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Smart Home Short and Long Term Optimization Technique

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Abstract:
The System Controller is what makes the system smart. On house level it is essentially a computer connected to all resources in the house such as loads (lamps, TV, dishwasher), possible generators (wind turbines, solar panels, car batteries) and a connector to the external grid. The connections enable information exchange. The System Controller takes information about consumption, production and requests from the end user and acts accordingly. The System Controller is also connected to the electricity market in order to receive current electricity prices. In this paper a high end optimization technique has been proposed to users configure the System Controller in order to achieve the desired behavior.

Key Words: Smart grid, Smart home, Modelica

INTRODUCTION

This configuration should be as simple as possible and could involve priority assignment for loads to assure that vital household component always is active. The configuration is optimally done through some *Graphical User Interface* preferably on a *smart phone* or *smart pad*. The medium voltage grid will essentially be controlled in the same manner. But the controller on this level will control external connections to houses instead of loads. The *System Controller* is what makes the system smart. On house level it is essentially a computer connected to all resources in the house such as loads (lamps, TV, dishwasher), possible generators (wind turbines, solar panels, car batteries) and a connector to the external grid. The connections enable information exchange. The *System Controller* takes information about consumption, production and requests from the end user and acts accordingly. The *System Controller* is also connected to the *electricity market* in order to receive current electricity prices. Users configure the *System Controller* in order to achieve the desired behavior. This configuration should be as simple as possible and could involve priority assignment for loads to assure that vital household component always is active. The configuration is optimally done through some *Graphical User Interface* preferably on a *smart phone* or *smart pad*. The medium voltage grid will essentially be controlled in the same manner. But the controller on this level will control external connections to houses instead of loads. The system controller on the medium voltage grid will use its connection to the high voltage grid as voltage controller. But will also use its energy storage during blackouts on the external grid. The system controller on all levels will always strive to have a fully charged battery. If there is enough power the battery will be charged. This is prioritized higher than turning on loads. The introduction of the paper should explain the nature of the problem, previous work, purpose, and the contribution of the paper. The contents of each section may be provided to understand easily about the paper.

The aim of this project was to develop a model of a smart house connected to an external grid using the *Modelica* based tool *Dymola* and to design control laws that control production and consumption on the grid using *C++*. The control structure was designed and implemented in C++ since the simulation in Dymola has no pre-defined causality which makes it difficult to do control of the system. By using Dymola to simulate the physical parts and using the imperative programming language C++ to make decisions, it is possible to use the strength of Dymola and the strength of C++. The control system continuously gathers information from the grid such as power consumption, voltage level and priorities for different loads and acts using this information to optimize the energy use. The grid should in an automated fashion act and gather information to keep the grid operating in an optimal way. Apart from modelling a DC grid on household level a grid connecting several households should also be modelled. This grid connecting several houses will form a model over a smart cell. Control laws for this cell should be able to distribute electricity from local wind farms, solar power plants and over production from households in an efficient way. To model and control smart grids is important [1]. These grids can be used to distribute variable produced electricity such as wind power, in a more efficient way than the current electricity grid. Furthermore these grids can be used to reduce consumption peaks and improve the reliability of the grid. A DC grid is modelled instead of AC since the basic smart control aspect is still the same with a DC grid and is easier to model. Furthermore some researchers believe that future smart grids will be implemented using DC components and DC grids. Since many micro generating sources are DC in their nature, such as solar power plants, it will be possible to avoid transformations losses using DC. Also an important role in future smart grids will be the ability to store energy, preferable in battery equipped cars, and since energy storage in batteries are done in DC, using DC grids will further avoid transformation losses[2]. This research is limited to develop a DC model of a household and a medium DC voltage grid. The household controls an arbitrary number of loads which importance is determined according to their priority. Furthermore the household model should be able to have micro production, such as wind power and solar power, and a battery to be able to operate when the external grid fails. The model of the mid voltage grid has the ability to connect wind power plants and batteries. The storage discharged during times of high electricity prices and charged during times of low prices to deliver cheaper electricity to the end user. Also the battery functions acts as a temporary buffer to be used when the transmission network fails. All control logics are developed in C++ and interfaced to Dymola using C.

