ADJUSTMENT OF AVAILABLE AND NEEDED ENERGY AND NECESSARY ADDITIONAL FUNCTIONALITIES IN THE DISTRIBUTION GRID, CAUSED BY THE ENERGY TRANSITION, CAN BETTER BE SOLVED BY DC DISTRIBUTION GRIDS

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ABSTRACT

As a result of the present energy transition, grid operators are facing problems caused from fast changes of (electronic) loads and their functionalities. With increasing usage of photovoltaic (PV), electric vehicles (EV), local storage and de-centralized feed-in, the present AC distribution grid in the "last mile" is not suitable anymore. Additional IT infrastructure for AC networks to manage demand and supply in a dynamic way is necessary. The latter is complex and with IT infrastructures the failure sensitivity will increase.

DC grids do not need additional IT infrastructure to solve congestion in the distribution grid. With a suitable DC grid the energy supply and demand can be managed much better. With DC, it is also possible to create a meshed network so that local feed-in of various sources can be managed as well. Naturally, DC introduces the necessity of additional and different type protection devices. Eaton's smart breakers and Direct Current B.V.'s current routers are specially designed for protecting DC grids.

INTRODUCTION

History

Electric power is needed almost everywhere and is a basic need for living. Around the late 1880s and early 1890s, Nikola Tesla and Thomas Edison created AC and DC power sources respectively. These sources were then available for electric power transmission. However, Tesla's AC solution turned out to be more practical for the distribution and transforming of the voltage at that time.

For many years this AC solution was indeed the best choice. However, times are changing and there is now a reasonable chance for Edison's DC to get its attention and help to fight back over the coming decades.

Political Trends

On the political level, there is now a reason for change as identified by the United Nations 2015 climate conference in Paris. Of course, there is no direct relation to the choice of AC or DC power grids; the agreement is about the reduction of CO_2 and the global warming of the planet. Nevertheless, the Paris agreement will indirectly change traditional energy sources like gas, oil and coal-fired power stations and use of alternative solutions will be increasingly stimulated. Governments have budgets for undertaking pilot projects in this energy transition phase.

The Electronics Revolution

For many years after the battle between Tesla and Edison there were no revolutionary technical solutions available to change the top-down AC grid distribution structure. Over the last few decades this situation has changed drastically. The switching losses of semiconductors and power electronics have reduced considerably and in the meantime almost every device, either it is a power supply or a power converter, no longer has an AC transformer, but instead a low weight, cheaper, compact and more efficient Switch Mode Power Supplies (SMPS). The availability of new semiconductor technologies has unquestionably started to change power distribution. Moreover, increasingly fast and cheap micro controllers, memory components, communication components, electronics storage parts, LED technology etc. make a great contribution to alternative energy distribution solutions. And do not forget the continuously improving silicon PV cells for green energy generation.

DESCRIPTION OF THE PROBLEM

The present AC top-down grid structure was not designed for the demands of modern energy needs. Most of the former consumers will change into prosumers, since a lot of buildings or "last mile" grids will have their own energy distribution systems. Consumers will then have zero-energy characteristics. The day-night sequence will be balanced within such a system too. However, a summer-winter variation is probably not included.

Also, power quality will be an issue. Not only EMC/Common mode disturbances due to the increasing converter use, but also the continuously changing AC voltage at every prosumer or grid node will be a challenging problem to solve. This power quality issue is already a contributory factor for grid reliability problems.

To handle this new "last mile" characteristic of the AC grid, an IT infrastructure is also needed. Privacy and hack issues arise then. This also makes the AC grid vulnerable.

Greenhouse Case

As an example, the business case and grid optimization of a 2.4ha-1.4MW greenhouse is considered [1]. A serious problem for traditional greenhouses connected to AC grids is EMC. Because of the high frequency switching and the filters in the numerous 600W or 1000W ballasts, the grid has a lot of common mode electromagnetic disturbances. This sometimes results in non-functioning communication for the control circuits that are used to manage the temperature, lighting and ventilation of the greenhouse. In general, the controllability of greenhouses with traditional AC grids is not optimal.

Figure 1: In greenhouses many "grow lights" are used.

Another problem with the lighting ballasts is the mean time between failures or the life time of the AC/DC converters which use electrolytic capacitors. For every 1000m^2 about €15.000 each year are required to replace defect traditional AC/DC ballasts.

Besides that, in greenhouses any energy saving directly results in more profit, since about 20% of the OPEX costs is energy. For greenhouses, the energy costs per m^2 are about €15 compared to a total turnover per m^2 of about €70 each year.

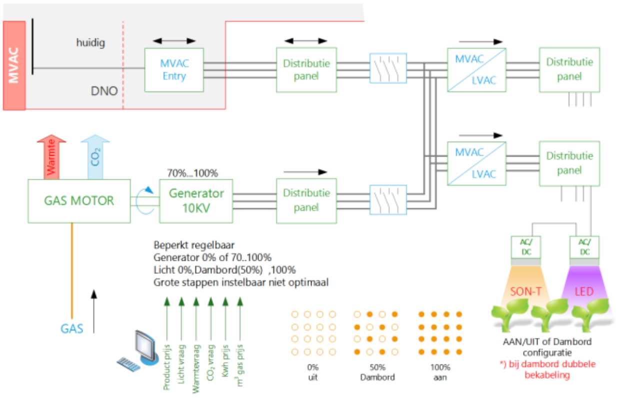

Figure 2: The existing AC grid for the greenhouse.

