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Energy Harvesting RMSA Field Test

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Abstract

Sandia National Laboratories (SNL) is investigating photovoltaic (PV) cell configurations, integrating them with the battery-operated Remotely Monitored Sealing Array (RMSA), and testing and evaluating performance for enhanced battery life under various environmental conditions at the K-Area Material Storage (KAMS) facility at the Savannah River Site (SRS). Unattended safeguards equipment (e.g. seals) incorporates many low-power electronic circuits, which are often powered by expensive and environmentally toxic lithium batteries. These batteries must periodically be replaced, adding a radiological hazard for both safeguards inspectors and operators. An extended field test of these prototype PV energy harvesting (EH) RMSAs at an operational nuclear facility will give additional data and allow for an analysis of this technology in a variety of realistic conditions, which will be documented in a final report. RMSAs are used for this testing, but SNL envisions energy harvesting technology may be applicable to other safeguards equipment.

Mission Relevance and Associated Work

A low-cost energy harvesting capability added to safeguards equipment that uses batteries as a primary energy source may significantly extend battery life. Successful implementation of this technology would save the IAEA many thousands of euros per year and reduce the frequency of personnel visits to radiation environments to change batteries. The work addresses the following IAEA milestones and objectives:

LTRD Milestone 6 (STR-375) - Ability to acquire and deploy safeguards equipment that is sustainable, standardized and modular, with increased use of commercial off-the-shelf products.

SGTS 011 Objective 6 (STR-382) - Increase the proportion of deployed unattended systems that are sustainable, standardized, and modular, with increased use of COTS products.

SGTS 002 Objective 4 (STR-382) - Research, develop, and implement new and novel technologies that can be applied for secure sealing and containment verification systems.

Associated Work

Energy harvesting was previously funded by the Office of International Nuclear Safeguards – Safeguards Technology Development Program in FY16 and FY17.

Scope of Work

Research in energy harvesting in FY17 showed promising results having tested a variety of COTS energy harvesting sensors and creating prototypes, optimizing on cost and efficacy. These lessons have been used to fabricate an array of photonic EH RMSA prototypes. In collaboration with the SRS KAMS facility, SNL will install prototypes in different locations/vault areas, placing them in varying lighting conditions, on pallets of SNM. Over the course of the field test, the RMSAs will be monitored for continuous and correct operation. After the 6-month field trial, the field test data will be analyzed to create an operational profile of EH RMSAs, which will detail 1) installation issues, 2) problems encountered over

the course of the field test, 3) the energy harvested over time, 4) comments from the facility operator, and 5) operational issues. The IAEA was initially consulted for requirements and will provide feedback based on its experience of deploying RMSAs at KAMS.

Task 1 – Gather requirements and develop a field test plan

SNL, SRS, NA-241, and the IAEA held several conversations during Q1 and Q2 regarding the field test and the field test plan. The IAEA was very much involved in this process, and they agreed to co-design components of the EH RMSA. SRS took light measurements in various KAMS field test locations, which vary in light type and intensity. These light measurements were sent to the IAEA so that they could design the EH RMSA enclosure and integrate an appropriate number/size of PV cells. After much interaction between all parties, a field test plan was approved by HQ and completed in Q3. Some details of the field test plan are provided here:

- Roughly 25 EH RMSA prototypes and baseline RMSA prototypes have been fabricated and will be installed in different locations at SRS. Each area will have one baseline RMSA and at least four EH RMSAs. The EH RMSAs will be tested with different lighting types available at the facility (i.e., incandescent, sodium gas discharge, and LED) and intensities (i.e., full light, medium, and in shadow). A stretch goal is to demonstrate other applications enabled by energy harvesting, so a handful of EH and baseline RMSAs will perform computationally expensive public key cryptography using the SNL PK Cryptoprocessor as an example of a more energy intensive application.
- The field test will show technical feasibility for most, if not all, lighting environments as well as EH prototype reliability and durability. It will also analyze for correct and uninterrupted EH RMSA prototype operation, PV cell vs. battery use duty cycle, PV cell efficiency over time, and RMSA battery performance data. Some EH RMSAs will be placed in low light areas to understand the limits of how much light is needed for continuous operation.
- The team expects EH RMSAs to reliably and continuously operate for the duration of the field test. This means that the RMSAs will create, store, and send all messages, and continuously respond to commands. Any RMSA that fails in some manner will be further analyzed to identify the cause. Each RMSA will be analyzed for energy harvested, which, for a given deployment, can help determine PV cell size, reservoir size, and backup battery capacity.
- At the end of the field test, we expect that the EH RMSA batteries will have the same capacity as new batteries, proving the battery was not used during the field test. If the EH batteries have been depleted, we will analyze the percent of depletion and the cause. Further, we will measure the baseline RMSAs' battery capacity, and expect them to have diminished capacity compared to new batteries. We will also test the efficiency of the PV cell and the current draw of major components at the end of the field test (as compared to the beginning) to understand if these components have degraded over time.

