THE MALDIVES NATIONAL UNIVERSITY

Application for MNU Research Grant

For Full-Time Staff and Higher Degrees Students

Information and Instructions. Full-time staff of MNU regardless of rank or duration of service at the university may apply for financial assistance to undertake research projects. Full-time research students (doctorate or masters by research) may also apply for a research grant. The funds are contestable and limited, and once a certain category of available funds is exhausted, no further funds will be available even if there are strong applications. The full application, including the detailed research proposal and other attachments MUST NOT EXCEED 25 pages.

For further details including eligibility and selection criteria please refer to the MNU Research Grants Committee & Guidelines found at http://mnu.edu.mv/index.php/research

LEAVE BLANK — FOR OFFICIAL USE ONLY		
APPLICATION RECEIVED		**APPLICATION NUMBER**
DATE / /	TIME :	
SELECTION MEETING	MONTH YEAR	
REVIEWED BY *(URGC Members)*	1.	
	2.	

GRANT CATEGORY

1a. GRANT APPLYING FOR	**1b.** AFFILIATION TO MNU	**1c.** HAVE YOU RECEIVED A RESEARCH GRANT FROM MNU BEFORE?
☐ Small (≤10K) ☐ Medium (≤100K) ☐ Large (≤1 Million)	☐ STAFF ☐ STUDENT	☐ YES ☐ NO

APPLICANT'S DETAILS *(Provide the relevant details of the principal investigator and the co-investigator. List other researchers in section 10).*

2. PRINCIPAL INVESTIGATOR *(The principal investigator/applicant must be a full-time staff of MNU or a full-time higher degrees student of MNU.*

2a. FULL NAME MUAVIYATH, MOHAMED	**2b.** HIGHEST QUALIFICATION PhD
2c. NATIONAL IDENTITY CARD NO.	**2d.** MNU STUDENT NUMBER
2e. POSITION TITLE DEAN	**2f.** MNU COURSE TITLE
2g. FACULTY/DEPARTMENT, SERVICE, LABORATORY, OR EQUIVALENT FET	**2h.** MAILING ADDRESS *(Street, city, island)*
2i. TELEPHONE AND FAX *(number and extension)*	**2j.** E-MAIL ADDRESS
TEL: FAX:	muaviyath.mohamed@mnu.edu.mv

2k. RESEARCH BACKGROUND (*Provide a summary of recent research activities and research outputs. Attach a brief CV with a list of recent publications).*

3. CO- INVESTIGATOR ***(****A full time researcher or a higher degrees student of MNU or a research collaborator from an external research institution).*

3a. FULL NAME RIFATH MOHAMED	**3b.** HIGHEST QUALIFICATION
3c. NATIONAL IDENTITY CARD NO.	**3d.** MNU STUDENT NUMBER
3e. POSITION TITLE	**3f.** MNU COURSE TITLE
3g. INSTITUTION, FACULTY/DEPARTMENT, SERVICE, LABORATORY, OR EQUIVALENT FM, MNU	**3h.** MAILING ADDRESS *(Street, city, island)*
3i. TELEPHONE AND FAX *(number and extension)*	**3j.** E-MAIL ADDRESS
TEL: 7781503 FAX:	

3k. RESEARCH BACKGROUND (*Provide a summary of recent research activities and research outputs. Attach a brief CV with a list of recent publications).*

PROJECT DETAILS

4a. TITLE OF PROJECT. *Do not exceed 80 characters, including spaces and punctuation.*			
4b. HUMAN SUBJECTS' RESEARCH? ☒ No ☐ Yes	**4c.** CLINICAL RESEARCH? ☒ No ☐ Yes	**4d.** VERTEBRATE ANIMALS? ☒ No ☐ Yes	*If 'Yes' to any of the items in 4b-4d, you should submit ethics approval before funding is disbursed.*
4e. DOES THIS PROJECT INVOLVE EXTERNAL AFFILIATION(S) ☒ No ☐ Yes	*If Yes, provide contact details of main research officer involved and any agreements signed with the institution.*		
	4f. NAME AND ADDRESS OF THE AFFILIATED INSTITUTION		
4g. DO YOU HAVE INSTITUTIONAL SUPPORT FOR THIS PROJECT ☐ No ☐ Yes	*If Yes, attach a supporting letter from the head of faculty/center justifying the alignment of the research with the strategic direction of the university and national research priority areas.*		
	4h. REGISTERED PROJECT ☐ No ☐ Yes	**4i.** *If Yes,* provide the PRC REG. NUMBER	

4j. SUMMARY OF RESEARCH PROPOSAL. *In no more than* ***500 words*** *provide a summary of the research proposed including the aims, significance, methodology and expected outcomes. All applications MUST accompany a detailed research proposal using the sample template provided.*

This project involves the comparative study of two types of photovoltaic (PV) power generation systems in two atoll campuses (Hithadhoo Campus and Thinadhoo Campus) to assess their impact on electricity bills, and to evaluate their technical performance. One system of 10 kW will be installed on a building in Hithadhoo Campus and will use string-type inverter. Another 10 kW PV system will be installed on a similar building in Thinadhoo Campus but will use microinverters and will be rated at the same power.