SMART HOME WORK FLOW:

Each time the System controller is updated the functions are called according to the main workflow. During this process the System Controller goes through all resources connected to its system and sends instructions to them if needed. The main workflow is seen in fig. 1. For short term simulations the work flow for figure 1(a) is used and for long term simulations the workflow for 1(b) is used. The difference between long term and short term is that for long term the voltage control is not considered. Furthermore behavior during islanding mode is not of interest. Instead the voltage is determined by an ideal voltage source and not by a PI-controller. By not considering the voltage control it is possible to sample the system much slower. This will make it possible to simulate the system for much longer times. Yearlong simulations were done to determine the systems power performance and cost. This would require a lot of computational power and time if voltage control would be done during these simulations. When the system controller needs to determine which resource should be used for voltage control the set controller function is used. The decision structure for this function is seen in Fig.2. Its objective is to find a suitable controller every time the system controller updates the system. The main goal is to always use the external net for voltage control if possible and thus using the battery only when the external net has a power outage. When the system controller needs to find a new suitable controller the find controller function is used. The workflow for this function is seen in Fig3a. It is fairly simple: if there is power available on the external net the external connection is chosen as controller otherwise the battery is chosen. Updating the PI-controllers which are used for voltage control are done by calling the update controller function. The function calculates the voltage error and calls a PI-controller to calculate the proper control signal. The system controller gives the energy storage unit instructions by calling the update battery function. This function will only instruct the energy storage to charge when it's not used for voltage control or is fully charged. Whether loads should be turned on or off is determined by the update loads function. Loads will be turned on if the voltage at the internal DC bus is at the correct level, at steady state and if there is power available. If there is a load in the waiting/ready queue and there is power available for this load, it is turned on. Loads that are configured with a price limit will only be placed in the queue if the price is below the price limit. Whether there is power available or not is determined by the difference between the total amount of power (external connection/battery and micro generation) and the current consumption of power.

