Control and Protection in Low Voltage DC Grids

Peter J. van Duijsen, Johan B. Woudstra, and Diëgo C. Zuidervliet

Abstract—Many office applications are low power such as computers, monitors, laptops, phones and even LED lighting. Powering them from a 48 volt DC grid is sufficient and has one great advantage. The 48volt is safe regarding touching, but protection to prevent excessive short circuit currents has to be provided. In this paper we discuss a 48 volt DC grid that is implemented as a living lab. In the living lab droop control and short circuit protection are implemented. The 48 volt DC grid is connected to a 350-400 volt DC grid via a bidirectional DCDC converter. The 350-400 volt DC grid is used for powering higher power levels such as air conditioning, battery storage, photovoltaic and AC grid-tied inverter for power exchange. The theory behind and implementation of droop control via a hybrid analog/digital controller is discussed along with measurements. Predictive short-circuit protection is discussed to prevent excessive short circuit current. Earth leakage detection via monitoring is discussed as well as its advantage for DC grids. Droop control and protection are combined in a Grid Manager that regulates each load individually.

Index Terms—DC Grid, Simulation, Living Lab, Protection, Droop Control, Power Electronics, Earth Leakage monitoring, Short Circuit Protection, Prosumers, Variable Load, Grid Manager.

1 INTRODUCTION

Implementing a DC Grid in office buildings or laboratories requires to comply with the legislation and regulations initially meant for AC Grids. Although the regulations contains provisions for DC voltages, there is no standard for voltage levels and protection yet. However most legislation and regulation allow a voltage level below 75 volts (with a large voltage ripple) or below 120 volt (smooth DC voltage) as safe. Therefore a voltage level of 48 volts is considered as safe for touching.
Control in low voltage DC grids is required to perform power management and congestion management[2]. Regulation nor standardization on the control in a DC grid is settled and various control methods emerged[5][6][7]. There seems to be two types of control methods; stand-alone droop control and control via communication between the prosumers, the first one is explored in this paper.
In the section “Droop Control”, the implementation of the stand-alone communication-free control method is along with its implementation is described[1].
Regarding protection, little is foreseen in the current legislation and regulation other than that there should be a galvanic circuit breaker[4]. Semiconductor solid state breakers are still not included in the regulation. In section 3 on "Protection", the current limiters as well as the short circuit protection and earth leakage protection is discussed.
In this paper a low voltage DC grid consisting of two voltage levels is described, see figure 1. A 48 volt grid is implemented for LED lighting, supplying office applications and low power laboratory devices. An unidirectional 350-400 volt DC grid is implemented for higher power appliances such as heating, ventilation and air conditioning as well as the connection to a larger scale photovoltaic sustainable energy source, energy storage by batteries and a grid-tied inverter for interfacing with the AC grid[8].

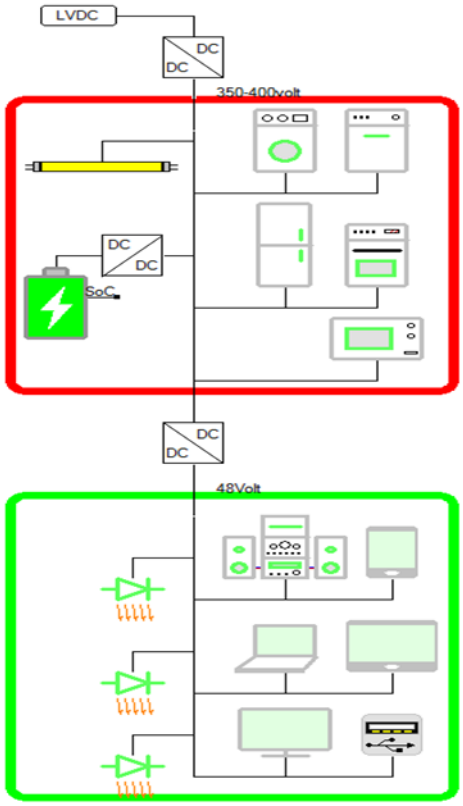

Fig. 1. Dual low voltage grid, Red: 350-400 V, Green: 48 V

2 DUAL LOW VOLTAGE GRID

The need for a dual voltage has two main reasons; many applications are low power and can thus be fed from a safe

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lower DC voltage, while higher power levels require a 350-400 volt DC grid. The 48 volt DC grid is safe regarding touching and has outlets for the user. The 350-400 volt DC grid is not accessible to the users and is only used to feed higher power applications, such as domestic appliances[1][9].
Depending on the application and its power level the decision is made to either connect to the 48 volt or to the 350-400 volt DC grid. The two grids are coupled by a bidirectional DCDC converter with galvanic isolation and short circuit protection. A single phase Dual Active Bridge with phase control is applied because of the galvanic isolation between the two grids, see section 7 on the "Bidirectional DCDC converter".
The first function of the bidirectional converter is to control the power flow between the two DC grids. The second function is to control the 48 volt level in the 48 volt DC grid.

