Challenges of Sustainable Solar Power Generation in Small Tropical Island Nations Such as Fiji Island

Akshay J Sahay
School of Engineering and Technology,
Central Queensland University
Perth, Western Austrailia
akshay.jsahay@yahoo.com

Andreas Helwig
School of Electrical and Mechanical Engineering
University of Southern Queensland
Toowoomba, Austrailia
Andreas.Helwig@usq.edu.au

Ziyad Abunada
School of Engineering and Technology
Central Queensland University
Melbourne, Austrailia
z.abunada@cqu.edu.au

Narottam Das
School of Engineering and Technology
Central Queensland University
Melborune, Austrailia
n.das@cqu.edu.au

***Abstract*—Small Tropical Island Nations such as Fiji Islands are under constant pressure to find effective, renewable, and sustainable means of generating energy. This paper is an investigation into quantifying challenges in designing sustainable PV systems for reliable and resilient energy supplies for isolated and vulnerable island communities' long term. Conclusions include an overview of challenges faced by small communities to establish sustainable solar power generation solutions.**

Keywords—Solar Power Generation Systems, PV Systems, Tropical Island Nations, Isolated and vulnerable communities, Sustainable PV Systems, Long term sustainable energy solutions

I. Introduction

In recent years, the global use of both domestic and large-scale solar farms for power generation have dramatically increased to meet the growing energy demands of the world. This has exposed PV technology to an array of different environmental and logistical conditions which raises questions regarding long-term sustainability of such systems. In 2017, Konges and team reviewed 1,211 Photo Voltaic (PV) systems globally as a longitudinal study of reliability and failure or degradation mechanisms found over a 20-year period of PV operation [1] [2].

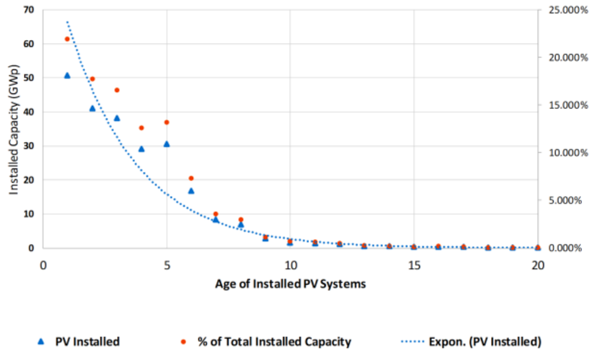

Figure 1Age profile of installed PV generation capacity installed in 2017, spanning the past 20 years backwards from the time reference [1]

Figure 1 above shows the trends of age of installed capacity from data as identified in the report by Konges and team. The near exponential growth of PV generation systems can be attributed to the significantly reduced cost of PV manufacturing and installations over the past 15 years. Whilst PV energy generation has become mainstream and the technology is continued to be refined from a efficiency in generation point of view, there is still a question regarding the reliability of solar energy generation. That is, "Will PV systems be able to reliably provide electrical energy to electricity grids over its nominal expected life of between 20 – 25 years?" This will than need to be compared against:

- Diesel IC engine alternators (1-100MW) with an 8 year on-line operational life to overhaul, with a usual useful operational life to 35 years.
- LPG Gas Turbine with up to 30 years of operational life.
- Steam coal thermal turbo generator with an expected operational life of 35 – 60 years.
- Hydro electric generation systems with an expected operational life of over 100 years.

The above-mentioned conventional fossil fuel-based energy generation systems and hydro electric generation system have quite specific maintenance and overhaul processes that needs to be undertaken to ensure increased efficiency and optimised maximum lifecycle. For PV systems, there are two operational expectations from the public, these are:

- PV systems will last 25 years or more.
- PV systems are installed and left to operate with maybe only cleaning operations to be undertaken to maintain electricity energy output.

Recent reliability studies of PV systems have brought to light several negative trends in the resilience of PV energy generation. Public perception of renewable energy expectations of life, reliability and utilisation factors may not be fully met or understood.

As part of this investigation, an initial survey was undertaken globally with a look then specifically at impacts on tropical island nations that are currently turning more and more to renewable energy for electricity generation. Both large population centres and remote island generation are using more installed PV capacity to supply domestic electricity. The impact of PV system reliability and energy production capacity over its life, is critical to providing electricity to a widespread population of the Indo-Pacific islands and national regions associated.

II. General PV Energy Reliability Trends Globally

Following are summaries of several prominent surveys and investigations into PV panel degradation and failure mechanisms, along with co-generation DC/AC inverters that are used for solar array string conversion for AC mains power use, or injection into electricity grids.

