Final Report

Project Name: The MidAmerica Regional Microgrid Education and Training (MARMET) Consortium

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HIGH-LEVEL PROJECT QUESTIONS

1. What is the optimal penetration from solar PV resources and other technology distributed energy resources (DERs) based on network feasibility?
2. How can energy storage and demand response be used to improve the utilization of PV systems in microgrids?
3. How can microgrids be utilized for participation in system performance such as frequency regulation and congestion management?
4. What are the key challenges to use grid-connected power electronic inverters for renewable energy generation, vehicle-to-grid, and other energy interface applications?
5. What are the curricular gaps with respect to emerging issues in microgrids?
6. What are the best methods to disseminate curriculum to interested faculty?
7. How can the research in this project be integrated with the coursework that is being offered for students – both undergraduate and graduate?
8. What is the best approach to present these results to industry?

KEY TAKEAWAYS

- Grid connected inverters are key enablers for successful implementation of distributed energy resources including solar, wind, V2G
- Robust distributed control algorithms are needed for microgrid frequency regulation.
- Energy storage and demand response programs can be successfully integrated to maximize the performance of high penetration PV distribution microgrids
- Curriculum repositories provide significant resources for faculty to rapidly integrate new material into courses and/or develop new courses
- A modular approach to curriculum update and development promotes ease of adoption across universities

OPEN QUESTONS

- What business case can be made to provide an incentive for industry to invest in microgrids for the purpose of improving system response to frequency regulation?
- What are the future needs of the distributed energy resources to incorporate grid connected inverters in a better way?
- What is the best and optimal strategy of coordinated control among various existing voltage control devices and solar PV smart inverters for different type of distribution feeders?
- How can more industry engineers be exposed to research findings?
- How can course sharing be made easier between universities?
- How can learning outcomes be measured to assess workplace readiness?

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The MidAmerica Regional Microgrid Education and Training (MARMET) Consortium

I. EXECUTIVE SUMMARY

The primary goal of this project was to integrate cutting-edge research and advanced instructional methods to create a flexible, evolving approach to microgrid and distributed energy resources training for all levels of student. This goal entailed the rapid development of modular material to capture and reflect the newest trends in electric power microgrid engineering and to make it available in traditional and non-traditional settings. It was our goal to develop course material that can be readily integrated into either existing courses or organized into new courses. The target audiences include technicians, contractors and consultants, inspectors, policy makers, supervisors, and engineers and undergraduate and graduate students. The main project objectives were to:

1) Perform a gap analysis to identify the research/educational/training needs and define specific implementation plans for these activities in distributed technology and Smart Grid power engineering by working with Department of Energy, the National Network Administrator (NNA) and other Distributed Technology Training Consortia (DTTC).
2) Develop learning content related to, and driven by, microgrid research, consisting of one or more multimedia-based modules. Over the life of the project MARMET provided training to 11,012 students and developed 154,432 contact hours of material (see the IREC NNA, DE-EE0006342, final project report for added details on MARMET evaluation and assessment metrics, as well as an overview of the entire GEARED network.
3) Provide a variety of delivery mechanisms and venues for face-to-face and on-line instruction in power system engineering and related smart grid operations, including university-based courses, short courses, and workshops.
4) Assemble and engage highly-qualified advisory and steering committees of experts from utilities, universities, national laboratories, and product suppliers for this DTTC, to guide and advise the activities of the DTTC, and to assist in creating student internships, coops, research projects and academic competitions for GEARED students within the DTTC and nationally.
5) Convene regular meetings of Consortia partners to disseminate research results among the participants (universities, utilities, and industry).
6) Develop recruitment mechanisms to publicize GEARED student opportunities and highlight the educational benefits of GEARED participation to assure long-term sustainability of student recruitment and retention.
7) Participate in GEARED National Network activities to identify and adopt best practices across all GEARED consortia.
8) Organize, host and manage at least one annual Student-Centered Research Conference on behalf of the GEARED Network during the period of performance; participate in each annual national Student-Centered Research Conference.

II. MOTIVATION FOR PROJECT AND RESEARCH QUESTIONS ADDRESSED

Traditionally, power system generation has been dominated by large fossil-fuel burning centralized power stations. However, the mix of generation is forecasted to dramatically shift in the coming decades with renewable resources assuming a much larger proportion of the generation mix. As residential photovoltaic (PV) systems proliferate, power system operation and control will increasingly be managed at the local level, with sources and loads comprising autonomous microgrids within the larger power system. This fundamental shift in operation has required new approaches in energy management, communication and control, protection, and energy policies. Across the nation, researchers in industry and academia have been engaged in research endeavors to better understand and promote efficient and safe operation of high PV penetration distribution microgrid systems. Despite researchers globally addressing these issues, the time lag for translating cutting-edge discovery to various constituencies can often be many years, with delays caused by curriculum and textbook inertia. To overcome these obstacles in preparing the next workforce generation, the MARMET consortium, as part of the DOE SunShot Initiative, endeavored to aggressively develop into curriculum appropriate for various audiences ranging from college students to practicing engineers to consumers and community leaders. The MARMET consortium addressed two primary focus areas: Research and Education. Key findings are found in the significant findings and takeaways in section V.

III. PROJECT TEAM

MARMET Executive Team

Team Member	Responsibilities
Suzanna Long Missouri University of Science & Technology Principal Investigator	Project Management and fiscal oversight, member of Geared Executive Committee (GEC), technical lead for energy sustainability curriculum development, Student Innovation Board advisor
Mariesa Crow Missouri University of Science & Technology Co-Principal Investigator	Back-up for PI Long, IEEE Power & Energy liaison, technical lead for power engineering curriculum oversight and microgrid curriculum development
James McCalley Iowa State University	Campus Director, technical lead for wind power curriculum development
Peter Sauer University of Illinois	Campus Director, technical lead for power electronics and PV curriculum development, Student Conference
Bulent Sarlioglu University of Wisconsin	Campus Director, Short Course Director, technical lead for energy storage curriculum development

Diane Rhodes-Michaely National Rural Electric Cooperative Association (NRECA)	Industrial Outreach Director, technical lead for community solar curriculum development
George Mues Ameren	Organized on-site workshops and research project meetings, provided practitioner feedback, founding member of Microgrid Research Consortium
Brent McKinney City Utilities	Organized on-site workshops, founding member of Microgrid Research Consortium

IV. SIGNIFICANT RESULTS AND KEY TAKEAWAYS

Education

The MARMET consortium integrated cutting-edge research and advanced instructional methods to create a flexible, evolving approach to microgrid training for all levels of student. Over the life of the project MARMET provided training to 11,012 students and developed 154,432 contact hours of material (see the IREC NNA, DE-EE0006342, final project report for added details on MARMET evaluation and assessment metrics, as well as an overview of the entire GEARED network. The MARMET consortium focused on the rapid development of modular material to capture and reflect the newest trends in electric power engineering and to make it available in traditional and non-traditional settings. Developed material is used in university courses, workshops, and industry shortcourses. The four universities have well-established, highly ranked power engineering programs, and along with their industry partners, they form a strong regional partnership serving the students and engineers of Mid-America. Although the National Rural Electric Cooperative Association (NRECA) is headquartered in Arlington, VA, many rural populations throughout mid-America are served by their utility members, making them an integral member of the MARMET team. As a result of their regional proximity and power engineering program focus, this curriculum development partnership was a natural extension. The project addressed the following educational questions:

1. How can the research in this project be integrated with the coursework that is being offered for students – both undergraduate and graduate? This includes the traditional mechanisms of course revisions plus new methods for course material sharing among universities.
2. How can these results be presented to industry through workshops, seminars, and publications? This includes on-site instruction as well as remote participation in webinars and tutorials.
3. What is the best mechanism for disseminating curriculum across universities?
4. How can industry be involved in directing curriculum development?
5. What extra-curricular activities can benefit student learning?

