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## **► To cite this version:**

Sameh Betamony, Jérôme Buire, Seddik Bacha, Thai-Phuong Do, Anthony Bier, et al.. Modeling and pre-installation stability assessment of a real grid-connected MV DC microgrid with 100% power electronics based generation. ISGT EUROPE 2023 - IEEE PES Innovative Smart Grid Technologies Europe, Oct 2023, Grenoble, France. pp.1-5, <10.1109/ISGTEUROPE56780.2023.10407355>. <hal-04912684>

**HAL Id: hal-04912684**

**<https://hal.science/hal-04912684v1>**

Submitted on 26 Jan 2025

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# Modeling and Pre-installation Stability Assessment Of a Real Grid-connected MV DC Microgrid With 100% Power Electronics Based Generation

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**Abstract**— This paper proposes a pre-installation stability assessment for a real test case of a 100% power electronics-based DC microgrid in the lack of some equipment models. The approach includes dynamical modeling and parameter tuning of the microgrid components, system stability and behavior analysis under different scenarios using simulation tools. The findings from this analysis may help system designers and operators identify potential stability challenges and identify critical operational conditions, which might require verification when connecting attempting real connection.

**Index Terms**— Control, DC microgrids, Modeling, Stability

## I. INTRODUCTION

Since their introduction [1], Microgrids are stepping in as a major player in the energy transition as a promising solution that offers different features such as the ability to work in both grid-connected mode and islanded mode. In addition to that, and with the rapid development of power electronics technology, grid-connected DC microgrids are gaining more and more attention [2][3], especially since most of the modern loads are DC by nature [4]. On the other hand, DC microgrids offer systems with fewer conversion steps, thus higher efficiency. Another factor increasing DC microgrids popularity is the network's control architecture simplifying compared to AC networks.

Recognizing the potential of hybrid DC-microgrids, the TIGON European project [5] [6] is one of the big projects that

aims to demonstrate the advantages of hybrid DC-based microgrids. Different real case demos are planned to be implemented and one of them will be in collaboration with the French Alternative Energies and Atomic Energy Commission (CEA). Although every piece of equipment went through different stability tests individually, system-level tests have to be done to make sure stability boundaries are respected. This paper investigates part of the efforts to evaluate microgrid stability and discusses different challenges in conducting the analysis. The test case architecture is illustrated in Figure 1. The test network consists of an AC/DC inverter (inverter number 1) which connects the DC side of the microgrid (3 kV) to the AC side (three-phase 400V grid). In the second stage, a DC/DC converter (converter number 2) steps down the voltage from 3 kV to 1.4 kV where there is a 50kWp PV farm connected through a DC/DC converter (converter number 3) and an AC 50 kW load connected through a DC/AC inverter (inverter number 4).

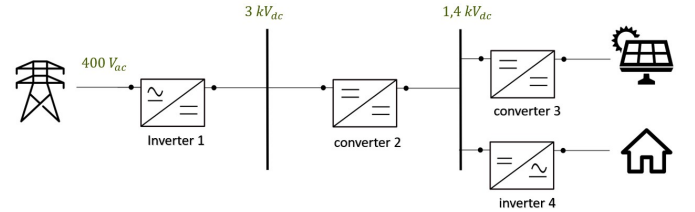


Figure 1 Network architecture

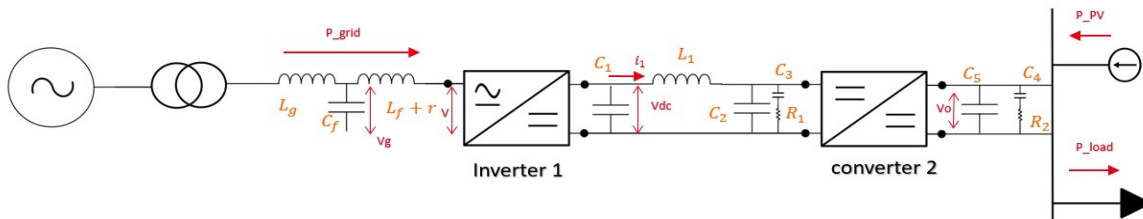


Figure 2 Microgrid model on Simulink

**Figure 4** small-signal model for the inner control of inverter 1

For inner loop, control parameter values obtained after tuning is  $K_p = 0.45$  and  $K_i = 232$ .

