A Low-Cost Remote Solar Energy Monitoring System for a Buoyed IoT Ocean Observation Platform

Aoife Hegarty
Centre for Robotics & Intelligent Systems
University of Limerick
Limerick, Ireland
aoife.hegarty@ul.ie

Guy Westbrook
Research Vessel Operations
Marine Institute
Galway, Ireland
Guy.Westbrook@marine.ie

Damien Glynn
Marine Offshore Services
P & O Maritime
Galway, Ireland
Damien.Glynn@pomaritime.com

Declan Murray
Marine Offshore Services
P & O Maritime
Galway, Ireland
Declan.Murray@pomaritime.com

Edin Omerdic
Centre for Robotics & Intelligent Systems
University of Limerick
Limerick, Ireland
edin.omerdic@ul.ie

Daniel Toal
Centre for Robotics & Intelligent Systems
University of Limerick
Limerick, Ireland
daniel.toal@ul.ie

***Abstract*—This paper describes the design, construction and testing of a low-cost Energy Monitoring System used to remotely monitor the condition of autonomous power generators (i.e. solar panels) for Marine IoT applications. The purpose of the device is to expedite remote troubleshooting, highlight potential problems and identify the need for service/recovery. It consists of a Forward Looking Infrared (FLIR) camera, an 8 megapixel video/stills camera, Raspberry pi Mini-PC, two VE.Direct® to USB interfaces, UHF transceiver, GPS and a power supply. Its method of non-invasive testing involves the transmission of GPS position and time stamped images, as well as infrared images of the Photovoltaic (PV) panels ashore by Slow Scan TV (SSTV). The image is modulated on a UHF carrier wave and received at an internet gateway using a Software Defined Radio (SDR) receiver on a parent buoy. It is then transmitted ashore for demodulation via TCP link across a subsea Ethernet cable. Invasive monitoring is carried out by attaching a USB interface to the Maximum Power Point Tracking (MPPT) Solar Charge Controllers on the buoy. A Linux shell script run on the Mini-PC logs values such as PV Voltage, Battery Voltage, Charge State and Daily Energy Yield from the PV panels. The device aims to reduce costs and down-time, enabling remote decisions to be made, working towards achieving energy continuum.**

Keywords—Energy Monitor, Marine IoT, SSTV, PV Panels, Autonomous Energy, Remote Buoy

I. Introduction

Solar autonomous energy generation and storage are currently the key enablers of offshore IoT, and are used in a wide variety of marine and coastal applications. The low-cost Solar Energy Monitoring System was developed and tested as part of a cluster of IoT projects centred around the expansion of the working footprint of a cabled sea-bed observatory node: A submarine cable was attached to one of the science ports on the Cable End Equipment (CEE) at the Spiddal subsea observatory in Galway Bay, Ireland. The cable terminated topsides in a purpose-built smart networked communications cabinet with a configurable gateway, housed in the super-structure of a Mobilis DB 8000 buoy. The buoy was anchored in close proximity to the CEE. The observatory is deployed at the Galway Bay Marine and Renewable Energy Test Site and is connected to the shore via a 4 km subsea fibre optic power and telecoms cable. This enabled the buoy to act as an internet gateway for IoT devices deployed within UHF radio range of the observatory.