The project team employed a rigorous and systematic approach to curriculum design and instructional systems deployment. We utilized a multi-faceted approach to

workforce training activities. As a foundation, we developed a variety of modular-based course material that was integrated into either existing courses or organized into new courses. These courses were targeted to senior undergraduate and graduate students. The topics of the updated and new courses can be broadly categorized (each University uses a slightly different course title):

- Advanced Power Systems (new material)
- Photovoltaic Systems (new course)
- Power Quality in Distribution Systems (new material)
- Microgrid Systems (new course)
- Power System Stability (new material)
- Power Electronics (new material)
- Advanced Power Electronics (substantial upgrade)
- Computer Methods in Power Systems (new material)
- Supply Chain Management Systems (new material)
- Power System Operations (new material)
- Power System Planning (new material)
- Power System Reliability (new material)
- Distribution System Analysis (substantial upgrade)
- Electromechanical Wind Energy Conversion & Grid Integration (new course)
- Green Electricity (new course)

The curriculum development approach employed was to develop course modules focused on specific topics. These modules typically consisted of one to five class periods (typically hour-length classes). Individual modules were introduced into existing courses as standalone topics. Multiple modules were assembled to upgrade “traditional” power courses or as a new class offering. Many new topics are not addressed in existing textbooks, and therefore supplemental material was developed. A few upgrade examples include:

- Differential Protection: As the penetration of residential PV facilities increases, the magnitude of fault currents may be masked during periods of high solar insolation leading to poor operation of overcurrent relays. Thus a module addressing differential and impedance protection was developed and added into the Advanced Power Systems course.
- IEEE Standard 1547: For operational safety, 1999 UL 1741 requires disconnection of distributed inverter-based generation systems during an outage, but was updated in 2011 to provide for islanded operation of microgrids. IEEE Standard 1547 provide guidance on islanding protocols and the use of inverters to produce reactive power for ancillary services. This material was included in several courses including Advanced Power Electronics, Advanced Power Systems, and Microgrid Systems.
- Virtual Inertia: As the penetration of PV and wind generation increases and large coal plants are retired from service, the apparent inertia of the power transmission system is decreasing leading to decreasing transient stability. The

concepts of inverter-based virtual inertia to stabilize power systems were developed and added into the Power System Stability course.

Each of the developed course modules includes written course material, presentation slides, example and assignable problems, and a comprehensive mastery exam. We have coordinated with the other DTTCs to have the course material archived on the IEEE Power & Energy Society Resource Center.

For post-BS engineering students, these lecture courses were offered as part of *graduate certificate* programs available from each of the partner universities. A graduate certificate program requires the equivalent of 12 semester hours, or 180 hours of instruction.

In addition to academic programs, a variety of workshops (1-4 hours of instruction) and short courses (8 or more hours of instruction) were developed. The workshops and short courses were targeted to address the needs of the practitioner including technicians, designers, contractors and consultants, inspectors, and supervisors. Workshop participants received a certificate of completion and short course participants received professional development hours (PDHs). The workshops and short courses were offered at multiple venues including on-site at the partner utility companies (Ameren and City Utilities), conferences, and on-line.

Ameren is an investor-owned utility which serves over 2.4 million electric customers across Illinois and Missouri and employs 8500 hundred people, which includes several hundred engineers. Throughout the project, Ameren personnel provided guidance and feedback to the MARMET team. Several times each year, the MARMET team would receive a list of suggested topics from Ameren around which to develop course material. This would then culminate in an annual workshop which was attended by approximately 100 engineers. After the workshop, each participant would submit a survey designed to provide specific feedback on the material. These workshops have been useful in initiating discussions between the university faculty and practicing engineers regarding the depth and breadth of the developed curricular material.

In addition to curriculum development, each of the partner universities were actively involved in providing extra-curricular development activities for students including

- Senior design projects
- Field trips
- Seminars
- Conferences
- Professional society (IEEE) participation, and
- Scholarly paper preparation and presentation.

Participation in senior design projects was one of the primary focus areas of MARMET. Senior design projects provide an opportunity for more practical implementation of subjects than do lecture courses. Students are increasingly interested in renewable energy and senior design projects enable them to explore these interests. Many of these projects have industry advisors:

- Off-grid residential microgrid (Alliant Energy)

- Substation design (Black and Veatch)
- Substation design (Burns and McDonnell)
- Distribution upgrade (Algona Municipal Utility)
- 3-phase, 10 kW test load (InnoCit)
- Distribution feeder expansion (Muscatine Power and Water)

Research

The main envisioned features of the future distributed microgrid system include: automatic controls for electric power at the customer side; a power distribution infrastructure that encourages renewable energy development, local energy storage energy; and customer loads that are capable of responding to changes in the grid. It is expected that these features will be implemented through the use of digital signal communication including pricing information; high speed electronic control of power; direct control of energy flows in distribution systems and at customer sites; and the utilization of optimal strategies for the operation (charge and discharge) of storage devices (potentially including plug-in electric vehicles). The smart microgrid offers many benefits to utilities and consumers – mostly seen in improvements in energy efficiency on the electricity grid. Realizing the envisioned smart distributed microgrid system requires a holistic understanding of the impact that a high penetration of renewable resources, energy storage, and distributed control has on system operation. The research questions addressed in this project included:

1. What is the optimal penetration from solar PV resources and other technology distributed energy resources (DERs) based on network feasibility? Specifically, we will identify the locations and maximum allowable capacity of the DGs in the distribution networks without requiring major upgrades. Furthermore, since some of the many benefits of integrating DGs into the microgrid system include voltage profile improvement, line loss reduction, and emission reductions we wanted to determine the ability of PV system smart inverters to improve secondary voltage control and grid security.
2. How can energy storage and demand response be used to improve the utilization of PV systems in microgrids? The main envisioned features of the future distributed microgrid system include: automatic controls for electric power at the customer side, a power distribution infrastructure that encourages renewable energy development, local energy storage, and customer loads capable of responding to changes in the grid. Even a modest infusion of energy storage technologies and demand response with intermittent generation such as PV will allow temporal shifts in balancing load and generation to provide improve reliability and economy.
3. How can microgrids be utilized for participation in system performance such as frequency regulation and congestion management? This includes the type of resource control strategies and communication architectures. Future microgrids will most likely rely on a distributed control architecture for frequency control and optimal dispatch. The architecture will be adaptable to the functionality needs across different applications, including disaster-relief installations, military microgrids, and

clusters of households with generation and storage capacity. The architecture should be able to self-synchronize and seamlessly adapt to changes induced by generating resources and loads coming online or going offline.