3 PROTECTION

Protection in the DC grid is required in the same manner as it is available in nowadays AC grids[10][11][12][13][14]. However extra safety can be added such as faster turn off while touching the grid to prevent hazardous shocks by humans and predictive short circuit protection to prevent excessive high short circuit currents. Furthermore earth leakage protection using Earth Leakage Monitoring in an isolated IT system can be implemented. Since most applications in the 48 volt DC grid are mobile and have no earth connection, earth leakage can be monitored and in case of an existing earth leakage a warning can be issued and send to the user of the application. If the earth leakage exceeds the maximum safety level for DC currents through the human body, the grid manager can turn off. If the earth leakage is still below the maximum level, only a warning can be send to the user, the application can remain functioning[18].
Short circuit protection is implemented by two methods. The first protection method is to limit the maximum short circuit current. This is implemented internally by the current mode controller of the synchronous buck converter.
Peak current mode control is a method to limit the output current from a DC converter[9], see figure 2. Also Constant On Time [COnT] and Constant Off Time [COffT] control as well as Boundary Conduction Mode [BCM] are explored to implement short circuit protection[15]. For all control methods current measurement with a high bandwidth is required. As the bandwidth of current sensors is limited, a shunt for measuring current is a viable option. The synchronous buck converter utilizes the winding resistance of the inductor for measuring the outgoing current[15], see figure 2.
The synchronous buck converter with current mode control has a reference value input for the maximum current it can deliver and therefore protects and limits the maximum short circuit current. By measuring the output voltage and knowing the maximum short circuit current, the short circuit resistance can be determined. If it is too small, there is a short circuit fault and the grid manager should turn off. This is indicated by an output voltage below the nominal voltage, while delivering the maximum current. Turning off the grid manager in this situation has to be done within the time limited as giving by IEC regulation.
The second protection is predictive short circuit protection. Basically it means that if a short circuit fault is occurring, the rise of the current is very steep. Before the current can rise to a dangerous high value, the steepness of the current is detected and the grid manager should turn off. The main advantage here is that the short circuit current will never reach a high value and therefore a dangerous fault can be prevented. An auxiliary circuit is connected in series with the output from the converter which measures the rate of change of current [ROCOC] of the output current. In case of short circuit the output current will increase rapidly and if the di/dt exceeds a threshold value, it is an indication for a

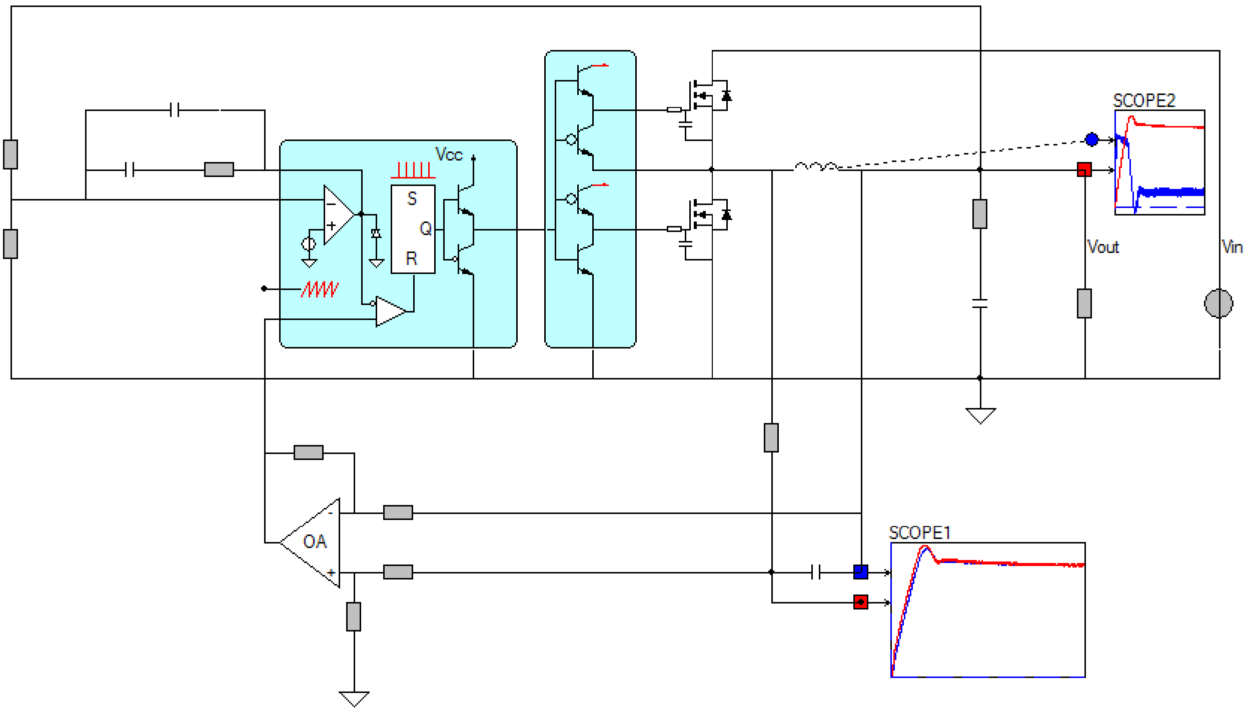

Fig. 2 Single leg of the grid manager with protection of the output current via DCR measurement