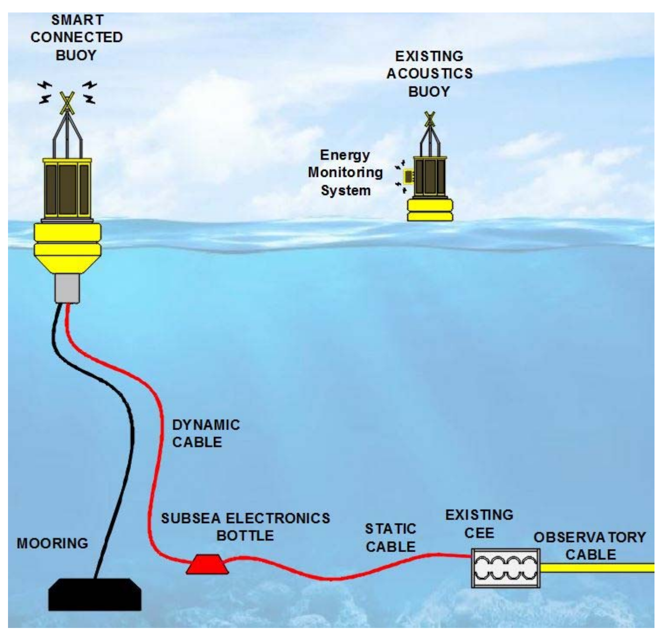

Figure I Energy Monitoring System deployed at Spiddal subsea observatory

The Energy Monitoring System was deployed on a second Mobilis DB 8000 buoy monitoring Acoustic Emissions, located some 2.3 km from the seabed cabled node – surface buoy interconnector. The Acoustic buoy is fitted with 14 x 100 W solar panels, mounted vertically on seven of its eight faces. The Energy Monitor used a UHF radio link to transmit images from the Acoustic buoy to the gateway in the communications cabinet on the seabed linked platform. See figure I above.

II. Background

Ireland's Ocean Economy created a turnover of €5.5bn in 2017, with an estimated GVA of just under €2bn [1]. This figure is targeted to exceed €6.4bn by 2020, with Ocean economy increasing to 2.4% of Ireland's GDP by 2030 [2]. This economy includes:

- The harvesting of marine bioresources such as wild & farmed fish, invertebrates, seaweed and algae for provision of foodstuffs, fuel and medicine.
- Sub-Sea resource mining e.g. Hydrocarbons used to create energy.
- Provision of Renewable Energy i.e. offshore wind/wave and tidal resources.
- Leisure and Tourism.
- Shipping (transport of personnel and cargo).
- Security and Technology (Marine ICT).

These key economic drivers, along with improved knowledge of Climate Change, Maritime Safety (including marine forecasting, search and rescue, earthquake warning systems etc.) and Marine Pollution are increasing the demand for Ocean Observations, Environmental Monitoring, Educational Awareness and Open source Ocean Data.

The Blue Internet of Things (IoT) or the 'IoT for the Sea' [3] is a fast growing market, struggling to satisfy the increasing demand for knowledge transfer from the harsh marine environment. Observational devices currently deployed off the Irish coastline include Weather and Wave Data Buoys, Tide Gauges, Argo Floats, tethered Scientific Monitoring Buoys and Deep Water Moorings. One of the key benefits of these autonomous systems is their ability to provide a continuous time series of data, as opposed to a short sampling period provided by a research vessel. However, it can be identified that three primary challenges need to be addressed in relation to the provision of IoT systems offshore:

1) Available Energy Challenge
    a. Autonomous Energy Generation and Storage
    b. Energy Management and Conservation
2) Real-time Communications Challenge and Connectivity (where necessary).
3) Requirement for System Robustness against Failure or Communications Interruption.

It is anticipated that the Energy Monitoring System developed as described below will principally assist with the first of these challenges: It will record energy production, assist with early identification of problems, and use smart technologies to determine their probable cause. However, it will also function as an independent IoT device, gathering energy data necessary to verify solar models and enabling reanalysis to be carried out on modelled data to determine actual energy output. This will facilitate with energy planning and budgeting for future system designs.

III. System Design

A. Mechanical Design

The prototype Energy Monitoring System was housed in a FIBOX® transparent/grey polycarbonate enclosure, fitted with a PUR gasket to give IP66/IP67 rated protection. The external dimensions of the enclosure were 300 High x 230 Wide x 87 mm Deep, and it was accessed with stainless steel cover screws. A marine plywood backing plate was fitted to the exterior of the enclosure, providing a mounting base for two stainless steel angle brackets. These brackets were purpose-made, and terminated in STAUFF® pipe clamps. This enabled the device to be clamped to the upright hand rail on the Mobilis DB 8000 Acoustic buoy, and angled to face a specific area on one of the solar panels, as per figure II below.

