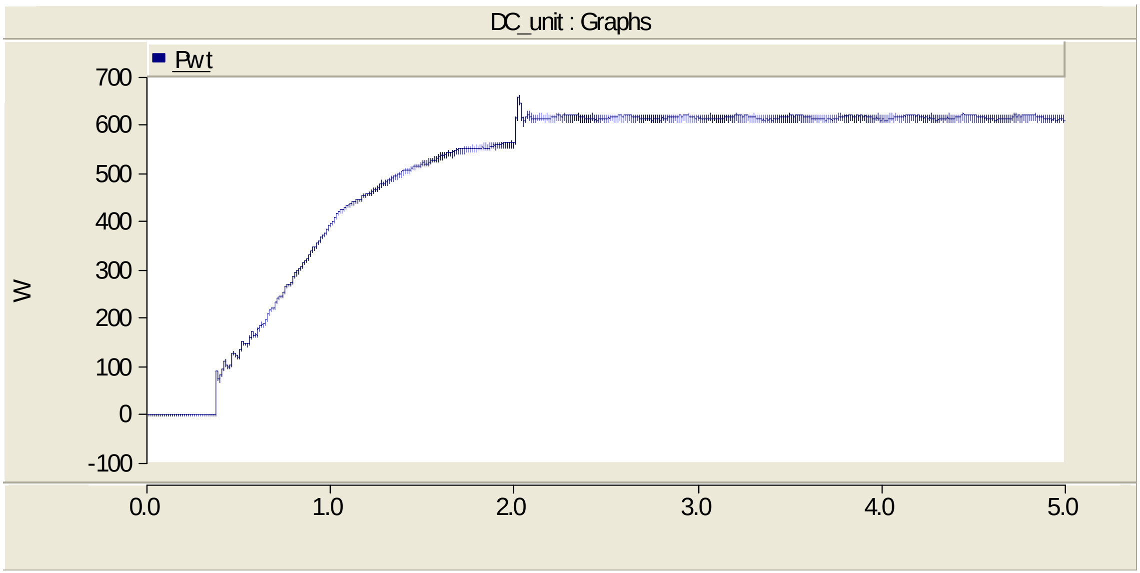

Figure 2.3. Wind power output.

Solar power plant finds a maximum power point quickly in low voltage level, but when unit voltage is up, power point finding takes more time. Maximum power of solar panel is reached approximately at 3.5s.

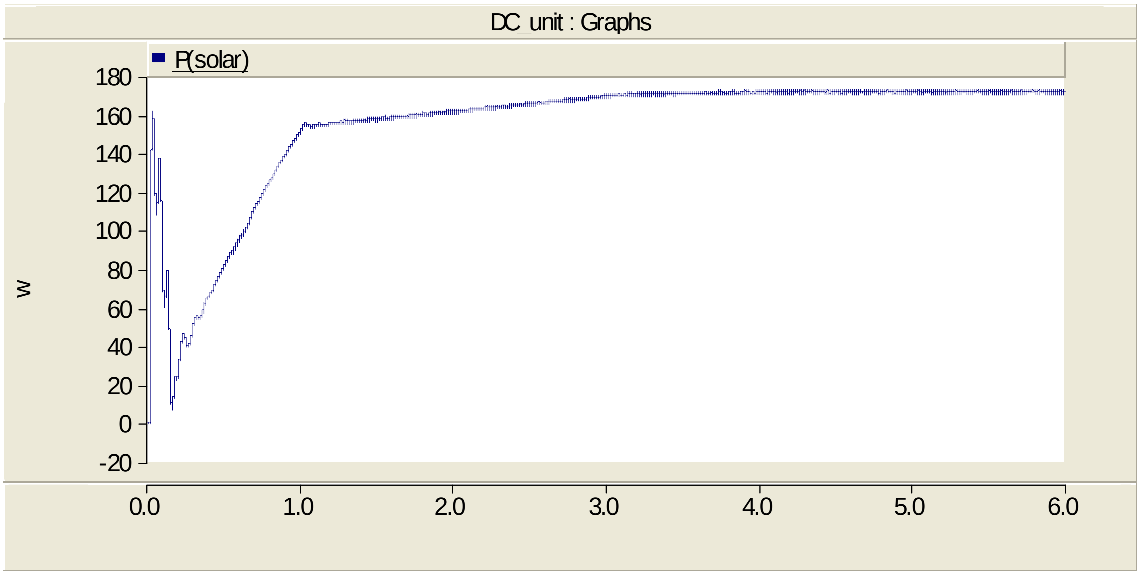

Figure 2.4. Solar panel output.

When SOC of 0.8 is reached (fig. 2.5), battery is at desired charge level and extra power is now supplied to distribution grid. At same time incoming battery power is limited to 4 W, so that battery remains in desired state of charge.