short circuit and the converter is turned off. There are various ways to implement this, digitally and analog. In case of a digital implementation, the sampling should have a high bandwidth and the processing should be fast enough to turn off the converter within, for example, 1 us. In an analog implementation, the voltage over an inductor carrying the output voltage is measured. The measured voltage over the inductor is a measure for the steepness of the current

$$U_L = L\,\frac{di}{dt}$$

Earth leakage protection [4] can be implemented in two ways; residual current [19] or via earth leakage monitoring[18].
The first method is to measure the difference between the outgoing and returning current. The difference in currents is the amount of leakage current. This method can be implemented in any grid system TT, TN, TNS, IT, etc. In any grid system, except the IT grid system, the grid manager has to be turned off in case of earth leakage. The residual current protection is standard in residential AC grids.
In critical systems, such as the intensive care in hospitals, an isolated IT grid system is preferred, since even during an earth leakage fault, the grid manager does not have to turn off. Only when an earth leakage fault in two applications is detected, a fault current can flow and the grid manager has to turn off. However in case of a single earth leakage fault, the grid manager can remain turned on, as long as the fault earth leakage current is below a certain level. This means that the earth leakage fault still has a large resistance. In that case the dc grid is still isolated from earth, so touching the DC grid will not lead to an excessive current through the human body. This is because the current through the human body during touching is limited not only by the resistance of the human body, but also by the resistance of the earth leakage. As long as this earth leakage resistance remains high, the touch current is low and therefore not dangerous.
The second method is to add an earth leakage detection circuit and implement the output as an isolated IT grid system [4] which has galvanic isolation from earth. Since most appliances for the 48 volt DC grid are mobile, the IT grid system is easily implemented. In case of an earth leakage there is no need to turn off the grid manager as long as there is only a single fault and the earth leakage current is low. A warning can be issued towards the user to remove the fault application[18].
The main advantage of the second method is that the grid manager does not have to turn off the application in case of an earth leakage.

In any case, short circuit or earth leakage, the grid manager should be able to turn off. This is done by turning off the high-side Mosfet in figure 4 " Grid manager". During turning off this Mosfet, the Mosfet is carrying the high short circuit current while at the same time the full dc grid voltage of 48 volt builds up across the device. The Forward Safe Operating Area [FSOA] of the device should include the 48 volt and the short circuit. Silicon Carbide Normally-On JFET's [SicJFET] are able to withstand excessive short circuits currents for a longer time. Also their positive temperature coefficient for RDSon is of advantage when paralleling the Mosfets. Not only is the power loss reduced by a factor of 4 when paralleling two Mosfets, also the even distribution of the current over the Mosfet Die is preventing the occurrence of hot spots on the Mosfet Die. Since the maximum current though a SiCJFET is limited to its saturation current, a SiCJFET is a good candidate for limiting and blocking the short circuit currents[14][16][17].

4 DROOP CONTROL

The value of the DC grid voltage determines the available power that can be consumed. Depending on the DC voltage an appliance can consume more or less power. A dc voltage below the nominal value means there is a shortage of power and an appliance has to lower the consumption. A DC voltage above the nominal voltage means that there is surplus of power and the appliance can consume the maximum power if required. In Fig. 3 the droop control parameters for a droop controller is displayed.

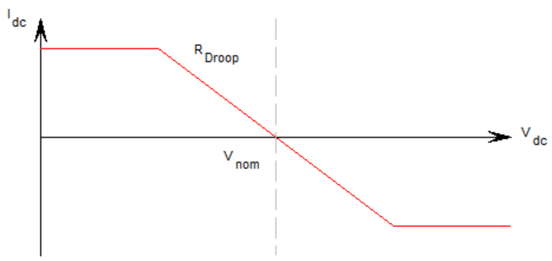

Fig. 3. Droop control parameters R_{droop} and V_{nom}

The droop constant R_{droop} defines the slope of the droop. R_{droop} can be set by its application in a DC grid with its own parameters. Depending on the requirements of the appliance, the droop constant R_{droop} can be increased or decreased. For each application or supply a droop controller can be programmed inside the DC grid manager[1].