Figure II Energy Monitoring System clamped to handrail on Acoustic Buoy

B. Hardware

A Raspberry Pi Model B+ V1.2 Mini-PC (running Raspbian OS), was used to control the system. It was built using a Broadcom BCM28305 SoC, and contained 512MB SDRAM.

The 8 megapixel video/stills camera used was a Raspberry Pi Camera Module V2, containing a Sony IMX219 image sensor. It was connected to the Raspberry Pi using a dedicated Camera Serial Interface (CSI). The FLIR Lepton® Long Wave Infrared (LWIR) micro thermal camera module (wavelength 8 – 14 µm) was mounted in a FLIR Lepton breakout board V1.4, connected to the GPIO pins on the Raspberry Pi. Serial Peripheral Interface (SPI) was enabled on the Pi to read the image from the sensor, the camera settings were controlled by Inter-Integrated Circuit (I^2C) protocol [4].

The images were date/time stamped using an Adafruit ultimate GPS V3 Breakout. It was connected to one of the USB ports on the Mini-PC using a USB to TTL adapter cable and was fitted with an external active antenna. The breakout board was built using a Media Tek MT3339 66 channel GPS chip with a 10 Hz update rate.

Signals were modulated (FM) and transmitted using a Binatone terrain 550 UHF transceiver, with an output power of 0.5W. The microphone/speaker jack was connected to the audio output of the Mini-PC, and the transceiver was set to voice-operated (VOX). Serial feeds from two of the MPPT solar charge controllers in the power cabinet were accessed by the Mini-PC via two VE.Direct® to USB interfaces. The hardware (except transceiver), was powered using a RS Pro Li-ion portable power bank, with a capacity of 10,400 mAh at 5V.

C. Programming, Encoding and Decoding

Slow-scan TV (SSTV) was chosen for image transmission as it is a narrowband mode that can be transmitted over analogue voice channels on shortwave bands. It was first developed by Copthorne McDonald, a student and amateur radio enthusiast, at the University of Kentucky in 1957 [5], and is currently used to periodically transmit images from the International Space Station [6]. SSTV uses frequency modulation to assign an audio frequency to different levels of brightness in a colour. The Martin 1 method of encoding uses the RGB colour model; the brightness of the green, blue and red components of the colour are transmitted separately. A Python SSTV generator (PySSTV) was used to encode the image into a WAV file on the mini PC [7]. It was then played using OmniPlayer radio automation software, modulated on to a UHF carrier wave, and transmitted by the Binatone transceiver. Once it was received by the SDR on the parent buoy, and piped ashore using a TCP link on the subsea cable, it was decoded on a remote machine using RX-SSTV V1.4.3 software [8].

D. Energy and Monetary Budget

The present energy budget for image capture and transmission is incomplete, as an imbedded transceiver has not yet been chosen. However, the figures below indicate actual (measured) and approximate energy consumption for the remaining components. Approximate consumption was taken from the product data-sheet, and is required to be measured at a later stage during the project. Voltage supplied was 5V DC:

TABLE I. POWER CALCUATIONS

Status	***Components***	***Average Current (A)***	***Power (W)***
Standby	Raspberry Pi B+	0.25	1.25
Standby	GPS, Active Antenna, Pi Camera Module	0.04	0.2
Active	Pi, GPS and Pi Camera taking image and Tx.	0.33	1.65
Active	FLIR Lepton®	N/A	0.15*

[a] Estimated from data sheet.

System energy consumption can be estimated using table 1, assuming one hour of operation in twenty four hours, and 23 hours standby: 1.8 + (1.45 x 23) = 35.15 Wh/24 hrs, or 7.03 Ah @ 5V. The cost of new materials totalled €470.40 ex. VAT and carriage. Note: Transceiver, mounting brackets and sundries not included as authors own materials were used.