Overseas experiences are restricted to mainly evaluations of string inverter PV systems. This comparative study of equal power string and micro- inverter systems is novel and unique. The project will support Government's drive to increase the penetration of PV in electricity generation at the same time contributing to reduce greenhouse gases and recurrent costs of the two campuses. The project will also improve the technical know-how and performance evaluation of PV systems within the country. Significantly, the project will be a laboratory for staff and students to gain experience in a sizeable PV installation.

PROJECT DURATION & FINANCE

5. DURATION. *Indicate the expected total duration of the project and the proposed period of financial support requested.*		
5.1 PROJECT START DATE 01 / 09 / 2014	**5.2** PROJECT END DATE 01 / 08 / 2015	**5.3** PROPOSED PERIOD OF SUPPORT REQUESTED FROM: 01 / 09 / 2014 THROUGH TO: 01 / 08 / 2015
6. FINANCE. *Provide the total budget estimated for the project comprising of 'direct costs' and 'in-kind' support from all the participating institutions including MNU.*		
6.1 TOTAL DIRECT COSTS (MVR) 1806000	**6.2** TOTAL 'IN-KIND' (MVR) 0	**6.3** TOTAL BUDGET (COST) OF THE PROJECT (MVR) 1806000
6.4 TOTAL FUNDS REQUSTED (MVR) 1806000	**6.5** APPLIED FOR EXTERNAL FUNDING? ☒ No ☐ Yes	**6.6** If Yes, the name of the EXTERNAL FUNDING AGENCY

7. BUDGET SUMMARY. *Provide estimated budget and justification for each category of expenditure for the entire project. Categories may include personnel, equipment, travel, dissemination, consultants, transport and other direct costs. Grants are available for a maximum of THREE years.*

CATEGORY	**Year 1**	**Year 2**	**Year 3**	**Justification for expenditure**
7.1 DIRECT COSTS				
7.1a.SALARIES/WAGES/FEES				See in detailed budget sheet
7.1b. EQUIPMENT	850,000	824,000		See in detailed budget sheet
7.1c. TRAVEL	66,000	66,000		See in detailed budget sheet
7.1d. DISSEMINATION				See in detailed budget sheet
7.1e. OTHER EXPENSES				
SUB TOTALS (PER ANNUM)				
TOTAL DIRECT COSTS (MVR)		1,806,000		(ONE MILLION EIGHT HUNDRED SIX THOUSAND)
7.2 IN-KIND SUPPORT				
7.2a. MNU 'IN-KIND'				
7.2b. EXTERNAL 'IN-KIND'				
TOTAL 'IN-KIND'				
TOTAL PROJECT COST (MVR)				**TOTAL RESEARCH GRANT APPLICATION (MVR)**

8.1 PROJECT KICK-OFF FUNDING REQUESTED ☐ No ☒ Yes	*If a portion of the total direct costs is required to initiate the project, give the total amount of the kick-off funding requested with justification for the expenditure.*
8.2 TOTAL AMOUNT REQUESTED (MVR) 850000	JUSTIFICATION

9. PROJECT MILESTONES. *Funds may only be disbursed after completion of the relevant milestones given below. For any additional items, include a separate sheet.*

MILESTONE	DATE OF COMPLETION	DELIVERABLE	DISBURSEMENT TO BE REQUESTED
1 Conclude baseline electricity expenditure and usage study	1 Aug 2015	Complete specification of the PV Systems	
2			
3			
4			
5			

10. OTHER RESEARCHERS OR KEY PERSONNEL. *List other key members of the research team. If more researchers are involved, use continuation pages as needed to provide the required information in the format shown below.*

10.1a.NAME	**10.1b.** HIGHEST QUALIFICATION	**10.1c.** ORGANIZATION	**10.1d.** ROLE ON THE PROJECT
ALI MOHAMED		MNU	ASSISTANT
10.1e. FACULTY/DEPARTMENT, SERVICE, LABORATORY, OR EQUIVALENT FET			

10.2a. NAME	**10.2b.** HIGHEST QUALIFICATION	**10.2c.** ORGANIZATION	**10.2d.** ROLE ON THE PROJECT
HASSAN HAMEED	PhD	MNU	FALLBACK PRINCIPAL INVESTIGATOR
10.2e. FACULTY/DEPARTMENT, SERVICE, LABORATORY, OR EQUIVALENT CHANCELLORY			

11. ADMINISTRATIVE OFFICIAL *(For correspondence only)*			
11a. FULL NAME	MUAVIYATH, MOHAMED		
11b. TITLE	DEAN		
11c. FACULTY/ADDRESS	FET		
11d. TELEPHONE	3345400	11e. FAX	
11f. E-MAIL	muaviyath.mohamed@mnu.edu.mv		

DECLARATION. *The principal investigator must sign the application as the legal representative. (In ink. "Per" signature not acceptable.)*		
PRINCIPAL INVESTIGATOR	☐ *I certify that the statements herein are true, complete and accurate to the best of my knowledge, and accept the obligation to comply with MNU terms and conditions if a grant is awarded as a result of this application. I am aware that any false, fictitious, or fraudulent statements or claims may subject me to criminal, civil, or administrative penalties.*	
NAME MUAVIYATH, MOHAMED	SIGNATURE …………………………………..	DATE 01 / 09 / 2014

