Smart House with Smart Electricity

The need for a DC Bus

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***Abstract*— The following work describes an ongoing idea that becomes more logical in the future of domestic and military electricity. This paper introduces the necessity for using a DC bus system in private homes as well as introducing an innovative bi-directional inverter for making the energy flow to and from the grid. The bi-directional inverter also enables smart control of the energy flow with harmonics cancelation, and the ability to be adjusted to the future demand of smart grids and multiple tariffs. The research also includes social aspects as an integrated subject in the control schemes of the electrical devices.**

Keywords- Smart house, Inverter, Smart grid, control circuits.

I. INTRODUCTION

THERE is a lot of interest in recent years in Smart Grid application. Dealing with these smart grid new concepts brings us back to basics and raises the question whether the current way of providing and consuming electricity is the correct or the best available way [1]. As for today, most of the electrical appliances that can be found in a typical house work on Direct Current (DC). A computer is assembled of DC circuits, TV is based on DC circuits, lighting and heating can also work on DC. The only appliances which require Alternating Current (AC) are the air-conditioners and the rotating machine based appliances, such as a washing machine and dryer. Although these appliances consume heavy loads, they consume only 30-60% of the total load. On the other hand, transporting energy for long distances is known to be more efficient in AC. Another factor that needs to be added to the new equation of the future energy world is the addition of renewable energy as a power source. Photovoltaic energy is DC and wind power which is AC based power sources. There is work done on DC distribution systems based on Photovoltaic generation and the electrical control strategy [3] , as well as on DC distributed systems for residential applications with the use of Bi directional Inverter [4].

The above mentioned situations lead to the question whether AC power in our home is the right way of providing our loads with the power [4],[5]. Moreover, the assimilation of communication and control capabilities in the future Smart grid enables us to control the efficiency of the power flow according to various criteria. These criteria can be influenced by the status of the total grid. As an example, let us consider a grid with over 30% renewable energy, and for stability issues the grid has to control the power flow from all renewable sources, namely, the photovoltaic inverters will not necessarily work in Maximum Power Point (MPP).

This paper reviews the idea of combining a local DC bus grid in a few applications for increasing the total efficiency of energy transformations in the overall grid. A Bi-Directional Inverter (BDI) for enabling the dual DC/AC and AC/DC power flow with reduction of harmonics and control is presented. The converting systems are treated as Time Variable Transformers with advanced control that combines also non-electrical parameters. The paper also deals with micro-grids and synchronization issues by using the DC bus and the social aspects of controlling this electricity in the Smart Grid environment.

II. DOMESTIC DC BUS

In recent years private installations of PV generators and wind generators are becoming common in many countries. There are differences in the supporting laws in each country but in general these renewable generators are a financial business in which the investor wants to restore the investment on the system and make a profit on the electricity he sells to the grid. For achieving this goal, the current installed inverters are equipped with Maximum Power Point Trackers (MPPT) for maximizing the power extracted to the grid.

When renewable energy will reach a dominant percentage of the grid current, other issues of stability of the grid will rise. In this case not all renewable generation will be allowed to penetrate the grid at all times. Furthermore, future storage that will be available, even in domestic facilities, will require a more complex control on the power flow.

The fact that most of the appliances in our homes are operating on DC raises the question whether it is logical to have a PV generator on the roof, then invert the DC to AC, then convert the AC back to DC to power all of our electronic circuits. This two conversion process is obviously not efficient since each energy conversion reduces the total efficiency of the process.

It is probably more logical to have a separate DC bus at our home, parallel to the AC grid (that will power all the AC appliances such as air conditioners etc.) as seen in Fig.1. In this case the future computer, TV and all other DC appliances will not need to have an AC/DC rectifier in their

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input power supply. This yields to more efficient and cheaper electrical appliances.