IV. TESTING

Imaging can be used in different ways to identify the probable cause of autonomous energy reduction/interruption. The purpose of static imaging is principally to identify areas of external damage or biofouling on marine solar panels. Figure III below shows an example of biofouling on one of the buoys from the Irish Weather Buoy Network, ashore for servicing.

Figure III Biofouling on a buoy from the Irish Weather Buoy Network

Infrared imaging can be used to highlight internal damage in PV panels, detecting 'hot spots' caused by short circuits within the system [9]. Figure IV features an image taken with the FLIR Lepton® using the Energy Monitoring System: The image shows damage to a PV panel on a buoy that was experiencing power problems. The 'hot spots' can be identified as the areas of lighter yellow.

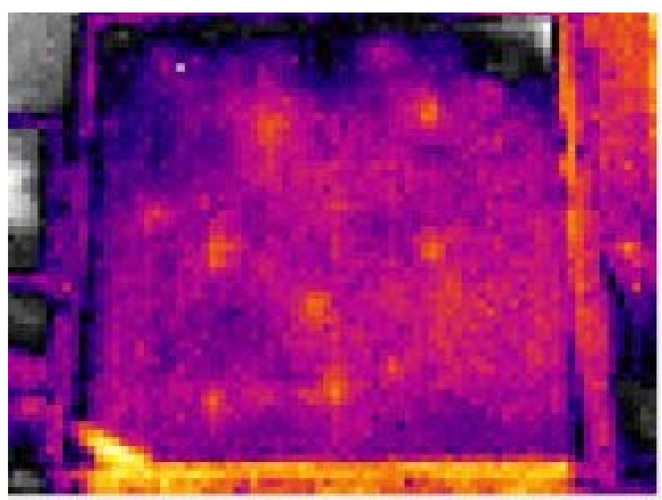

Figure IV 'Hot spots' detectable on an infrared image of a PV panel

A. Image Capture and Transmission – Initial Results

A series of exercises was carried out, initially on Lough Furnace at the Marine Institute's Newport Catchment Facility before moving to the Galway Bay Marine and Renewable Energy Test site. Images from both Sony and FLIR cameras were transmitted and decoded successfully during both deployments. Figure V below shows the Energy Monitoring System being mounted on the Automatic Water Quality Monitoring Station (AWQMS) at Lough Furnace.

Figure V Energy Monitoring System being mounted on the AWQMS

Figure VI shows an infrared image of one of the PV panels on the AWQMS after it was transmitted and decoded. Note: The lighter area that is visible diagonally across the panel is a reflection of one of the railings on the buoy, and not an area of concern.

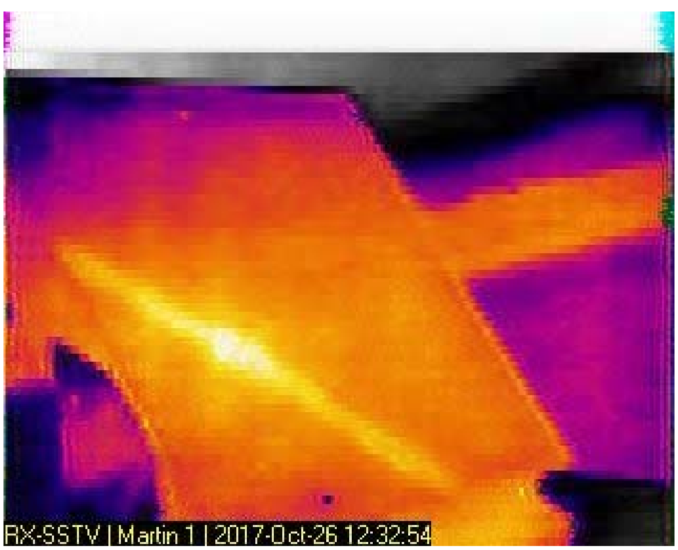

Figure VI Infrared Image of the PV panel on the AWQMS

Figure VII shows a photo transmission of a section of one of the PV panels on the Acoustic Buoy in Galway Bay, including the decoding software. It was concluded that the radio-link and Ethernet gateway were working successfully, however, shared traffic on the radio network was occasionally causing interference, as per image in figure VIII.