Realini and team carried out one of the first longitudinal studies of a 10kW PV ARC 16-2300 array of module coupled with a TISO Inverter with modules operating over the 21-year period 1982 to 2003 [3]. Their findings were:

- 59% of PV modules exhibited a decrease of lower than -10% capacity over this period;
- 35% of PV modules resulted with a -16% of energy generation capacity;
- 6% accumulated degradation of greater than -20% reduced generation capacity,
- The overall array after 21 years was producing 88.5% of the initial commissioned capacity.

Reviewing the operational data for this longitudinal study also revealed that average capacity loss for the first 16 years of generation was -0.386%/annum, while in the last 5 years, this rate of capacity loss had increased to -1.2%/annum average for this period. Overall, the system was still operating satisfactorily, but one PV panel junction box had severely corroded, and the internal connections and junction box needed replacement to repair the solar panel. In general, this system was operating overall at greater than the normal guarantee at 20years operation to be at 80% of original generation capacity at commissioning. This system used quite expensive earlier generation mono-crystalline panel.

Moser and team provided a financial and risk technical briefing under the EU H2020 scheme funding the Solar Bankability project. Here 772 PV system plants of generation rating of 442MW involving over 2.4 million components of average operational period of 2.7 years. These PV systems surveyed included 2 million solar panels and 12,000 inverters. On average it was found that affected components occurred at a rate of:

- 12%/annum for PV modules (including shading and soiling).
- 8%/annum for PV inverters.

Of these affected components, the following failure modes overall for PV systems were most common:

- 40.3% due to soiling or shading issues, which appear to be major siting and possibly pollution related issues in the EU.
- 23.2% due to panel faults, which from the average of the panels at 2.7 years would be considered infantile failures and appears to be quite high with half of these related to EVA discolouration, and another quarter related to glass breakage (i.e., residual manufacturing internal stress, transport / installation issues and weather events). In the overall picture of panel infantile faults (excluding weather events and other potential induced degradation [PID] issues) appears to be nominally 4.38%/annum. This indicates the infantile failure rate for the average operation of 2.7 years is 11.84% due to EVA discolouration, which to the authors indicates issues in the manufacturing process in the use/application of the EVA encapsulant materials and any additives.
- 37.5% due to inverter failure (again considered as infantile failures) giving an indication of life endurance of an expected 7.2 years for inverters. Various thermal related failures were responsible for over 60% of the inverter failures.

Kontges and team provide a report of Performance and Reliability of Photovoltaic Systems (Subtask 3.2 Review of Failures of Photovoltaic Modules) as directed by the EU IEA PVPAS Task 12 March 2016 ISB 978-3-906042 requirements. Failure rates listed in this report were based on investigation of customer complaints for PV systems that involved approximately 2 million PV panels delivered during the period 2006 to 2010, or a five year period within the EU. Again referring to figure 1 that had an end date of 2017, this period of investigation based on customer complaints covers modules that were installed in the transition period of initial growth in the renewable industry since installation rates accounts for nominally 6.0% of the total installed capacity in 2017. The results of the report findings are tabulated in table 1. As shown in this table, there is a total of 1.15% faulted PV panels per year. For the infantile failure period to 6 years this would accumulate up to 6.71% of panels in this EU survey could defective out of approximately 2 million PV panels estimated to be involved in this report.

Table 1: Summary of Customer PV Fault Complaints 2006-2010

PV Panel Complaint	% total complaints	% of total 2 million PV Panels	Comments	MTBF from Customer Fault Reports in1st 5 years	
Optical Defect (AR Coating damage / soiling)	20%	0.400%	Variety of reasons (AR coating, shading, contamination, dust, pollution)	0.000625	/year
Power loss	19%	0.380%	(Cell breakage, internal corrosion,	0.00065789	/year
J-box and cables	19%	0.380%	Installation / manufacture infant	0.00065789	/year
Glass breakage	10%	0.200%	(Weather events mainly)	0.00125	/year
Defective Cell Interconn	10%	0.200%	Normally a mid-life failure	0.00125	/year
Loose Frame	6%	0.120%	Installation / manufacture infant	0.00208	/year
Transport damage	5%	0.100%	Installation / manufacture infant	0.00250	/year
Delamination	5%	0.100%	Normally a fatigue mech/flexure	0.00250	/year
		Total	0.011524 / year or	1.15%	/year

Klise and team recently conducted an operations survey of PV systems (large and small) in Arizona between the years of 2007 and 2015 [4]. Some of these systems reached 30 years of operation by 2015. Referring to figure 1, these systems operational data investigated would put these panels between >20 years of age to 2 years of age. This report covers 189 PV systems representing 780MW (DC) generation capacity, involving over two and a half million panels, and 1,132 co-generation inverters. The faults logged were representative of issues with 510MW (DC) generation capacity (i.e., the faults / failures were logged across 65% of the systems whose data was examined). The following table 2 summarises the findings, noting that a fault does not necessarily indicate a total system failure. Referring to figure 1, these panels would be from the cohort of 60% of the 2017 installed capacity of PV systems globally.