APPLICATION CHECKLIST. *Tick the relevant boxes below to confirm that you have attached all the necessary documentation with your application.*

- ☒ Completed MNU Research Grant application form with signature of the principal investigator
- ☒ A copy of national ID card of the principal investigator
- ☒ Detailed research proposal (as per the research proposal template provided)
- ☒ A brief CV of the principal investigator including a list of recent publications (2 pages maximum)
- ☒ A brief CV of the co-investigator including a list of recent publications (2 pages maximum)
- ☒ Supporting letter from head of faculty/centre for staff applications, indicating absence of potential conflicts with assigned workload.
- ☐ Supporting letter from principal supervisor for higher degrees student applications
- ☐ Letter or agreement from affiliated institutions involved in this research where applicable

RESEARCH NARRATIVE

The project narrative provides the meat of your proposal and may require several subsections. The project narrative should supply all the details of the project including a detailed statement of problem research objectives or goals hypotheses Methods procedures outcomes or deliverables and evaluation and dissemination of the research. In this section you should present the reviewer with the information necessary to understand what is known in your field of study and why this led you to propose this experiment. This section could also include any general background information about the methods used and other work done in the field if there is no separate literature review. You will need to clearly link your research objectives research questions hypotheses procedures and how you would arrive at the outcomes

PROJECT SUMMARY

This section clearly and concisely summarizes the request. It should provide the reader with a framework that will help him/her visualize the project. The remainder of the proposal will then serve to deepen and amplify the "vision" presented in the summary section at the beginning.

Maldives faces a serious energy crisis. The total energy consumption has been increasing at more than 10% per year. Petroleum imports accounted for 31% of GDP in 2013. In fact, petroleum products constitute the largest category of imports. More than 50% of the oil imported is used for electric power generation. Aware of the gravity of the burgeoning oil imports for the economy and to reduce greenhouse gas emissions, the Government plans to produce 50% of the electricity needs from renewable energy by 2020. Further, the expenditure on electricity at atoll campuses is growing rapidly reducing funds available for staff and operations of MNU.

This project involves the comparative study of two types of photovoltaic (PV) power generation systems in two atoll campuses (Hithadhoo Campus and Thinadhoo Campus) to assess their impact on electricity bills, and to evaluate their technical performance. One system of 10 kW will be installed on a building in Hithadhoo Campus and will use string-type inverter. Another 10 kW PV system will be installed on a similar building in Thinadhoo Campus but will use microinverters and will be rated at the same power.

Overseas experiences are restricted to mainly evaluations of string inverter PV systems. This comparative study of equal power string and micro- inverter systems is novel and unique. The project will support Government's drive to increase the penetration of PV in electricity generation at the same time contributing to reduce greenhouse gases and recurrent costs of the two campuses. The project will also improve the technical know-how and performance evaluation of PV systems within the country. Significantly, the project will be a laboratory for staff and students to gain experience in a sizeable PV installation.

INTRODUCTION

Maldives faces a serious energy crisis. According to JICA (2009) the total energy consumption has been increasing at more than 10% per year. Already, petroleum imports accounted for 31% of GDP in 2013. In fact, petroleum products constitute the largest category of imports. Compared to 2011, the expenditure on fuel rose by 33% in 2012. Electricity generation consumed the largest share of the imported fuel (Ministry of Economic Development, 2013). Dependence on imported fuel is a serious impediment to national development. The population increase envisaged in the future is likely to exacerbate the crisis.

One of the most viable ways of mitigating the energy crisis would be to invest in renewable energy. Of different forms of renewable energy available to the Maldives, namely, geothermal, wind, ocean current and solar, photovoltaic (PV) solar power systems appear to be most promising. Maldives does not have regular strong winds nor rivers for hydroelectric power generation—two of the most common renewable energy resources in other countries. However, Maldives is blessed with a solar irradiation intensity of average 5.2 $kWh/m^2/day$ for most days of the year (JICA, 2009). The average sunshine hours are 2784.5 per year. This level of irradiation is promising for most solar energy applications. PV solar power has the following advantages: the technology is mature, cost almost at par with diesel engine generated electricity, scalable, the systems are modular, and energy availability is not location-specific.

However, despite the advantages the take-up of PV systems has been rather sluggish. Of the 250 MW installed capacity of electricity generation, just over 2 MW or 0.8% constitutes PV systems (Ministry of Economic Development, 2013). In terms of national development greater utilization of solar energy, more particularly PV systems is a necessity. In fact, the Government wishes to ensure that 50% of power generation by 2025 is by renewable energy (Ministry of Economic Development, 2013). A number of initiatives to encourage businesses and the public to invest in PV systems has been proposed, but, at present, they are not well implemented.

Statement of the Problem

Against the above background one notes that the rising energy usage. Both JICA (2009) and the Ministry of Economic Development (2013) notes that the electrical energy usage has been rising at a value greater than 10% annually. This level of growth will impact the recurrent costs of public institutions harshly especially at a time of national austerity.