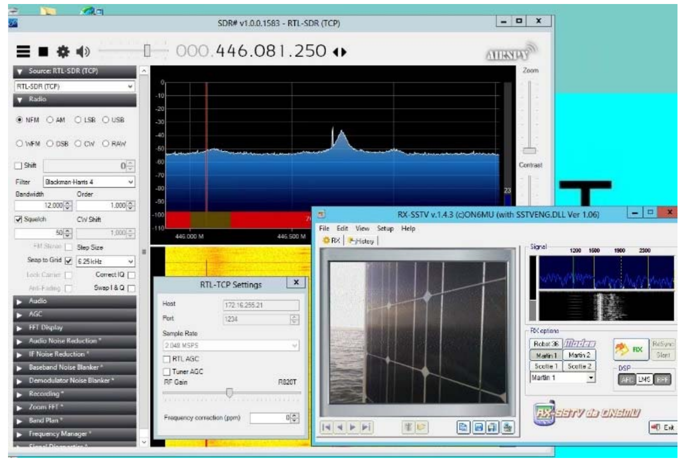

Figure VII Image being decoded after transmission from Acoustic Buoy

B. Energy Monitoring – Initial Results

The two VE.Direct® to USB interfaces were connected to two of the MPPT's in the power cabinet (controlling PV panels on Faces 1 and 4) of the Mobilis DB 8000 buoy when it was deployed in September 2017. They have logged energy data to date (12/12/18). A portion of the data has been analysed, and the following two applications were found:

(a) Example of Fault Detection:

A time series of daily Maximum PV Voltage values from September 2017 to June 2018 was graphed as per figure IX overleaf. Starting from April 2018, PV Voltage levels can be seen to decrease over time on Face 4, indicating degradation in performance and need for intervention. Indeed, when the panels were removed from Face 4 of the buoy, the connections were found to be corroded, necessitating panel replacement.