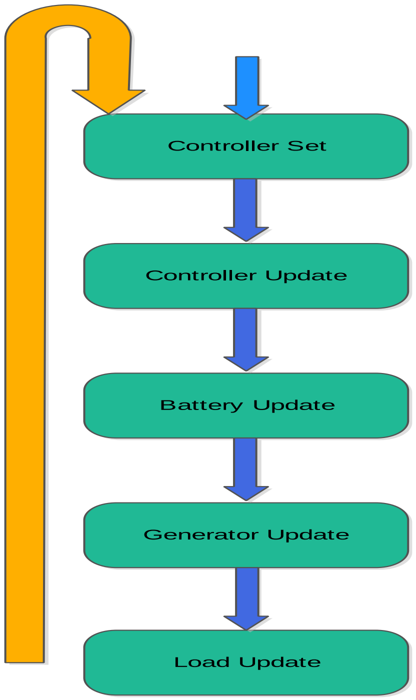

Figure1 (a) Short term workflow

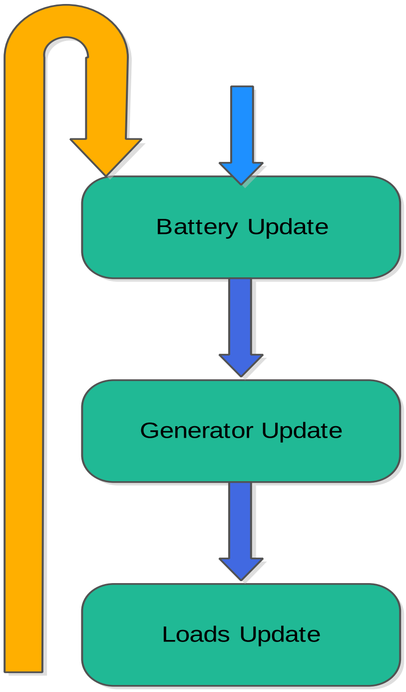

Figure (b) Main workflow long term

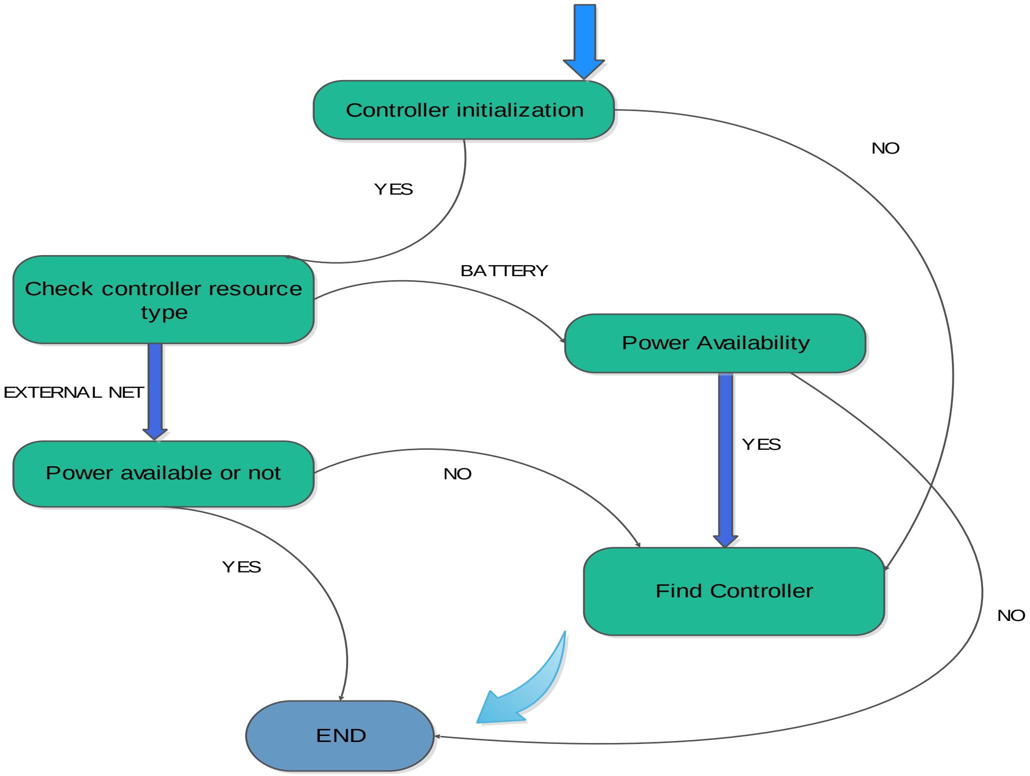

Figure2. Decision structure for set control operation

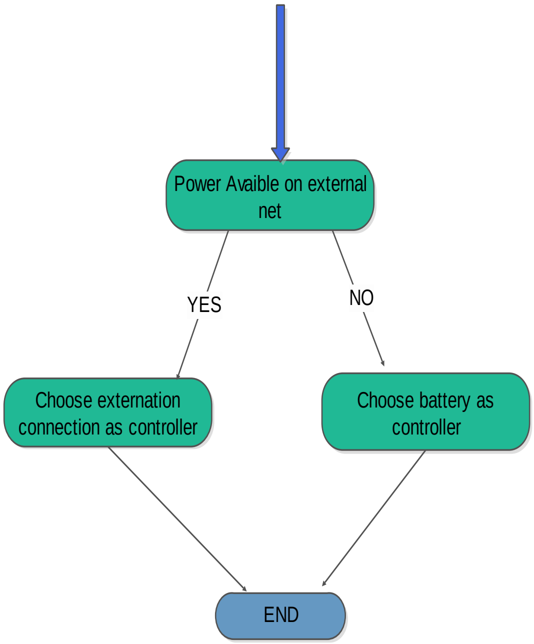

Figure 3 (a) Controller finder

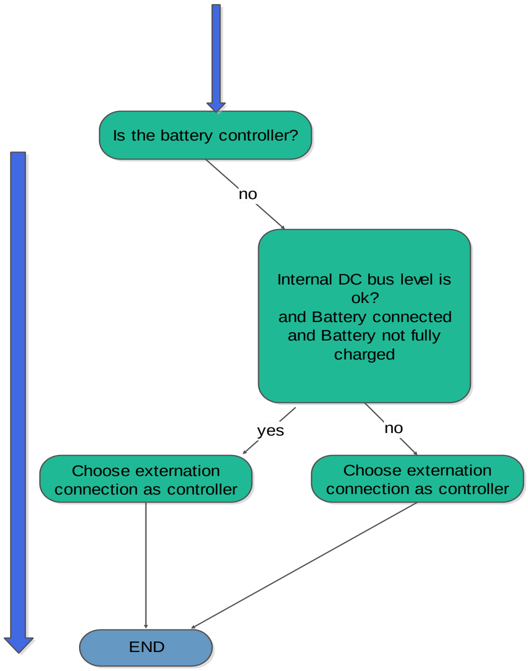

Figure 3 (b) Battery update

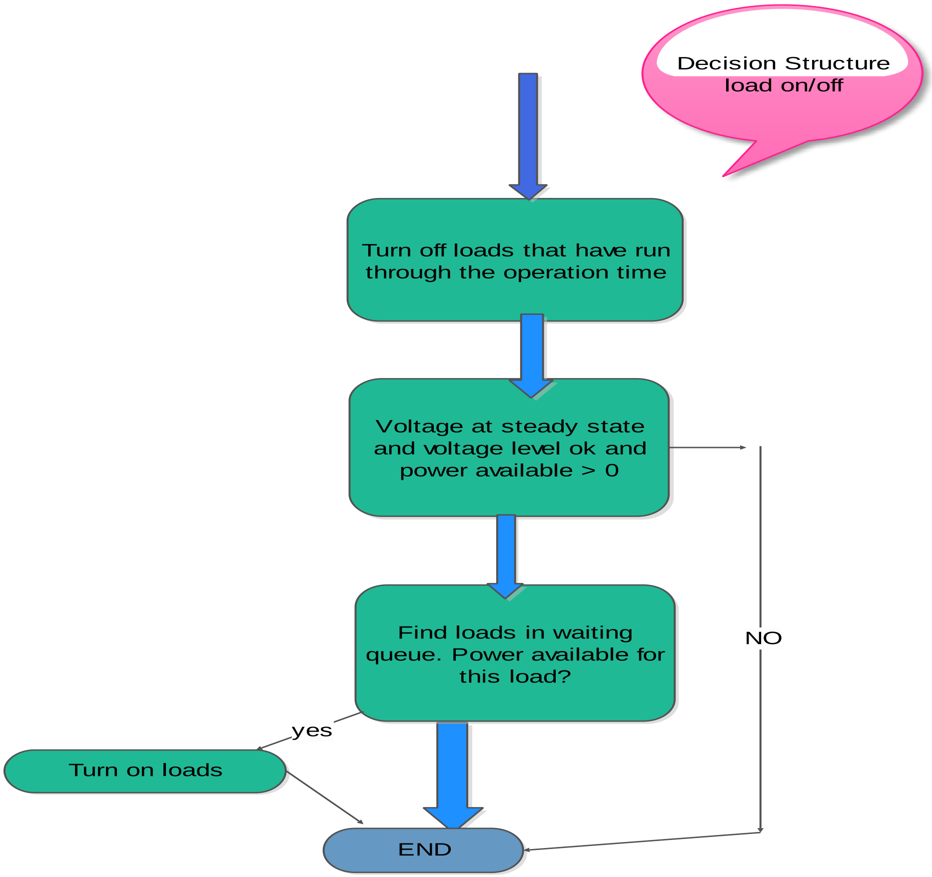

Figure 4: Decision structure for updating loads called every time whether load should be turn on or off

The system controller for the external grid is similar to the controller on house level. The difference lies in that no loads are connected to the system controller. Instead the controller needs to manage a number of external connections. These connections are connecting houses and other external grids to the grid. Therefore the update loads functions are not used by the system controller on this level. Instead a function called update external connections is used.