5 48 VOLT DC GRID MANAGER

In fig 4 the grid manager with four independent loads and an hybrid analog/digital control is displayed. Each leg is configured to create a constant output voltage, depending on the need of the load. For 5 volt USB applications a 5 volt, maximum 2 ampere output is created. For usb-c applications a 20 volt, maximum 5 ampere output is generated, and the other two loads can be user specific, for example a 12 volt car battery interface or a 24 volt car battery interface. The DC bus is set to 48 volt, coming either from the DCDC bidirectional converter connected to the 350-400 volt DC grid, see section 7 on the "Bidirectional DCDC converter". The internal analog control regulates the output voltage level and limits the maximum current per load. This is configured as shown in figure 2. An industry standard current mode control IC drives the gate driver and bridge leg, configured as a synchronous buck converter. A set up as shown in figure 8 is the Universal Four Leg [U4L] board[21]. This U4L is configured as a grid manager with four outputs as shown schematically in figure 2. The delay by the internal protection circuitry on the U4L introduces a

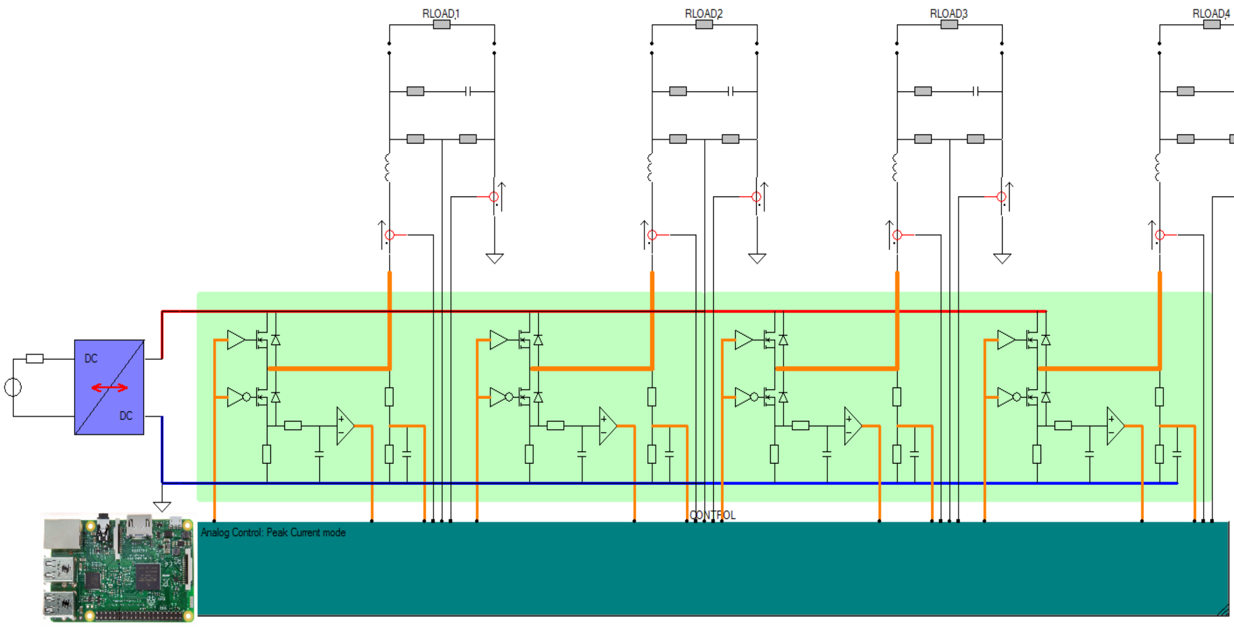

Fig. 4 Grid manager with 4 loads and hybrid analog/digital droop control

small delay time between the output of the current mode control IC and the input of the gate driver, but this effect is negligible compared to the delay times of the gate driver and the Mosfet turn-On and Turn-Off times. The measured current at the output on the U4L board is fed back to the control IC. Also here the time delay and scaling are not influencing the overall control performance. The buffering and scaling by the internal current measurement on the U4L is of benefit to the control structure, since a smaller current sense resistor can be used with lower on state losses. The output voltage of the synchronous buck converter is measured using a resistive divider that is connected to the output of the synchronous buck converter, not located on the U4L board. This is the standard configuration for the current model control IC and no buffering or scaling is required.
A digital controller sets the reference values for the analog control depending on the loads and the actual voltage of the 48 volt DC grid. The droop controller is implemented in the digital control and sets the reference output voltage and maximum current for each synchronous buck converter depending on the level of the 48 volt DC grid.
Lets clarify this by an example. Suppose that one load is charging a battery via the usb 5 volt. If the momentaneous voltage level on the 48 volt dc grid is higher than the nominal 48 volt, enough power is available to charge the battery and the maximum output current level can be set to 2 amperes, which is the maximum value for usb 5 volt applications. At the moment when the momentaneous voltage level drops below the nominal 48 volt, the amount of power on the dc grid is limited. This means that the maximum output current of the usb 5 volt charging applications has to be lowered accordingly. The application that gets charged will only experience a reduced charging current, but will remain charging. The exact relation between the 48 volt dc grid voltage and the maximum current is defined in a droop control diagram such as, for example, figure 3[1].