HOW THE PROBLEM WAS ADDRESSED

The greenhouse was optimized by changing the 3 phase 400/690VAC installation into an active DC grid. A grid voltage of ±700VDC was selected, which is within the low voltage directive scope. The cabling of the installation was not changed.

The lighting ballasts were changed from AC to 700VDC. The DC-ballasts are smaller, cheaper and have no electrolytic capacitors which increases their life time significantly [2]. Also, the common mode disturbance was reduced so that even power line communication was possible.

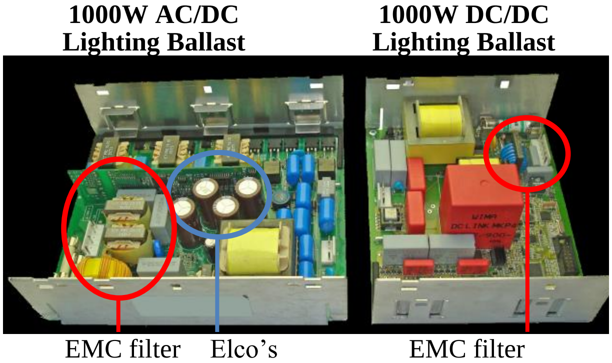

Figure 3: AC and DC lighting ballasts.

Power regulation was implemented on the CPH gas motor to continuously balance the required energy.

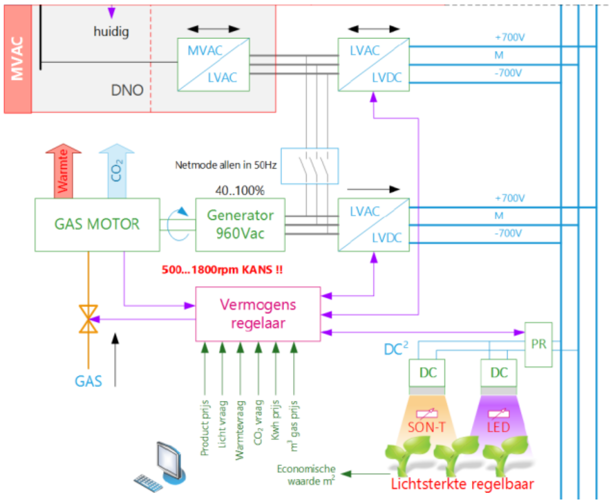

Figure 4: The improved active DC grid for the greenhouse.

The total investment for the conversion to an active DC grid was approximately €300.000, including the extra converters, ballasts and power routers [3]. In the future, when these devices are commonly available, the investment cost is expected to be much lower.

RESULTS OF THE ACTIVE DC GRID

After changing to the DC grid, the controllability of the temperature, lighting and ventilation of the greenhouse was much improved and, because of the CPH balancing, a gas use reduction of 33% was achieved. This resulted in a reduction of 33% × €15 × 24000m^2 = €120.000 per year. The payback time of the investment was approximately 2.5 years. Of course, this energy reduction also equals a significant CO_2 reduction, which is also the goal of the Paris agreement.

The optimized total converter and cable losses of the active DC grid were about 3% and did not significantly contribute to the total business case. The total reliability of the system was improved. The greenhouse project proves that there are great benefits in upgrading existing AC installations.

An even better situation can be realized when also PV and the CPH are integrated into the active DC grid and balancing their power. By changing the DC grid voltage, the power regulation of the CPH motor can be managed. For example, on a sunny day the DC grid voltage will be high due to the power generated from the PV and the CPH can be balanced to provide minimum power generation.

This active DC grid management is defined in the grid code "Current/OS".

CURRENT/OS

To achieve the maximum benefit of an active smart DC grid, an operation standard must be provided. However, this is currently not yet widely available. Although there is within IEC a Systems Committee involved in the coordination of DC standardization, there is not yet a working group preparing an active DC grid standard.

In The Netherlands however, Direct Current B.V. and a couple of big industrial partners such as Eaton Industries (The Netherlands) B.V., are participating in a foundation which promotes a highly sophisticated professional Current Operating System, the "Current/OS". This Current/OS is an open grid system code, where the behavior of the grid and its components are described just as in a typical standard. It is available for licensed users, participating in the foundation.

The Current/OS grid code contains the full definitions for protection, safety, communication, congestion management, start-up behavior of loads etc., which makes it a general guideline applicable in many different applications. The Current/OS grid is scalable to any size and prepared for multiple sources, storage and all different kinds of DC loads. It performs an automatic configuration, based on parameterizing, so no additional programming is needed.

In the DC grid a high grade of information exchange is possible, while the privacy of users can be guaranteed by design. No additional privacy protection is needed. There is a built-in communication layer, but this is mainly used for parameterization of the system. The fast responses of any changes in the system are not using the communication layer and no further real time control is needed.