Task 2 – Fabricate and test photonic energy harvesting and baseline RMSAs for field test

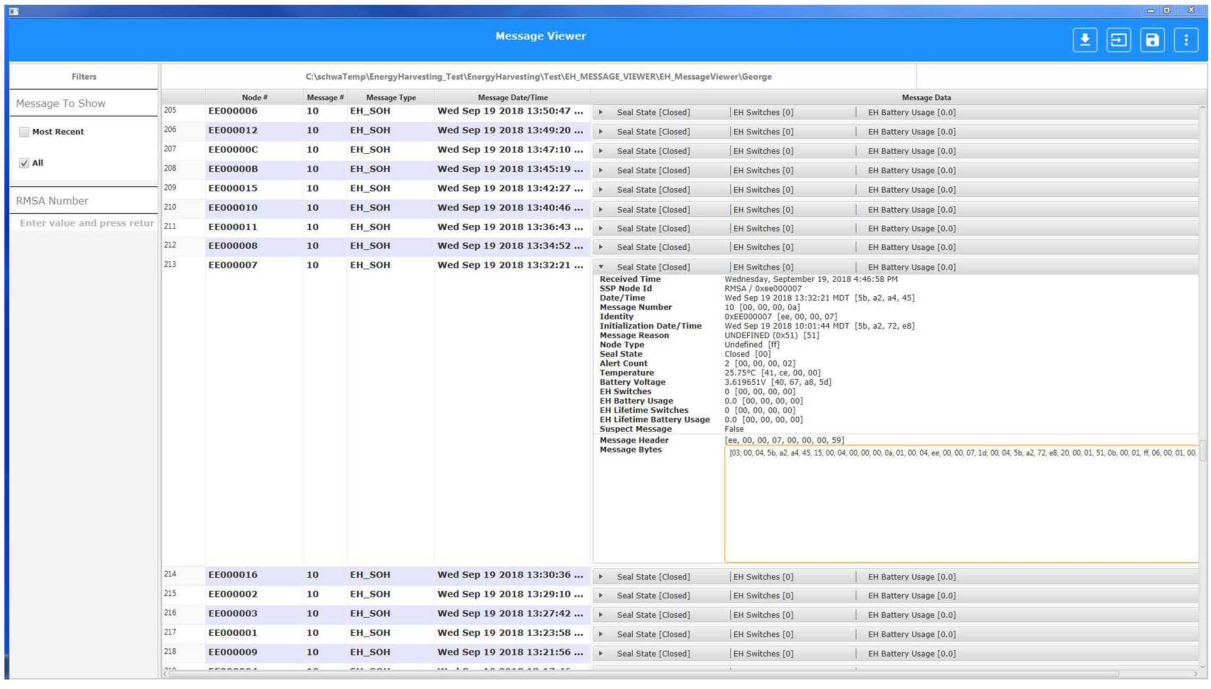
During Q2 (in parallel with development of the field test plan), the IAEA and SNL jointly designed the EH RMSA prototypes' enclosure, printed circuit board, and additions to firmware. New logic was added to some field test prototypes to determine the duty cycle usage between battery and PV cells.

During Q3, select EH RMSA prototypes were sent to the IAEA. The IAEA designed an enclosure for the new prototypes and sent the design files to SNL for fabrication.

SNL debugged a hardware issue caused by obsolescence of a circuit board part. When the boards arrived, they did not store charge properly. New super capacitors were installed which solved the issue. SNL suspects that the board fabricator did not hand-solder the capacitors which damaged them.

The EH RMSA prototypes were completed in Q4 and will be sent to SRS in Q1 of FY19 to begin the field test.

Eight of the completed EH prototypes set up for testing



Message Viewer software showing messages coming from the EH RMSAs

Task 3 – Prototype installation

In Q1 of FY19 SNL will ship the EH RMSA's (boards, cases, hardware, etc.) to SRS for evaluation and in-house testing. After this is completed, SRS will install the prototypes per the field test plan.

Task 4 – Conduct field test

In Q1 of FY19, the 6-month field trial will begin. SRS will periodically check the status of the prototype units and supply data to SNL for analysis. There will be weekly phone meetings with SRS on the status of the field test and the team will address any issues that arise.

Task 5 – Analyze field test data

SNL will analyze data received from SRS to understand the prototypes' behavior over time. Analysis will be conducted monthly to understand progress and address any issues as quickly as possible (e.g., replacement of a defective unit, operator concerns, etc.).

At the end of the field trial, SNL will also analyze the batteries used during the trial using one of two methods. The first is measuring residual battery capacity under a constant current discharge. The second is by performing a battery titration test to assess battery capacity. This will be done on both energy harvesting and baseline RMSAs. If deemed necessary for analysis, SNL will also perform a battery passivation test to characterize depletion of capacity when switching between PV and battery power.

Task 6 – Final report

SNL will create a final report documenting the results of the field test.

Pertinent references

Hymel, R. "Energy Harvesting for Increased Safeguards Equipment Battery Life," ESARDA 39th Annual Meeting, May 2017, Dusseldorf, Germany.