Table 2: Summary Fault/Failure Statistics for 189 PV systems in Arizona 2007 - 2015 period operation.

Fault/Fail	Incidence	Calculated MTBFault (over 8 year period)
Inverters	1227	7.38 years
Grid connection	109	13.87 years
Combiner connections	79	19.14 years
Envionmental Impacts	36	42.00 years
AC disconnect	36	42.00 years
String failures	32	47.25 years
Module failure	30	50.40 years
Tracker (single axis)	23	65.74 years

From this the main area of concern is the inverter 7.38 years MTB Fault/Failure, and grid connections of 13.87 years MTB Fault/Failure. This latter fault could also be likely to be connected to inverter issues. This indicates for this cohort of PV systems, that the inverters will not last the expected 12 -15 years to renewable industry normal projected life. Other than that, the dry hot environment tends to give good results, with only normal electrical connection fatigue issues (i.e. Combiner connections) and some bypass diode failures (as indicated by the low number of module failures). The report summarized the outcome of maintenance and maintenance observations by industry specialist organizations as follows:

- 0.5 - 5% infant failures within first 2 year period; additional 2% with Diode failures;
- Cell interconnect breakage = 2.5% to 7.5% range of PV panel failure by 10 years of service;
- 3% accumulated degradation of anti-reflective coating damage,
- 10% degradation due to EVA encapsulant discoloration,
- 30% degradation due to delamination or cracked cell isolation.

Konges's report and derivation from figure 1, also reported the following findings looking at infantile, mid-term and end of life (EOL) fatigue faults / failures. The data for review was more global than the other surveys mentioned. Most data were collected in order of significance from the EU, Australia, USA, India and China PV systems. Data sample weightings for environ climate were:

- Moderate Climate => 45%
- Hot/Dry Climate => 26%
- Cold & Snow Climate => 19%
- Hot & Humid Climate => 10%

Reviewing the data presented and analyzing into manufacturing/transport/installation, early operation failure, mid-operation failures and EOL fatigue failures, and then collated are presented in figures 2 and 3. In figure 2, failures do not mean total failures, but includes observed degradation. Figure 3, however, are the failures that resulted in measurable PV system power loss.

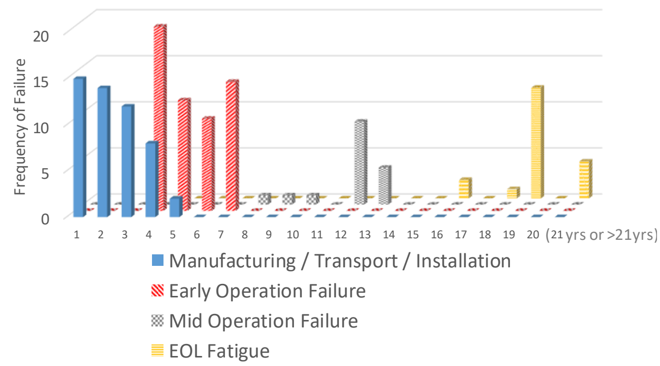

Figure 2: PV Panel Degradation for Könges M, et al, Global Survey 2017

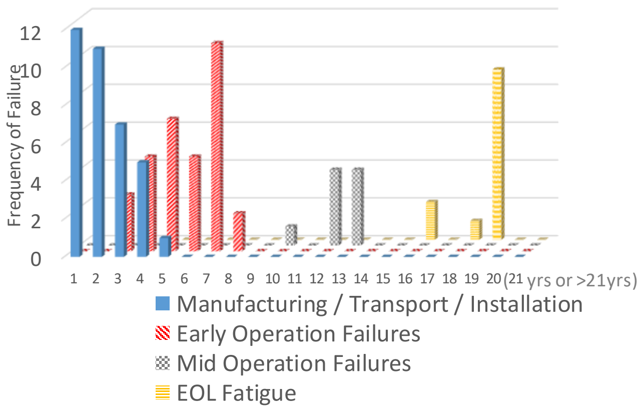

Figure 3: PV Panel Failure Causing Measurable Power Loss for Könges M, et al, Global Survey 2017.