OTHER USE CASES

Active DC Grids for Industrial Estates

For industrial estates an active DC grid will also generate a positive business case [4]. Also for this use case decreasing the total converter and cable losses did not make the overall business case.

As an example, the fully DC powered ABN AMRO pavilion is considered.

Figure 5: DC powered ABN AMRO pavilion in Amsterdam.

All 84 power socket outlets will be provided by Current/OS connected USB-C outlets. The USB-C outlets provide all the power required for laptops up to 100W. The internal power supply is connected to the 350VDC grid of the building by the Current/OS defined standard. In the USB-C protocol high speed internet is also included, so additional Ethernet connections are not needed.

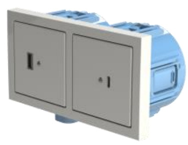

Figure 6: USB-C wall socket.

Using the Current/OS balanced DC grid, the PV energy is balanced with the 60kWh battery storage to mainly equalize peak demands of the DC/AC converter connected kitchen-equipment. Together with the 150kW front end AC/DC connection, the PV, the storage, the 27kW of LED lighting and the USB-C connected laptops, the DC grid is balanced for an AC grid connection of 160kVA.

The business case is, in addition to the energy saving and equivalent CO_2 reduction, the savings of a smaller AC connection and internal distribution required. Without this balanced grid, a 200kVA AC connection would be required.

Active DC Grids for the Residential Area

Active DC grids are not limited to buildings, but as shown in the use case of a "last mile" residential area future hybrid smart grid as well.

In this concept, an integrated traditional AC and active DC grid is provided [5]. The houses have through micro-converters a connected rooftop-PV installation with heat pumps and a hot water supply. The traditional AC installations and underground AC grid infrastructure are not changed.

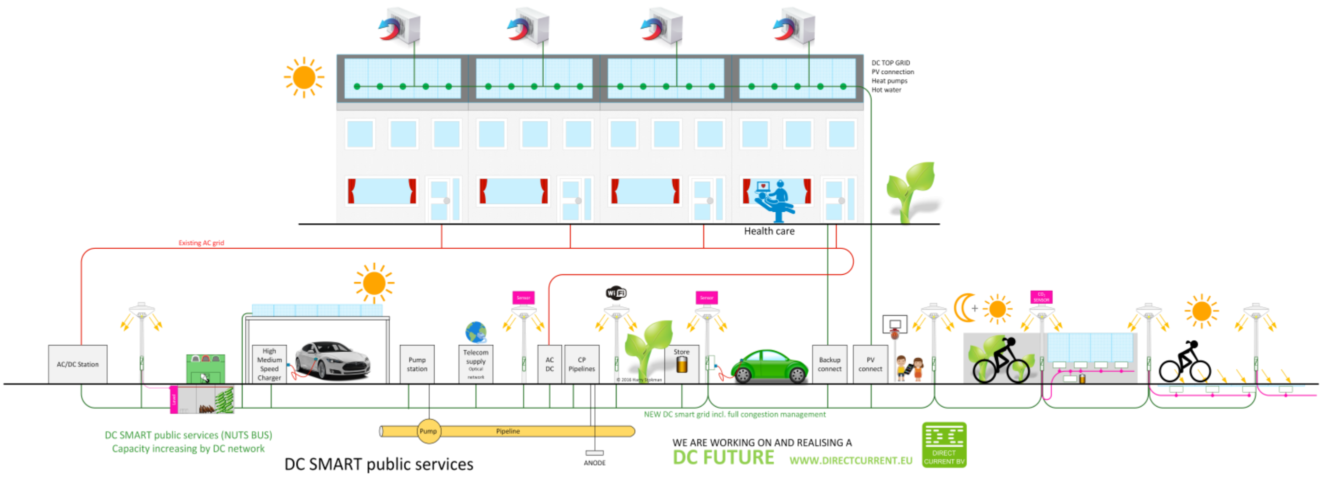

Figure 7: Smart DC concept for residential areas.

An additional DC grid is used to connect the renewables, the EV chargers and smart city applications. This contains sensors for waste containers, light and CO_2, battery storage, further PV installations, street lighting and information/IT infrastructure. This is all possible in a "last mile" active DC grid with congestion management included.

CONCLUSION

The overall conclusion is that there is a positive business case for the greenhouse active DC grid, because of the better controllability of the lighting, ventilation and temperature. An energy reduction of 30% could be reached. The payback time of the investment was within a very small time period of 2.5 years.

Similar positive business cases for active DC grids are possible for industrial estates, "last mile" grids, data centers etc. The additional functionality, the natural congestion management and the balancing of multiple sources with multiple storage derives, bring the major advantages of a DC distribution grid.

When existing AC grids are transformed to active DC grids, in general the installation wiring can be maintained. At the same time power quality problems are solved and there is an overall increased capacity for the meshed grid.

Because of the energy transition phase, the renewables and integration of power and IT will influence the "last mile" grid. When additional functionalities are required, there is a great opportunity with the implementation of active DC grids.

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REMARKS

Additional information about the cases presented in this paper can be found at Direct Current B.V.'s website: http://www.directcurrent.eu/en/.