Figure 1 shows the utility charges for the atoll campuses of the Maldives National University (MNU), 2004–2013. It can be seen that for the past three years, the expenditure on utility charges has been increasing steadily. Because of the way accounting is carried for annual reports, the utility charge group includes postage though postage represents only a small, almost a negligible amount of the total expenditure. Water charges are excluded as municipal water connections were unavailable until the end of 2013.

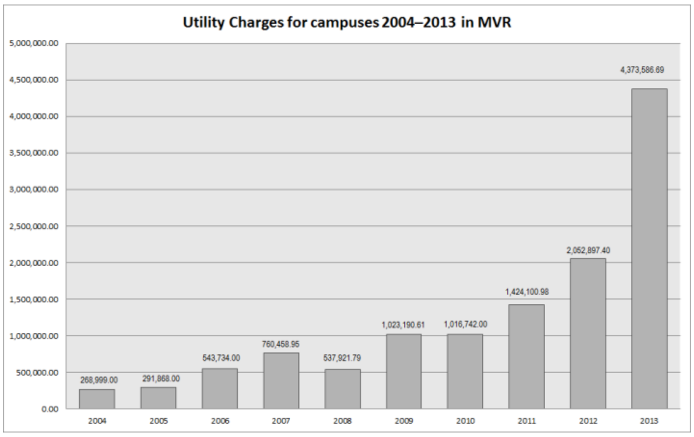

Figure 1. The expenditure on utility charges (mainly electricity costs) has been rising in the past four years.

From Figure 1, one observes that for the past five years, except for a slight dip in 2010, the trend is a rise in the expenditure on electricity. From 2012 to 2013, the expenditure has more than doubled. This increase is attributed to increased consumption of electricity arising from the establishment of the Gan Campus in Hadhdhumathi Atoll and other causes. Many teaching spaces previously not air-conditioned have been air-conditioned. The atoll campus operations have also become more extensive with night classes become regular activities. Electricity costs have also increased in the past few years.

Utility charges constitute the third highest expenditure of MNU after staff costs and expenditure on teaching resources. In 2013, it constituted 12% of the total expenditure. Air-conditioned working spaces are becoming the norm in public institutions; therefore, it is likely that the electricity costs would increase in the future. The increase would arise from increased tariffs due to global petroleum price increases and from air-conditioning more working spaces. Additionally, such spaces are used more regularly. Therefore, there is an urgent need to reduce electricity consumption and find other ways decrease the expenditure on electricity. Several energy conservation measures are already in place. In the future, further steps will have to be taken.

The proposed research seeks to install a 10 kW PV system on the roof of a classroom block in Hithadhoo Campus in Addu Atoll. Another system of equivalent power based on a different technology will be installed on Thinadhoo Campus. A classroom block has been especially constructed with PV power integration at design stage.

Research Objectives

The main research objective is to find out the impact of a 10 kW grid-tied system on the annual expenditure on electricity at two campuses. Other aims of the research are the following:

1. Improve the technical know-how and performance evaluation of PV systems.
   (a) Record system energy production
   (b) Calculate system efficiencies under various conditions of weather and cloud cover
   (c) Determine savings on expenditure on electricity and pay back periods under various conditions.
   (d) Calculate life cycle costs and system pay back periods.
   (e) Calculate greenhouse gases emissions averted.
   (f) Investigate different maintenance operations.
2. Develop opportunities for staff and students to gain experience in “real world” PV systems.
3. Support staff to incorporate real world PV systems in their teaching.
4. Evaluate investment risk in installing more PV systems in university energy systems.
5. Evaluate the design of the new green building for improved energy efficiency.
6. Compare the reliability and performance of string or central inverter based PV systems and microinverter based PV systems.

Hypotheses and Research Questions

One hypothesis that we wish to research in the proposed study is that it makes economic sense for MNU to invest in PV systems in the short term (5 to 7 years) in all atoll campuses up to at least 30% of the total electric power load during the day. There are three reasons why this hypothesis is plausible. First, the government will become increasingly concerned about the high expenditure on petroleum imports and the annual increase of over 10% of those imports. Therefore, the impediments to PV system imports and installations are like likely to reduce in the future. At the same time, incentives to install PV systems are likely to increase. Second, because of the burgeoning demand for PV systems globally, the costs of the systems are likely to reduce in the future due to economies of scale and better technological and stream-lined production methods. Third, the price of oil in the international markets has risen over the years and this increase is likely in the future, further making PV systems attractive. The second hypothesis is that microinverter based PV systems are more reliable and less prone to failure compared to central inverters because there is a greater redundancy built into the system.

The study will answer the following research questions:

1. What is the actual solar insolation or irradiation in Hithadhoo Campus and Thinadhoo Campus and how does it vary daily and across the months?
2. What are the differences in the PV system variables between the actual and computed or designed values?
3. What is the internal rate of return for the PV system?
4. What is the payback period for the PV system?
5. What are some of the issues in the maintenance and upkeep of the PV system?
6. How does microinverter based PV systems perform compared to central or string inverter based PV systems?

