Institution: University of Aberdeen

Unit of Assessment: 12 (Engineering)

Title of case study: [IC1] Design optimisation of hybrid renewable energy systems

Period when the underpinning research was undertaken: 2016-2020

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Alireza Maheri	Senior Lecturer in Engineering	01/09/2016-current

Period when the claimed impact occurred: 2018-2020

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact (indicative maximum 100 words)

A novel design tool developed at the University of Aberdeen has been used around the world to enable optimal, user-centred design of hybrid renewable energy installations that meet local needs. The tool uses 'multi-objective optimisation' to allow both system developers and customers to contribute to solutions for renewable energy systems (comprising two or more energy sources) at the design stage. The design tool improves performance prediction by providing increased transparency, leading to increased end-user confidence. The work has led to improved, user-centred designs supporting customers in the UK and Jordan, addressed the needs of disadvantaged, off-grid communities in both Turkey and Malaysia, and enabled the development and production of mobile, affordable water makers in sub-Saharan Africa and India.

2. Underpinning research (indicative maximum 500 words)

Hybrid renewable energy systems (HRES) are systems that rely on more than one energy source (e.g. wind, solar). Prior to installation, the system designer has to evaluate what renewable resources are available, estimate demand load for a particular build and decide on the appropriate HRES configuration, which presents a challenge. Ideally, this planning stage will result in a size-optimised combination of renewable, non-renewable (e.g. diesel), storage and backup components.

HRES design methods are not traditionally developed with the end-user in mind. Rather methods have focussed on the system designer and on supporting the installation process. This has presented an issue since traditional performance measures (e.g., average annual power production and unmet load) produce non-specific readouts and provide little meaningful information that can enable customers to assess the cost-benefit of a particular design. This can lead to an unsatisfactory design, poor value for money and reputational damage for the designer. These issues have hindered the worldwide growth of the renewable energy market, due to discrepancy between the predicted (expected) and actual performance.

A well-formulated HRES customer-focused design would correlate any tolerable loss in power to a gain in the cost. Since joining the School of Engineering in 2016, Dr Alireza Maheri, has developed a design methodology capable of addressing the root cause of the planning-design problem [1, 2, 4 and 5], building on previous research undertaken at Northumbria University. By introducing new reliability measures, namely, the 'blackout distribution', 'mean time between failures' and 'plannable load' the HRES system developed at Aberdeen can be tailored more effectively towards end-user requirements and translated into the tolerability of a power cut [1].

By using nondeterministic analysis to subject test systems to simulations of real-world uncertainties in model parameters (such as available renewable resources, demand load, power and cost), Maheri found that industry-standard deterministic design methods, regarded as

'traditional' methods, were often overdesigned resulting in costly, unreliable and/or unpredictable performance [1].

In particular, the integration of high safety factors to overcompensate for the uncertainties, was found to increase in the cost of the system without necessarily increasing the reliability of the system's power supply [1]. Maheri has shown that exclusion of end users from the design phase, leads to unrealistic expectations and a lack of understanding of the role of technical assessment criteria. By introducing new reliability measures such as the annual blackout (power cut) distribution and the mean time between failures and assigning a level of confidence (LoC) to each criterion, Maheri has developed an HRES system that provides the end user with performance measures that are both tangible and realistic (e.g., a total annual power cut of 30 hours @ 99% LoC instead of the unrealistic claim of no unmet load). This specificity leaves much less room for misinterpretation and increased customer confidence [P1; 4].

Maheri's most recent research has also focussed on addressing machinery-load planning issues for production lines where the energy is supplied entirely or partially by renewable resources leading to the development of a robust multi objective algorithm for minimising the production cost and maximising the share of renewables in power supply [5]. This new nondeterministic assessment, design optimisation and load planning method has been successfully implemented in a software tool for Multi Objective Optimisation of HRES (MOHRES). A web-based (open access) version of the tool, with limited functionality, is available via the University of Aberdeen [3]. The full version of the tool is available to provider/consultancy companies on request.

MOHRES translates the end-user requirements into the system's technical performance through new performance measures which can be easily interpreted by the end user, thus providing a bespoke and cost-effective solution (type and size of renewable, storage and/or auxiliary components in the system) [1, 2, 4 and 5]. MOHRES works by providing a realistic analysis of the system performance by accounting for uncertainties (renewable resources, demand load, power and cost models) and applying operational characteristics [1, 4]. Moreover, its flexible formulation provides additional features such as integrated configuration-size optimisation and inclusion of energy management system characteristics [5].