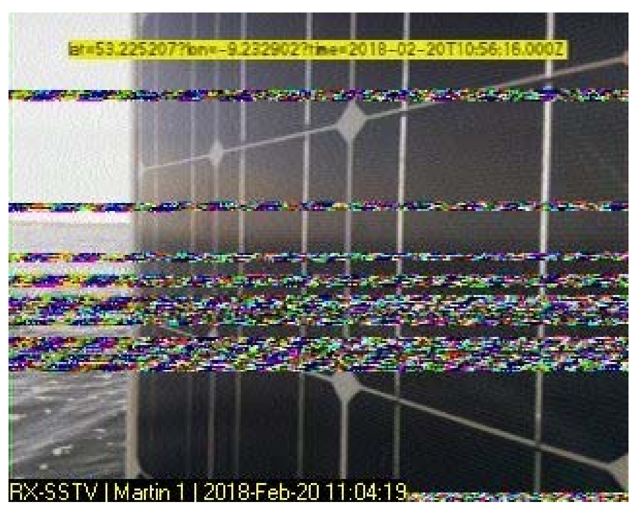

Figure VIII Traffic on the radio network causing interference with the signal

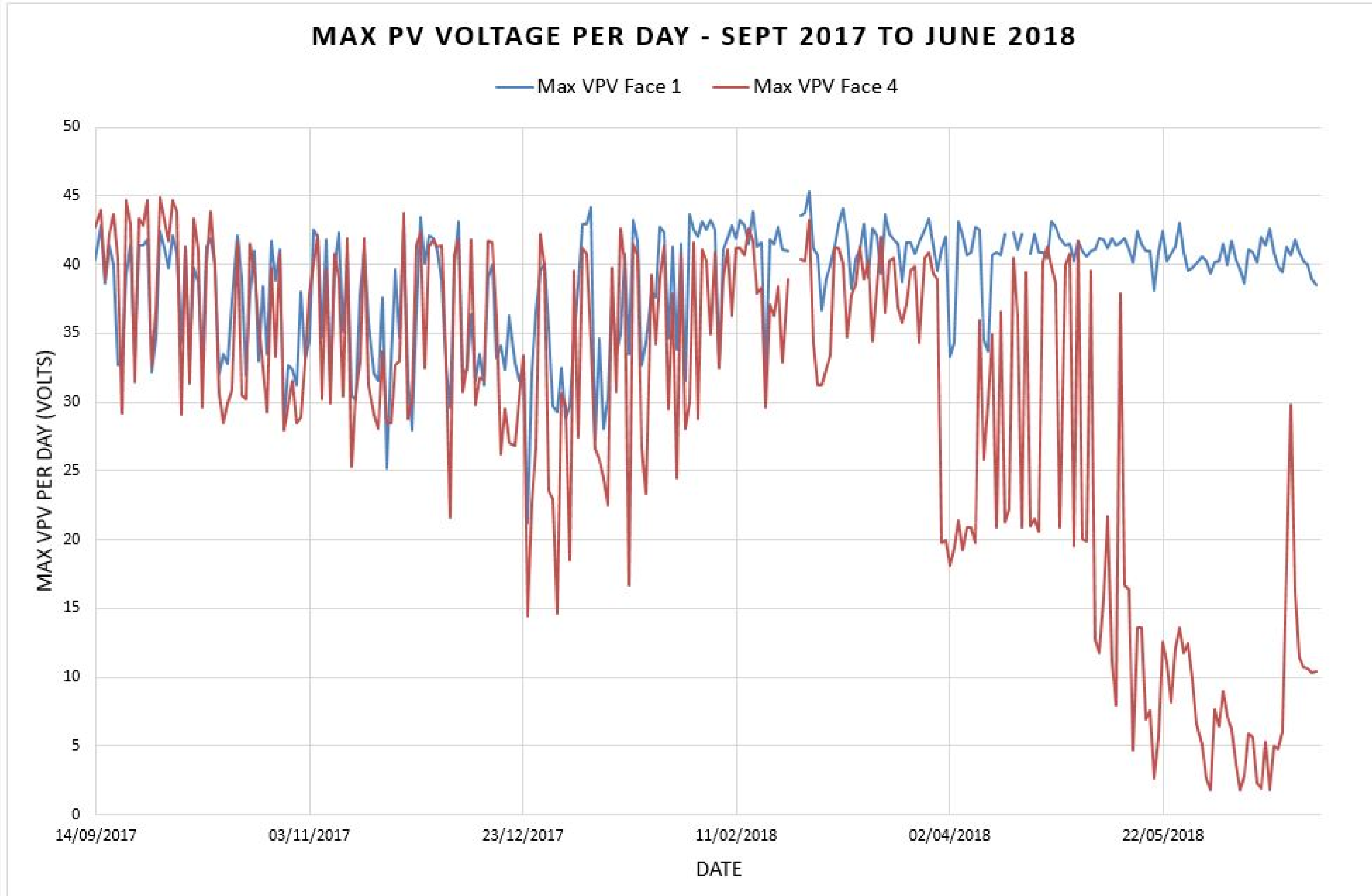

Figure IX Daily Max. PV voltage values from September 2017 to June 2018

(b) Example of using Measured Energy values:

Daily Energy Yield values from the PV panels on Face 1 of the buoy were plotted for a time period from 20th – 26th December, 2017. The plotted values were then compared to modelled values derived from the European Commission's PVGIS interactive software, using solar radiation databases relevant to the location of the buoy i.e. CMSAF, COSMO and SARAH [10]. The combined plot is illustrated in Figure X overleaf. It can be concluded that average values fell well below expected values for this time period, demonstrating the use of the Energy Monitoring System in determining actual energy output versus modelled values.