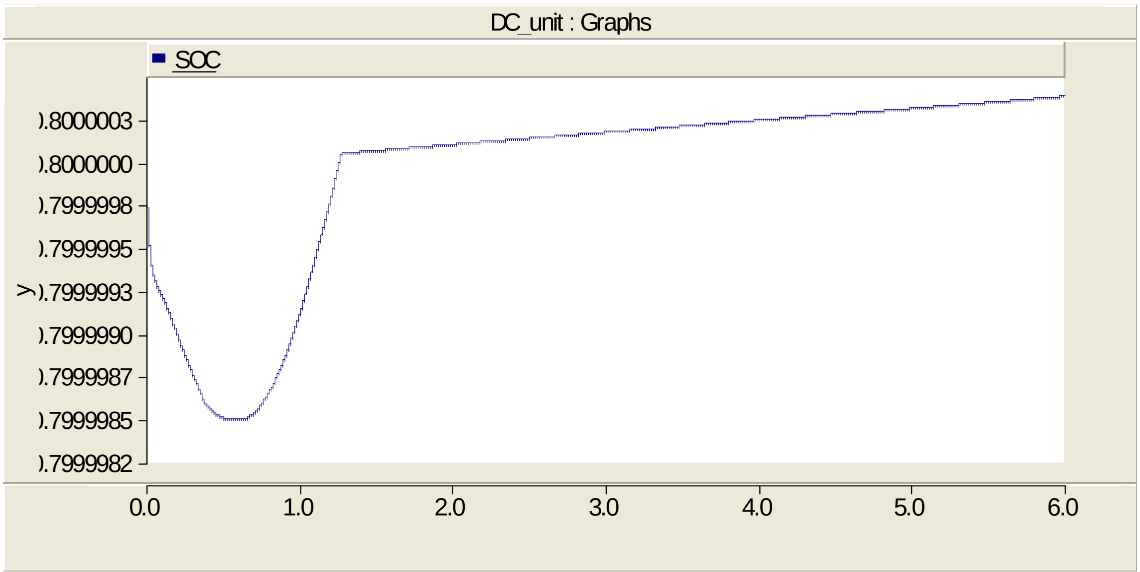

Figure 2.5 State of battery charge.

Power outputted to AC grid is presented in kW in figure 2.6.

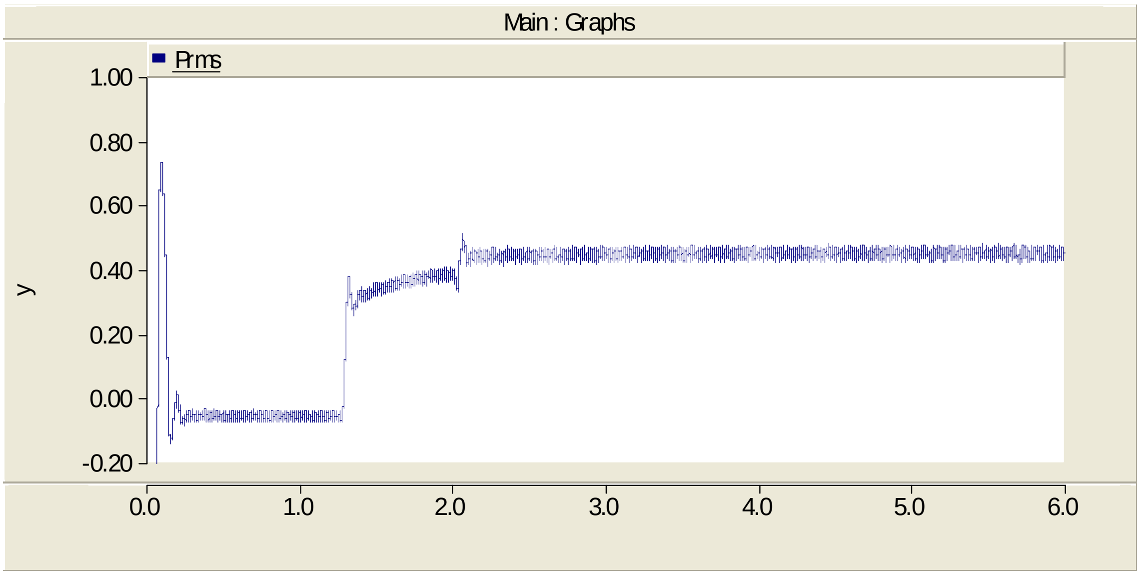

Figure 2.6 Power output to AC-grid.

REFERENCES

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[3] Gergaud,O.,Rogib,G.,Multon,B., Ben Ahmed,H.” Energy modelling of a lead-acid battery within hybrid wind/photovoltaic systems” Bruz, France 2003.