MOHRES also offers retrofitting capability, which allows the system designer to introduce new components into an existent system (e.g. diesel), in order to gradually transition to renewables and thereby define energy transition scenarios. Maheri has been working with the Universite Des Mascareignes (Mauritius) since 2018 to develop and evaluate a series of different energy transition scenarios using MOHRES in order to aid efforts to meet national climate mitigation ambitions, including the uptake of 35% mixed renewable energy generation by 2025. Maheri acts as an advisor to the Faculty of Sustainable Development and Engineering at the Universite Des Mascareignes, Business Mauritius, the Central Electricity Board and the private sector in Mauritius [S5].

3. References to the research (indicative maximum of six references)

[1] **Maheri A**., Bokah A (2019), Plannable demand load in size optimisation of hybrid renewable energy systems. Institute of Electrical and Electronics Engineers Inc., 5th International Symposium on Environment-Friendly Energies and Applications, EFEA 2018, Rome, Italy. DOI: 10.1109/efea.2018.8617048 (conference paper)

[2] **Maheri A.,** 'Multi-criteria Size Optimization of Hybrid Renewable Energy Systems Incorporating End-User's Requirements - Case Studies using MOHRES' at EFEA 2018-Rome (http://efeaconf.com/EFEA2018/ss&workshop.html) (workshop/conference)

[3] MOHRES website: http//mohres.com (software, v 2019)

[4] **Maheri A.** (Accepted/In press – 30 Nov 2020). Maheri, A., 2020, November. MOHRES, a Software Tool for Analysis and Multiobjective Optimisation of Hybrid Renewable Energy Systems: An Overview of Capabilities. In *6th International Symposium on Environment Friendly Energies and Applications*. IEEE Explore.

[5] Bokah, A., & **Maheri, A.** (Accepted/In press – 30 Nov 2020). An Algorithm for Load Planning of Renewable Powered Machinery with Variable Operation Time. In *6th International Symposium on Environment Friendly Energies and Applications.* IEEE Explore.

Grants

[P1] Collaborative Industrial Doctoral Project with Energy Renewable UK, 'Renewable Energy Systems Tailored for End User (REST4U)'; 2015-2018 (GDP66,000). This project was awarded to Maheri while employed at Northumbria and transitioned when he joined Aberdeen on 01/09/16.

[P2] Solar Powered Watermaker, Scottish Funding Council (Innovation voucher); 01/07/2019-30/04/2020, (GBP5,000). This funding has enabled proof-of-concept work with Aashraya Ltd.

4. Details of the impact (indicative maximum 750 words)

One of the key issues facing the renewables market, specifically design and installation of HRES has been the lack of consideration around end-user design and ultimately user requirements. Since 2016, Maheri has focussed on developing a user-centric design, which caters to the end user needs and takes into account the user's financial constraints. MOHRES [2, 3], developed at the University of Aberdeen has underpinned the development of made-to-measure energy systems that are designed with direct input from the end user, ensuring that the resultant HRES can feasibly meet the demands and mitigate the cost for the customer.

At the system-design and supplier level, particularly in the renewables sector, this user-centric design acts as a crucial form of risk reduction, given that end-user demands are comprehensively addressed at the design phase. Maheri's research has led to impact in the following ways:

- Addressing shortcomings of 'traditional' deterministic design methods across industry and differentiating the product offer
- Supporting growth of renewable energy companies in highly competitive markets such as Jordan and Sub-Saharan Africa
- Providing research and expertise to facilitate change in traditional industry practice in UK and Malaysia
- Improving the welfare of off-grid communities in Turkey, Malaysia, sub-Saharan Africa

Speaking the same language: MOHRES helps energy consultancies and providers gain the trust of current and new end users through intuitive design

In order to build awareness of MOHRES in the engineering community of the 'plannable load' algorithm, Maheri has actively demonstrated its capabilities at a series of workshops for industry in close collaboration with the University of Northumbria (September 2018, with another due to take place in March 2021). These workshops have enabled participants to see the tool 'in action' and have led to direct requests by companies to have access to the full version of the software for conducting comparative assessments. This has facilitated the wide adoption and deployment of MOHRES in UK, Malaysia, Turkey, Mauritius and Jordan.

