

Addressing some issues relating to hybrid mini grid failures in Fiji

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Abstract— Rural electrification, regardless of whichever electrification scheme is utilized (grid extension, mini grids, or autonomous energy home systems) has many potential benefits. In particular, hybrid mini grid power systems are potentially highly valuable electrification scheme for remote rural electrification in comparison with other electrification schemes but they involve significant complexities in terms of design, implementation, and operation and maintenance. This implies that there are many challenges that have to be overcome before the benefits of hybrid systems can be achieved. A detail literature review and targeted consultations with a range of Fijian stakeholders were undertaken to better understand options for addressing some of the technical as well as the non-technical issues leading to the failure of hybrid mini grids in Fiji. Key findings suggest that lack of proper documentation on systems, carrying out system designs in isolation, failure to incorporate learnt from previous projects into newer projects and failure to understand the system and limitations; all are the contributing factors for an unsuccessful and unsustainable hybrid mini-grid in Fiji. Finally, this paper suggests some useful guidelines for successful and sustainable hybrid mini grid systems.

Index Terms— mini grid, rural electrification, sustainable,

I. INTRODUCTION

The hybrid mini-grid concept can best be understood as the intelligent coordination of a range of small-scale renewable and conventional generation technologies, along with associated power control equipment and often some form of energy storage, which are connected with each other and a range of loads through a relatively small distribution network. Besides being a cost-effective technology solution for remote and rural electrification, such systems have the capability to provide conventional grid quality and highly reliable electricity for domestic, commercial, health services, communications and small industrial applications [1].

Though significant experience has now been gained from successful examples of a wide-range of hybrid mini-grid systems in several developing countries, particularly in Asia [2], [3], Fiji's experience with hybrid mini grid have been

problematic [3], [4], [5], [6], [7]. It is widely accepted that successful design, implementation and operation of hybrid mini grid systems can be more difficult than grid extension or autonomous systems. This implies that successful operation followed by optimum outcomes of hybrid mini-grid technology for rural electrification can only be assured if technical and non-technical issues leading to its failure are correctly understood and addressed.

Technical issues of hybrid mini grids are linked to system design (component selection and system sizing) and operational management (component coordination, system operation and technology mix) while the non-technical issues are associated with economics, ownership and management, and the social and environmental context within which hybrid mini grid systems are implemented. Any flaws in either category of issues will impact system outcomes which then leads to end-users losing confidence in the system or the technology itself.

Thus, this paper presents the outcomes of the effort that was applied to study and address some of the many technical and non-technical issues leading to the failure of hybrid mini grid systems in Fiji. Finally, this paper has commences with the review of literature on hybrid mini grid followed by the outcome of consultation work carried out in Fiji. Finally, the paper concludes by suggesting some guidelines for successful and sustainable hybrid mini grid.

II. SOME STRENGTHS AND LIMITATIONS OF HYBRID MINI GRIDS

Hybrid mini-grid power systems have significant potential advantages by comparison with single technology power systems. For instance, performance of a single Renewable Energy Technology (RET) system depends on the variability of the underlying energy resource but not on imported fuel supply such as diesel generator set. Multiple RETs can add value by diversifying supply across a number of different energy sources that, hopefully, aren't highly correlated with each other. Joining multiple loads in the one system also adds valuable diversity for power system operation. Adding energy storage such as a battery system with associated power electronics can greatly improve the reliability of supply. Adding a diesel generator set can further improve system performance because of their high controllability and significant energy storage (in terms of diesel fuel). Thus, when

appropriately designed and implemented, hybrid mini-grid power systems should be able to serve a number of load points with adequate power quality and acceptable system reliability by comparison with single technology systems. Mini-grids operating in hybrid mode also increase the redundancy in the systems' generation end, thereby increasing total system reliability. However, this redundancy can increase system complexity in terms of operation and control thereby countering the reliability of the hybrid mini-grid.

In addition, hybrid mini-grids can in some circumstances be more sustainable solutions for rural electrification than conventional grids. They allow maximum utilization of renewable resources present on the site thus minimizing the fossil fuel use and reducing atmospheric emissions. Also, maximum utilization of renewable energy with diesel generators can significantly reduce the size of energy storage needed in the hybrid mini-grid. It is preferable by far if renewable resources employed in power generation can complement traditional methods of generation.

