FY23 SBIR I:
Fuel Cell Integrated Power Electronics Module

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AMR Project ID #MNF-BIL014

PROJECT GOAL

Develop an advanced power electronics module to eliminate the common drawbacks of relying on commercial off-the-shelf (COTS) inverters for fuel cell generator applications, with the specific objectives of improving fuel cell data communications, achieving power characteristics more compatible with end user requirements, and reducing integration cost and complexity

OVERVIEW

Timeline and Budget

- **Project start date: July 2023**
- **Project end date: April 2024**
- **Total Project Budget: $198,141**
  - Total DOE share: $198,141
  - Total cost share: 0
  - Total DOE funds spent: $198,141
  - Total cost share spent: $28,500

Barriers and Targets

- Compact design
- Integration cost and complexity
- High power output power quality
- Use of wide bandgap devices
- Transition from island operation to grid forming operation

Partners

- RockeTruck, Inc., Project Lead
- Sandia National Laboratories
- Infineon/GaN Systems
- AVL Mobility Technologies
- ARRS, Inc.
- Southern California Gas

POTENTIAL IMPACT

- Reduced size, by utilizing higher switching frequency GaN HEMT transistors to reduce filter component size and eliminate bulky transformers
- Smoother transition from islanded grid forming mode (backup) to grid-connect mode and back, enabled with advanced algorithms
- Flexible application due to ease of parallel operation, enabling installation ratings from 42kW to 420kW three-phase, 28kW to 280kW single-phase.
- Multi-port operation enabled with 330VDC to 440VDC input range, allowing direct connection to Li-ion battery paralleled with fuel cell module.

POTENTIAL IMPACT

DOE Goals

- Reduce greenhouse gases and criteria pollutants
- Support and improve energy, environmental, and social justice
- Create high-wage/high-skill jobs in the U.S.
- Build clean energy infrastructure
- Strengthen U.S. manufacturing

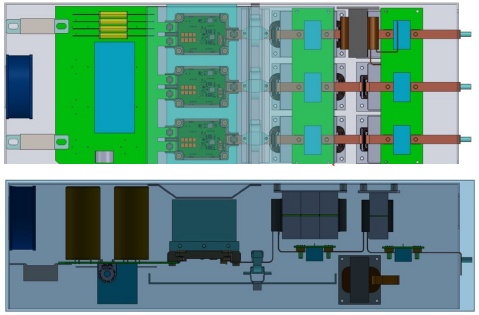
Project Impacts

- Bidirectional AC/DC Module also applicable as off-ramp/on ramp from/to 380VDC microgrids to 208Y/120VAC power system, enabling fuel cell backup in commercial buildings.
- Module can be applied as 60kW, 0-380V/380V DC/DC converter. This will enable a wide variety of distributed energy sources and storage media.
- This effort will expand the role of GaN as a higher frequency, higher efficiency more compact alternative to existing devices in the clean energy space.

APPROACH

COTS HIGH-POWER INVERTER

GAN-BASED CONVERTER-INVERTER



- **Define the requirements for end uses:**
  - 380VDC recognized as common for solar strings, DC microgrids and it **supports:**
  - 120/240VAC, single-phase, 3 wire for light commercial and residential
  - 208Y/120VAC, three-phase, 4 wire for large commercial.
    - → Meeting IEEE-519 and UL-1741 specs
    - → Ensure flexible application range
- **Find core inverter switching components**
  - Define “dream” device in GaN
  - Selected GaN/AMOTEK 200A module
- **Define feasible multi-application inverter module**
- **LT spice models of inverter and filter circuits**

