Design and Implementation of Distributed Control Architecture of an AC-Stacked PV Inverter

Hamidreza Jafarian, Iman Mazhari, Mehrdad Biglarbegian, Babak Parkhideh
University of North Carolina, Charlotte
Electrical and Computer Engineering Department
Charlotte, North Carolina, USA
Email: bparkhideh@uncc.edu

Saurabh Trivedi, Deepak Somayajula, Robert Cox, Shibashis Bhowmik
SineWatts Incorporated
9319 Robert D. Snyder Road #304D
Charlotte, North Carolina, 28223 USA
Email: robert.cox@sinewatts.com

***Abstract*— A control scheme for a distributed Inverter Molecule™ architecture is analyzed and implemented in this paper. An Inverter Molecule is a building block for a novel distributed inverter architecture suitable for PV/Battery applications which exceeds the performance metrics obtained by Central/String- inverters with or without DC/DC optimizers or by Micro-Inverters. The proposed transformerless architecture utilizes low-voltage semiconductor devices with much higher yields than their high-voltage counterparts. A group of Inverter Molecules operate autonomously and cooperatively to maintain the grid interconnection requirements while providing maximum power control on each molecule's PV panel. This paper establishes a *distributed* control scheme for Inverter Molecule architecture that does not need any high bandwidth communications except a heartbeat signal at line frequency. Experimental results are presented for a lab-scaled prototype.**

Keywords*— Single Phase inverter; Distributed Control; Photovoltaic System; Battery; Energy Storage System; Inverter Molecule; Micro Inverter; Cascaded H-bridge; AC-stacked Inverter

I. Introduction

Recently, due to increased (green) electricity demand, there is unprecedented interest in electrical power generation from renewable energy. Moreover, renewable energy systems are playing an increasingly important role in power production, due to growing environmental concerns and energy independence. Wind energy and Photovoltaic are the major sources of renewable energy which are the 81.6% of renewable power capacity all over the world by the end of 2013 [1] and [2]. Due to advent of new technologies and cost reduction, Solar PV energy has received significant attention in recent years such that, in 2013 solar PV capacity in the world increased by 39%. However, still the role of power generated by PV is very small in when compared to other sources of energy [2]. The main challenge involved in this, is the cost of power production by using solar energy.

In recent years there has been a great effort from policy makers, researchers and industry to reduce the cost of PV energy production. One example is the 'SunShot" initiative which was introduced by US Department of Energy in 2011. This program that has the goal to reduce the cost of utility scaled PV system to $1/W by 2020, was significantly successful in the first three years [3]. More than 80% of this cost reduction was due to the dramatic pricing pressures observed in the PV module marketplace during the last 3-4 years [4]. PV inverter prices have also reduced 10-15% during that time [2]; however, substantial performance and inverter smartness is now required for making the PV power plants suitable for high penetration of PV onto the electrical grid [5]. An innovative distributed inverter architecture, based on Inverter Molecule™ that promises to deliver utility-grade reliability and performance is being developed in this paper [6].

This work and any subject invention is part of activities being performed under the US Department of Energy (DoE), SunShot Incubator Program, Incubator Round(s) 8 and 9. The information, data, or work presented herein was funded in part by the Office of Energy Efficiency and Renewable Energy (EERE), U.S. Department of Energy, under Award Number(s) DE-EE0006459 and DE-0006692.

This paper in part will be presented at IEEE ECCE 2015.

II. Inverter Molecule and Proposed Control Architecture

Inverter Molecule™ is a building block for a novel distributed inverter architecture suitable for PV/Battery applications which exceeds the performance metrics obtained by Central/String- and Micro Inverter combined. A few number of Inverter Molecules operate cooperatively together to maintain the grid connection requirements while providing maximum power control on each member, i.e. PV panel or a low voltage battery pack.

The Inverter Molecule™ in its core utilizes low voltage semiconductor devices. This configuration and its tangible advantages were introduced in [6]. The proposed panel-level configuration has an advantage of utilizing low-voltage semiconductor devices like MOSFETs which can switch at much higher frequencies compared with high voltage switches such as IGBTs. As a result, there are significant opportunities in shrinking the size of passive components hence increasing the power density, implementing efficiency enhancement circuitries, and designing high performance converters with extremely enhanced control bandwidth. It is worth noting that having the Inverter Molecule with distributed control simplifies (if not enable) the implementation of high frequency converters.

The control architecture and a schematic of Inverter Molecule string consists of two inverters is presented in Fig. 1. Unlike, other presented control architectures, in this novel configuration, there is no need for communications between inverters. The control architecture is completely distributed and there are no links between inverters. Individual molecules are controlled locally by measuring individual voltage and current.