Nevertheless, hybrid mini-grid has some limitations such as the high cost involved and a lack of experience and knowledge of these systems worldwide due to the limited experience with their use to date. Natural resource availability and increased system complexity in terms of controls, requires professionals to carry out operation and maintenance which may be difficult in remote settings.

III. PRESENT AND FUTURE OF HYBRID MINI GRIDS WORLDWIDE

In spite of identified challenges, many examples of village-scale hybrid mini-grid power systems are in operation in Asia. China has more than 60,000 mini-grid systems and India, Nepal, Vietnam and Sri Lanka each have some 100 to 1000 [8]. However, the literature is unclear in identifying whether these existing mini-grids are just diesel based or are integrated with RETs. A limited number (approximately 150) of hybrid mini-grid systems are known to exist in developing countries [8] as they still cannot generally compete with diesel generation. Thus hybrid systems need partial funding from government or donors. Nonetheless, hybrid systems would appear to offer significant environmental and sustainability benefits compared to diesel generation.

Based on the self-examination of the World Bank reports and reports from other agencies such as IEA and ARE, several renewable energy markets are expected to expand in the near future. The cost of renewable energy technologies is dropping and markets are expanding, thus underpinning sustainable industry development. These markets include rural residential lighting through solar home systems; the hybrid mini-grid technology market for rural and remote electrification as well as mini and micro grid connection to utility grids. Nonetheless, developing countries may still be donor dependent to some extent if these technologies are to be realized [9], [10], [11].

Finally, it is worth highlighting that the hybrid mini-grid is a relatively new concept [12] and considerable research and development activities are still continuing in the area to help

address existing challenges and facilitate these systems in playing a valuable role in the world's future energy system [13], [14].

IV. FINDINGS FROM CONSULTATION WITH STAKEHOLDERS IN FIJI

After consultation with some of the relevant authorities in Fiji, it was noted that some of the survey information delivered was already apparent from the literature review. However, details on end-user preferences with regard to different electrification schemes, typical failures in diesel mini grids, some of the reasons for hybrid system failure represented useful additions to current knowledge of the Fijian context.

A. Preferred type of rural electrification scheme

Under the existing Fijian rural electrification arrangements, village level mini grids are highly preferred over grid extensions or a centralized island grid by authorities. This preference is based upon the high operational cost of a centralized island grid while grid extensions are often neither technically nor financially viable solutions for Fiji's remote locations. Sparsely distributed villages, complex topography, low electrical energy consumption demands and high costs are some of the reasons for preference biasing against grid extensions or centralized island grid.

B. Preferred rural electrification technology

The consultation also highlighted that the preferred technology used for village electrification in Fiji was the diesel mini grid. The reason for utilization of diesel generators for electrification was due to the fact that they have lower capital cost and rural communities find it easy to collect the 5% contribution of the capital cost specified in Rural Electrification Policy (REP). Additionally, they are very familiar technology. However, erratic fuel supply, fuel price volatility and delayed maintenance pose great threat to reliability of electricity supply by diesel mini grids.

It was also revealed through consultations with the technical officers at Fiji Department of Energy (FDoE) that their current sizing practice for diesel generator for mini grids application assumes a peak hourly load per household of 500W over the next 30 years. The underlying reason given for this estimate was that Fiji Electricity Authority (FEA) has a domestic load sizing of 400W per household so FDoE made an allowance of an extra 100W per household and also, the budget under diesel electrification scheme only allows to purchase diesel generator ones over the span of 30 years. It is not clear whether the current sizing method used by FDoE in any way affects the operational performance of diesel generators by way of fuel efficiency or increase in wear and tear of diesel generators due to light loading.

No technical evaluation reports on the performance of existing diesel mini grids were found through either the literature review or in discussions with agencies in Fiji. It implies that either such information is not being appropriately collected, or that information flow is not taking place to support research and development activities. The presence of evaluation reports provides opportunities for better

understanding of existing systems and a basis for working out more efficient strategies to improve system performance in the future. However, through discussions it was revealed that the failure rate of diesel generators varied considerably. Some diesel generators had 1 to 2 failures per year while some continue to work problem free for the first 4 to 5 years. In any case, the diesel systems that are looked after by FDoE undergo major overhauls every 8 to 10 years.

