# Project Summary

<table>
<thead>
<tr>
<th>Project Title:</th>
<th>Adaptive Protective Relaying for Microgrids</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organization:</td>
<td>Sandia National Laboratories</td>
</tr>
<tr>
<td>Presenter:</td>
<td>Mohamed El Khatib</td>
</tr>
<tr>
<td>FY 2016 Funding ($K):</td>
<td>$100K</td>
</tr>
</tbody>
</table>

## Project Objectives and Outcomes

Type text here (length: ~1/3 of a page)

The objective of this project is to study the challenges facing the development of efficient protection systems for microgrids and to develop potential solutions. Developing a standardized microgrid protection design is very difficult since microgrids differ in their topology, generation mix, short circuit levels, feeder sizes and fault interruption devices types and locations. Microgrids with significant inverter-interfaced generation, renewable generation for example, are particularly challenging since fault currents could be very limited and overcurrent protection could fail completely to pick up the fault in the first place. Additionally, using transmission-grade element-based protection schemes, such as differential protection, would require significant investments in installing fault interrupting devices on each feeder segment of the microgrid and that is not typically justified based on the amount of load served by the microgrid.

This project targets the development of protection schemes for general topology microgrids with dynamic boundaries. Developed schemes are non-overcurrent based to ensure efficient operation for low-fault microgrids but also are not element-based to minimize the associated cost. First, detailed study of the challenges facing the development of microgrid protection was completed. Second, survey of current and proposed microgrid protection schemes was completed. Third, a new impedance-based protection scheme for low-fault level microgrids was developed. Lastly, transient-based protection schemes for low-fault microgrids were investigated and the challenges facing the development of such protection schemes are being studied.
**Significance and Impact**

This project provides the foundational work needed for the development of advanced protection schemes for microgrids and distribution systems. For FY17, we plan to continue the development and demonstration of advanced non-overcurrent based protection schemes. Development of efficient non-overcurrent based protection schemes is a prerequisite for significantly increasing the penetration of renewables in microgrids. Currently, lack of efficient protection schemes is impeding the deployment of networked microgrids and other advanced DS operation functions such as splitting DS into microgrids and automatic reconfiguration. More broadly, as the penetration of inverter-interfaced DERs increases in the distribution system, existing overcurrent protection schemes will fail to work efficiently. Therefore, developing efficient microgrid protection schemes will also be beneficial for protecting distribution systems with very high penetration of inverter-interfaced. Furthermore, advanced protection schemes could be designed to protect against high-impedance faults which represent a major public safety issue and which traditional protection schemes are unable to detect.

**Technical Approach**

Entity microgrids such as university campuses and military bases microgrids could be equipped with custom-made protection schemes tailored to the particular application. On the other hand, efficient protection of microgrids generated by splitting parts of the distribution system (DS) is very challenging. From one hand, microgrids created by splitting the DS could be large in size, have high penetration of inverter-interfaced DERs and have dynamic boundaries based on load-generation balance before system split. Moreover, those microgrids will inherit their protection system from the DS. As a result, upgrading the protection system of these microgrids necessitates upgrading the protection system of the host DS protection system which could be prohibitively expensive.

The approach of this project is to develop microgrid-specific protection schemes that could fill the gap between low-cost low-reliability schemes like overcurrent protection and high-cost high reliability schemes like differential protection. This approach is depicted in Fig. 1.
First, a detailed study of the challenges facing microgrid protection design was carried out. This study illustrated the challenge of maintaining proper overcurrent protection coordination under various operating modes of microgrids. Second, existing and proposed microgrid protection schemes were surveyed. The survey concluded that there is a gap in the available microgrid protection methods. The only credible protection solution available in literature for low-fault inverter-dominated microgrids is differential protection scheme which represents a robust transmission-grade protection solution but at a very high cost. Therefore, there is a need to develop microgrid-specific protection schemes which are non-overcurrent based to ensure efficient operation for low-fault microgrids but also are not element-based to minimize the associated cost and ensure applicability in the field. Based on this conclusion, two non-overcurrent protection schemes were investigated as part of this project; impedance-based protection and transient-based protection.

The impedance-based protection scheme is comprised of impedance relays at fault interrupting devices and a Central Protection Unit (CPU). The scheme is based on comparing the impedance measured by different feeder impedance relays to locate the fault. The Central Protection Unit handles the impact of microgrid topology change by updating a set of protection mappings that relate fault interrupting devices to different protection zones. Compared to differential protection, the proposed scheme is far less expensive thus it could represent a viable alternative for the protection of renewable-rich microgrids particularly when the use of overcurrent protection is not possible due to low fault current.

Transient-based protection relies on analyzing high frequency transients to detect and locate faults. This approach is very promising but its implementation in the field faces several challenges. For example, high frequency transients due to faults can be confused with transients due to other events...
such as capacitor switching. Additionally, while detecting faults by analyzing transients could be doable, locating faults based on analyzing transients is still an open question. In this project, we performed several case studies for detecting faults based on analyzing fault-generated transients using an S-transform-based algorithm. Currently, we are studying the sensitivity of transient-based protection to grid configuration, inverter controls, other connected equipment and fault inception instance. Development of a protection scheme based on a combination between transient-based and voltage-based analysis is being developed. Challenges facing the implementation of transient-based protection in the field will be studied and extension of this approach to detect high-impedance faults is also planned.

**Project Collaborations and Technology Transfer**

We are collaborating with New Mexico State University in investigating transient-based protection methods for microgrids. This collaboration is planned to extend through next year. For FY17, we are planning to collaborate with an industrial partner during the development of advanced protection schemes. Currently, we are in talks with SEL and Eaton Corporation for potential collaboration. For the development and demonstration of advanced protection schemes planned for the next year, we are planning to collaborate with Los Alamos DPU. Los Alamos county DUP operates a microgrid test bed in Los Alamos with real customers testing high penetration of renewable energy onto a residential distribution feeder. Included are a 1 MW solar array, an 8.2 MWh utility scale battery storage system, and a micro energy management system tied to a microgrid with 1600 residential customers with smart meters.