V. FUTURE WORK

Proposed factors to be considered for future prototype development include independent autonomous energy generation, a software defined transceiver to allow testing across a wider range of radio frequencies, and housing development that will include consideration for the prevention of biofouling.

Future programming plans include the development of an image recognition algorithm using the Open Source Computer Vision Library (OpenCV) for python. This would enable remote decision making, increasing machine intelligence:

The algorithm would 'recognise' signs of damage/degradation on the panel, and only encode and transmit an image when it found inconsistency. A text signal would be transmitted in the case of no fault being found.

Once programmed, the device will be capable of feeding back energy status reports to other IoT devices deployed on the parent buoy via the buoy's central control system. This will enable remote decision making to be made to ensure that energy production levels satisfy energy consumption. E.g. when energy levels are detected as being low, only low energy/housekeeping tasks will be completed. Higher energy tasks/devices will only come into operation when the daily energy yield of the parent buoy exceeds the daily system energy requirement of these devices.

VI. CONCLUSION

This paper presents the design, testing and early analysis of a low-cost PV Energy Monitoring System suitable for deployment on a remote buoy/platform. The detail above describes how the device can be used to quantify energy production from the PV system, identifying when the system becomes problematic by carrying out routine invasive monitoring, and recording values such as PV Voltage, Energy Yield and Battery Voltage.

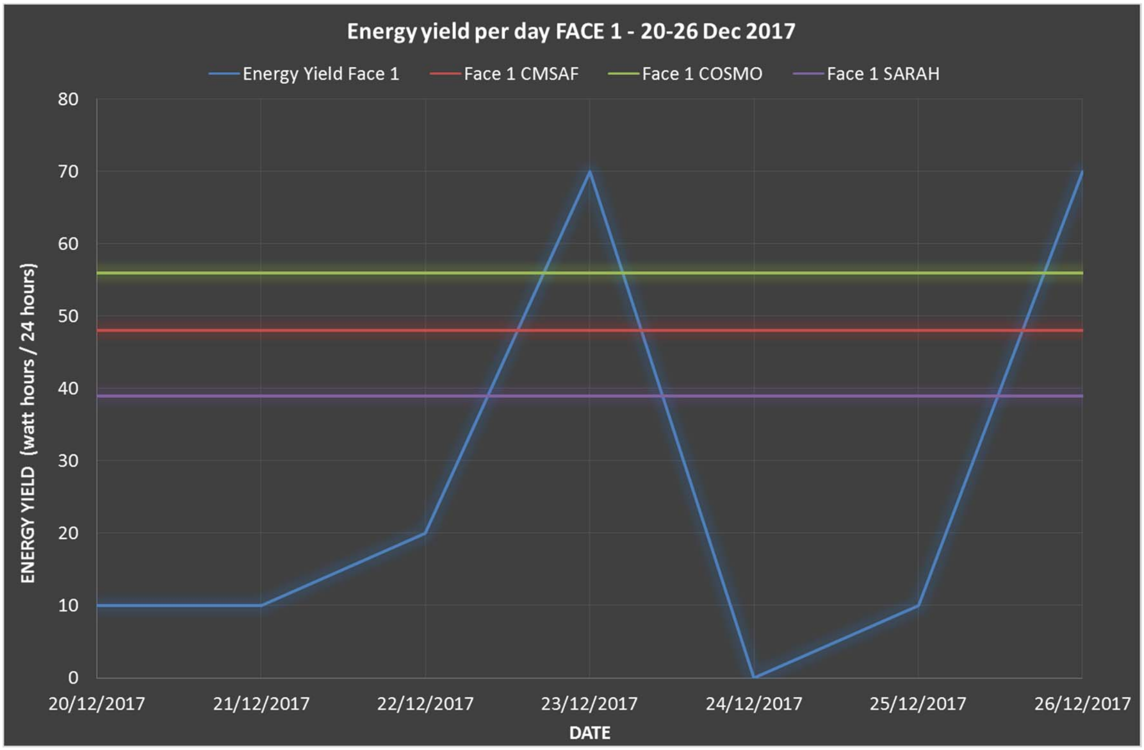

Figure X Daily Energy Yield Face 1, 20 – 26 December 2017.