Concerning the outer loop [8], a relationship between the output current and the input voltage was derived to obtain the small signal model.

$$\frac{3}{2}(v_{gd}i_d + v_{gq}i_q) = -v_{dc}C_1 \frac{dv_{dc}}{dt} + v_{dc}i_l \quad (3)$$

Note that the left hand part of equation 3 represents the input power from the grid side, and the right hand term represents the output power on the DC side.  $V_{dc}$  is the input dc link voltage,  $C_1$  represents the capacitance of the dc link and finally  $i_l$  represents the output current in the dc side. Linearizing the above equation and applying Laplace transformation, a relation between the d components of the grid current and the DC link voltage can be established and a plant model can be derived, where  $R_o = V_o/I_o$  (at the operation point). A closed loop small signal model shown in figure 5 can then be used to tune the controllers.

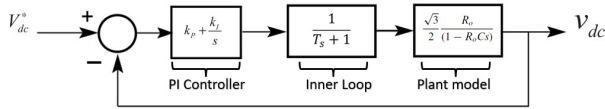


Figure 5 Small-signal model for the outer loop of inverter 1

For outer loop, control parameter values obtained after tuning  $K_p = -0.8$  and  $K_i = -16$ .

Since there are no clear specifications on the dynamical response of the inverter, the only constraint we used is to have a much smaller bandwidth of the outer loop than the inner loop, to decouple the dynamics of the two loops avoiding stability problems[10]. Hence; outer loop was tuned to be 10 times slower than the inner loop allowing us to represent it as a first order transfer function with a time constant  $T_s$  in the small signal model for the outer loop.

Finally, the simulation model of inverter 1 was verified using a test case where we reversed the power flow at  $t=1\text{sec}$  and observed the voltage on the 3 kV DC link as can be seen in figure 6.

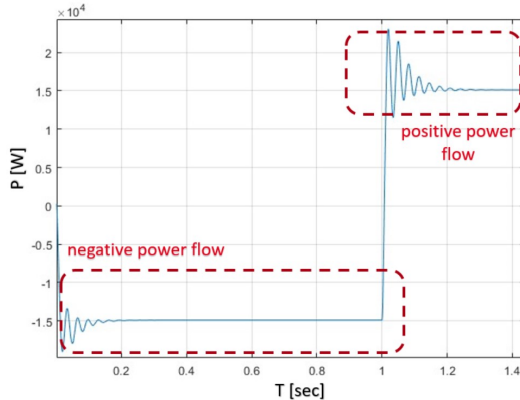


Figure 6 Power flow dynamics for inverter 1

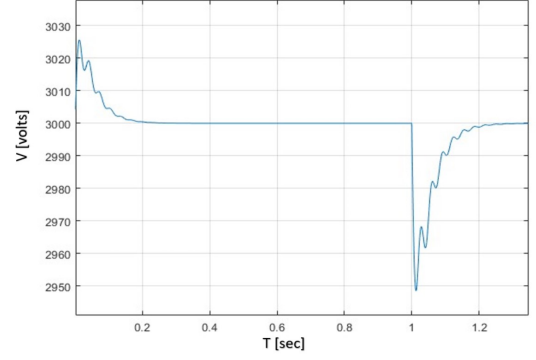


Figure 7 Voltage dynamics on 3 kV bus due to power flow change

As can be seen in the graph, the change in power flow caused a voltage drop on the DC link and the inverter has managed to restore the 3 kV reference on the DC link. It is unexpected for the inverter to lose stability, but the main focus would be on two main points: 1) The over/undershoot value of the voltage, as the overshoot value is critical for the insulation of different equipment such as cables, and undershoot is critical for the stability of converter 2.