Significance of the Research Project

The significance of the PV system research project may be inferred from the statement of the problem outlined earlier. The project is significant for the following reasons.

1. An important goal of the Maldives economic diversification strategy is to ensure that 50% of the total installed capacity for power generation is derived from renewable sources by 2025 (Ministry of Economic Development, 2013). At present (2014), the percentage is 0.8 and with almost 10 years left to reach the goal, Maldives must accelerate its investment in renewable

energy, most notably PV systems. This study is aligned along the government goals and will encourage public institutions to invest in PV energy.

2. Since it is being installed in an MNU campus where electronics engineering is taught, the project will support training in PV system installation and maintenance. A functional medium capacity system (10 kW) can contribute significantly to future research and teaching. The project aims to obtain research data on performance and maintenance issues which will directly support research in this important area and assist to develop trained manpower in the discipline.

   The system will be setup to monitor the performance over varying parameters including temperature variations, shading effects, wind loading effects, the effect of dirt on panels and various configurations of individual panels. The system can enhance the delivery and content of existing courses. Students will be able to interact with a medium sized PV system through practical projects observing real-time performance parameters and making comparisons with numerical predictions and real data/modeling. Additionally, the emerging technology of microinverters is used in one system, giving staff and students opportunities to become familiar with this technology.

3. It is hypothesized that the system will payback costs of procuring and installation in about 5 to 7 years, decreasing recurrent costs on electric charges. The study will support further investments on renewable energy if the internal rate of return is attractive. The relative reduction on electricity will enable MNU to spend more in areas of needs.

Methods and Design of the PV Systems

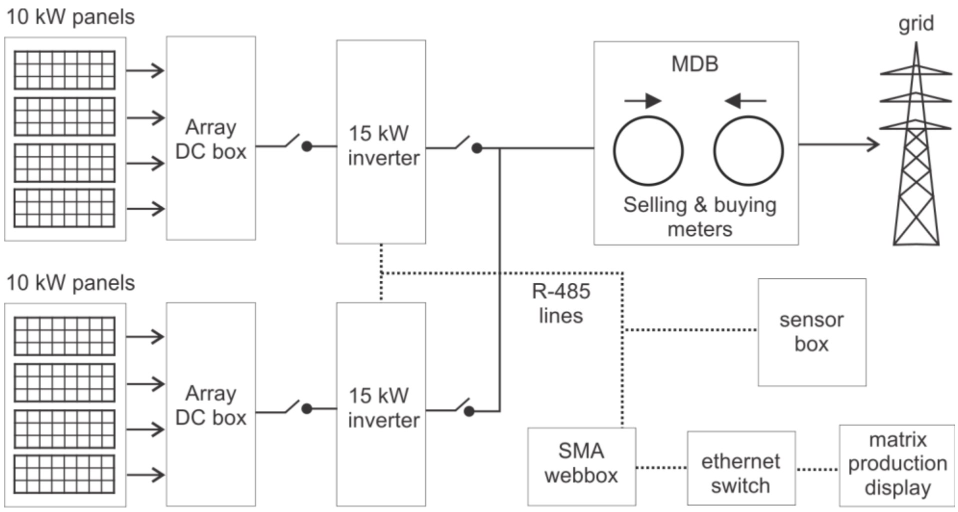

Figure 2. Proposed PV system for Hithadhoo Campus. There are two independent systems of 10 kW to spread risk. The latter system will be installed in the future through another project. The inverters are overrated following the findings of international evaluations of modes of failure of PV systems.MDB is the main distribution board or panel.

The reason 10 kW systems have been chosen is because the roof area available for the installation is about 20 metres by 11 metres. The maximum power that can be generated from the site using monocrystalline panels is about 30 kW. This would leave no room on roof for cleaning and maintenance. Generating 20 kW will leave 1/3 of roof surface free for access to the panels. It is to be noted that one 10 kW PV system is a future undertaking.

The irradiation data and energy produced will be collected from the pyranometer and from the sensors through electronic data loggers for the study period. The total energy produced by PV can be measured from energy meters; and the daily variation can be found out from logged data. The internal rate of return for the PV system can be calculated once the monthly electric energy produced is known. A log book will be kept for recording maintenance events so that issues relating to operation and maintenance of the system can be noted for reporting. Another system using microinverter technology located in Thinadhoo Campus will enable comparative performance analysis of central and micro- inverter based PV systems.

METHODOLOGY

The research will involve mainly fours steps: (a) specifying the PV system, (b) bidding for the procurement and installation of the system, (c) monitoring the performance of the system, and (d) disseminating the results.

One 10 kW PV string inverter system will be installed in Hithadhoo Campus New Block. This is a three storey building purposefully made for energy conservation with necessary facilities for PV on roof. In the future it is hoped to install another 10 kW system to complement the system installed in this project. The system specification for Hithadhoo Campus PV system will be the following or equivalent:

1. SMA 15000 SUNNY TRIPOWER 15000 TL or equivalent.
2. Monocrystalline PV panels to suit with a rated power of 10 kW. Installation hardware.
3. Sunny matrix display.
4. Ethernet switch.
5. PV System hardware (breakers, etc.) as required by MEA.
6. SMA Sunny webbox.
7. SMA Sensor box.
8. Meteorological weather station including pyranometer for irradiation measurements.