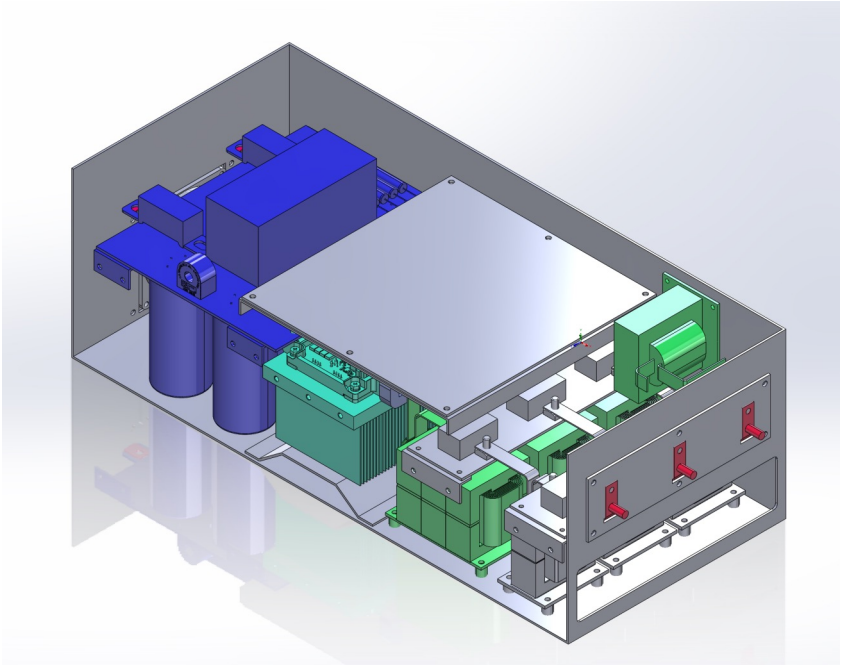
APPROACH: PRODUCT PLANNING & SAFETY

- **Examined various approaches for 3rd and 4th wire derivation for single and three-phase inverters, respectively**
  - Adopted tapped filter capacitor approach
  - Conducted reliability study for electrolytic capacitors via Sandia National Labs
- **Conducted tradeoff study for inverter control microprocessor, examing three candidates in detail – Adopted TI Dual-core Delfino.**
- **Examined Dual and Triple Active bridge DC/DC converters (DAB and TAB):**
  - Functions are to provide Galvanic isolation and regulation at converter ports
  - If different port voltages are needed inverter module can be adapted via software modification as non-isolated DC/DC converter at lower cost.
- **Reviewed EMI performance and added filter stage to meet contemporary standards**
- **Thermal study of low-cost filter component design by SNL**
- **Safety:**
  - Added DC input fuses to minimize consequences of shoot thru failure.
  - AMOTEK/GaN module to get desaturation protection to minimize failure consequence