Negative Results and/or Changes to Original Project Plan

One of the primary barriers encountered was the inability to create a formalized course-sharing agreement across university partners. The lead institution (Missouri S&T) had entered into several course-sharing agreements prior to the GEARED program (with institutions such as Arizona State University, North Carolina State University, and Kansas State University) so it was anticipated that this would not be problematic in this project. However, several areas proved to be difficult for the individual faculty to persuade their respective administrations to approve. They are briefly summarized:

- Tuition revenues: distance courses are seen as revenue producing endeavors with production costs covered by the (sometimes much) higher tuition paid by distance students. University administrators were reluctant to waive the tuition differential required by the agreement.
- Course quality: there is no formal process to ensure the quality of instruction, exams, and material from faculty employed at partner institutions.

These issues tended to be more problematic for the higher "ranked" partner institutions. Less prestigious partners were more likely to approve these agreements in anticipation of fostering research partnerships outside of the educational aspects.

Another difficulty encountered was the lack of a formal process to assess the learning outcome impact of the project. The metrics tracked across the DTTCs were quantitative and essentially consisted of a headcount of the students (both university and industry). Although there was internal MARMET assessment of the curriculum material (via survey feedback, interaction with industry partners, evaluation by partner faculty), this assessment was never formalized by rubric or other pedagogical approach by an external evaluator.

This project successfully updated the "traditional" power engineering curriculum across DTTCs. This in itself was a massive undertaking. Future projects should be encouraged to perform rigorous gap analyses to determine what additional material can be developed. Suggested topics include communications and architectures, big data, systems engineering, and socio-technical aspects.

V. PUBLICATIONS, OUTREACH, AND OTHER OUTPUTS

Select publications from the MARMET consortium follow. Note that all have been held to rigorous peer review. Those publications listed as proceedings include presentations at professional conferences.

1. J. A. Mueller, M. Rasheduzzaman, and J. W. Kimball, "A Model Modification Process for Grid-Connected Inverters Used in Islanded Microgrids," *IEEE Transactions on Energy Conversion*, vol. 31, no. 1, pp. 240–250, Mar. 2016.
2. Brian Johnson, Philip Krein, “An Analytical Time-Domain Expression for the Net Ripple Produced by Parallel Interleaved Converters,” accepted for publication in IEEE Transactions on Circuits and Systems II: Express Briefs, 2016.
3. J. A. Magerko, P. T. Krein, “Opportunities for Photovoltaic System Operation Below Parity: Costs and Benefits of Active Grid Support,” accepted for publication in Proc. IEEE Photovoltaic Specialists Conf., 2016.
4. J. Galtieri, P. T. Krein, “Energy Improvements from subpanel DC-DC converters in PV-arrays with Distributed Mismatch,” accepted for publication in Proc. IEEE Photovoltaic Specialists Conf., 2016.
5. J. Galtieri, P. T. Krein, “Incorporating Subpanel DC-DC Converters into Solar Array Design,” accepted for publication in Proc. IEEE Photovoltaic Specialists Conf., 2016.
6. Jhi-Young Joo, Sriram Raghavan, and Zeyi Sun, “Integration of Manufacturing Systems into Smart Grids with Penetration of Renewable Energy Resources,” IEEE Green Technologies, April 2016, accepted
7. Hui Lin, Adam Slagell, Zbigniew Kalbarczyk, Peter W. Sauer, and Ravishankar K. Iyer, “Runtime Semantic Security Analysis to Detect and Mitigate Control-related Attacks in Power Grids,” Accepted for the IEEE Transactions on Smart Grid, 2016.
8. W. Choi, W. Lee, C. Morris, and B. Sarlioglu, “Modeling three-phase grid-connected inverter system using complex vector in synchronous dq reference frame and analysis on the influence of tuning parameters of synchronous frame PI controller,” in Proc. of IEEE Power and Energy Conf. at Illinois, February 2016.
9. W. Choi, W. Lee, and B. Sarlioglu, "Effect of grid inductance on grid current quality of parallel grid-connected inverter system with output LCL filter and closed-loop control,” in Proc. of IEEE Appl. Power Electron. Conf., March 2016
10. R. Venkatraman and S. Khaitan, "Optimal Reactive Power Allocation to Minimize Line and DG Losses in a Radial Distribution System” to appear in PES GM 2016. W. Choi, W. Lee, and B. Sarlioglu, "Reactive power control of grid-connected inverter in vehicle-to-grid application for voltage regulation," in *Proc. IEEE Transportation Electrification Conf. Expo*, Jun. 2016, pp. 1-8.
11. W. Choi, W. Lee, and B. Sarlioglu, "Reactive power compensation of grid-connected inverter in vehicle-to-grid application to mitigate balanced grid voltage sag," in *Proc. IEEE Power and Energy Soc. General Meeting*, Jul. 2016, pp. 1-8.
12. W. Choi, W. Lee, D. Han, and B. Sarlioglu, "New configuration of multi-functional grid-connected inverter to improve both current-based and voltage-based power quality,” in *Proc. IEEE Energy Conversion Conf. and Expo*, Sept. 2016.
13. S. Mukherjee, P. Shamsi and M. Ferdowsi, "Small signal modeling and control

of a grid tied converter without a syncronization unit," 2016 IEEE Applied Power Electronics Conference and Exposition (APEC), Long Beach, CA, 2016, pp. 2687-2692.
14. A. Shen, P. Shamsi and M. Ferdowsi, "Ultra-low ripple inverters for distributed generation applications," 2016 IEEE Applied Power Electronics Conference and Exposition (APEC), Long Beach, CA, 2016, pp. 1962-1966.
15. W. Choi, W. Lee, and B. Sarlioglu, "Reactive power compensation of grid-connected inverter in vehicle-to-grid application to mitigate balanced grid voltage sag," in *Proc. IEEE Power and Energy Soc. General Meeting*, Jul. 2016, pp. 1-8.
16. W. Choi, W. Lee, D. Han, and B. Sarlioglu, "New configuration of multi-functional grid-connected inverter to improve both current-based and voltage-based power quality," in *Proc. IEEE Energy Conversion Conf. and Expo*, Sept. 2016.
17. Y. Wu, W. Choi, D. Han, J. Gorman, W. Lee, and B. Sarlioglu, "Introduction to micro-grid, grid-connected inverter, vehicle-to-grid technology, and energy storage system," *in Transportation Electrification Conference and Expo (ITEC)*, Chicago, Illinois, June 14-17, 2017.
18. D. Apostolopoulou, A. D. Dominguez-Garcia, and P. W. Sauer, "Balancing Authority Area Model and its Application to the Design of Adaptive AGC Systems," IEEE Transactions on Power Systems, vol. 31, no. 5, 3756-3764, September 2016.
19. Y. C. Chen, J. Wang, A. D. Dominguez-Garcia, and P. W. Sauer, "Measurement-Based Estimation of the Power Flow Jacobian Matrix," IEEE Transactions on Smart Grid, vol. 7, no. 5, 2507-2515, September 2016.
20. K. E. Van Horn, A. D. Dominguez-Garcia, and P. W. Sauer, "Measurement-Based Real-Time Security-Constrained Economic Dispatch," IEEE Transactions on Power Systems, vol. 31, no. 5, 3548-3560, September 2016.
21. B. Gharesifard, T. Basar, and A. D. Dominguez-Garcia, "Price-Based Coordination of Networked Distributed Energy Resources," IEEE Transactions on Automatic Control, vol. 61, no. 10, 2936-2946, October 2016.
22. J. T. Hughes, A. D. Dominguez-Garcia, and K. Poolla, "Identification of Virtual Battery Models for Flexible Loads," IEEE Transactions on Power Systems, vol. 31, no. 6, 4660-4669, November 2016.
23. M. Zholbaryssov and A. D. Domínguez-García, "Exploiting Phase Cohesiveness for Frequency Control of Islanded Inverter-Based Microgrids," in Proc. of the IEEE Control and Decision Conference, Las Vegas, NV, December 2016.
24. S. T. Cady, M. Zholbaryssov, A. D. Domínguez-García, C. N. Hadjicostis, "A Distributed Frequency Regulation Architecture for Islanded Inertia-Less AC Microgrids," IEEE Transactions on Control Systems Technology, Accepted for Publication.
25. M. Zholbaryssov, and A. D. Domínguez-García, "Distributed Enforcement of Phase-Cohesiveness for Frequency Control of Islanded Inverter-Based Microgrids," IEEE Transactions on Control of Network Systems, Accepted for Publication.
26. P. Shamsi and H. Xie, "Preemptive control: A paradigm in supporting high renewable penetration levels," 2016 North American Power Symposium (NAPS), Denver, CO, Sep. 2016, pp. 1-5.

