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Smart Grid Simulator

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***Abstract*—**The Smart Grid Simulator is a computer software based on advance algorithms which has as the main purpose to lower the energy bill in the most optimized price efficient way as possible for private households, companies or energy providers. It combines the energy provided by a number of solar modules and wind turbines with the consumption of one household or a cluster of nearby households and information regarding weather conditions and energy prices in order to predict the amount of energy that can be produced by renewable energy sources and the amount of energy that will be bought from the distributor for the following day. The user of the system will not only be able to minimize his expenditures on energy factures, but also he will be informed about his hourly consumption, electricity prices fluctuation and money spent for energy bought as well as how much money he saved each day and since he installed the system. The paper outlines the algorithm that supports the Smart Grid Simulator idea and presents preliminary test results that supports the discussion and implementation of the system.

***Keywords*—**Applied Science, Renewable energy sources, Smart Grid, Sustainable energy.

I. Introduction

THE way we receive our electricity has not changed much in the past hundred years. Coal, nuclear or hydropower plants send electricity through transmission lines to substations and on to transformers, through finer wires and smaller voltages until the transmission reaches our households. As the technology advances, sensors are being installed all over the grid, informing the Utility facility in real time about the market's demand in terms of energy, therefore lowering the possibility of a black out and giving opportunity to use other sources of electricity, less reliable but green energy, such as wind turbines and solar modules to be installed all over the grid. Due to these circumstances, different companies or house owners started to mount solar cells or wind turbines to produce their own electricity, in order to buy less from the electricity company. But this comes at a risk, for example, if the owner is producing too much of its own electricity the electricity companies are not able to sell the proper amount; therefore instead of saving money they spend more. This is the result of an unbalanced energy grid.

In terms of appliances, better and more sophisticated equipment is being used. From washing machines and dryers to electrical cars, each device is using a big amount of energy. The bigger the quantity of electricity used, the more money has to be paid. Another important fact to be considered is that the price for electrical power is fluctuating, therefore more money spent.

Furthermore, nowadays we have access to vast quantity of information, from weather forecast (temperature, weather conditions, wind speed and even sun and sky conditions) to production prices of energy for the following day including fluctuations, peaks and off-peaks during the day. This information can be used in predicting the amount of electricity which can be produced by renewable energy sources, as well as determining whether is better to consume the self-produced energy, to store it for later usage and even sell it to overcome the grid starvation.

The idea of Smart Grid Simulator depicted in this paper combines information regarding hourly energy consumption, production energy prices before and after taxes as well as the self-produced energy circumstances for the following day with a number of solar modules, wind turbines and a storage facility in order to:

- Predict the amount of energy bought from the distributor for the next day on hourly basis
- Lower the energy costs of the owner of the system by lowering the electricity bill
- Optimize utilization of electricity during peak and low-peak electricity production periods
- Raise awareness on the amount of energy used as well as the amount of money saved per day and since the system has been installed
- Compare energy prices before and after taxes on hourly based
- Compare the amount of money spent on energy bough by using and without using renewable energy sources on hourly based
- Run a brokering algorithm ensuring the energy is being bought/stored/sold when feasible for the system owner
- Predicting the amount of energy that can be produced by a number of solar modules/wind turbines
- Providing an energy storage facility

The Smart Grid Simulator principle can be used by companies, energy providers as well as one or a number of households connected to the same system, therefore introducing the idea of "friendly neighborhood".

II. Overview of the System

The following diagram depicts the overall idea of the Smart Grid Simulator.

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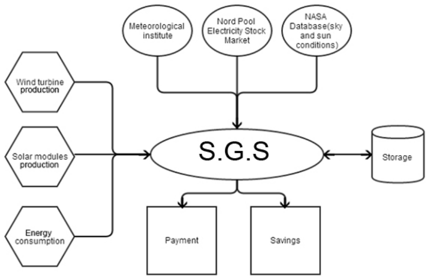

Fig. 1 Smart Grid System overview

The information needed and how they are being used can be described as follows:

- *Meteorological Institute* [1] provides the system with information regarding the weather forecast such as the temperature and the conditions for the next day. The most important information represents the wind speed for the following day, as this information is being used to calculate the energy produced by the wind turbine.
- *NASA Database* [2] or any other source that can provide information regarding the sun and sky conditions for the following day. This information is being used in calculating the amount of energy a number of solar modules can produce.
- *Nord Pool Electricity Stock Market* [3] provides valuable information regarding the energy pool prices of electrical energy for the following day for all distribution zones of Scandinavian countries. The website provides as well information regarding the fluctuation of the prices over time, such as peaks and off-peaks, information which is mandatory in determining the best approach in the algorithm (Section IV)
- Data regarding the production from the *Wind Turbines* [4] and *Solar Modules* [5] is required in order to calculate the amount of energy these sources can provide under tomorrow's weather circumstances.
- The *Energy Consumption* of a household, a number of households or an institution on the specific day is needed in order to calculate and predict the amount of energy that can be consumed on the following day. Furthermore, this information is also needed in determining the best approach in the algorithm (Section IV)

The Smart Grid Simulator is based on advanced algorithm that is using all the information depicted above in order to calculate and predict the amount of electricity will be bought from the distributor based on the seven days hourly average consumption and stored energy from today plus the self-producing circumstances for tomorrow. It calculates when to use the self-produced energy and when to store it based on the previous day hourly consumption and the following energy prices from distributor on hourly basis. It will choose whether is better to buy energy from the Energy Company, use the own-produced and stored energy or sell it in order to lower the electricity bill with maximum potency. In terms of storing the energy produced, hydrogen storage systems [6], thermal storage tanks [7] or batteries can be used [8]. Further investigations will occur.

In the end, the user is able to analyze the amount of energy he will be able to produce on hourly basis for the following day, the amount of money he will spend on energy bought as well as the amount of money he saved for the specific day and in total since he installed the system.

The entire software has been developed using LabView from National Instruments, mostly because of its easy scalable and modeling properties. An overview of the early development stage of the system can be seen in the following picture.

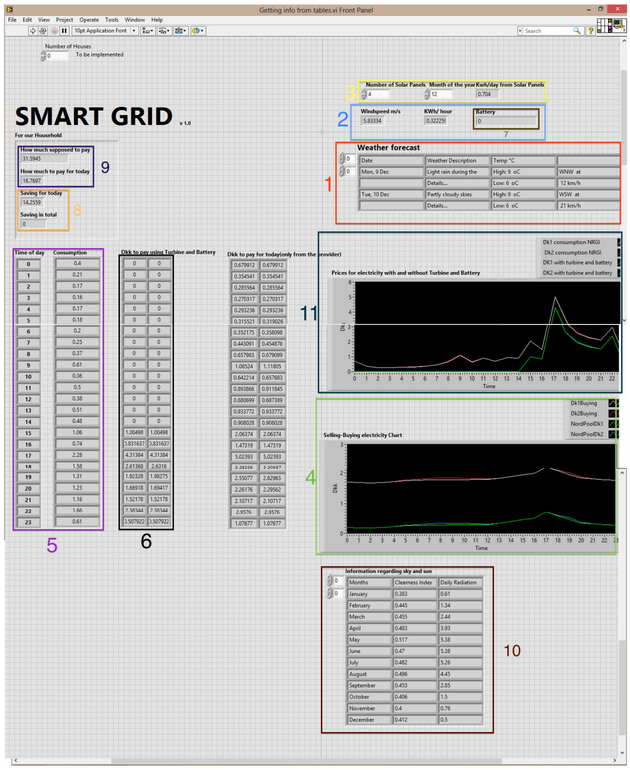

Fig. 2 Smart Grid System user interface

Features of the Smart Grid Simulator:

1. Weather forecast for 2 days (red)
2. Electricity produced by the wind turbine on hourly basis (blue)
3. Production from solar modules (yellow)
4. Production and distribution prices in Denmark for the next day (green)
5. Consumption of a household(or a cluster of houses) on hourly basis (purple)
6. The amount of money the user has to pay for electricity for each hour (black)
7. Battery storage status (brown)
8. Money saved for the specific day and in total (orange)
9. Money expenditures for electricity (the amount he was supposed to pay and the actual amount needed to be paid) (dark purple)

10. Information regarding clearness index and daily radiation (dark red)
11. Comparison between prices by using and not using the system (blue marine)