A detailed description is given as to how non-invasive imaging methods can be used to identify the possible cause of energy interruption e.g. by identifying areas of biofouling, external damage or short circuitry. Methods of image encoding, transmission and decoding are explained, illustrated by examples. It can be concluded that the radio-link and Ethernet gateway are capable of successful image transmission, enabling remote troubleshooting and highlighting potential problems.

Initial test results are presented and discussed, highlighting how early analysis can be used in the identification of a problem with PV panels on the Mobilis DB 8000 buoy, concluding that the device is successfully capable of fault detection. Discrepancies between modelled and measured energy production levels are highlighted, and it was concluded that this measured data could be used to carry out reanalysis on modelled data: This would facilitate accurate energy estimation and aid with future IoT systems design.

Future works are then proposed, outlining how the second prototype of the device will be designed and modified to increase its level of operation. Future programming requisites were outlined, requiring the device to operate with increased intelligence and autonomy, reducing unnecessary backhaul and increasing communication with other IoT devices deployed on the parent buoy. This latter function would enable the device to assist with the overall energy management on the central control system.

Acknowledgment

This material is based on works supported by the Marine Institute grant-aid agreement no. CF/14/07, funded under the Marine Research Programme by the Irish Government. Equipment was funded under National Infrastructure Access Programme reference number NIAP-LS-16009.

References

[1] Socio-Economic Marine Research Unit, “Ireland ’ s Ocean Economy,” 2018. [Online]. Available: https://www.ouroceanwealth.ie/sites/default/files/Publications/oe_infographic_oct_2018.pdf. [Accessed: 12-Dec-2018].

[2] Inter-Departmental Marine Coordination Group, “Harnessing Our Ocean Wealth: An Integrated Marine Plan for Ireland.” Inter-Departmental Marine Coordination Group, 2012.

[3] Marine Institute, “Ireland’s Marine Internet of things to the fore at Digital Ocean Conference 2017,” 2018. [Online]. Available: https://www.marine.ie/Home/site-area/news-events/news/irelands-marine-internet-things-fore-digital-ocean-conference-2017?language=ga. [Accessed: 12-Dec-2018].

[4] FLIR, “FLIR LEPTON ® Long Wave Infrared (LWIR) Datasheet.” datasheet, pp. 1–50, 2015.

[5] Martin Bruchanov, “Image Communication on Short Waves,” 2013. [Online]. Available: http://www.sstv-handbook.com/. [Accessed: 11-Dec-2018].

[6] C. Ariotti and A. De Carolis, “ISS Fan Club,” 2018. [Online]. Available: https://issfanclub.com/image/tid/54. [Accessed: 11-Dec-2018].

[7] A. Veres-Szentkirályi, “PySSTV.” [Software] Budapest: PyPi 2016, 2013.

[8] G. Roels, “RX-SSTV.” [Software] version 1.4.3. Belguim: 2016.

[9] O. Menéndez, R. Guamán, M. Pérez, and F. A. Cheein, “Photovoltaic modules diagnosis using artifical vision techniques for artifact minimization,” *Energies*, vol. 11, no. 7, 2018.

[10] European Comission, “Photovoltaic Geographical Information System,” 2018. [Online]. Available: http://re.jrc.ec.europa.eu/pvg_tools/en/tools.html#SA. [Accessed: 12-Dec-2018].