The system for Thinadhoo Campus will be the same except that the inverters will be microinverters to the required power of 10 kW. The system will be installed in a similar building in Thinadhoo Campus. A system level diagram of the Hithadhoo Campus installation is shown in Figure 2.

DETAILED BUDGET (Year 1)		
4.1 DETAILED BUDGET FOR INITIAL BUDGET PERIOD (YEAR 1 DIRECT COSTS ONLY)	**FROM** **AUG '14**	**THROUGH** **DEC '14**

SALARIES/WAGES/ALLOWANCES

NAME	ROLE ON PROJECT	Cal. Mnths	Acad. Mnths	Holiday Mnths	BASE SALARY	SALARY REQUESTED	ALLOWANCES	TOTAL
	Principal Investigator							
	Co-Investigator							
	SUBTOTALS →							
TOTAL SALARIES								NIL

EQUIPEMT AND SUPPLIES

EQUIPMENT *(Itemize)*	UNIT PRICE	QUANTITY REQUIRED	TOTAL
STRING OR CENTRAL TYPE INSTALLATION Roof top PV system 10 KW @ USD5.00 string type (installed) Ethernet switch W box Matrix display SMA sensor box	 US$5000 US$150 US$900 US$2000 US$100	 x 1 x 1 x 1 x 1 x 1	
TOTAL COST FOR PURCHASE OF EQUIPMENT			850,000

SUPPLIES *(Itemize by category)*	UNIT PRICE	QUANTITY REQUIRED	TOTAL
TOTAL COST FOR SUPPLIES			

TRAVEL Travel associated with monitoring, evaluation and dissemination	66000
OTHER EXPENSES *(Itemize by category)*	
TOTAL DIRECT COSTS FOR YEAR ONE	**MVR 916,000**

DETAILED BUDGET (Year 2)		
4.2 DETAILED BUDGET FOR INITIAL BUDGET PERIOD (YEAR 2 DIRECT COSTS ONLY)	**FROM**	**THROUGH**
	JAN '15	**JUN '15**

SALARIES/WAGES/ALLOWANCES

NAME	ROLE ON PROJECT	Cal. Mnths	Acad. Mnths	Holiday Mnths	BASE SALARY	SALARY REQUESTED	ALLOWANCES	TOTAL
	Principal Investigator							
	Co-Investigator							
	SUBTOTALS →							
TOTAL SALARIES								NIL

EQUIPEMT AND SUPPLIES

EQUIPMENT *(Itemize)*	UNIT PRICE	QUANTITY REQUIRED	TOTAL
MICROINVERTER BASED INSTALLATION (SECOND PHASE) Roof top PV system 10 KW @ USD5.00 (microinverter) 50000 System monitoring hardware 1500 Total in USD 51,500 **Total in Rf (assumes 1USD=1Rf, inflation) 824,000**	US$5000 US$150	x 1 x 1	
TOTAL COST FOR PURCHASE OF EQUIPMENT			824,000

SUPPLIES *(Itemize by category)*	UNIT PRICE	QUANTITY REQUIRED	TOTAL
TOTAL COST FOR SUPPLIES			
TRAVEL Travel associated with monitoring, evaluation and dissemination			66000
OTHER EXPENSES *(Itemize by category)*			
TOTAL DIRECT COSTS FOR YEAR TWO		**MVR**	**890,000**

SUMMARY OF BUDGET FOR ENTIRE PROPOSED PROJECT PERIOD (DIRECT COSTS ONLY)		
BUDGET CATEGORY TOTALS	**YEAR 1**	**YEAR 2**
PERSONNEL: *Salary and fringe benefits. Applicant organization only*.	NIL	NIL
CONSULTANT COSTS	NIL	NIL
EQUIPMENT	**850,000**	**824,000**
SUPPLIES		
TRAVEL Travel associated with monitoring, evaluation and dissemination	**66,000**	**66,000**
RESEARCH DISSEMINATION		
OTHER EXPENSES		
TOTAL DIRECT COSTS	**916,000**	**890,000**
TOTAL DIRECT COSTS FOR ENTIRE PROPOSED PROJECT PERIOD	**MVR**	**1,806,000**

4.4 SUMMARY OF IN-KIND SUPPORT FOR THE ENTIRE PROPOSED PROJECT PERIOD				
	MNU IN-KIND		**OTHER INSTITUTION IN-KIND**	
BUDGET CATEGORY TOTALS	**YEAR 1**	**YEAR 2**	**YEAR 1**	**YEAR 2**
TOTAL IN-KIND SUPPORT				
TOTAL IN-KIND COST FOR ENTIRE PROJECT PERIOD				

BUDGET JUSTIFICATION		
Budget justification should give additional information for each category of expenditure. Categories may include personnel, equipment, travel, dissemination, consultants, transport and other direct costs.	FROM	THROUGH