From this survey, the worrying trend is the number of failures occurring due to Manufacturing / Transport / Installation and early operational failures (or latent manufacturing faults). However, this is tempered with the fact that in the year ages of 1 to 9, this indicates the failures have occurred in the bulk of panels (i.e. 95%) of all panels or 221GW of 230.6 GW globally installed capacity. So, the infantile failure are skewed towards this large group of panels installed from 2009 – 2017. Taking the panel numbers installed for each year of age as a base, then the failure rate curves can be developed from figures 2 and 3 to give figure 4.

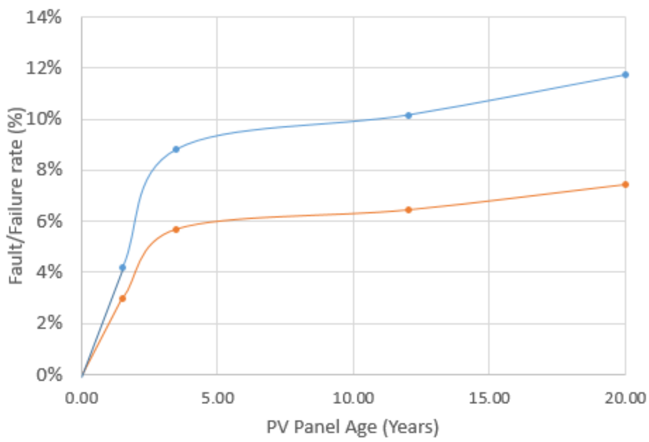

Figure 4: PV Panel Degradation Fault (i.e. upper curve) and Failure Rate (i.e. lower curve) Causing Measurable Power Loss for Könges M, et al, Global Survey 2017.

Figure 4 now indicates that there is an infantile/early operations failures impacting PV generation capacity for up to 8 years where it tapers off to around 6.5% in total failures. This global based data then in general agrees with the findings of Köntges M, et al, (2016) results discussed earlier that was based purely on EU figures. This remains a significant number of early failures up to year 8 that impacts the early generation capacity of a significant number of PV panels. Add to this the findings in USA that average MTBF for cogeneration PV inverters also coming into the first 8 years of operations, there is a suspicion that the expectations for generation capacity of large or small PV arrays in remote places, and especially may not live up to expectations in the tropical conditions in the Indo-Pacific Island nations.

III. Specific Impacts on PV Energy Due to Tropical Island Environs

There was a specific recent excellent report that begins to highlight other long-term design and specification best-practice issues for Indo-Pacific Island nations. Howard Lu's report prepared for Asia Pacific Cooperation Secretariat looking specifically at a maritime tropical island based longitudinal study of a PV system on Pengu Island that first came into operation in 1999 [5]. Since then, it has undergone significant maintenance in 2007. The PV system on these islands was again re-inspected in 2016. During the longitudinal review of the systems operation, the inverter was the shortest life component with a nominal life of 3 to 5 years. The findings of fault/failures can be summarized by the following in order of priority of inspection results in 2016 for the PV panel failures:

- Corrosion of panels / frame / junction box / connections => 69%
- Broken Cells => 10%
- Bypass diode failure => 10%
- Non-performance => 7%
- Ground Faults => 4%

Salt laden air was the main factor in corrosion in this island's environ, that experiences extreme summer heat and cool moist storm conditions. PV panels that had holes punched in the panel construction members with no secondary anodizing were found to have severe mounting corrosion, particularly that they were also mounted on steel support frames. Galvanic action had literally eroded away the mechanical frame with the result many panels' mountings was no longer fully secure. This could also account for the 10% broken cells as panels flexed and lifted with the loss of one or more mechanical mounting points in stormy windy conditions. Corrosion in the junction box and connectors also suffered from salt air conditions. Bypass diode failure was related to the thermal cycling of the junction box over many years resulting in both movement/corrosion attack on the flex mountings. Corrosion erosion of aluminum and copper connections, and the inability to stop salt related galvanic corrosion needs accounting for in current PV system designs, as well as a best practice specification for PV Systems for remote tropical island renewable systems.

IV. Conclusion:

In conclusion, further investigations are required over a period to fully validate long term sustainability of solar power generation systems. From the studies to date, it can further be concluded that the geographical location of a PV power generation system is important as the environs and the local climate has an impact on the performance and the life cycle of the system.

A. Authors and Affiliations

Akshay Sahay: is a registered Engineer in Electrical and Electronics Engineering currently completing a PhD. Akshay is affiliated with Central Queensland University, University of Southern Queensland, and Curtin University in various capacities.

Andreas Helwig: is an Associate Professor of Electrical and Electronics Engineering at the University of Southern Queensland.

Ziyad Abunada: is an Associate Professor in Project Management and Asset Management at Central Queensland University.

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VI. References

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