At the workshop held on September 2018 in Rome [2], Jordanian-based energy company Al-Narjes Energy, requested access to MOHRES, which they have now utilised, for planning and delivering of 60 HRES projects with total capacity of 1.5 MW (as of April 2020) in Jordan for private clients [*text removed for publication*], applying the approach to operations ranging from telecommuting, electricity and construction of roads. This has enabled the company to compete in Jordan, which is considered to be one of the most competitive investment environments in the renewables market and is ranked third by Bloomberg's Climatescope [S1]. Al-Narjes Energy have confirmed that the new design methodology offers a cost-effective solution relative to current standard practice, noting that the tool had enabled "*provision of high level of confidence in both customer satisfaction and reliability and subsequent increase in our customer base by 30% [equivalent of 12 projects].*" Since September 2018, several systems have been installed for commercial and residential projects, including places of worship, schools and private farms, introducing cost saving and reducing dependency on fossil fuels [S1].

Energy Renewable UK (Ltd), with whom Maheri has collaborated as part of [P1] since joining Aberdeen, have also adopted MOHRES in their configuration and size optimisation tool. The

company have used it to deliver a number of projects towards decreasing the dependency of automated dairy industry to grid (UK) [5], and a cost-effective transition from a diesel-powered to a renewable-powered system in a rural off-grid crop processing community in Malaysia [3]. Energy Renewable UK have found the tool to be extremely effective in tailoring HRES based on customers' needs, taking into account financial limitations and power supply requirements for off-grid communities and compatibility with productions line for industry stating:

'*Undoubtedly, we owe our success in expanding our business overseas, competing against prominent local companies, and the high success rate in our responses to tender to this collaboration (with Aberdeen)*." [S2]

New reliability measures, enabled through MOHRES and employed by Energy Renewable UK, have been of particular interest to customers with limited financial resources and have introduced capacity for sustainable energy production in low- and middle-income countries. As a testament to their diverse portfolio, Energy Renewable UK (Ltd) has now employed the new reliability measures (load planning) to deliver a project for a remote off-grid community in Turkey (wind-PV-battery) [5]. The case study from this project shows how tolerability of a power cut with a maximum length and frequency can lead to significant cost saving (agreed as minimum requirements by the end users) and could be easily translated into new reliability measures. These measures, which are incorporated into the optimisation of the HRES, enable the company to find a solution which matches the end-user requirements and has a total lifespan cost only 55% of that of a system designed traditionally, leading to significant cost savings for the customer [5; S3].

End user centered design - support for small industries in energy transition

In 2019, Maheri was awarded an Innovation Voucher [P2] as part of a start-up venture with UK-based oil & gas manufacturing company Aashraya Ltd and provider of components to the oil & gas sector. In 2020, and as a result of the collaboration, Aashraya Ltd entered the renewables market in sub-Saharan Africa and India, one which is dominated by non-renewable energy sources such as diesel, particularly in remote, low-income communities. By working with the company to integrate MOHRES into their current systems, Maheri has supported Aashraya Ltd in bringing their first prototype system with load-planning capabilities to market trial. The system developed, a solar-powered water-maker, is cheaper than diesel-based systems (currently dominating the market). The lower total lifespan cost of the prototype gives the company a marketable advantage over potential renewable-powered competitors [S4].

In conjunction with the company's own in-house expertise, MOHRES has facilitated the design of a portable, renewable-powered (PV-battery) system that operates optimally in different geographical sites with variable water demand, complex weather and variable solar resources, in direct contrast to systems that are designed to operate optimally in one site and hence are inefficient or unadaptable to sites with complex demands (e.g. variable weather systems). By using the 'plannable load' algorithm implemented in MOHRES, the company have been able to identify the best operation time throughout the day to produce the targeted amount of water whilst minimising the operational hours of the water-maker to maximise the lifespan of the system. The reported case study in [5] is based on Aashraya Ltd water-makers, showing 29% and 49% longer lifespans for the water maker unit and the battery bank when the load planning algorithm in MOHRES is used [S4].

5. Sources to corroborate the impact (indicative maximum of 10 references)

[S1] Letter of support from Al-Narjes Energy (Ltd), detailing the ways by which MOHRES has increased their customer base and provided a cost-effective solution

[S2] Letter of support from Energy Renewable UK (Ltd), which allows the expansion of their portfolio following collaboration with Aberdeen

[S3] Design Tool-Energy Renewable UK (http://www.energyrenewableuk.com/design.html) demonstrates the total lifespan cost of their design tool upon adoption of MOHRES

[S4] Letter of support from Aashraya Ltd outlining the advantage of utilising MOHRES in their system design, its facilitation of entry to the renewables market and development of the water maker

[S5] Letter of support from Universite Des Mascareignes confirming Dr Maheri's role as advisor