It was also noted that up to 15 diesel generator failure cases out of approximately 400 diesel generators that operate across Fiji were reported to FDoE annually (FDoE 2010). This gives an annual probability failure of 0.0375 for the diesel generators operating in remote and rural locations in Fiji. Some of the common problems associated with diesel mini grids operating in remote and rural locations in Fiji are the short operational life of fuel filters, oil leakage, alternator burnout, and shorting of underground reticulation systems. There are also issues with delayed maintenance (due to availability of funds, remoteness of site or shipping schedules). Delayed maintenance can cause electricity disruption for several days to several weeks due to the complete reliance of these systems on diesel operation.

C. Experience of hybrid mini grid in Fiji

A hybrid mini-grid power system has also been attempted at Nabouwalu – Vanua Levu in Fiji. It has a daily load demand of 720 kWh and was designed by Pacific International Centre for Higher Technology Research (PICHTR) which integrated solar and wind resources with the existing government owned diesel generator mini-grid system. This overseas funded project was commissioned in 1998 with a renewable energy fraction of 60% which steadily fell to 15% over the operational period of 4 years [7].

Some of the reasons documented for system failure were loss of technical support from overseas installers, inadequate local capacity to train technicians and operators, inappropriate tariff structure which only covered 30% of the operating cost of the hybrid power system and system complexity in terms of control and coordination of system components. Currently, this system operates as a diesel based mini-grid power system.

D. Reasons for mini grid (hybrid/diesel) failures in Fiji

Most of the specific reasons for hybrid system failures in the Fijian context were derived from consultations with relevant government agencies and the researcher's observations. The reasons can potentially be very broad as shown in fig. 1.

Apart from the reasons shown in fig. 1, it is also possible for the renewable projects to underperform due to poor site selection. In some cases, the sites might be selected for political reasons without sufficient consideration of resources and local skill levels.

Moreover, remote and rural area power system designing (system sizing, component selection, load assessment and forecasting) and awareness on system design standards was also flagged as a highly problematic area in Fiji. The reason explaining this fact is that most designing work is not done locally. When the designs are carried out in isolation, the

system upon installation faces lot of mismatch between the resources, other local conditions as well as load demand. Though unrestrained load growth on a village level mini grid cannot be supported, estimating future load growth possibilities precisely is extremely difficult. Undersized systems certainly lead to system failure and end-sure dissatisfaction while oversized systems incur unnecessary operational costs due to inefficient operation.

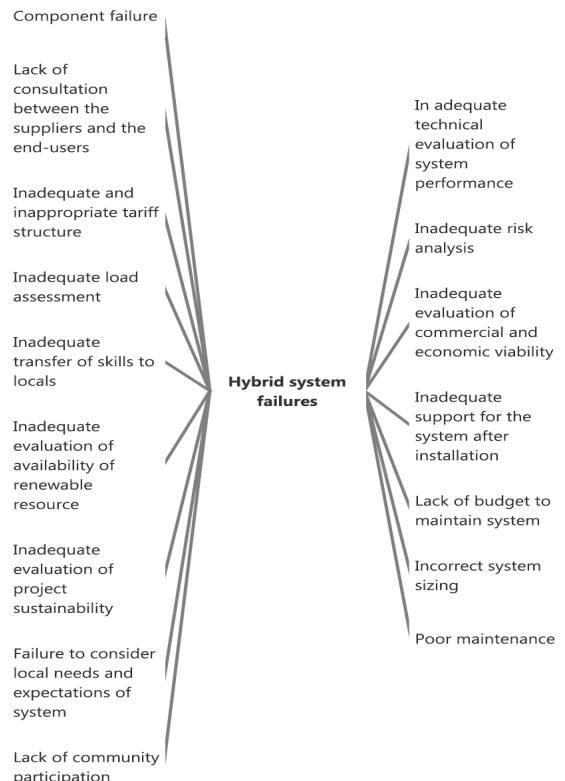


Fig. 1 Some of the reasons for hybrid system failure in Fiji

V. SOME GUIDELINES FOR SUCCESSFUL AND SUSTAINABLE HYBRID MINI GRID SYSTEMS

Undertaking a rural electrification project from the concept and design point without an appreciation of prior, often hard earned, experiences with such projects puts resources and stakeholder good will at risk. For the work undertaken for this paper including an extensive literature review and stakeholder consultation, a number of key issues have continued to be identified as critical for successful implementation and sustainable operation of hybrid mini grid power systems.