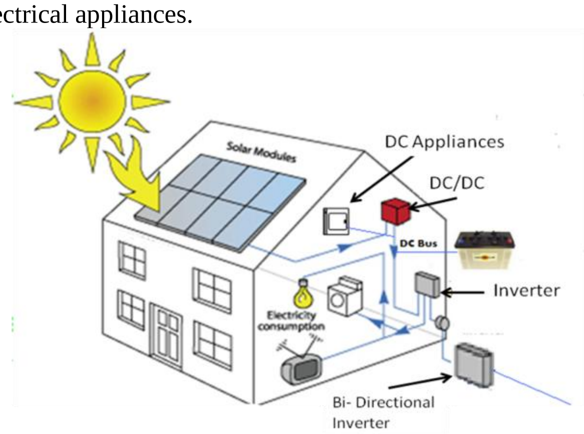

Figure 1. A combined DC and AC grid in a house

Fig. 1 shows the components that are necessary for assembling an integrated DC and AC home.

The house has two power grids: one is an AC grid and the other is the DC bus. The PV panels on the roof are connected to a DC/DC converter that has an MPPT and control schemes for various grid constrains algorithms. This converter powers the DC bus. Moreover, there are storage capabilities that are connected to the DC bus also. Furthermore, there is an option of charging the DC bus from the grid with a bidirectional inverter that will be discussed later on. The purpose of the bi-directional inverter is to enable bidirectional power flow in cases such as:

- PV energy must be controlled due to grid constrains.
- PV is not available and DC power is required.
- Grid electricity is cheaper and DC power is required for charging the storage device.

A. *The bidirectional inverter*

The core of the system is the bidirectional inverter. A schematic drawing of the whole system is presented in Fig. 2.

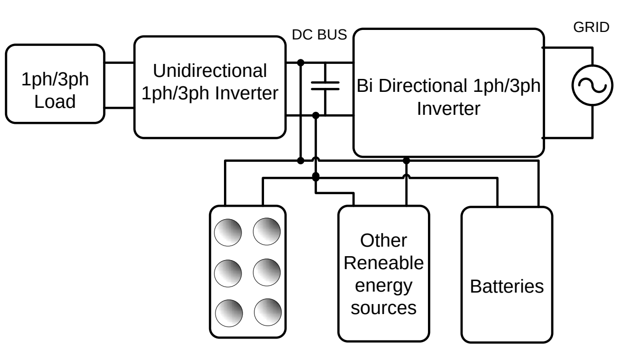

Figure 2. A block diagram of the electrical system in a future house.

In Fig. 2, it is clear that the gateway from the domestic electric grid to the "main" grid, namely, the utility, is the bi-directional inverter. This inverter, in one direction, can transfer power flow from the power grid towards the loads and DC bus. In the other direction, it can transfer the power from the house back to the grid. The advantage of this device is the ability to control the power flow as well as controlling the power quality. The bidirectional inverter is equipped with a bidirectional power factor corrector and control that is also influenced by dynamic tariffs, social aspect such as nonintrusive algorithms and electrical efficiency control.

This system is designated for small to medium loads of up to 15kW with modularity capabilities for expansion. The system is connected in one side via a Bi Directional one phase or three phase inverter to the grid. On the DC side of the inverter there is a unidirectional one phase or three phase inverter for supplying the load (home, commercial, industrial).

When no renewable energy is available, the system is acting as an active filter for reducing harmonics [6]. When renewable energy is available, it produces energy directly to the DC bus and will smoothly supply energy. The system will then divide the amount of energy that the grid supplies and the energy from the renewable sources. If there is excess supply from the renewable energy sources, the system will return energy back to the grid or store it in the storage bank. Moreover, if at any time electricity prices decrease, the system can store energy in the storage bank for later use.

The main challenge is the development of optimal control strategies for energy usage aiming to maximize customer economic savings, while preserving user preferences and quality of experience, based on a proper subscribed power supply contract. The key aspect of the research is the optimal trade-off between the exploitation of convenient fares and the overload management, by considering the following electric devices:

- Loads characterized by different controllability degrees.
- Storage units.
- Uncontrollable Micro Generation.
- Other small size traditional power plants.

Preliminary evaluation of the problem suggests that the control signals to be optimally generated consist of:

- The best times to run programmable loads.
- Power recharge/release evolution of the storage units.
- Evolution of generation set-points of traditional power plants.