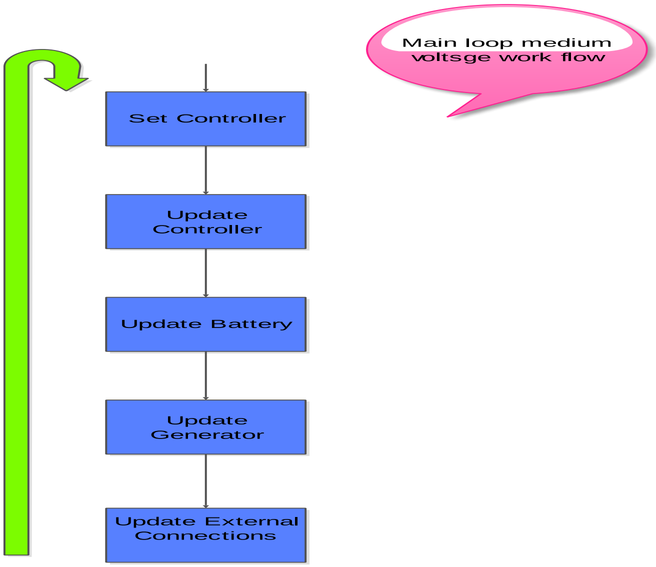

Figure 5: work flow structure for the medium voltage main loop system controller

It also takes information about the available power from the high voltage grid together with the power from the generators and energy storage (battery) and divides it equally among the rest of the external connections (houses). The main objective for the battery on this level is to act as a buffer. The power storage is charged when the electricity price is below a certain level (usually night time) but can also be configured to discharged during times of high price (usually in the evening). This is done to reduce power peaks and to reduce the overall electricity cost. Furthermore the energy storage is used for voltage control when the high voltage grid fails. The workflow for the energy storage at the external grid is seen in fig.5.

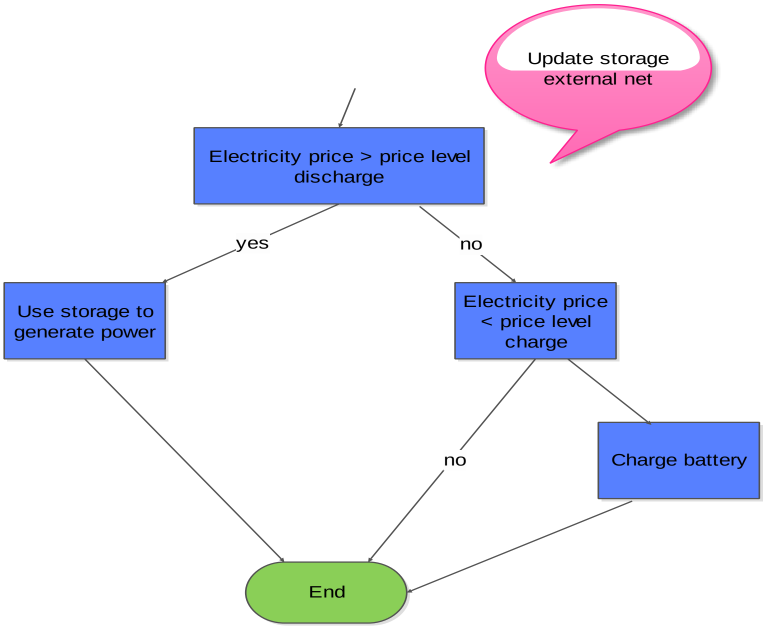

Figure 6: This terminal calls every time to know the pricing limit or how storage should be used?

The external connector is used to connect houses with external grids and external grids with other grids. Therefore this resource is a shared resource. Both systems, the house controller and the grid controller need to be able to send and receive signals and measurements to the external connector.