A. Feasibility study

It is imperative that a thorough feasibility study is carry out before implementation of a hybrid mini grid. Such studies help to determine the availability of renewable resources, ability and willingness of customers to pay, potential load demands and expected load growth. The analysis in the previous sections has highlighted that even relatively small errors in the assessment of renewable resources can have a significant

effect on total energy production or the design of the system. Moreover, a thorough load assessment plays a crucial role in system sizing. Willingness and ability to pay would show people's preference towards the system and whether the system is affordable for them.

B. Proper database for application to electrify

It is important to treat the process of electrification as a formal process. It may not be sufficient to say that the entire village must be electrified. Thus, each end-user (load point) within the village intending to be electrified needs to be documented. Generally, the levelised cost of energy (LCOE) of a system decreases with increasing load points. A detailed database to store such information should be established by the authority responsible for the hybrid mini grid. Later on, such a database can be expanded to store other relevant information such as system failures, complaints and payment details.

C. Consultations

Significant consultation among all the stakeholders such as field experts, designers, energy planners, end-users, donor agencies, government and system operators is essential. Moreover, records of each session of consultation should be well documented and kept for future reference.

D. Project development and management

Project development and management is also a crucial factor. Successful project management requires anticipating, identifying and planning for events that can impede the project. Inputs from all stakeholders are essential and emphasis needs to be placed on project specification, planning process budget allocation, responsibility allocation, documentation and commissioning.

Firstly, any project undertaken needs to be very clearly specified. It is important that the project specification consider the requirements of end-users which could be done through their involvement during project development and management. Clear documentation of the project and a robust change control mechanism are also vital if phenomena such as scope creep (that is, drift from the original design specification) is to be avoided. In addition, clear project specifications provide a reference to evaluate project delivery. Project sustainability is highly dependent on project delivery according to the project specifications. In sum, end-users lose confidence and interest in the project if its delivery is poor.

Secondly, a thorough planning process will certainly increase the probability of success. Proper risk management also helps in planning by identifying potential problems and working out strategies to avoid or mitigate them. Also, appropriate resources and skill requirements need to be planned beforehand. Furthermore, stakeholders frequently ask for project completion within unrealistic time frames so it is very important that an achievable timeframe is established. In particular, a budget for the project should be backed by historical information and economic evaluations. In other words, each and every process needs to be given attention during pre-planning and should be well-documented for

retrospective reference as the project gets underway. Planning should be viewed as a dynamic process and if any discrepancies are noted then immediate re-planning should be done such that any future events are controlled.

Thirdly, all stakeholders must have a clear understanding of their roles and responsibilities. Failure could stop project delivery thus putting the project's sustainability at risk. Any form of monopoly in the decision making process must be totally discouraged among the stakeholders.

Fourthly, proper documentation of the project is also essential. This process can check whether every task involved in the project is carried out according to the plan. It also provides a way to evaluate milestones reached. During the implementation process the contractors should use site log books to record relevant project details. Upon completion, project implementation documents (for instance technical specifications, legal documents, warranty documents and safety manuals) and operation documents (system installation manuals and system control specifications) must be submitted to the authority owning the project. In addition, basic system operational manuals, maintenance and training manuals should also be submitted. Moreover, the basic system operational manual should be written using simple language and simplified diagrams so that it enables a local system technician to easily operate the system and correctly report the faults for higher level of interventions. On the other hand, the maintenance manual should provide all required details for the system and should be targeted for more highly skilled technicians and engineers.

Fifthly, the project upon completion should undergo commissioning in the presence of the project manager or an independent engineer. The commissioning test should meet all the requirements of the project specification. Apart from the commissioning tests, the technicians should be evaluated to confirm they have been adequately trained to operate the project. A similar test could be carried out with the end-users to obtain feedback on whether they have been given sufficient knowledge about the project and the electricity service they can now receive. Sixthly, before the warranty period ends, a verification test should be conducted on the status of project functionality. Furthermore, all such tests should be documented and kept for future reference.