6 HIGHER POWER DC GRID

Applications requiring a higher power level are connected to a 350-40 volt DC grid. Because of the droop control, the voltage on the DC grid can easily vary 10% around the nominal DC grid voltage level. Each application connected to this grid should have internal soft start and short circuit protection and can either directly be connected to the 350-400 volt grid or a DCDC converter is required to regulate the power transfer. In the living lab we have implemented off the shelf current routers[20].

7 BIDIRECTIONAL DCDC CONVERTERS

The bidirectional converter with galvanic isolation connects the 48 volt DC grid with the 350-40 volt DC grid. The Dual Active Bridge [DAB] converter is built around two full bridge converters with galvanic isolation provided by the internal coupled inductors. The difference in voltage level, see figure 5, (48 volt and 350-400 volt) is managed via the winding ratio of the primary and secondary coupled inductors. Using phase-shift control, the power flow can be controlled [15] . Since the DAB is fully symmetrical, bidirectional power flow is possible via the phase-shift control. Next to the control of the bidirectional power flow, the DAB also controls the voltage level of the 48 volt DC grid depending on the voltage level of the 350-400 volt DC grid.

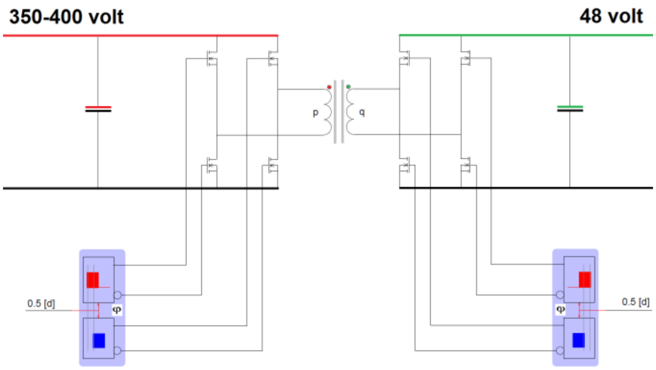

Fig. 5. Dual Active Bridges

7.1 Power flow control:

A droop control regulates the output 48 volt DC voltage. If the output voltage is equal to the nominal output voltage V_{nom} =48 volt, there is no need for power flow and the DAB can be turned off. As soon as the 48 volt DC grid voltage level gets lower than the nominal V_{nom} level, a power flow from the 350-400 volt DC grid to the 48 volt dc grid will be controlled by the DAB. When the voltage level on the 48 volt DC grid exceeds the nominal V_{nom} voltage level, a power flow from the 48 volt DC grid to the 350-400 volt DC grid is controlled by the DAB. Depending on the 48 volt DC grid voltage level, the power flow is controlled by the DAB according to the droop control diagram in figure 6.

7.2 Voltage level control:

The maximum value of the power flow is regulated by the voltage level of the 350-400 volt DC grid. The voltage level of the 350-400 volt DC grid is an indication on how much energy is available and regulates the amplitude of the droop control diagram in figure 6. Notice the non-symmetrical amplitudes for each direction of the power flow.

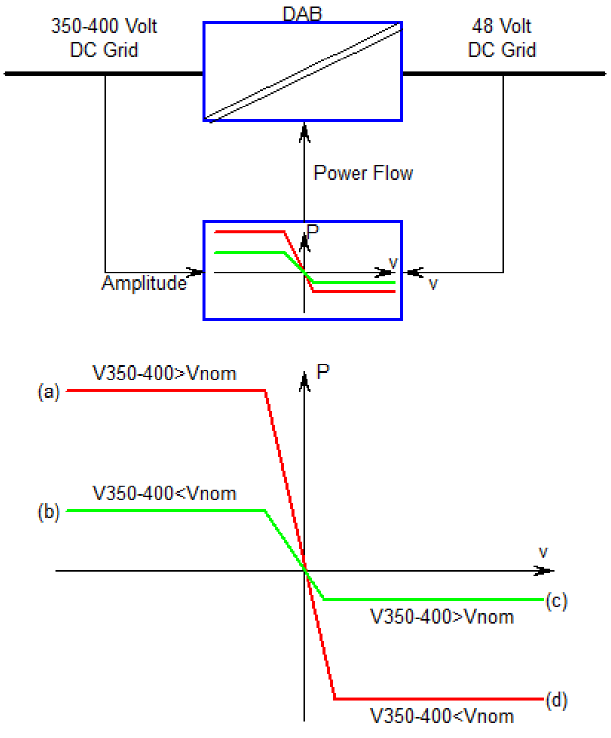

Fig. 6. Droop control for the DAB, High energy availability on the 350-400 volt DC grid: (a,d), Limited energy availability: (b,c), Positive powerflow: (a,b), Negative powerflow from 48 V DC grid to 350-400 V grid: (c,d)