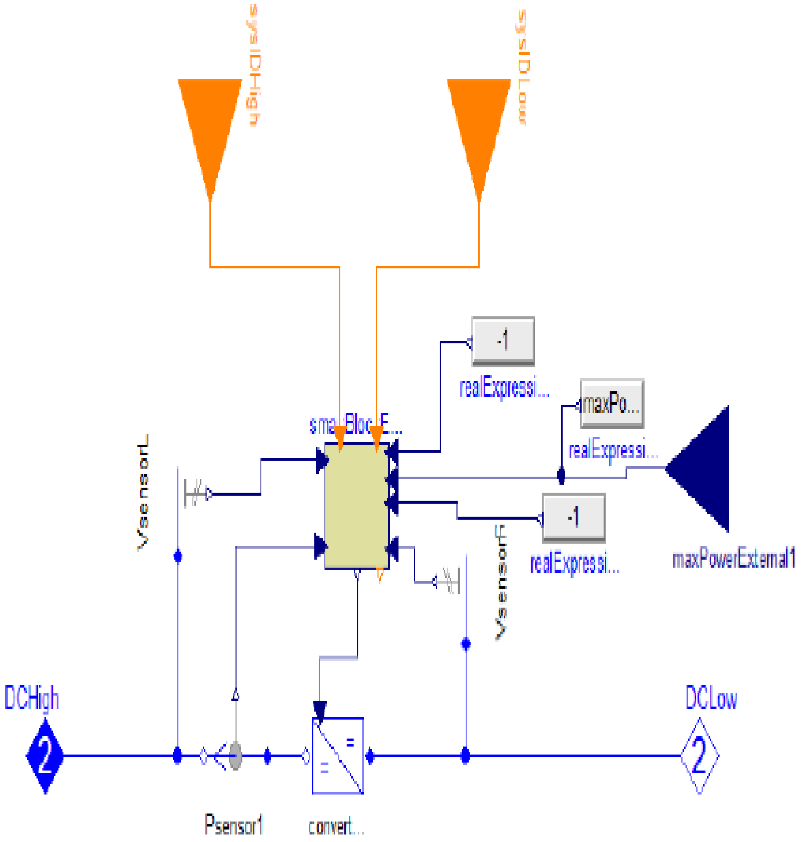

Figure 7: Modelica external connection

1. RESULT ANALYSIS:

2. This scenario was designed to test if the external medium voltage grid and the smart houses were able to adapt to changing conditions of the external high voltage grid fig.8. At t = 0 sec the medium voltage grid voltage v = 0 volt. The voltage at both the medium voltage grid and the houses internal grids were controlled to the desired voltage level. At t = 80s the external high voltage grid fails and the medium voltage grid goes into islanding mode and operates without any external connection. The system controller at this level is forced to use all its resources to try to maintain the voltage level.

In figure 9 the voltage levels for the three houses are presented. This figure is divided into the same three zones. Notice that all houses manage to keep their voltage level close to the reference value of 230 V. Small voltage drops are noticed in zone 1 when the loads are turned on. Entering zone 2 house 1 maintains its voltage. House 2 and 3 experience a small voltage change since the system controller is forced to turn off the lowest priority load. Entering zone 3 all houses experience voltage drops. This is due to that the battery start to control voltage instead of the external connection.

It takes a few seconds for the new controller to achieve good control of the voltage. House 1 and 2 experience larger voltage drops since these houses also needs to turn off loads. During zone 1 and zone 2 the batteries at house level charges since there is power capacity to do so. The battery *SOC* can be seen in figure 8.3. In zone 3, when the houses operate in islanding mode, the battery is controlling voltage and the *SOC* is therefore decreasing for all houses. Except for house 2 after *t* = 900 s. The *SOC* for the battery in house 2 drops below 0.1 at *t* = 900 s and the system controller therefore tries to recharge the battery by using the power from the micro generation and by disconnecting loads.