III. Decision Algorithm in Smart Grid Simulator

The main idea behind Smart Grid Simulator is how to save money by lowering the electricity bill as much as possible. After getting all information depicted above (Section III), Smart Grid can decide the best approach in calculating when to use self-produced energy, when to buy from the distributor and even selling it back to the grid. The decision algorithm is taking into considerations major possibilities in terms of buying/storing/selling energy per hour ensuring that at the end of the day the customer will have the lowest expenditures for electricity. The possibilities taken into account can be stated as follow:

- When the production is bigger than the consumption, the excess is being sold back to the grid
- When the production is not enough to cover the consumption, the amount needed to fulfill the usage of energy is being bought from the distributor
- When the production is bigger than the consumption, the excess is being stored in a battery either for later usage or selling
- Using from the battery the necessary energy to cover the consumption for the specific hour
- Sell everything from the battery and the produced energy for that specific hour back to the grid
- Buy the necessary energy in order to assure the difference between the consumption, production and a full battery.

Being a preliminary version of the algorithm, there are constrains in terms of using the battery. For example, each time when the energy is being sold from the battery to the grid, the entire quantity of electricity is being disposed, and each time when the energy is being bought from the grid in order to be stored, the battery will be fully charged.

An important factor to be noticed is that the last two possibilities regarding the decision algorithm are part of the brokering capability of the Smart Grid Simulation. Each country might have different regulations and policies regarding the energy sold to the grid, therefore there might be some constrains in terms of brokering. In Denmark, for example, for the energy sold to the grid, only a sum of money is being subtracted from the energy bill.

Due to the fact that the entire decision algorithm is based on whether the self-produced energy from tomorrow can cover the consumption, Smart Grid Simulator is analyzing all the possibilities stated above. Afterwards, it will choose the best approach for each hour in terms of using, storing, buying or selling energy in such a way that by the end of the day the user of the system will pay the least to the distributor. For example:

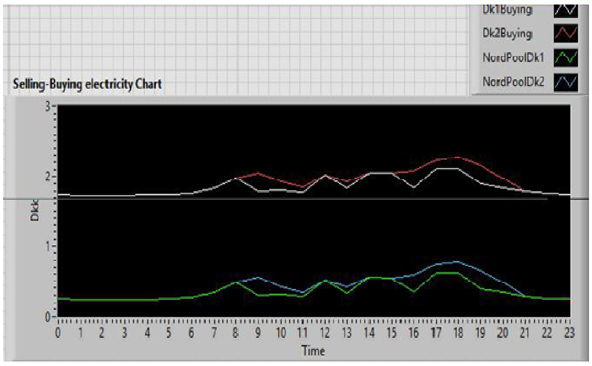

Fig. 3 Energy stock market prices before and after taxes

- The image above depicts production (blue and green) and distribution (white and red) prices for Denmark in Dkk/KWh, as well as the distribution zones that include: Western Denmark (green and white) and Eastern Denmark (blue and red). A visible change in the price can be seen throughout the entire day for both distribution zones.

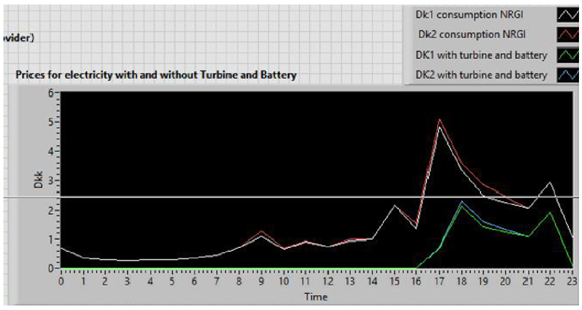

Fig. 4 Prices per hour when using and without using renewable energy sources

- The image above depicts the amount of money spent accordingly the consumption throughout the entire day by both using (blue and green) and not using (red and white) the Smart Grid Simulator system. This is done as well for both distribution zones with the energy prices presented above. It can be noticed when the renewable energy has been used, and when the system bought from the distributor in order to cover the consumption.

IV. Test Results

Several tests depicting different circumstances have been simulated in order to find how Smart Grid Simulator is acting. All the test results have been recorded properly.