8 GRID-TIED INVERTER

Power exchange and back up ca be implemented via a connection to the AC grid. A Grid-Tied inverter or Active Front End [AFE] is used here that can regulate a bidirectional power flow between the 400 volt AC grid and the 350-400 volt DC grid[15].
Figure 7 shows the basic configuration of the AFE. Only the interface to the AC grid is shown here, on the DC side DCDC converters are required for galvanic isolation and protection as well as scaling the output voltage from the AFE to the required 350-400 volt DC grid voltage level. The output voltage of the AFE has to be higher than 536 volts, otherwise the AFE will function like a rectifier.
Internally a Voltage Oriented Control [VOC] regulates the semiconductor switches using Space Vector Modulation [SVM] to control the active and reactive power flow P and Q by means of controlling the amplitude of the AC current and phase shift between te AC voltage and AC current. The AFE maintains a constant DC output voltage as its primary task. If the amount of reactive power flow is set to zero, the controlled active power flow to and from the AC grid is depending on the level of the output voltage of the AFE. If the output DC voltage at the output is too high, the power flow is from the DC side into the AC grid, if the DC output voltage is too low, power flow is from the AC grid to the DC side.
The control of the DC output voltage level regulates the power flow between the AC grid and the 350-400 volt DC grid. If power is taken from the 350-400 volt DC grid, its voltage level will decrease and this will be compensated by an extra power from the AC grid into the 350-400 volt DC grid. If the solar panels are delivering power tot the 350-400 volt DC grid, the voltage level will rise above the nominal level and the AFE will control a power flow from the 350-400 volt grid into the AC grid and thereby lower the voltage level on the 350-400 volt DC grid until its nominal level. Reactive power can be generated on demand by the AFE independent on the voltage level and power demand on the DC side. The required extra power for the AFE are covered by active power from the AC grid. This required active power are merely the losses inside the inverter. Figure 7 shows the simulation of an AFE and bidirectional DCDC converter in Caspoc [3]. The inverter operates at 50 kHz and has space vector modulation (SVM). Scop6 6 shows the input three phase AV voltage, scope 2 the input currents. Scope 7 shows the internal inverter voltage created according to the SVM, where scope 5 shows this SVM voltage in the alpha-beta coordinate system being a pure circle. Scope 4 shows the positive and negative voltage of the bipolar 350-400 volt DC grid.

9 EXPERIMENTAL RESULTS

Figure 8 shows the experimental set up for the 48 volt DC grid manager using the U4L[21]. The digital control regulates the output voltage of each leg from the grid manager. The first and fourth leg from the grid manager are connected to an LC filter with resistive load as schematically shown in figure 4.