Category	Amount	Justification
Equipment	1,674,000	The equipment costs represent 93% of the cost of the total value of the project. The equipment is long lasting, carrying warranties of over 20 years in most cases. The solar PV panels constitute the major items of the equipment. The values were obtained were from those vendors who have been installing such systems in the Maldives. The value they quoted was USD5 per installed watt. This value was multiplied by the total power of the systems to get the final cost. It is expected that when RFBs (request for bids) are floated that the value will be somewhat lower. This lower cost will offset the cost of the larger inverter. The larger inverter was included because literature cites inverters to be the weakest item for long term reliability of the system. Literature recommends overrating inverter to be 60 to 100% of the PV system's rating. Other pieces of equipment were valued based on internet searches of their price adjusted appropriately for freight and markups.
Travel	72,000	Five trips to teach campus. Two during installation and three for data collection, maintenance and operational issues. Two persons travel in each trip. Includes food and accommodation costs.
Dissemination	30,000	Attendance at one international conference on PV held overseas. Includes registration fee, DSA. Two to three days. One person.

PROJECT TIME LINE AND MILESTONES

Explain the timeframe for the research project in some detail. A graphical representation is helpful. For simple time sequences such as single event requests, a table format may be sufficient. The project timeline will help reviewers to evaluate the planning and feasibility of the project. If the funding amount in large, the funds may be disbursed in phases. You may have to indicate the project progress in milestones with deliverables. Funding for a follow-on phase may be contingent on successful delivery of earlier milestones outcomes

The project is divided into two phases. The first phase is mainly about specifying, installing and commissioning the central inverter based PV system. The second phase is about installing the microinverter based PV system, monitoring, evaluating and reporting the findings. The activities of the phases and their timing are shown in Table 1 and 2.

Table 7.1. *Activities of the First Phase of the Project*

FIRST PHASE			**2014 Aug-Dec**					
Task	Status	Deadline	JUL	AUG	SEP	OCT	NOV	DEC
Create Project Website	Open	Jul 31						
Update Project Website	Open							
Conclude baseline electricity expenditure and usage study	Open	Aug 31						
Review specifications	Open	July 31						
Tender for bids	Open	Aug 1						
Award bids	Open	Aug 31						
Installation of equipment	Open							
Commissioning	Open	Dec 15						
Phase 1: Project Report	Open	Dec 31						

Table 7.2. *Activities of the Second Phase of the Project*

SECOND PHASE			**2015 Jan-Jun**					
Task	Status	Deadline	JAN	FEB	MAR	APR	MAY	JUN
Update Project Website	Open							
Bid for Thinadhoo system	Open	Jan 31						
Install the Thinadhoo system	Open	Mar 31						
Monitoring	Open							
Cleaning and maintenance	Open							
Data collection	Open							
Commissioning	Open	Dec 15						
Phase 1: Project Report	Open	Dec 31						

The results of the study will be presented at international conferences and papers will be written for relevant journals.

Milestones

1. Deliverable: Complete specification of the PV Systems. Due date: August 15.
2. Deliverable: Evaluation sheet of bids. Due date: August September 15.
3. Deliverable: Acceptance certificate of the commissioned systems. Due date: December 31, 2014
4. Deliverable: Interim report. Due date: March 31, 2015
5. Deliverable: Final report. Due date: July 31, 2015

7. RISK MANAGEMENT

The reviewers would want you to identify the financial and other risks involved, especially if the funding requested is large. You should identify the risks and their relationships, the impact of the risk and steps to mitigate the risks.

There are a number of risks associated with the project. The risks and the steps to manage the risk are as follows:

Financial Risks

- The installation of the PV systems does not take place before the end of the year. The funds remain undisbursed. *Management:* Reputable firms will be selected for installation.
- The hypothesis was not correct. The system does not deliver the economic benefits. *Management:* More than 93% of the funds are used to procure and install the PV systems which usually have a warranty of over 20 years. The payback time will be prolonged but in the end it would still benefit the institution.
- Costs estimated were incorrect and the funds allocated do not suffice to install the systems. *Management:* Estimates were obtained from reliable sources. The shortfall will be met by installing a PV system with reduced power. Additional funds may be sought from other sources.

Operational/Technical risks

- The system breaks down in a few weeks following installation. *Management:* The risks are low as PV arrays have a warranty of over 25 years. For Thinadhoo Campus, as microinverters are used, the risk is reduced to a single panel. MNU will try to include a warranty period for the system so the risks are transferred to the vendor.
- Investigator turnover disrupts project. A key investigator leaves MNU leaving the project in disarray. *Management:* More than one key or significant investigator is included in the project, each of whom can lead on the project in the event the primary investigator no longer works at MNU.

Strategic Risks

- FENAKA refused to connect the PV systems to the grid because of incompatibilities. *Management:* Prior agreement will be sought from FENAKA before awarding the bid. Risk will be transferred to the bidder by making compatibility a condition of awarding.
- PV system architecture is not fit for purpose. *Management:* The approval of experts in the area will be sought before floating Request for Bids (RFB). Additionally, PV technology is now almost risk-free in terms of their reliability.

Safety Risks

- There have been some safety issues with regard to PV system. Fires due to arching at joints and high voltage DC is the main issue. *Management:* Australian guidelines on PV installation will be insisted upon including double insulated DC cables and certified switches.

