Executive Summary

Project Name: “GR-17-05-Power Flow Controller for Medium-Voltage Silicon-Carbide Three-Phase Compensators”

The first goal of this project is developing a controller for 15-kV class three-phase multilevel shunt compensators for mitigating unbalanced currents and correcting power factors in electric power distribution feeders.

Multilevel converters required to achieve medium-voltage outputs with silicon devices require many voltage levels and suffer from higher losses due to limitations of the device technology. High-voltage (HV) silicon-carbide (SiC) devices should allow for multilevel converters with reduced voltage levels as well as other advantages such as higher switching frequencies that minimize the sizes of filter passive components. These SiC-based multilevel compensators will connect to 15-kV distribution feeders without using step-up transformers. HV SiC devices are then proposed as replacement to the traditional silicon devices in an effort to increase the viability of transformerless compensators, and thus, increase the penetration of power electronics in power grids.

An initial topology evaluation resulted in selecting the modular multilevel converter and the flying-capacitor converter for further analysis. The compensator controller will have the following main functions:

1. Full compensation of negative- and zero-sequence currents, and
2. Up to 10% reactive power compensation at the point of installation complementing the use of shunt capacitor banks for power factor correction.

The second goal of this project is to design and build a scale-down prototype demonstrating the feasibility of the proposed ideas and serve as a platform for testing the proposed control algorithms.

The third goal of this project is identifying the advantages that HV SiC devices when compared to HV silicon devices for applications in electric power distribution feeders.

A parallel effort involving interested GRAPES IAB members will be conducted to identify a suitable manufacturer interested in building a prototype to be tested at a utility distribution feeder and commercialize the technology.

In summary, this GRAPES project complements a research project that will be submitted to PowerAmerica Institute, a DOE-funded manufacturing consortium, for funding the manufacturing of switching assemblies based on HV SiC devices for building multilevel converters for utility applications. The above goals are broadly classified as technology readiness level (TRL) 3 which is below TRL 4, which could be funded by PowerAmerica Institute.
1. Project Description and Objectives

This project addresses power quality (PQ) research needs of GRAPES, in particular, current imbalances in three-phase distribution systems. Based on feedback from the IAB on GRAPES project GR-13-07, a multilevel shunt compensator based on high-voltage (HV) silicon-carbide (SiC) devices is proposed for three-phase four-wire systems that connect to medium-voltage (MV) systems without step-up transformers. HV SiC devices for this project are the 10 kV (80 A) and 3.3 kV (408 A) SiC MOSFET modules from Wolfspeed since they are suitable for this application and are very close to becoming commercially available.

This project (a) is a continuation of the previous GRAPES research project GR-13-07 that developed an unbalanced current static compensator using low-voltage silicon devices and connecting to the distribution feeder via step-up transformers, and (b) complements a research project to be submitted to PowerAmerica Institute, a DOE-funded manufacturing consortium, for funding the manufacturing of switching assemblies based on HV SiC devices for building multilevel converters. The proposed compensator should be also useful for overcoming current imbalances that may occur in distribution feeders with greater penetration of single-phase distributed generation (e.g., solar power).

It is envisioned that the outcomes of the GRAPES project and those of the PowerAmerica project (that if funded will start on June 1 2017) will lead to a follow-up project for building a 15-kV, 1-MVA prototype by vendor to be tested at a utility feeder belonging to one of the utilities in GRAPES IAB. The ultimate goal is that a vendor will end up offering a commercial product for this utility application.

Achieving direct connection to MV levels requires multilevel converters with the modular multilevel converter (MMC) and the flying-capacitor converter (FCC) already identified for further analysis after an initial evaluation of several topologies [1]. Shunt compensators based on silicon devices are unattractive when considering the number of voltage levels needed to reach the required feeder MV level, the associated device losses and the limited switching frequency. The addition of each two-level pair requires four devices and two capacitors for the Neutral Point Clamped (NPC) MMC solution. The total capacitance required for the NPC FCC increases exponentially with the number of levels [1]. HV SiC devices have the potentials to reduce the required voltage levels and increase the performance of these multilevel converters [2]. Single-phase five-level versions of the MMC and FCC converters using 10-kV SiC devices are shown in Fig. 1. Using 3.3-kV devices would require eleven levels. Therefore, the main goals of this project are:

(i) Designing the controller for multilevel compensator solutions enabled by HV SiC devices,
(ii) Build a scaled-down prototype to demonstrate the proposed control algorithms, and
(iii) Analyze the advantages provided by HV SiC technology to determine improvements of the proposed multilevel shunt compensator over its silicon counterpart.

The above goals are broadly classified as technology readiness level (TRL) 3 which is below TRL 4, which could be funded by PowerAmerica Institute. The compensator controller will perform the following two functions:

- Fully compensate for negative- and zero-sequence currents, and
- Provide up to 10% reactive power compensation as a complement to shunt capacitors.

2. Background and Evaluation of State of the Art

Commercial shunt compensator solutions for utility applications based on silicon devices are fewer and complex requiring step-up transformers. There is no utility-scale compensator for mitigating negative- and zero-sequence currents. There are no solutions based on SiC devices.

3. Proposed Novel Approach

The use of HV SiC devices provides many advantages (e.g., lower on-resistance, higher operating temperature, faster switching than comparable HV silicon devices), but their use for MV applications has
yet to become mainstream. For the considered 15-kV application, 10-kV SiC devices reduce the required number of voltage levels for direct connection to MV systems, and thus simplify the system.

Figure 1. Single-phase five-level MMC (left) and FCC (right)

Therefore, HV SiC devices shows promise for facilitating wide adoption of shunt compensators based on power electronics into electric distribution systems.

In summary, this project will determine the challenges associated with these HV SiC devices and seek the solutions that could help solidify MV compensators as viable solutions to PQ issues.

4. Potential Benefits if Successful

Funding of a full-size prototype for field testing is beyond the scope of a GRAPES-funded project. This project extends the work of a previous GRAPES project, and demonstrating the feasibility of the proposed shunt compensator based on HV SiC devices via simulations will enable the researchers to identify a suitable vendor for building a full-size 15-kV, 1-MVA prototype, and hopefully, leading to commercialization of a product for distribution systems.

5. Potential Risks to Project Success

No risks are envisioned at this time.

6. Milestones for Mid-Project (Y1) and End of Project (Y2):

May 2017: - Development of the control algorithms for start-up conditions and continuous operation.
November 2017: - Design and fabrication of a scaled-down prototype
May 2018: - Prototype testing completed
November 2018: - Final report

7. References


## Relevant Data and Metrics for Project

### A. Personnel

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<th>Demographics</th>
<th>University</th>
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<tr>
<td><strong>Project Leader</strong></td>
<td>Juan Carlos Balda</td>
<td>Arkansas</td>
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<tr>
<td><strong>Other Faculty</strong></td>
<td>Cheng Deng</td>
<td>Arkansas</td>
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### B. Products (Note: include only those that explicitly acknowledge NSF support)

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## Salaries and Wages

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