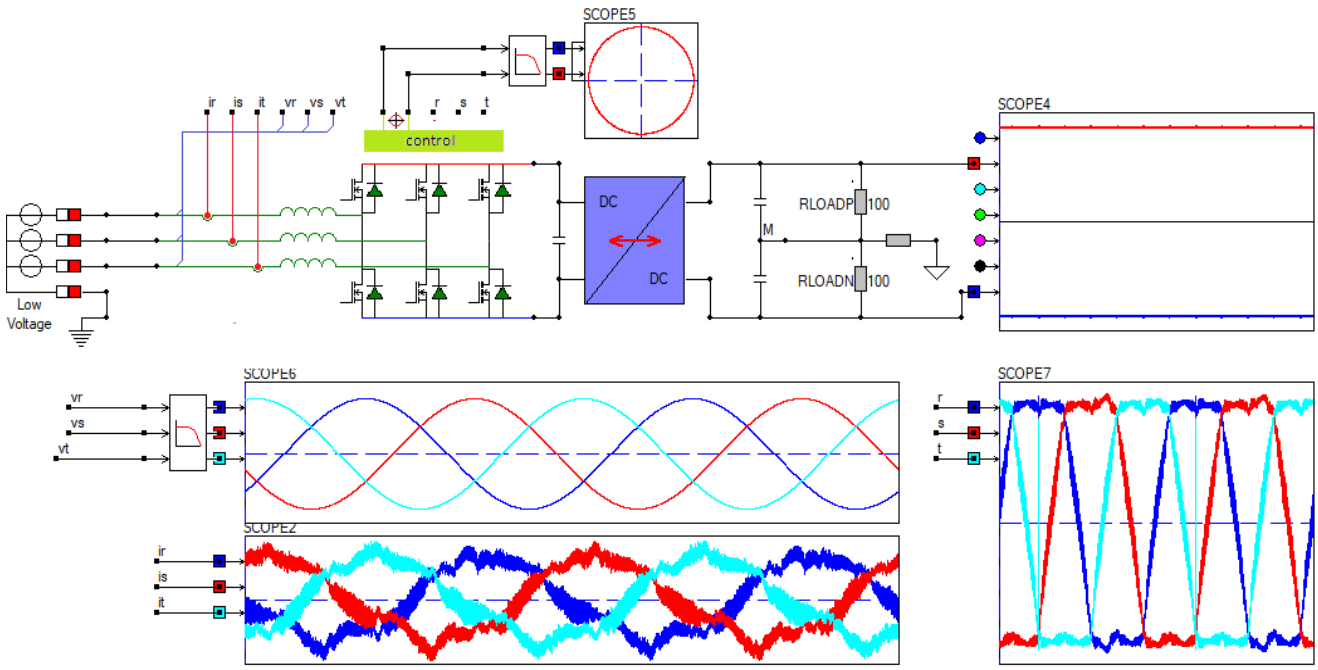

Fig. 7. Grid-Tied inverter for feeding the 350-400 volt DC grid

This typical set up is used to perform duration tests on the grid manager and to test the implemented protection methods. In this particular set up the maximum short circuit current limit is implemented.
The four different output voltages of the U4L are displayed together in the scope as shown in figure 9. The U4L can independently control each output voltage and maximum current.

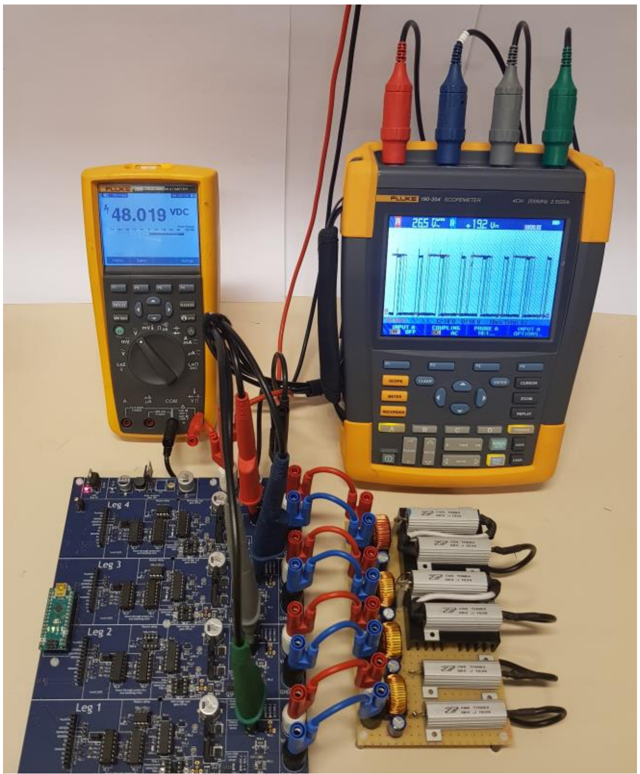

Fig. 8. Experimental setup for 48 V DC grid manager

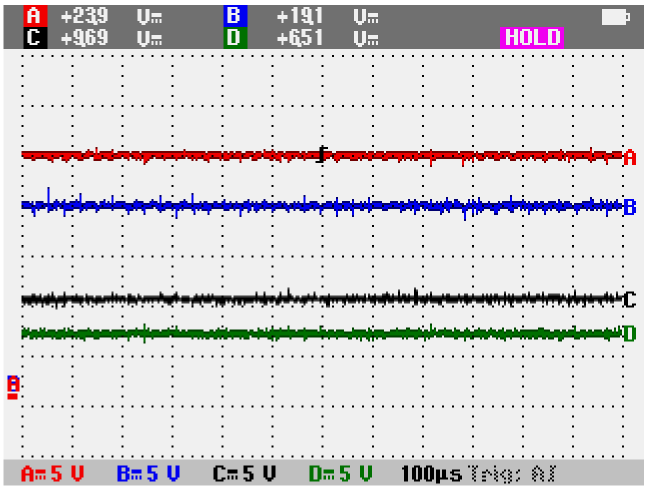

Fig. 9. Four output voltages as measured by the scope 5V, 9V,20V,24V

10 CONCLUSION

Low power applications can be fed from a low voltage 48 volt DC grid. Because of the low voltage level, the DC grid becomes safe. However there is still need for short circuit protection and earth leakage protection. Both are implemented inside the grid manager, being a current mode controlled synchronous buck converter. SiC normally-On JFETs can be of benefit as current limiter because of their wide FSOA. Experimental results show the feasibility of a synchronous buck converter with hybrid digital/analog control as a grid manager. Predictive short current detection can be implemented at the output of the grid manager. Earth leakage current monitoring can be used if the outputs of the grid manger are IT grid systems. This will make the 48 volt DC grid safe.