E. Suitable design criteria

Intention to electrify a rural or a remote area should not only focus on least cost technical solutions. It is important to note that the success of hybrid mini grid projects that can adapt to local conditions is likely to be higher compared with a project that requires end-users to adapt to it. The importance of local conditions should be recognized during the project design phase. Moreover, a project's robustness and resilience to failure is another important criterion. Projects that can continue to perform at some level during failure are more likely to secure end-users' confidence in the system, a propitious indicator to project success and sustainability. Robustness and resilience are likely to be more valuable from the perspective of end-users than high levels of efficiency.

F. Capacity building on technical, non-technical and institutional aspects

It is very important that the process of developing the technical skills, infrastructure, and institutional capabilities such as legislation, policies and standards in a developing country like Fiji is formal, structured and resourced. The process must also be seen as a continual one with the clear intention of attaining greater competency, achieving self-sufficiency and greater efficiency in dealing with issues related to hybrid mini grids locally. Again, the involvement of all stakeholders is essential in capacity building.

G. Subsidy, tariffs and business model

Appropriate tariff structures are one of the key factors in project sustainability. A subsidy (or even large donations) can aid in setting appropriate tariff rates that may not only ease the financial burden of end-users but also have the capability of boosting private sector involvement. However, subsidy or donation schemes need to be accompanied by sustainable business strategies. Long-term dependence on on-going subsidies for a project put its longer term sustainability at risk. Models should be chosen so that they are practical and appropriate for the local context. This is not to underestimate the challenges of creating appropriate business models for rural electrification.

H. Education and training

It is important that end-users are well informed about the hybrid mini grid project and its technology before it commences. Each end-user should also be fully aware of the conditions for connection to the mini grid. The conditions should clearly outline the potential limitations of the system, the tariff and methods of payment. End-users should also be given education on energy efficiency products and information on how to better utilize the electricity service. In rural locations, end-users frequently try dubious and possibly illegal ways of using the project and such activities should be strictly discouraged by educating end-users of its consequences or impact on project operation and performance. They should also be given detailed consumer training on hybrid mini grid power system limitations and electricity usage.

The technicians responsible for operating the system and carrying out maintenance should fully be trained before the project is implemented. Further training must be provided over the lifetime of the project. Some form of incentive (for instances, appreciation of their presence and contributions, bonus pay or the like) should also be part of this training program in order to limit the migration of trained technicians to urban areas.

I. Operation, maintenance and management (OM&M)

OM&M is one of the key components towards the sustainability of the hybrid mini grid. The budget or cash flow schemes must be planned from very beginning such that the OM&M costs are well covered and managed over the project's lifetime. A particular challenge is the potential

lumpiness of some O&M expenditure such as in the case of major unexpected equipment failure.

J. Monitoring, project evaluation and research

After implementation, hybrid mini grid projects should never be left to survive, or fail, on their own. Operation and performance must be monitored and the project must be evaluated (technically and financially) periodically over the lifetime of the project. Apart from the evaluation reports, a database on problems and failures must be developed and well maintained. Unless evaluation reports and database on failures are available, it is difficult to determine the areas where greater efforts and research emphasis should be placed and what future improvements can be made.

VI. CONCLUSIONS

A successful hybrid mini grid power system must be both cost-competitive and reliable. The reliability of such a system is not only a technical issue but is also influenced by the background conditions of rural areas, for instance poor infrastructure, difficult accessibility due to remoteness of site or lack of trained personnel. It should also be noted that mature standards and best practices are already available globally for hybrid mini grid systems and can be deployed locally, that is in Fiji. However, a prime problem with adoption seems to be a lack of awareness of those standards by those involved in designing hybrid systems as well as a lack of clear best practices and regulatory guidelines for applying them in local conditions.

Moreover, a lack of understanding of the technology, limited knowledge of regulatory frameworks, overlooking of site specific aspects that require substantial preparation and development in order to match local requirements with the technologies, lack of training for system operators and the failure to incorporate lessons learnt from past experiences; all contribute to hybrid mini grid to fail or significantly underperform.

The costs of poorly implemented hybrid mini-grids are invariably high. Beyond the expense of the system itself, such failures risk the loss of any potential future donors, create complications in tariff structure (as loss of confidence in systems due to reliability issues will naturally develop resistance in end-users to pay for the service) and create potential barriers for their greater deployment in future.

In order to avoid such future scenarios, the suggested guideline if followed could prove its usefulness not only in Fiji but in other Pacific Island Countries too.

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