ACCOMPLISHMENTS AND PROGRESS

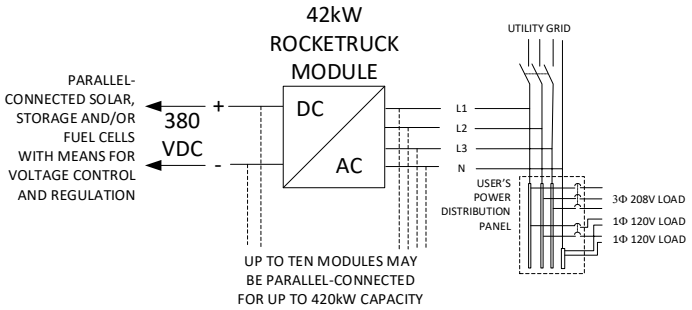
PAGE 1 OF 1: SUMMARY

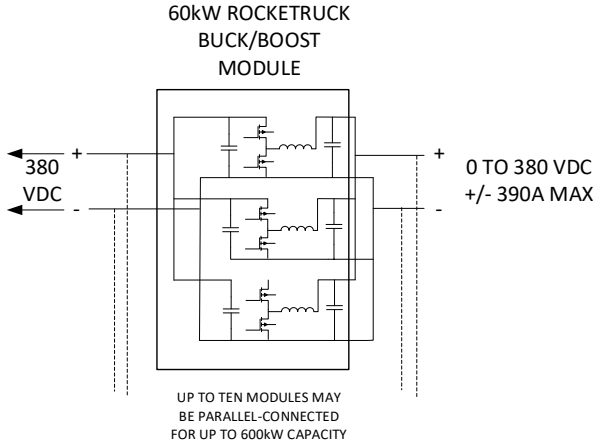
- **Detailed overall schematic**
- **Defined control requirements:**
  - Independent regulation and PWM for each phase
  - DQ regulators to provide current limiting without excess distortion.
  - Developed synchronization and contactor sequencing for connecting to grid.
- **Defined control hardware:**
  - Developed and finalized control block diagram.
  - Motherboard to have all control and data comm interfaces; Daughterboard to be off-the shelf TI control card.
  - Developed preliminary schematic of all motherboard circuitry



ACCOMPLISHMENTS AND PROGRESS

PAGE 2 OF 2: ADVANCEMENT OF KEY ENABLING TECHNOLOGIES





- Developed design for a more compact fuel cell power converter ("FCIPEM" SBIR Ph I)
  - Gallium nitride (GaN) semiconductors
  - Smaller filter components and heat sink
  - Multiple DC input ports (fuel cell + battery)
- Preliminary design funded by a separate DOE SBIR Phase I project ("FCIPEM)
- Future plans
  - Develop bench prototype with combination of company funds and funds expected from Southern California Gas
  - Develop operational prototype and demonstrate on MFCG Mini if FCIPEM project continues to Phase II