REFERENCES

[1] van Duijsen P., Zuidervliet D.C., Woudstra J., Requirements on Power Electronics for converting Kitchen Appliances from AC to DC, 2019 International Conference on the Domestic Use of Energy (DUE), Cape Town, 2019
[2] DC-Grid Manager, https://www.iisb.fraunhofer.de/, Fraunhofer IISB, 2018
[3] Caspoc, http://www.caspoc.com, 2019.
[4] Desmet J.,Knockaert J., Sergeant P., et.al., Laagspanningsinstallaties : technologie en ontwerp, 3th Edition, University Gent. Campus Kortrijk. Vakgroep Energie en Systemen, 2015, ISBN:9789081549837
[5] G. Deconinck, K. De Craemer, B Claessens, "Combining Market-Based Control with Distribution Grid Constraints when Coordinating Electric Vehicle Charging", Engineering Volume 1 Issue 4 December 2015 https://doi.org/10.15302/J-ENG-2015095
[6] D. Salomonsson, L. Soder and A. Sannino, "Protection of Low-Voltage DC Microgrids," in IEEE Transactions on Power Delivery, vol. 24, no. 3, pp. 1045-1053, July 2009., doi: 10.1109/TPWRD.2009.2016622
[7] W. A. G. de Jager and P. J. Bos, "Design of a public DC grid of a business park," 2017 19th European Conference on Power Electronics and Applications (EPE'17 ECCE Europe), Warsaw, 2017, pp. P.1-P.9. doi: 10.23919/EPE17ECCEEurope.2017.8099272
[8] W. Aerts, S.Willems, D. Haeseldonckx, P. van Willigenburg, J.Woudstra and S. De Jonge, "Study and simulation of DC micro grid topologies in Caspoc," Twenty-Second Domestic Use of Energy, Cape Town, 2014, pp. 1-6., doi: 10.1109/DUE.2014.6827760
[9] B. Nanhekhan, P. van Duijsen and J. Woudstra, "DC Readiness of a vacuum cleaner," 2018 International Conference on the Domestic Use of Energy (DUE), Cape Town, 2018, pp. 1-9. doi: 10.23919/DUE.2018.8384398
[10] Li, C., Rakhra, P., Norman, P., Niewczas, P., Burt, G., and Clarkson, P. (2017). Practical computation of di/dt for high-speed protection of DC microgrids. 2017 IEEE Second International Conference on DC Microgrids (ICDCM). doi:10.1109/icdcm.2017.8001037
[11] Meghwani, A., Srivastava, S. C., and Chakrabarti, S. (2017). A Nonunit Protection Scheme for DC Microgrid Based on Local Measurements. IEEE Transactions on Power Delivery, 32(1), 172181. doi:10.1109/tpwrd.2016.2555844
[12] Meghwani, A., Chakrabarti, S., and Srivastava, S. C. (2016). A fast scheme for fault detection in DC microgrid based on voltage prediction. 2016 National Power Systems Conference (NPSC). doi:10.1109/npsc.2016.7858867
[13] Wang, D., Emhemed, A., Norman, P., and Burt, G. (2017). Evaluation of existing DC protection solutions on an active LVDC distribution network under different fault conditions . CIRED - Open Access Proceedings Journal, 2017(1), 11121116. doi:10.1049/oap-cired.2017.0673, https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=8315930
[14] Z. Miao, G. Sabui, A. Moradkhani Roshandeh and Z. J. Shen, "Design and Analysis of DC Solid-State Circuit Breakers Using SiC JFETs," in IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 4, no. 3, pp. 863-873, Sept. 2016. doi: 10.1109/JESTPE.2016.2558448
[15] Ang S., Oliva A., Power-Switching Converters, Third edition, CRC press 2011, ISBN 978-1-4398-1533-5
[16] DodgeJ. , UnitedSiC JFET in Active Mode Applications, Application note:UnitedSiC_AN0016, April 2018
[17] Gu, Chunyang and Wheeler, Pat and Castellazzi, Alberto and Watson, Alan J. and Effah, Francis, Semiconductor Devices in Solid-State/Hybrid Circuit Breakers: Current Status and Future Trends, Energies Vol 10- 2017-4, www.mdpi.com/1996-1073/10/4/495, ISSN:1996-1073
[18] Hofheinz W., Protective Measures with Insulation Monitoring, Third edition, VDE-Verlag, ISBN 978-3-8007-2958-6
[19] Hofheinz W., Fault Current Monitoring in Electrical Installations, VDE-Verlag, ISBN 978-3-8007-2796-X
[20] DC current router, DC current, 2019, The Netherlands, url: www.directcurrent.eu/nl/producten/170-current-router
[21] Woudstra J., van Duijsen P., van Willigenburg P., WitteP.M., DC Educational Development, Improving understanding of DC to DC / DC to AC conversion, Proceedings of the 46th Sefi Annual Conference, September 17-21, 2018 Copenhagen, ISBN 978-2-87352-016-8.

Authors bios and photographs

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Presenting author: The paper will be presented by Diëgo Zuidervliet