27. S. Mukherjee, P. Shamsi and M. Ferdowsi, "An improved control scheme for a standalone DFIG with unbalanced and nonlinear loads using proportional-resonant controllers," 2016 North American Power Symposium (NAPS), Denver, CO, Sep. 2016, pp. 1-6.
28. S. Mukherjee, P. Shamsi and M. Ferdowsi, "Improved virtual inertia based control of a grid connected voltage source converter with fault ride-through ability," 2016 North American Power Symposium (NAPS), Denver, CO, Sep. 2016, pp. 1-5.
29. P. Shamsi, H. Xie, A. Longe and J. Y. Joo, "Economic Dispatch for an Agent-Based Community Microgrid," in IEEE Transactions on Smart Grid, vol. 7, no. 5, pp. 2317-2324, Sept. 2016.
30. P. Shamsi, A. Shen, "Design and Analysis of a Class of Zero Fundamental Ripple Converters," in IEEE Transactions on Power Electronics, early access.
31. Maigha and M. L. Crow, “Cost-Constrained Dynamic Optimal Electric Vehicle Charging,” IEEE *Transactions on Sustainable Energy,* (early access).
32. Tu A. Nguyen and M. L. Crow, “Stochastic Optimization of Renewable-Based Microgrid Operation Incorporating Battery Operating Cost,” *IEEE Transactions on Power Systems,* vol. 31, no. 3, pp. 2289-2296, May 2016.
33. Xin Qiu, Tu Nguyen, and M. L. Crow, “Heterogeneous Energy Storage Optimization for
Microgrids” IEEE Transactions on Smart Grid, vol. 7, no. 3, May 2016.
34. Maigha and M. L. Crow, “Economic and Battery Health Conscious Vehicle-to-Grid Electric Vehicle Operation” Proceedings of the 2016 IEEE PES Innovative Smart Grid Technologies Conference, Minneapolis, MN, September 2016.
35. M. R. Narimani, P. Nauert, J-Y Joo, M. L. Crow “Reliability assesment of power system at the presence of demand side management,” Power and Energy Conference at Illinois (PECI), Urbana, IL, February 2016.
36. L. Grant* and M. L. Crow, “A Chain Method for Preconditioned Iterative Linear Solvers for Power System Matrices,” IEEE Transactions on Power Systems, vol. 33, no. 1, January 2018.
37. Maigha* and M. L. Crow, “Electric Vehicle Scheduling Considering Co-optimized Customer and System Objectives,” IEEE Transactions on Sustainable Energy, vol. 9, no. 1, pp. 410-419, January 2018.
38. W. Choi, W. Lee, D. Han, and B. Sarlioglu, "Shunt-series-switched multi-functional grid-connected inverter for voltage regulation in vehicle-to-grid application," in Proc. IEEE Transportation Electrification Conf. Expo, 2018, pp. 1-8.
39. P. Castro Palavicino, Y. Wu, M. Smuda, W. Choi, W. Lee, B. Sarlioglu, “Methodology for evaluating potential benefits and economic value of residential photovoltaic and battery energy storage system,” in Proc. IEEE Transportation Electrification Conference and Expo (ITEC), 2018, pp. 1–6."
40. W. Choi, W. Lee, D. Han, and B. Sarlioglu, " New configuration of multi-functional grid-connected inverter to improve both current-based and voltage-based power quality," IEEE Transactions on Industrial Application, 2018. Accepted.
41. M. G. Fikru, G. Gelles, A.-M. Ichim, J. W. Kimball, J. D. Smith, and M. J. Zawodniok, "An Economic Model for Residential Energy Consumption,

Generation, Storage and Reliance on Cleaner Energy," Renewable Energy, vol. 118, pp. 429–438, Apr. 2018.
42. Hale, JM and Long, SK, “Determining Microgrid Energy Systems Dynamic Model Inputs Using a SAM Analysis,” in Proc. of the ASEM, October 2018.

VI. JOB CREATION AND ECONOMIC STIMULUS ACTIVITIES

Category	Number of Jobs	Median Salary
Graduate Research Assistant	12	$20,000
Undergraduate Research Assistants	2	$3,200
Research Scientist	2@0.2%	$14,700 (dedicated project salary only)

Representative Summary of Top companies hiring S&T Power Students (Fall 2018)	# of Positions	Plans to Work in Power Industry
Burns & McDonnell	12	Definitely YES: 24
Boeing	10	Probably YES: 28
Ameren	8	Probably NO: 27
Emerson Electric	4	Definitely NO: 5
Northrop Grumman	4	
Sandia	4	
NASA	3	
Black & Veatch	2	
ComEd	2	
Dynetics	2	
Google	2	
IBM	2	
Intel	2	
Los Alamos	2	
Microsoft	2	
Raytheon	2	
Texas Instruments	2	

VII. PATH FORWARD:

Dissemination of the developed curriculum outside of MARMET is paramount. The current pace of power engineering technology advancement is too fast for faculty members to address on an individual basis. In the absence of textbooks, the time investment in developing new course material can be substantial. This includes the development of lecture materials, examples, homework exercises, and exams. Instructors employed at smaller universities or recently graduated professors do not often have access to comprehensive resources. It is therefore imperative to have a repository in which the GEARED material can be archived for public access.

The MARMET faculty participants have agreed to make all developed material available under the *Creative Commons* license which allows for others to use and further modify the material as long as attribution for the original material is given. The power engineering community would be best served if there was a common GEARED repository as opposed to each consortium hosting their material. Several challenges exist for extending hosting of material: faculty may leave their current institution, IT platforms may change, or individual storage capacity limits may impede upload of supporting documentation (i.e. videos). Universities are extremely fickle about maintaining archival websites. For these reasons, it is recommended that an external site be contracted to host the material.

The MARMET team, as well as the larger GEARED network, have established productive collaborative working relationships over the course of the project. Through professional contacts (such as the IEEE Power & Energy Society meetings), many of these interactions will continue to thrive and produce. The GEARED program has raised the visibility across the professional community regarding the need for updated material.

VIII. PROJECT SPENDING

Project spending, as well as cost-share followed the approved budget.