The scenario depicted beneath is illustrating how the wind turbine is working. Parameters used are stated as follows:

- Energy production prices from 12.12.2013
- Wind speed : 7.22 m/s
- No solar modules involved
- Empty storage
- Exchange rate: 1 Euro= 7.5 Dkk

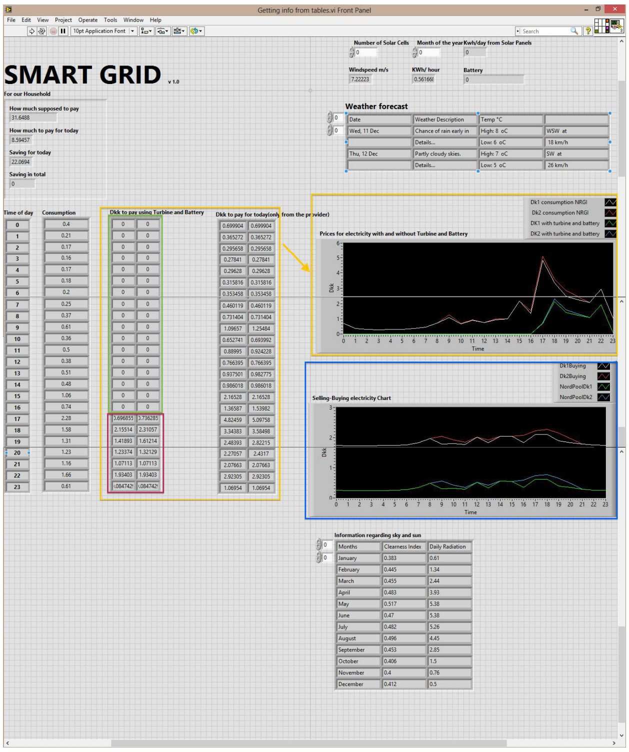

Fig. 5 Smart Grid Simulator simulation output

Focus points:

- Fluctuation of the production and distribution prices on a 24 hour period (blue)
- Energy consumption covered by wind turbine and battery from 00.00 until 16:00 (the household does not need to buy from distributor) (green)
- Lower prices for energy for the rest of the day (red)
- For comparison of prices with and without using wind turbine please refer to *Dkk using wind turbine* and *Dkk to pay for today (only from producer)*. The first table indicates the amount of money the user has per hour for the energy bought from distributor. The second one indicates the amount of money the user was supposed to pay if none of the renewable energy sources have been used. (orange)

Furthermore, the user can see how much money he was supposed to pay for today, how much money he has to pay as well as how much money he saved for the specific day and since he installed the system. He will be as well prompted with different information such as the weather forecast for two days, wind speed, the amount of KWh/h the wind turbine produces, the amount of energy stored as well as the amount of solar modules connected to the system and how many Kwh they can produce for that specific day.

V. Future Work

The system offers a number of interesting areas for future work. First of all, the current implementation does not take historical data into account. In the actual state, the decisions taken are based on seven days average hourly consumption, stored energy from today and tomorrow's energy production and prices. The system could be connected to a database in order to record all the information on which the decision has been made that day and this information could be aggregated and included in the algorithm to take, for example, seasonal changes or habits into account. To make the system automatic adjustable to historical data the artificial intelligence method is considered.

Another idea is to extend it with a website and/or applications for mobile or tablets, so that the system can be remotely monitored and historical data to be accessed.

In the actual state, the energy production and energy storing units are being simulated virtually. By creating an interface to support actual hardware, all the information will be more accurate and this will represent an important step in deploying the system.

Setting different privacy levels is also part of a further improvement of the system. In the actual state, there are no limitations in sharing and viewing the information.

Finally, the biggest step would be to actual implement the Smart Grid Simulator into a Smart Grid embedded system in order to see how it is reacting in real-life situation.

VI. Conclusion

This paper shows the application of leading edge technology within the area of Smart Grid [9] and sustainable energy, implementing an autonomous system capable of predicting the amount of energy bought from the distributor for the following day based on the consumption and stored energy plus the self-producing circumstances as well as the energy prices for tomorrow. An overview of the system has been presented as well as the key characteristics of the decision algorithm. In the end were presented test results depicting a scenario from the prototype system. These results demonstrate the valid behavior of Smart Grid Simulator.

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