System Level Simulation of Micro Grid Power Electronic System

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Abstract. In this paper, the modelling procedure of comparison of non-modular and modular power electronic concept for household DC microgrid system (10 kW) is being described. The aim was to develop simulation model with accurate behaviour compared to experimental sample, due to implementation of the model within system-level simulations of complex microgrid systems. Simulations have been performed with PLECS circuit simulator. Also, experimental sample similar to circuit topology of simulation model was realized within reduced power ration of the target application (1:10). Based on achieved experimental results, optimization of simulation models have been realized in order to achieve as close accuracy of operational properties as possible. This approach consequently enables to develop simulation models of DC microgrid system with high level of accuracy thus giving possibility to investigate any operational scenarios at required power delivery. Proposed simulation model analyses two different energy flow scenarios between photovoltaics (PV), battery storage system (BSS) and AC grid (load), while efficiency of power flow and qualitative indicators on AC grid are evaluated.

1. Introduction
The increasing penetration of renewable energy resources and new sizeable loads, like Electric Vehicles (EV) charging stations, has posed many technical and operational challenges in the distribution grids. Encouraged by the attractive tariffs and promotion policies, the end-consumers in the local grids are not only consumers of electricity but in many cases also producers. The actual electric distribution system limits the penetration of renewable energy resources and is based on a unidirectional information flow from sources to control centres. With gradual deployment and a combination of various energy sources with the possibility of cooperation with the public grid, the development of so-called intelligent or smart grids has been started.

With the help of SG networks, we can also ensure a significant reduction in transmission losses by moving energy over short distances, which leads to a reduction in conductivity losses in particular [1-8].
Initially, circuit description of DC microgrid in variety of non-modular and modular type of converters are being modelled using PLECS simulator. The results of time-waveform operations have been compared to experimental samples of converters. In order to verify the accuracy of the HIL model, efficiency of simulation model and experimental sample have been evaluated, while the procedure is being presented for comparison of non-modular and modular topologies of bidirectional converters.

2. Materials and methods

A principal block diagram of the proposed microgrid is shown in Fig. 1. The block diagram is proposed for the standard installation of PV panels and an energy storage system of the household, which reflects the power level of approximately 10 kW. Presented concept consist of these main functional blocks:

- photovoltaic cells,
- MPPT DC-DC converter,
- energy management block,
- one-phase inverter,
- energy storage block
- bidirectional DC-DC converter for energy flow control from and into the energy storage system,
- control and communication block.

![Figure 1. Block diagram of proposed microgrid for households.](image)

Principal schematic considering non-modular and modular solutions are shown in Fig. 2. Block diagram indicates the voltage levels selected for practical experiments, while the values are reduced for power delivery of 1kW full power (real system operates at 10 kW). The converters in modular solution are phase-shifted by 360/8 ° to achieve low output voltage and current ripple. However, these emulations are reflected also within components design of the converters main circuit in order to provide as the most realistic conditions as possible.

![Figure 2. Principal block schematic of non-modular and modular solution of microgrid.](image)
The non-modular concept utilizes SiC transistors operates at lower switching frequencies (app. 100 kHz) and uses standard inductors. On the other side in order to provide increase of power density performance, the modular concept utilizes low voltage/high-speed GaN transistors (operating over 300 kHz) with planar inductors. The aim of the study is to verify possibilities of the bidirectional system optimization with the use of perspective variations of power electronics solutions [9-14].

2.1. MPPT converter solution
Main task of MPPT converter within proposed microgrid is to convert the fluctuating DC voltage obtained from photovoltaic panels to a stable DC voltage. The MPPT algorithm, i.e. the algorithm for achieving the highest possible panel performance, will be implemented in within the inverter control system if HIL is considered [11].

![Figure 3. Circuit diagram of perspective dual interleaved boost converter with magnetic flux reset circuitry.](image)

2.2 Bidirectional DC-DC converter for energy flow control
This sub-system of considered microgrid provides a bidirectional interface between the DC link and the energy storage system (ESS). It provides charging / discharging of the batteries depending on the selected power delivery or based on pre-defined state of charge control of the batteries. The principle of the operation e is simple and is based on operation of traditional step-up converter with a synchronous rectifier. The circuit modified in this way already enables bidirectional energy transmission and its correct operation is already the task of a suitable control circuit [12-13].

![Figure 4. Circuit schematic of (a) non-modular; (b) one module of modular Bi-BB converter.](image)

The converter has a high efficiency (up to 98 percent). The interleaved solution is requested in a high-power operation (above 10kW) [15-16]. The evaluation of the properties of a dual interleaved bi-
directional buck-boost converter as the non-modular topology is the focus of the analysis of the consider DC smart-grid concept utilizing HIL and in relationship to the design of the microgrid's ESS power converter system (Figure 4a).

2.3 Alternatives for DC link and AC grid
The interface between the DC micro-grid and the AC distribution grid is represented by a three-phase inverter. It ensures the flow of produced energy from the DC microgrid towards the AC distribution system, depending on the selected energy flow control plan. The inverter’s control system should allow the compensation of reactive power components so that the production of quality energy is achieved with the lowest possible content of harmonics and other interfering signals. A conventional full-bridge inverter has been selected for the DC / AC inverter part, which provides enough parameters for the use within considered application [14].

![Figure 5. Circuit schematic of three-phase DC/AC inverter.](image)

3. HIL simulation models
The demonstration of the presented approach is validated through simulation of microgrid operation. To investigate the behaviour of the proposed microgrid concept, two operational scenarios were proposed, and are described. The HIL simulation models was created according to Fig. 2 and have been performed with PLECS. The thermal performance together with magnetic components modelling are designed according to parameters of the physical sample. Also, semiconductor devices use exact data of the losses received from manufacturer’s datasheets. The simulation models of each converter are shown in figures (see Fig. 6, 7, 8) [17-19].