CUMULATIVE SPENDING		BUDGET REMAINING	
Fed Share $	$4,294,909.65	**Fed Share $**	$4,946.35
Cost Share$	$1,980,048.00	**Cost Share$**	$0.00

COMPLETED TASKS AND MILESTONES

✓ **< All completed and MET**

Budget Period	Quarter	Milestone or Go/No-Go ID	DTTC Acronym - Milestone or Go/No-Go Description	Relevant Task(s) and Subtask(s)
2	5	M1.1	Established an evaluation plan for use in MARMET partner institutions, following protocols established by the Consortia.	1.1
		M5.1	Updated website at least monthly with new activities	5.1
		M5.2	Encouraged all MARMET SIB students to join the GEARED linked-in site	
		M6.1	Established learning outcomes for each GEARED-created new university course module.	
		M8.1	Hosted student-centered Power & Energy Conference @ Illinois (PECI) in Champaign, IL	
2	6	M1.2	Developed target numbers by project quarter for number of students participating in each of the following: university courses, short courses, workshops	1.2
		M1.3	Developed target numbers by project quarter for the number of teaching venues within MARMET, taking into account new university partners who may join MARMET over time.	1.3
		M1.4	Developed target numbers by project year for number of conference publications and journal publications (faculty, industry participants)	1.4
		M1.5	Developed target numbers by project year for number of certificates, theses, and dissertations (students)	1.5
		M2.1	Established an Executive Committee for the DTTC; provide DTTC members as requested to the National Network Administrator Advisory Board.	2.1-2.2
		M2.3	Established a dissemination protocol for materials (research, course content, and GEARED student chapter events, internships, and coop positions), news and shared learning, and a communication plan within the Consortium. This plan included specific measures for outreach to target diverse demographics such as veterans, women, and minorities.	2.3
			The Consortium partners developed, organized and maintained at least 70 content hours of material based on consortium research results	3.1
		M3.1	Criteria for selection of MARMET representatives to the national GEARED SIB were established.	

		M4.1 M4.2 M4.3 M5.1 M5.3 M6.3 M6.4 M7.1 M7.2 M7.3 M7.4	With the GEC, MARMET established a schedule for its own regional Student-Centered Conference. MARMET allowed students and faculty to participate in its regional conferences, and MARMET encouraged its university and student members to participate in other DTTC student-centered conferences in turn. MARMET selected and publicized a full roster of SIB members for the 2014-15 academic year. Posted at least one additional course material module quarterly (15-20 hours) Have at least one MARMET representative on each GEARED NNA teleconference Developed a content review process for educational modules to assess syllabi, lecture materials, multimedia content, written text material, exercises and examinations, laboratory/demonstrations, and delivery. Developed mechanisms for implementing updates to educational modules. Reported research activities in the sub-task areas quarterly Published at least one journal publication annually Completed at least one thesis/dissertation annually Sponsored at least four student presentations at conferences annually and provided professional development mentoring to encourage proper student follow up with utility and company partners. Provided any success stories to DOE and NNA for branding and communications.	4.1 3.1 7.1-7.4 7.1-7.4 1.4 1.5, 4.4, 8.4
2-5	**Q7-Q20**			
2	7	M2.5 M5.3 M5.4 M5.5 M5.6 M5.7 M5.8 M5.9 M6.3	Facilitated internships and hands-on experiences for students enrolled in GEARED university partners' relevant engineering programming, Had at least one MARMET representative on each GEARED NNA teleconference Posted biographies of all MARMET SIB students to website Posted biographies of all MARMET faculty to website Populated/updated links to sponsoring/collaborative industry partners and internship opportunities Developed a MARMET brochure advertising careers in energy (general) Involved students in developing social media presence Provided NNA with all requested outreach material Conducted content review process assessments; reported outcomes internally to	2.5 5.3 5.1 5.1 5.1 5.2 5.3

			faculty and university staff as appropriate.	6.1-6.3
		M6.4	Updated educational modules as necessary, signaled by outcomes of the content review process (M6.3 above).	6.1-6.3
		M7.1	Reported research activities in the sub-task areas quarterly	7.1-7.4
		M7.2	Published at least one journal per sub-task publication annually	7.1-7.4
		M7.3	Completed at least one thesis/dissertation per sub-task annually	7.1-7.4
		M7.4	Sponsored at least four student presentations at conferences annually	7.1-7.4
2	8	M2.4	Updated the Strategic Plan as necessary to continue to meet the ongoing objectives of the GEARED award, using input from the GEARED NNA, evaluation mechanisms, and feedback from partners and DOE.	2.4
		M3.4	MARMET university partners offered Educational training modules and/or short courses to NRECA membership.	3.4
		M3.5	MARMET offered select short courses and workshops and/or educational modules to the public.	3.4-3.5
		M5.3	Had at least one MARMET representative on each GEARED NNA teleconference	5.3
		M5.4	Posted biographies of all MARMET SIB students to website	5.1
		M5.5	Posted biographies of all MARMET faculty to website	5.1
		M5.6	Populated/updated links to sponsoring/collaborative industry partners and internship opportunities	5.1
		M5.7	Developed a MARMET brochure advertising careers in energy (general)	5.2
		M5.8	Involved students in developing social media presence	5.1
		M5.9	Provided NNA with all requested outreach material	5.3
		M6.3	Conducted content review process assessments; reported outcomes internally to faculty and university staff as appropriate.	6.3
		M6.4	Updated educational modules as necessary, signaled by outcomes of the content review process (M6.3 above).	3.4-3.5, 6.4
		M7.1	Reported research activities in the sub-task areas quarterly	7.1-7.4
		M7.2	Published at least one journal publication annually	7.1-7.4
		M7.3	Completed at least one thesis/dissertation annually	7.1-7.4
		M7.4	Sponsored at least four student presentations at conferences annually	7.1-7.4, 8.4

BP 3->		BP3 GNG 9-12		
3	9	M1.2	Developed target numbers by project quarter for number of students participating in each of the following: university courses, short courses, workshops	1.2
		M1.3	Developed target numbers by project quarter for the number of teaching venues within MARMET, taking into account new university partners who may join MARMET over time.	1.3
		M1.4	Developed target numbers by project year for number of conference publications and journal publications (faculty, industry participants)	1.4
		M1.5	Developed target numbers by project year for number of certificates, theses, and dissertations (students)	1.5
		M2.5	Facilitated internships and hands-on experiences for students enrolled in GEARED university partners' relevant engineering programming,	2.5
		M5.3	Had at least one MARMET representative on each GEARED NNA teleconference	5.3
		M5.4	Posted biographies of all MARMET SIB students to website	5.1
		M5.5	Posted biographies of all MARMET faculty to website	5.1
		M5.6	Populated/updated links to sponsoring/collaborative industry partners and internship opportunities	5.1
		M5.7	Developed a MARMET brochure advertising careers in energy (general)	5.2
		M5.8	Involved students in developing social media presence	5.1
		M5.9	Provided NNA with all requested outreach material	5.3
		M6.3	Conducted content review process assessments; reported outcomes internally to faculty and university staff as appropriate.	6.3
		M6.4	Updated educational modules as necessary, signaled by outcomes of the content review process (M6.3 above).	3.4-3.5, 6.4
		M7.1	Reported research activities in the sub-task areas quarterly	7.1-7.4
		M7.2	Published at least one journal per sub-task publication annually	7.1-7.4
		M7.3	Completed at least one thesis/dissertation per sub-task annually	7.1-7.4
		M7.4	Sponsored at least four student presentations at conferences annually	7.1-7.4, 8.4
		M7.5	Explored suitability of developing a student version of OMF	7.2
		M7.6	Sponsored at least two research seminars per institution per semester (16 total) annually	7.1-7.4
		M7.7	Hosted at least one faculty seminar exchange per year	
		M8.1	Hosted PECI in Champaign, increase attendance by 5% over previous year	