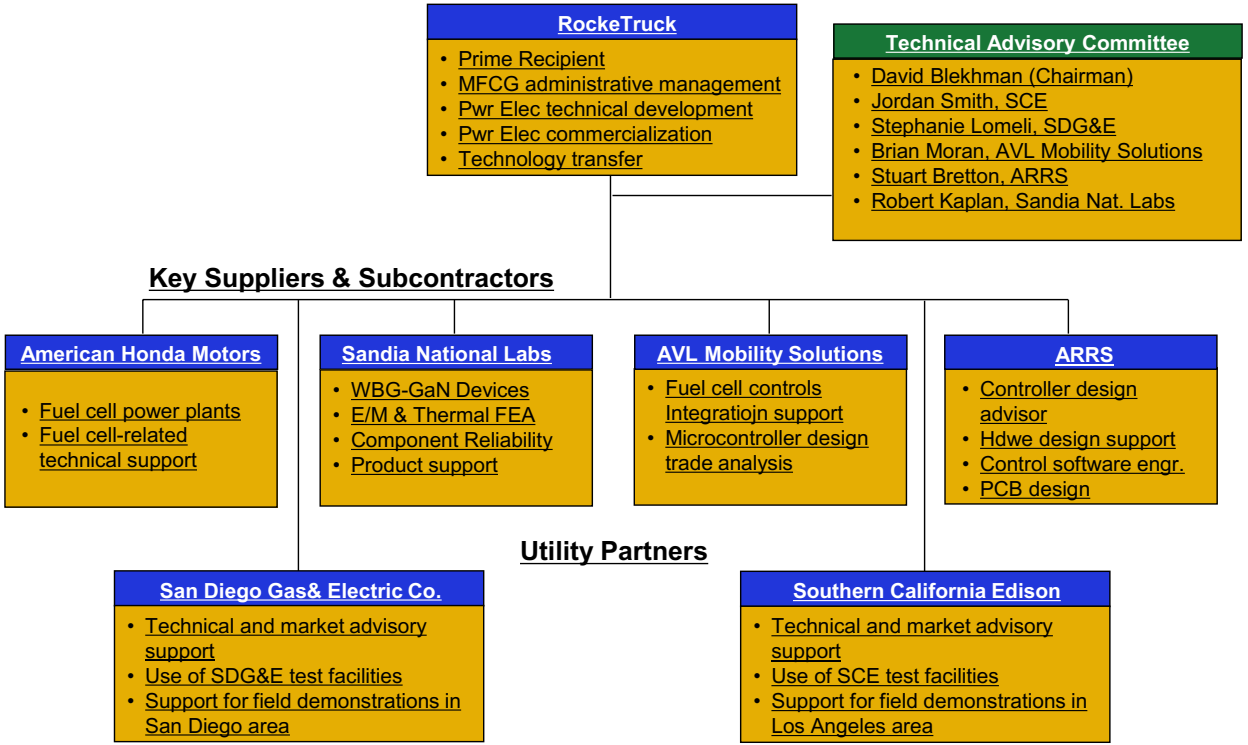
COLLABORATION AND COORDINATION

PAGE 1 OF 2: TABULAR LISTING OF KEY COLLABORATORS

Organization	Relationship	Role
RockeTruck, Inc.	Prime	Project lead, management & coordination, lead converter design and manufacturing activities
Sandia National Laboratories	Research Institution	• Perform FEA electromagnetic loss analysis of filter components • Perform FEA thermal studies and electrolytic capacitor reliability studies
AVL Mobility Technologies	Engineering consultant	Support development of software and controls for fuel cell and energy management systems
ARRS	TI Delfino software expert	Provide expert guidance on processor application to inverter control
American Honda Motors	Non-funded collaborator	Supply fuel cell for mobile generator to be used as FCIPEM testbed
Southern California Edison	Non-funded collaborator	Provide technical advice and access to lab facilities on an as-needed basis
California Energy Commission	Non-funded collaborator	Funding partner on Mobile Fuel Cell Generator project and providing informal power electronics technical advice

COLLABORATION AND COORDINATION

PAGE 2 OF 2: TEAM ORG CHART



COMMUNITY BENEFITS ACTIVITIES

- **Integrated into RockeTruck's Mobile Fuel Cell Generator (MFCG), FCIPEM project will leverage community benefits activities already planned for MFCG**
  - MFCG outreach activities are being led by California State University (CalState LA), a minority-serving institution
  - MFCG demonstrations are planned at several locations throughout the greater San Diego and Los Angeles communities (see below)
  - CalState LA students will be involved in demonstrations

- **Planned MFCG field demonstration sites:**
  - Hydrogen Research and Fueling Facility (HRFF) on the CalState LA campus
  - Three different community centers in the Los Angeles region (Malibu, Idyllwild, Tehachapi)
  - San Diego Gas & Electric facility in Julian, CA
  - Idyllwild and Julian are mountainous regions close to numerous Native American Tribal Lands

- **Community-based goals include:**
  - Demonstrate ability to charge emergency devices such as cell phones and oxygen generators
  - Demonstrate portability necessary to provide access to remote, off-grid communities

REMAINING CHALLENGES AND BARRIERS

- Develop inverter controls compatible with high switching frequency GaN
- Incorporate functionality of grid-connect to island backup modes
- Test current-limiting and overload recovery capability
- Verify EMI and noise immunity of controls
- Expand functionality of software to address all potential use cases

PROPOSED FUTURE WORK

- Complete inverter controls PCB design
- Develop converter control software
- Complete lab setup for fully functional testing
- Assemble prototype converter
- Complete lab/bench testing of converter
- Fully validate prototype converter by integrating it into existing Mobile Fuel Cell Generator (MFCG) and testing MFCG using the new converter under real-world operating conditions

SUMMARY

Readiness to build a prototype fuel cell power converter using gallium nitride technology has been achieved

- Detailed electrical and thermal analyses have been completed and numerous case studies evaluated
- A converter preliminary design has been developed, driven by the known requirements of a mobile fuel cell-based power generating system
- Benefits of replacing COTS inverters with the new GaN-based converter have been identified and quantified
- Commercial outreach and customer discovery have been initiated
- Plans for development and validation of a prototype GaN-based converter have been developed