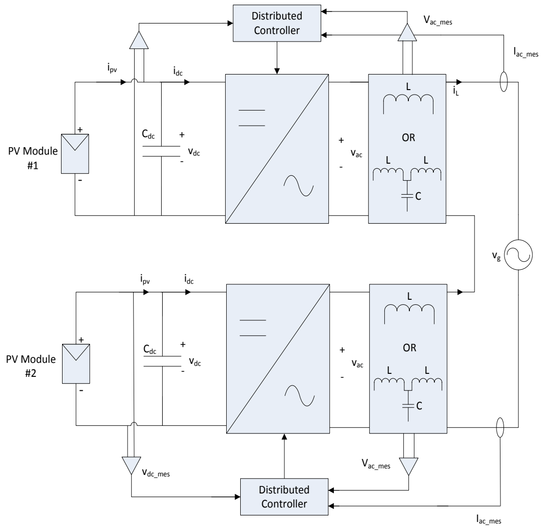


Fig. 1. Inverter Molecule string architecture circuitry scheme

In this PV string configuration, one of the Inverter Molecule is assigned to regulate the string output current. This Inverter Molecule is called the Current Administrator Voltage Compensator (CAVC). The remaining (n-1) inverters operate as Voltage Mode Molecules (VMM). These molecules are controlling their own DC voltage and generate the required output voltage to maintain MPP of their respective PV panel. In other words, the string current which is common for all the series connected inverters is controlled by CAVC and each VMM controls its own input voltage in order to deliver the maximum power of the respective PV panel.

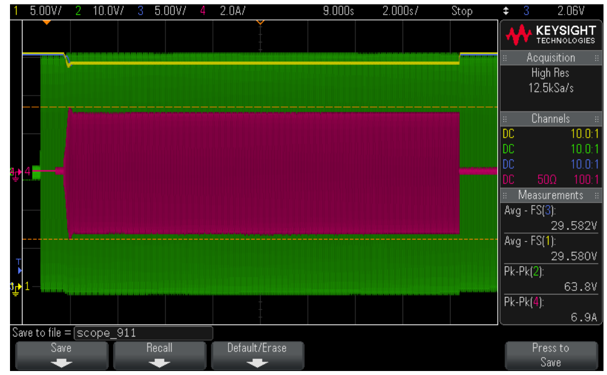
MM

III. Experimental Results

In order to verify the proposed PV string configuration and control method, a hardware setup consisting two PV inverters, two PV emulators and a grid emulator is used. The string of inverters is connected to the grid through a relay. The overview of grid-tied operation of a lab-scaled string consisting of two inverters (one CAVC and one VMM) for 16 seconds is illustrated in Fig 2.a. In this figure, green waveform represents grid voltage and red waveform is string output current. Blue and yellow are VMM and CAVC DC voltage respectively. Fig 2.b shows the system start-up. The system reaches to steady-state in 14 cycles as shown in Fig. 2.a and Fig. 2.c.

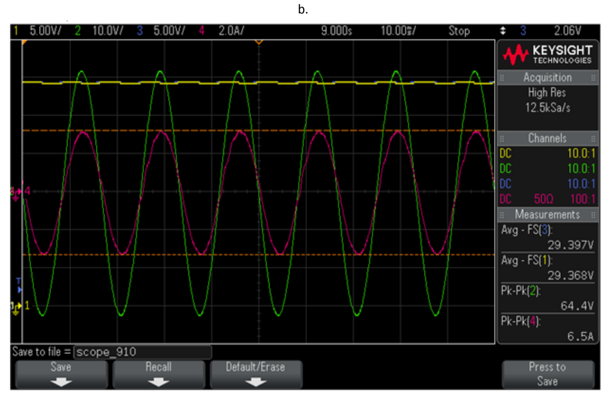
IV. Conclusion

This paper introduced a novel distributed PV inverter architecture called Inverter Molecule™. The proposed architecture presents superior efficiency and reliability figures than what have been reported for conventional architectures including central-, string-, and micro-inverters. To fully utilize the potentials of the proposed architecture, inverter members in the string should work cooperatively and autonomously and there must be no high bandwidth communications among the members. Therefore, we proposed a novel distributed control scheme for Inverter Molecule™ in which one string administers the string current and the rest of the inverters control their output voltages. The effectiveness of the proposed distributed control scheme was demonstrated on a lab-scaled prototype and some preliminary results were presented.



a.

b.



c.

Fig. 2. Experimental results of lab-scaled string of two Inverter Molecules with the proposed distributed control scheme. a) 16 seconds of operation with MPP of 30W for each inverter; b) ramp-up transient operation for a 30W DC power command as MPP for each molecule; c) steady-state operation of the string at 60W (30W per molecule)

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