All these aspects need to be taken into account, together with time varying energy prices, estimated power consumption from not programmable loads and the forecast of generation from renewable and uncontrollable units. The solution of integrating distributed control algorithms with dynamic programming approaches will be investigated. The Implications on the Power Grid are considered too.

The state of the art technology offers inverters with harmonics reduction. The common method is to use simple PWM controlled inverters and multilevel topologies for reduction of the harmonics content. Other techniques involve a controller that samples the current and phase shifts the current for achieving PFC. This research is offering a different approach by namely considering the Inverter/Converter as a Time Variable Transformer (TVT)

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whose power stage is designed to be a simple Inverter and with flexibility and enhanced characteristics which are obtained by advanced control schemes. In this research the following control schemes are being developed, analyzed, simulated and implemented:

- Power flow control that enables the BDI to perform as an Inverter or as a Rectifier by demand.
- Control scheme to reduce harmonics at inversion.
- Control scheme to reduce harmonics at rectification.

In general, the system is considered as a TVT, as seen in Fig. 3,[7],[8]:

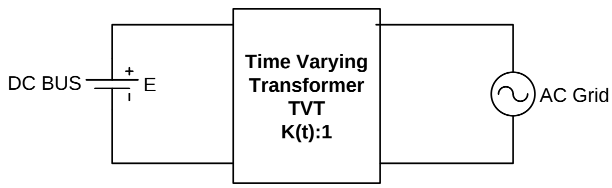

Figure 3. TVT presentation of Bi- Directional Inverter

The DC side is held at voltage E by either a storage bank or a large capacitor. The AC grid side is either a one phase or a three phase system. Namely, for the one phase system, the voltage is:

$$v(t) = V_m \sin(\omega t + \theta) \tag{1}$$

For the 3 phase system the AC grid will have three phase voltages as follows:

$$\begin{aligned} v_1(t) &= V_m \sin(\omega t + \theta) \\ v_2(t) &= V_m \sin(\omega t + \theta - 120^0) \\ v_2(t) &= V_m \sin(\omega t + \theta + 120^0) \end{aligned} \tag{2}$$

In the case of a three phase system, the power injected or drawn from the grid is constant and in the case of a one phase system, it is time dependant and fluctuating in a frequency that is double the grid's frequency [9]. By applying an appropriate control signal k(t), the AC and DC sides can be matched in a way that harmonics will be eliminated. For example, in an AC to DC conversion in a one phase system, the control signal for eliminating the harmonics, the transfer ratio of the TVT is: (when considering a realistic system with an internal resistance of the DC source of r) [8], [10]:

$$k(t) = \frac{2V_m \sin \omega t}{E\left[1 + \sqrt{1 + \frac{2rI_m\left[\cos\phi - \cos\left(2\omega t - \phi\right)\right]}{E^2}}\right]} \tag{3}$$

In a three phase system, the control due to the constant power behavior is simpler. However, the hardware is more complex and therefore there are more control signals (for each phase). The control can be represented as:

$$\left[k(t)\right] = \begin{bmatrix} k_1(t) & 0 & 0 \\ 0 & k_2(t) & 0 \\ 0 & 0 & k_3(t) \end{bmatrix} \tag{4}$$

Each element in the matrix (4) can be subdivided into the signals relative to each one of the switches (FET, IGBT, etc). In this way each element can be represented as a sub matrix.

B. Local and Grid Control

The existence of a BDI at the entrance to each house yields a lot of opportunities. Since each BDI is equipped with a unit that has a control and ability to be programmed, the general system can be divided into two main controls, as seen in Fig. 4.

In Fig.4 the two control schemes are presented. Each BDI is controlled for maximizing the energy efficiency in the house. This control has distributed characteristics. On the other end, the units are connected to the smart grid and have a centralized grid control. This control can also be in a few hierarchies (neighborhood, city, country, etc.). The grid control takes into account constrains of the grid, namely, the ability of the grid to absorb energy from renewable energy sources, reducing the losses on main transmission lines, overload and frequency changes in the grid, stability etc. The local domestic control then responds to the grids demands and can change the profile of the prosumer for achieving efficiency in all levels.