		M8.2 M8.4	Developed best practices for student-centered conferences with other DTTCs Supported students to attend NAPS in Charlotte, NC	7.1-7.4 8.1 8.2 4.4, 8.3
3	10	M1.1-5 M2.3 M2.4 M2.5 M3.4 M3.5 M5.3 M5.6 M5.8 M5.9 M6.3 M6.4 M7.1 M7.2 M7.3	Used the established Evaluation Protocol to provide DOE, and MARMET internal stakeholders with quarterly status updates of quantitative metrics in each defined measurement area. Reviewed and revised protocols as necessary over the period of performance. Monitored and revised as necessary the dissemination protocol for materials (research, course content, and GEARED student chapter events, internships, and coop positions), news and shared learning; measure outcomes as per Task 1 evaluation protocols. Updated the Strategic Plan as necessary to continue to meet the ongoing objectives of the GEARED award, using input from the GEARED NNA, evaluation mechanisms, and feedback from partners and DOE Facilitated internships and hands-on experiences for students enrolled in GEARED university partners' relevant engineering programming, MARMET university partners offered Educational training modules and/or short courses to NRECA membership. MARMET offered select short courses and workshops and/or educational modules to the public. Had at least one MARMET representative on each GEARED NNA teleconference Populated/updated links to sponsoring/collaborative industry partners and internship opportunities Involved students in developing social media presence Provided NNA with all requested outreach material Conducted content review process assessments; reported outcomes internally to faculty and university staff as appropriate. Updated educational modules as necessary, signaled by outcomes of the content review process (M6.3 above). Reported research activities in the sub-task areas quarterly Published at least one journal per sub-task publication annually Completed at least one thesis/dissertation per sub-task annually	1.1-1.5 2.3 2.4 2.5 3.4 3.4-3.5 5.3 5.1 5.1 5.1 5.2 5.1 6.3

				3.4-3.5, 6.4
		M7.4	Sponsored at least four student presentations at conferences annually	7.1-7.4
		M7.6	Sponsored at least two research seminars per institution per semester (16 total) annually	7.1-7.4 7.1-7.4 7.1-7.4, 8.4
3	11	M1.1-5	Used the established Evaluation Protocol to provide DOE, and MARMET internal stakeholders with quarterly status updates of quantitative metrics in each defined measurement area. Reviewed and revised protocols as necessary over the period of performance.	1.1-1.5
		M2.3	Monitored and revised as necessary the dissemination protocol for materials (research, course content, and GEARED student chapter events, internships, and coop positions), news and shared learning; measure outcomes as per Task 1 evaluation protocols.	2.3
		M2.4	Updated the Strategic Plan as necessary to continue to meet the ongoing objectives of the GEARED award, using input from the GEARED NNA, evaluation mechanisms, and feedback from partners and DOE	2.4
		M2.5	Facilitated internships and hands-on experiences for students enrolled in GEARED university partners' relevant engineering programming,	3.4
		M3.4	MARMET university partners offered Educational training modules and/or short courses to NRECA membership.	3.4-3.5
		M3.5	MARMET offered select short courses and workshops and/or educational modules to the public.	5.3
		M5.3	Had at least one MARMET representative on each GEARED NNA teleconference	5.1
		M5.6	Populate/update links to sponsoring/collaborative industry partners and internship opportunities	5.1
		M5.8	Involved students in developing social media presence	5.1
		M5.9	Provide NNA with all requested outreach material	
		M6.3	Conducted content review process assessments; reported outcomes internally to faculty and university staff as appropriate.	5.2 5.1
		M6.4	Updated educational modules as necessary, signaled by outcomes of the content review process (M6.3 above).	6.3
		M7.1	Reported research activities in the sub-task areas quarterly	3.4-3.5, 6.4
		M7.2	Published at least one journal per sub-task publication annually	
		M7.3	Completed at least one thesis/dissertation per sub-task annually	

				7.1-7.4
		M7.4	Sponsored at least four student presentations at conferences annually	7.1-7.4
		M7.6	Sponsored at least two research seminars per institution per semester (16 total) annually	7.1-7.4
				7.1-7.4, 8.4
3	12	M1.1-5	Used the established Evaluation Protocol to provide DOE, and MARMET internal stakeholders with quarterly status updates of quantitative metrics in each defined measurement area. Reviewed and revised protocols as necessary over the period of performance.	1.1-1.5
		M2.3	Monitored and revised as necessary the dissemination protocol for materials (research, course content, and GEARED student chapter events, internships, and coop positions), news and shared learning; measure outcomes as per Task 1 evaluation protocols.	2.3
		M2.4	Updated the Strategic Plan as necessary to continue to meet the ongoing objectives of the GEARED award, using input from the GEARED NNA, evaluation mechanisms, and feedback from partners and DOE	2.4
		M2.5	Facilitated internships and hands-on experiences for students enrolled in GEARED university partners' relevant engineering programming,	3.4
		M3.4	MARMET university partners offered Educational training modules and/or short courses to NRECA membership.	3.4-3.5
		M3.5	MARMET offered select short courses and workshops and/or educational modules to the public.	
		M3.8	MARMET university partners established and shared content from the developed courses	
		M5.3	Had at least one MARMET representative on each GEARED NNA teleconference	
		M5.6	Populate/update links to sponsoring/collaborative industry partners and internship opportunities	5.3
		M5.8	Involved students in developing social media presence	5.1
		M5.9	Provided NNA with all requested outreach material	5.1
		M6.3	Conducted content review process assessments; reported outcomes internally to faculty and university staff as appropriate.	5.1 5.3
		M6.4	Updated educational modules as necessary, signaled by outcomes of the content review process (M6.3 above).	6.3
		M7.1	Reported research activities in the sub-task areas quarterly	3.4-3.5, 6.4
		M7.2	Published at least one journal per sub-task publication annually	
		M7.3	Completed at least one thesis/dissertation per sub-task annually	

		M7.4	Sponsored at least four student presentations at conferences annually	7.1-7.4
		M7.6	Sponsored at least two research seminars per institution per semester (16 total) annually	7.1-7.4 7.1-7.4
BP 4->		**BP4 GNG 13-16**		
4	13	M1.2	Developed target numbers by project quarter for number of students participating in each of the following: university courses, short courses, workshops	1.2
		M1.3	Developed target numbers by project quarter for the number of teaching venues within MARMET, taking into account new university partners who may join MARMET over time.	1.3
		M1.4	Developed target numbers by project year for number of conference publications and journal publications (faculty, industry participants)	1.4
		M1.5	Developed target numbers by project year for number of certificates, theses, and dissertations (students)	1.5
		M2.5	Facilitated internships and hands-on experiences for students enrolled in GEARED university partners' relevant engineering programming,	2.5
		M5.3	Had at least one MARMET representative on each GEARED NNA teleconference	5.3
		M5.4	Updated biographies of all MARMET SIB students to website	5.1
		M5.5	Updated biographies of all MARMET faculty to website	5.1
		M5.6	Populated/updated links to sponsoring/collaborative industry partners and internship opportunities	5.1
		M5.7	Updated a MARMET brochure advertising careers in energy (general)	5.2
		M5.8	Involved students in developing social media presence	5.1
		M5.9	Provided NNA with all requested outreach material	5.3
		M6.3	Conducted content review process assessments; reported outcomes internally to faculty and university staff as appropriate.	6.3
		M6.4	Updated educational modules as necessary, signaled by outcomes of the content review process (M6.3 above).	3.4-3.5, 6.4
		M7.1	Reported research activities in the sub-task areas quarterly	7.1-7.4
		M7.2	Published at least one journal per sub-task publication annually	7.1-7.4
		M7.3	Completed at least one thesis/dissertation per sub-task annually	
		M7.4	Sponsored at least four student presentations at conferences annually	