![Figure 6. Simulation model of perspective MPPT converter.](image)
3.1. Operational scenario 1

The first operational scenario is graphically depicted on Fig. 9. It is assumed that 50% of the available power will be sourced from MPPT converter and photovoltaic panels into DC bus. Remaining power required by the grid will be supplied from energy storage system. In summary, 4 kW is supplied by renewable sources and 4 kW by energy storage system and thus 8 kW are sourced within the supply grid.

![Block diagram of power flow in scenario 1.](image)

**Figure 9.** Block diagram of power flow in scenario 1.

![Battery and inductor currents of Bi-BB converter.](image)

**Figure 10.** Battery and inductor currents of Bi-BB converter (a) non-modular; (b) modular solution.
Figure 11. Current and voltage of DC bus (a) non-modular; (b) modular solution.

Figure 12. Current and voltage of load (a) non-modular; (b) modular solution.

|                      | Non-modular solution | Modular solution |
|----------------------|----------------------|------------------|
| $U_{BUS}$ [V]        | 600.029              | 599.89           |
| $\Delta U_{BUS}$ [V] | 1.26                 | 0.078            |
| $I_L$ [A]            | 7.15                 | 19.6             |
| $\Delta I_L$ [A]     | 3.1                  | 0.62             |
| $U_{GRID}$ [V RMS]   | 230                  | 230              |
| PF [-]               | 0.99                 | 0.99             |
| Efficiency [%]       | 96.79                | 99.25            |
| THD [-]              | 0.03                 | 0.03             |
The values of DC microgrid voltages for operational scenario 1 and voltage ripples for modular and non-modular solutions are given in Tab. 1. The coil currents of the transducers of the individual solutions and their ripple are also given. The comparison shows that according to the simulation results, lower ripple of the output voltage is achieved by the modular solution as well as lower ripple of the coil currents is achieved in this solution. The achieved efficiency is higher in case of modular solution in comparison with non-modular solution.

3.2. Operational scenario 2
The second scenario is graphically described on fig. 13. This scenario describes the use of electric vehicle batteries as an energy storage connected to smart-grid. In this scenario, the power supplied from the PV panels is 5 kW and the power supplied from the AC grid is 5 kW. The added power (10 kW) is supplied to the batteries. This scenario is a situation that can actually happen if we want to recharge batteries from renewable sources, but these sources are not able to deliver the necessary power. Therefore, the additional required power will be supplied from the AC network.

Since the used topology of the DC/AC inverter with it’s control did not allow bidirectional operation at the selected value of DC microgrid voltage (600 V) the simulation parameters were adjusted so that the DC microgrid voltage (300 V) was lower than the maximum value of rectified AC mains voltage (325 V). At this voltage level, the inverter allowed the flow of energy from the AC network to the DC microgrid.

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**Figure 13.** Block diagram of power flow in scenario 2.

**Figure 14.** Battery and inductor currents of Bi-BB converter (a) non-modular; (b) modular solution.
Figure 15. Current and voltage of DC bus (a) non-modular; (b) modular solution.

Figure 16. Current and voltage of load (a) non-modular; (b) modular solution.

Table 2. Comparison of output voltages, voltage ripples and currents by coils of non-modular and modular solutions for operational scenario 2.

|                  | Non-modular solution | Modular solution |
|------------------|----------------------|------------------|
| $U_{BUS}$ [V]    | 299.1                | 296.3            |
| $\Delta U_{BUS}$ [V] | 8.57               | 6.4              |
| $I_L$ [A]        | 54.2                 | 55.8             |
| $\Delta I_L$ [A] | 2.3                  | 1.5              |
| $U_{GRID}$ [V RMS] | 230                 | 230              |
| $PF$ [-]         | 0.86                 | 0.92             |
| Efficiency [%]   | 88.06                | 95.26            |
| THD [-]          | 0.023                | 0.03             |
The values of DC microgrid voltages for operational scenario 2 and voltage ripples for modular and non-modular solutions are given in Tab. 2. The coil currents of the transducers of the individual solutions and their ripple are also given. The comparison shows that according to the simulation results, lower ripple of the output voltage is achieved by the modular solution as well as lower ripple of the coil currents is achieved in this solution. The achieved efficiency is higher in case of modular solution, but the value of total harmonic distortion is also higher in comparison with non-modular solution.

4. Conclusion
In this paper the comparison of non-modular and modular solution of DC microgrid was described. Selected parts of the node were intended for simulation analysis (with PLECS circuit simulator) of converters in a reduced scale of 1:10. A modular solution consisting of 8 identical modules based on GaN semiconductor technology and a non-modular converter solution based on SiC technology were investigated. Due to the different possibilities of topology adaptation, high efficiency in the whole spectrum of output power and low ripple of output quantities, despite the high demands on the control system, we would recommend a modular system based on GaN semiconductor technology for further research.

The relative deviations of the simulation results are caused by various parasitic parameters. Most of these components are exhibiting high thermal dependency, i.e. the values are changing based on the temperature variation. These effects cannot be simply included within proposed model, because the level of complexity will rise significantly as a result of what will be inappropriateness for HIL modelling. Another possible source of deviation can be the PLECS simulation software itself (Piece-wise Linear Electric Circuit Simulator), which uses simplified linearized component models to simplify and speed up calculations. This means that it is possible to increase the speed at the cost of accuracy reduction.

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