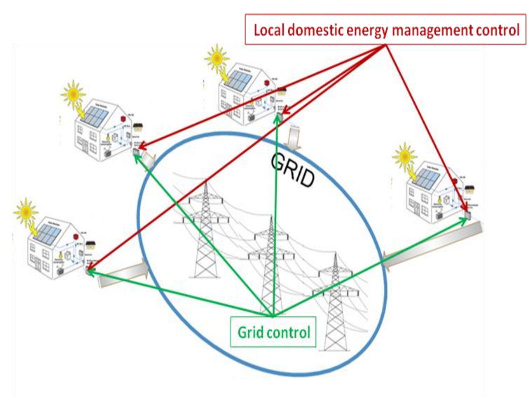

Figure 4. A block diagram of the electrical system in the future home.

III. MICRO-GRID APPLICATION

Another important application can be micro-grids, as seen in Fig.5.

In this example a small grid is being established (such as in field deployment applications). The grid is constructed by small generators, storage devices, renewable (PV and wind), DC and AC loads and an optional grid connection. The mixture of sources types and load types makes a single AC grid very difficult to implement.

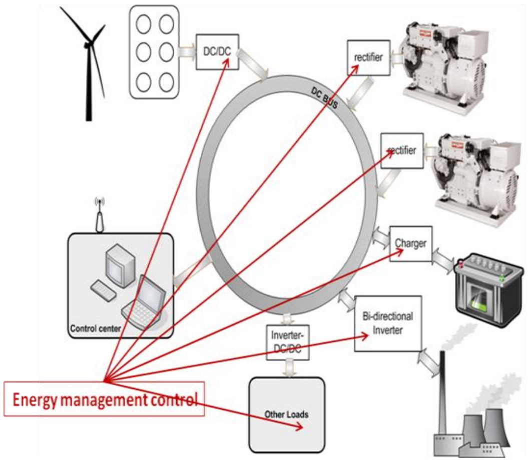

Figure 5. A DC bus in a micro-grid application

In a micro-grid, the synchronization of the various sources is difficult due to stability issues. The DC bus is then the natural solution due to the fact that no synchronization is necessary. All sources are contributing the power to the common DC bus via a DC/DC converter or an AC/DC inverter. The optional BDI enables connection to the general grid for emergency power need or for injecting power to the grid.

IV. SOCIAL ASPECTS OF SMART ELECTRICITY

This research will engage all stake holders up-front. The assumption is that in order to speed up the adoption of any new technology, all stake holders must be involved [11]. In the case of the DC Bus, the stake holders have to be mapped. First, they have to be identified and then discover their real needs. Another aspect that is highlighted here is the fact that in a large project a full engagement of the end-users is necessary. This methodology is named: 'user centered design' (UCD) or a 'living laboratory'. Another important aspect for knowledge-based development is the notion that change can happen only if all stakeholders are involved A Living Lab has to be created in which the consumers will become full partners in the iterative research and development cycle. This methodology was successfully used in other research projects where developing systems with state of the art technology of wearable computing was introduced into different environments [12], (www.wearitatwork.com). Social aspects will thus be studied using an Action Research approach producing guidelines to the developers to be followed by further ethnographic research and interviews for data collection, once prototypes have been introduced and then followed by further guidelines to the developers of the new technology. The conclusions of the social research will be implemented as control schemes for controlling the electrical equipment as non- intrusive operation.

Thus, this research is interdisciplinary with better probability of quick exploitation by all stakeholders.

V. CONCLUSION

This paper describes an ongoing research which aims to enable the insertion of a separate DC bus to private homes and other applications where it is natural to use this idea. The main reason for utilizing this idea is the fact that most loads are DC operated as opposed to the load characteristics in the past (30 to 40 years ago). The system is based on BDI with control schemes that are designed for maximizing the power efficiency, minimize the harmonics for maintaining power quality and take into consideration the social aspects of the prosumer.

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