		M7.6	Sponsored at least two research seminars per institution per semester (16 total) annually	7.1-7.4
		M7.7	Hosted at least one faculty seminar exchange per year	7.1-7.4, 8.4
		M8.1	Hosted PECI in Champaign, increase attendance by 5% over previous year	7.2
		M8.2	Developed best practices for student-centered conferences with other DTTCs	7.1-7.4
		M8.4	Support students to attend NAPS or other DTTC sponsored national conference	7.1-7.4 8.1 8.2 4.4, 8.3
4	14	M1.1-5	Used the established Evaluation Protocol to provide DOE, and MARMET internal stakeholders with quarterly status updates of quantitative metrics in each defined measurement area. Reviewed and revised protocols as necessary over the period of performance.	1.1-1.5
		M2.3	Monitored and revised as necessary the dissemination protocol for materials (research, course content, and GEARED student chapter events, internships, and coop positions), news and shared learning; measure outcomes as per Task 1 evaluation protocols.	2.3
		M2.4	Updated the Strategic Plan as necessary to continue to meet the ongoing objectives of the GEARED award, using input from the GEARED NNA, evaluation mechanisms, and feedback from partners and DOE	2.4
		M2.5	Facilitated internships and hands-on experiences for students enrolled in GEARED university partners' relevant engineering programming,	2.5
		M3.4	MARMET university partners offered Educational training modules and/or short courses to NRECA membership.	3.4
		M3.5	MARMET offered select short courses and workshops and/or educational modules to the public.	3.4-3.5
		M5.3	Had at least one MARMET representative on each GEARED NNA teleconference	5.3
		M5.6	Populated/updated links to sponsoring/collaborative industry partners and internship opportunities	5.1
		M5.8	Involved students in developing social media presence	5.1
		M5.9	Provided NNA with all requested outreach material	5.1
		M6.3	Conducted content review process assessments; reported outcomes internally to faculty and university staff as appropriate.	5.1

		M6.4	Updated educational modules as necessary, signaled by outcomes of the content review process (M6.3 above).	6.3
		M7.1	Reported research activities in the sub-task areas quarterly	3.4-3.5, 6.4
		M7.2	Published at least one journal per sub-task publication annually	
		M7.3	Completed at least one thesis/dissertation per sub-task annually	7.1-7.4
		M7.4	Sponsored at least four student presentations at conferences annually	7.1-7.4
		M7.6	Sponsored at least two research seminars per institution per semester (16 total) annually	7.1-7.4 7.1-7.4, 8.4
4	15	M1.1-5	Used the established Evaluation Protocol to provide DOE, and MARMET internal stakeholders with quarterly status updates of quantitative metrics in each defined measurement area. Reviewed and revised protocols as necessary over the period of performance.	1.1-1.5
		M2.3	Monitored and revised as necessary the dissemination protocol for materials (research, course content, and GEARED student chapter events, internships, and coop positions), news and shared learning; measure outcomes as per Task 1 evaluation protocols.	2.3
		M2.4	Updated the Strategic Plan as necessary to continue to meet the ongoing objectives of the GEARED award, using input from the GEARED NNA, evaluation mechanisms, and feedback from partners and DOE	2.4
		M2.5	Facilitated internships and hands-on experiences for students enrolled in GEARED university partners' relevant engineering programming,	3.4
		M3.4	MARMET university partners offered Educational training modules and/or short courses to NRECA membership.	3.4-3.5
		M3.5	MARMET offered select short courses and workshops and/or educational modules to the public.	5.3
		M5.3	Had at least one MARMET representative on each GEARED NNA teleconference	5.1
		M5.6	Populated/updated links to sponsoring/collaborative industry partners and internship opportunities	5.1
		M5.8	Involved students in developing social media presence	5.1
		M5.9	Provided NNA with all requested outreach material	
		M6.3	Conducted content review process assessments; reported outcomes internally to faculty and university staff as appropriate.	5.2 5.1
		M6.4	Updated educational modules as necessary, signaled by outcomes of the content review process (M6.3 above).	6.3
		M7.1	Reported research activities in the sub-task areas quarterly	

		M7.2	Published at least one journal per sub-task publication annually	3.4-3.5, 6.4
		M7.3	Completed at least one thesis/dissertation per sub-task annually	7.1-7.4
		M7.4	Sponsored at least four student presentations at conferences annually	7.1-7.4
		M7.6	Sponsored at least two research seminars per institution per semester (16 total) annually	7.1-7.4, 8.4
4	16	M1.1-5	Used the established Evaluation Protocol to provide DOE, and MARMET internal stakeholders with quarterly status updates of quantitative metrics in each defined measurement area. Reviewed and revised protocols as necessary over the period of performance.	1.1-1.5
		M2.3	Monitored and revised as necessary the dissemination protocol for materials (research, course content, and GEARED student chapter events, internships, and coop positions), news and shared learning; measure outcomes as per Task 1 evaluation protocols.	2.3
		M2.4	Updated the Strategic Plan as necessary to continue to meet the ongoing objectives of the GEARED award, using input from the GEARED NNA, evaluation mechanisms, and feedback from partners and DOE	2.4
		M2.5	Facilitated internships and hands-on experiences for students enrolled in GEARED university partners' relevant engineering programming,	3.4
		M3.4	MARMET university partners offered Educational training modules and/or short courses to NRECA membership.	3.4-3.5
		M3.5	MARMET offered select short courses and workshops and/or educational modules to the public.	5.3
		M5.3	Had at least one MARMET representative on each GEARED NNA teleconference	5.1
		M5.6	Populate/update links to sponsoring/collaborative industry partners and internship opportunities	5.1
		M5.8	Involved students in developing social media presence	5.1
		M5.9	Provided NNA with all requested outreach material	
		M6.3	Conducted content review process assessments; reported outcomes internally to faculty and university staff as appropriate.	5.2 5.1
		M6.4	Updated educational modules as necessary, signaled by outcomes of the content review process (M6.3 above).	6.3
		M7.1	Reported research activities in the sub-task areas quarterly	3.4-3.5, 6.4
		M7.2	Published at least one journal per sub-task publication annually	
		M7.3	Completed at least one thesis/dissertation per sub-task annually	