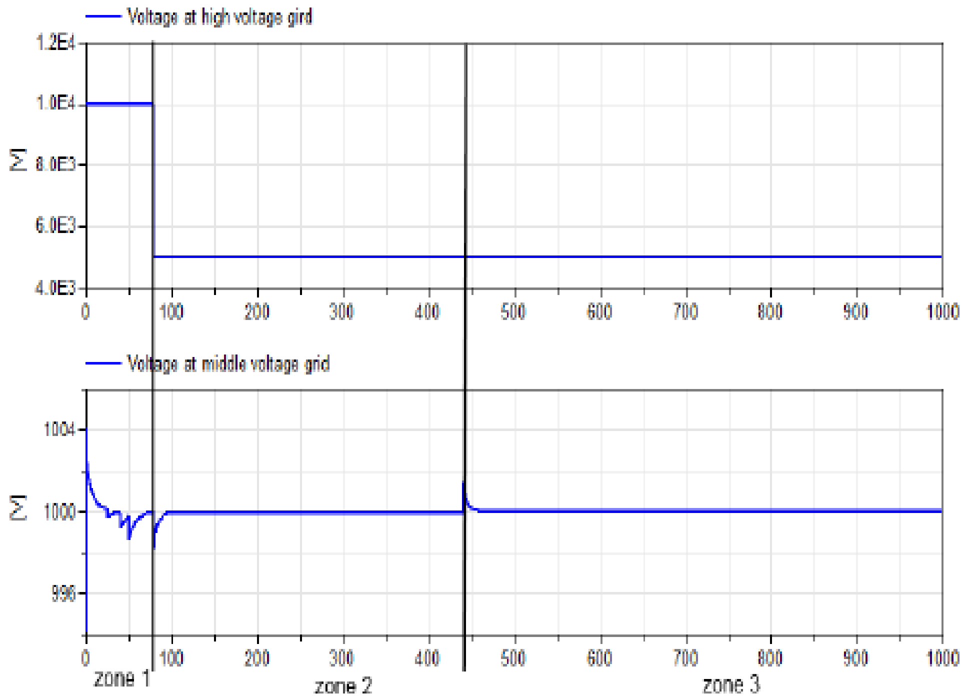

Figure 8: Simulation result short term

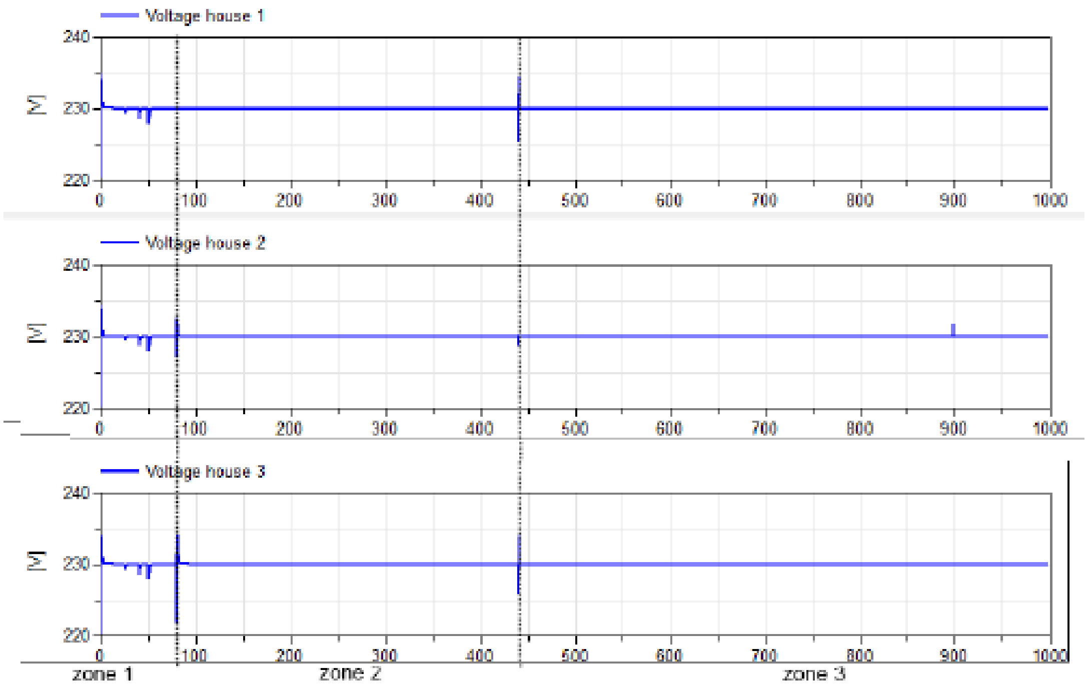

Figure 9: Long term simulation

3. CONCLUSION:

These results show that the controller program handles blackouts on the external high voltage grid well. With the help of energy storage the system can maintain voltage and keep the highest priority loads turned on. The system is also capable to recharge the batteries to prepare the grid for further blackouts. The grid robustness is mainly determined by the size of the energy storage. In these simulations the storage has been chosen rather small to illustrate the different zones in a quite small time frame. If the energy storage were dimensioned larger the system controller would be able to keep the houses/loads connected longer.

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