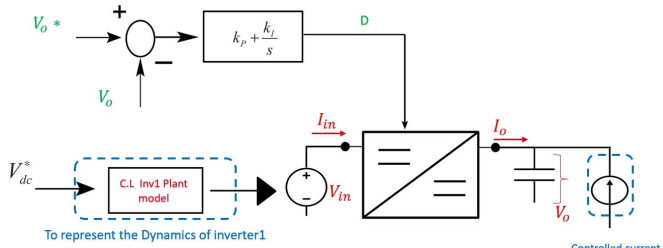
## B. Converter 2

Converter 2 is a 200 kW interconnection of LV and MV DC grid with a 3 kV input voltage and 1.4 kV output voltage. The main control objective is to maintain a constant voltage on the 1.4 kV (LV DC) side. Since converter 2 is in-house designed, it is possible to optimize its dynamic response through control parameter tuning. For that and for the sake of the stability analysis we consider the converter 2 as an average buck-boost converter with the following equations:

$$V_o = \frac{D}{1-D} \cdot V_{in} \quad (4)$$

$$I_{in} = \frac{D}{1-D} \cdot I_o \quad (5)$$

Where  $I_{in}$  and  $I_o$  are the input and output currents,  $I_{in}$  here represents the input of converter 2 which is the output current of inverter 1.  $V_{in}$  and  $V_o$  are the input and output voltages where  $V_{in}$  is the same as the output voltage of inverter 1. Moreover,  $D$  represents the duty cycle. Since the main control objective of the DC-DC converter is to maintain a fixed voltage at the output 1.4 kV DC side, one can say that if inverter 1 provided a stable DC link voltage, where placed physically close to inverter 1 (i.e. low impedance connection line) the duty cycle can be fixed and the output voltage dynamics will follow the dynamics of the DC link between inverter 1 and converter 2. Hence, in this case converter 2 can be represented as a gain. In order to maintain a more stable DC voltage on the 1.4 kV side, we added a PI with a very small  $K_p$  value ( $1 \times 10^{-5}$ ) and  $K_i = 0.8$  that can vary the duty cycle based on the variation in the DC link voltage, maintain a more stable voltage around the reference value of 1.4 kV.



**Figure 8 Converter 2 control loop**

We then tested a step down of the input voltage (which it the 3 kV DC link controlled by inverter 1 including the dynamics of it, which is done by adding the closed loop equivalent of Figure 5 to observe any dynamical interactions that could lead to instabilities. The results shows that the converter managed to maintain stability with a voltage drop of 3.3% on the input DC-link and. However, due to the dynamics of this change, we see some oscillations on the 1.4 kV, which could cause some problems on the load side based on its nature.

**Figure 9 Voltage dynamics on the 1.4 kV bus due to a change on voltage on the 3 kV bus**

### C. PV and load

The PV solar panels are connected through a DC-DC converter, which uses an MPPT algorithm to inject the maximum available power. This is a commercial product and in this study, we consider the PV as a current source where  $I = P_{pv}/V$ .  $V$  here is considered a constant voltage of 1.4 kV. Load modeled as a dynamic load where we define three main parameters,  $P_{in}$ ,  $P_{min}$ , and  $V_{min}$ .  $P_{actual}$  is the actual load

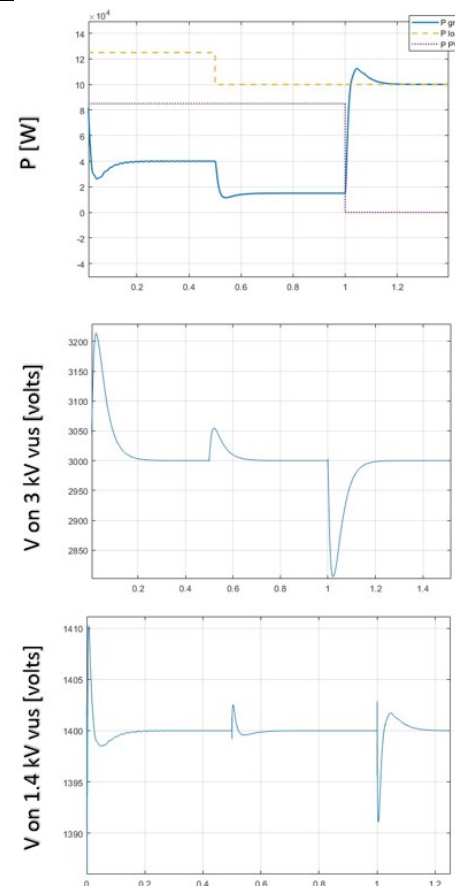
consumption that will vary with the following table 2:

Table 2: Model behavior with different values [11]

Applicable range of V values	Applicable range of Pin values	Corresponding Consumed Active Power
$V > V_{min}$	$P_{in} > P_{min}$	$P_{actual} = P_{in}$
	$P_{in} < P_{min}$	$P_{actual} = P_{min}$
$V < V_{min}$	$P_{in} > P_{min}$	$R = \frac{V_{min}^2 P_{actual}}{p_2^2 P_{actual} + Q_2^2 P_{actual}}$ $X = \frac{V_{min}^2 Q_2 P_{actual}}{p_2^2 P_{actual} + Q_2^2 P_{actual}}$ $Z = \sqrt{R^2 + X^2}$
	$P_{in} < P_{min}$	$P_{actual} = P_{min}$

### III. STABILITY SIMULATION

Variable [initial value]	Event time	New value
P <sub>load</sub> [125 kW]	T= 0.5 seconds	100 kW
P <sub>PV</sub> [85e3]	T= 1 seconds	0 kW



As expected, decreasing the load caused an overvoltage on the 1.4 kV bus which was reflected on the 3 kV. Then it was compensated by decreasing the power imported from the grid. The 20% decrease in load caused a 2% voltage overshoot on the 3kV DC link, and a slight overshoot on the 1.4 kV link. An opposite effect is obtained when the system faced a loss of generation (the PV). The system has maintained stability in both tests but special attention should be paid to the values of voltages undershoot or overshoot, especially for expected operational scenarios such as connecting or disconnecting a load. It is worth noting here that in the studied system, converter 2 represents a voltage step-down point, which one can think about it as a buffer or a filter. This means that in some cases by lowering the speed of the outer control loop of converter 2 it can improve the stability of inverter 1 by reducing the overshoot values. One also can think about the size of the DC link capacitor as it also plays a role in this. The main outcome of this stage was to indicate that there were no instabilities due to dynamics interaction in the system and verified that all controllers worked as intended by restoring the referenced set points after disturbances.

#### IV. DISCUSSION, CONCLUSIONS AND FUTURE WORK

This paper aims to contribute to a DC microgrid demonstration validation through the simulation of its stability analysis. Literature-based models were developed to fulfill the main control objectives of different equipment in the real test case. After that, model verification was made on each piece of equipment using simulation to test the control and to observe the response. Finally, a whole system simulation was done to analyze the system response to two events. Events were chosen to represent a normal operation disturbance and a transient one, which can occur due to a failure in the system. The main purpose of this paper is not to give a definitive answer on the stability of the real test case microgrid; this is due to the lack of full models for different equipment in the network. Rather than that, the main goal is to obtain models, which enable us to indicate critical potential interactions between the two converters' controls. Further simulation will be performed to reinforce the analysis, e.g. sensibility analysis according to the different variables, such as the L1 inductance value in Figure 2 which then makes the inverter's physical locations important at the installation. Scenarios of disturbance events can be also completed, with load step values. A more accurate component model can be developed, once real device experimental characterization can be performed. Finally, due to the simpler control architecture of DC microgrids and the lack of some requirements such as synchronization in comparison with AC microgrids, the stability Analysis of DC microgrids can be simplified. Looking from a system point of view, voltages values on different DC busses can be taken as the main indicator. Due to their relatively smaller sizes (DC microgrids), one must pay attention to the impact of different disturbances on the voltages as a small change can reflect very quickly on the different DC busses which to verify that control response and physical elements such as DC link capacitors are well chosen.

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#### VI. ACKNOWLEDGEMENTS

This work has been realized with the participation from members of INES.2S and received funding from the French State under its investment for the future programme with the reference ANR-10-IEED-0014-01 and the support of the Embassy of France in Jordan.