		M7.4	Sponsored at least four student presentations at conferences annually	7.1-7.4
		M7.6	Sponsored at least two research seminars per institution per semester (16 total) annually	7.1-7.4 7.1-7.4, 8.4
BP 5->		**BP5 GNG 17-20**		
5	17	M1.2	Developed target numbers by project quarter for number of students participating in each of the following: university courses, short courses, workshops	1.2
		M1.3	Developed target numbers by project quarter for the number of teaching venues within MARMET, taking into account new university partners who may join MARMET over time.	1.3
		M1.4	Developed target numbers by project year for number of conference publications and journal publications (faculty, industry participants)	1.4
		M1.5	Developed target numbers by project year for number of certificates, theses, and dissertations (students)	1.5
		M2.5	Facilitated internships and hands-on experiences for students enrolled in GEARED university partners' relevant engineering programming,	2.5
		M5.3	Had at least one MARMET representative on each GEARED NNA teleconference	
		M5.4	Posted biographies of all MARMET SIB students to website	5.3
		M5.5	Posted biographies of all MARMET faculty to website	5.1
		M5.6	Populated/updated links to sponsoring/collaborative industry partners and internship opportunities	5.1
		M5.7	Developed a MARMET brochure advertising careers in energy (general)	5.1
		M5.8	Involve students in developing social media presence	
		M5.9	Provided NNA with all requested outreach material	5.2
		M6.3	Conducted content review process assessments; reported outcomes internally to faculty and university staff as appropriate.	5.1 5.3
		M6.4	Updated educational modules as necessary, signaled by outcomes of the content review process (M6.3 above).	6.3
		M7.1	Reported research activities in the sub-task areas quarterly	3.4-3.5, 6.4
		M7.2	Published at least one journal per sub-task publication annually	
		M7.3	Completed at least one thesis/dissertation per sub-task annually	7.1-7.4
		M7.4	Sponsored at least four student presentations at conferences annually	7.1-7.4
		M7.5	Explored suitability of developing a student version of OMF	7.1-7.4
		M7.6	Sponsored at least two research seminars per institution per semester (16 total)	

			annually	
		M7.7	Hosted at least one faculty seminar exchange per year	7.1-7.4, 8.4
		M8.1	Hosted PECI in Champaign, increase attendance by 5% over previous year	7.2
		M8.2	Developed best practices for student-centered conferences with other DTTCs	7.1-7.4
		M8.4	Supported students to attend NAPS or other DTTC sponsored national conference	7.1-7.4 8.1 8.2 4.4, 8.3
5	18	M1.1-5	Used the established Evaluation Protocol to provide DOE, and MARMET internal stakeholders with quarterly status updates of quantitative metrics in each defined measurement area. Reviewed and revised protocols as necessary over the period of performance.	1.1-1.5
		M2.3	Monitored and revised as necessary the dissemination protocol for materials (research, course content, and GEARED student chapter events, internships, and coop positions), news and shared learning; measure outcomes as per Task 1 evaluation protocols.	2.3
		M2.4	Updated the Strategic Plan as necessary to continue to meet the ongoing objectives of the GEARED award, using input from the GEARED NNA, evaluation mechanisms, and feedback from partners and DOE	2.4
		M2.5	Facilitated internships and hands-on experiences for students enrolled in GEARED university partners' relevant engineering programming,	2.5
		M3.4	MARMET university partners offered Educational training modules and/or short courses to NRECA membership.	3.4
		M3.5	MARMET offered select short courses and workshops and/or educational modules to the public.	3.4-3.5
		M5.3	Had at least one MARMET representative on each GEARED NNA teleconference	
		M5.6	Populated/updated links to sponsoring/collaborative industry partners and internship opportunities	5.3
		M5.8	Involved students in developing social media presence	5.1
		M5.9	Provided NNA with all requested outreach material	
		M6.3	Conducted content review process assessments; reported outcomes internally to faculty and university staff as appropriate.	5.1 5.1
		M6.4	Updated educational modules as necessary, signaled by outcomes of the content	6.3

			review process (M6.3 above).	
		M7.1	Reported research activities in the sub-task areas quarterly	3.4-3.5, 6.4
		M7.2	Published at least one journal per sub-task publication annually	
		M7.3	Complete at least one thesis/dissertation per sub-task annually	7.1-7.4
		M7.4	Sponsored at least four student presentations at conferences annually	7.1-7.4
		M7.6	Sponsored at least two research seminars per institution per semester (16 total) annually	7.1-7.4 7.1-7.4, 8.4
5	19	M1.1-5	Used the established Evaluation Protocol to provide DOE, and MARMET internal stakeholders with quarterly status updates of quantitative metrics in each defined measurement area. Reviewed and revised protocols as necessary over the period of performance.	1.1-1.5
		M2.3	Monitored and revised as necessary the dissemination protocol for materials (research, course content, and GEARED student chapter events, internships, and coop positions), news and shared learning; measure outcomes as per Task 1 evaluation protocols.	2.3
		M2.4	Updated the Strategic Plan as necessary to continue to meet the ongoing objectives of the GEARED award, using input from the GEARED NNA, evaluation mechanisms, and feedback from partners and DOE	2.4
		M2.5	Facilitatedd internships and hands-on experiences for students enrolled in GEARED university partners' relevant engineering programming,	2.5
		M3.4	MARMET university partners offered Educational training modules and/or short courses to NRECA membership.	3.4
		M3.5	MARMET offered select short courses and workshops and/or educational modules to the public.	3.4-3.5
		M3.7	MARMET coordinated the Compilation of written material created through its GEARED consortia into textbook format.	3.7
		M5.3	Had at least one MARMET representative on each GEARED NNA teleconference	
		M5.6	Populate/update links to sponsoring/collaborative industry partners and internship opportunities	5.3
		M5.8	Involve students in developing social media presence	5.1
		M5.9	Provided NNA with all requested outreach material	
		M6.3	Conducted content review process assessments; reported outcomes internally to faculty and university staff as appropriate.	5.1 5.1
		M6.4	Updated educational modules as necessary, signaled by outcomes of the content	

			review process (M6.3 above).	6.3
		M7.1	Reported research activities in the sub-task areas quarterly	
		M7.2	Published at least one journal per sub-task publication annually	3.4-3.5, 6.4
		M7.3	Completed at least one thesis/dissertation per sub-task annually	
		M7.4	Sponsored at least four student presentations at conferences annually	7.1-7.4
		M7.6	Sponsored at least two research seminars per institution per semester (16 total) annually	7.1-7.4 7.1-7.4 7.1-7.4, 8.4
5	20	**BP5 GNG 17-20**		
			Facilitated internships and hands-on experiences for students enrolled in GEARED university partners' relevant engineering programming,	2.5
		M2.5	Had at least one MARMET representative on each GEARED NNA teleconference	3.4
		M5.3	Updated biographies of all MARMET SIB students to website	5.1
		M5.4	Updated biographies of all MARMET faculty to website	5.1
		M5.5	Populated/updated links to sponsoring/collaborative industry partners and internship opportunities	5.1
		M5.6	Updated a MARMET brochure advertising careers in energy (general)	
		M5.7	Provided NNA with all requested outreach material	5.2
		M5.9	Conducted content review process assessments; reported outcomes internally to faculty and university staff as appropriate.	5.3 6.3
		M6.3	Updated educational modules as necessary, signaled by outcomes of the content review process (M6.3 above).	3.4-3.5, 6.4
		M6.4	Reported research activities in the sub-task areas quarterly	
		M7.1	Published at least one journal per sub-task publication annually	7.1-7.4
		M7.2	Completed at least one thesis/dissertation per sub-task annually	7.1-7.4
		M7.3	Sponsored at least four student presentations at conferences annually	7.1-7.4
		M7.4	Sponsored at least two research seminars per institution per semester (16 total) annually	7.1-7.4, 8.4
		M7.6		

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