8. RESEARCH DISSEMINATION

No matter how ground-breaking hour research is, it will not make a difference unless you disseminate it to the relevant communities, in an appropriate and timely manner. Describe how you wish to disseminate your findings.

The findings of the project will be disseminated nationally and internationally through informal and formal channels.

1. *Policy-maker and community:* The findings will be disseminated to the policy makers as a report so that the project would have national impact. Additionally, the findings will be shared with MNU management so that decisions on further investments of PV can be considered.
2. *Journals and bulletins:* It is expected that the findings of this research will be of great interest to the research being done in grid-tied PV systems, especially because of the twin installations of equal power. We have not been able find any other study where there has been a comparison of microinverters and string inverters with the same power in a small island context.
3. *Conference presentations:* It is hoped that the results of the project will be interesting and exciting to the PV engineering audience in a conference context. We have accounted for participation in a relevant conference.
4. *News media, websites and social networks:* We hope to have regular updates of the project on a project website. Achievements at various milestones will be shared through news media and social networks.

Dissemination costs have been budgeted.

9. LITERATURE REVIEW

Proposals require a literature review. Reviewers want to know to be sure that you have done preliminary research are has sufficient competence to undertake your project. Literature reviews should be organized, selective and critical. Reviewers want to see your evaluation of previous and relevant

This review begins with a brief outline of PV usage in the Maldives followed by a discussion of PV systems in general with a special emphasis on grid-tied systems. Irradiation levels in the Maldives are then outlined. A short review of the components of grid-tied PV systems and their technical requirements are then presented. The review concludes briefly noting the findings of studies carried out to evaluate reliability, modes of failure and recommendations for installation of grid tied PV systems. .

Photovoltaic Solar Power Systems in the Maldives—a brief history

Solar photovoltaic (PV) power had been used in the Maldives since the mid-70s of the twentieth century. The first use of PV power was to charge batteries for island to island communication. At that time, walkie-talkies and Citizen Band communication sets were used among the islands for official telephony. According to Abdulla Waheed (personal communication, June 20, 2014), a medical doctor who worked in Kulhudhuffushi island in Haa Dhaalu Atoll, photovoltaic power was used to run vaccine coolers in the early 1980s in Kulhudhuffushi. When he started work in Kulhudhuffushi hospital in 1984, the system, installed by UNICEF had ceased to function due to battery failure. In 1987 in Ugoofaaru Hospital (established in 1986 through an IHAP by USAID), a PV system was installed in the hospital which powered the fans, lights and other small loads (Hameed, Nott, & Reid, 1985).
A similar PV system set up by UNICEF was in operation in the 18-bed Addu Regional Hospital. The latter system in Addu Atoll Hospital was donated to the Maldives College of Higher Education in 2000 as it became unnecessary when reliable public electric power became available.

Maldives College of Higher Education, the precursor to the Maldives National University, maintained a campus in Addu Atoll. The PV system donated by the Addu Regional Hospital was installed on the roof of the Campus for demonstration. It was a polycrystalline PV system of 4 kW. When the Campus took ownership of the system, neither the inverter nor the batteries were in working order. The system was used to power a fountain pump with a new inverter. It is operational as of today.

Dhiraagu, a telecom company partly owned by the government is an early adopter of solar energy. In the 1990s, one author witnessed one of their PV systems to power microwave links used in Laamu Atoll. According to Dhiraagu (2012), there were 174 islands where PV systems were operating with a total area of 1,901 square metres producing 228,476 KWh of renewable energy per year. In terms of distribution this is by far the most extensive utilization of PV power from the beginning—a use for which PV power is most appropriate. However, these systems are small as the power requirements for microwave relay stations are not a heavy as for domestic or civil use. Throughout the 1980s and 1990s, small PV systems were in common use on fishing vessels for charging navigation light batteries and other shipboard uses.

The first PV-Diesel hybrid system was installed in Mandhoo Island in 2005 as a collaboration pilot project by "Strengthening Maldivian Initiatives for a Long-term Energy Strategy (SMILES) and Renewable Energy Technology and Development and Application Project (RETDAP). These projects were funded by the French Agency for Environment and Energy Management (ADEME) and the Utrecht Energy Research of the Netherlands and Global Environment Facility and the United Nations Development Program respectively (JICA, 2009). The PV system in Mandhoo island, located in 100 km south west of the capital, Male', has a population of 373 persons. The system comprises 160 panels of 80 Watts made by BP Solar giving a total of about 12.5 kW. The system was modeled on HOMER, a popular microgrid modeling software from Homer Energy. The design and performance of the system have been widely reported in the literature (Van Alphen, Van Sark, & Hekkert, 2006; Van Sark, et al., 2007).

From 2000 onwards, the economies of PV systems were well realized and adoption rate increased dramatically. Following the 2004 Tsunami, the Japanese Government installed two PV power systems in Laamu atoll. One was in the Multipurpose

Building in Gan and the other was in the island office in Fonadhoo (JICA, 2009). The Laamu atoll systems are connected to the 400/230 V distribution line and power supply for emergency loads can be continued in the event of the failure of the main distribution line.

In January 2008, reportedly the world's first Hybrid AC Coupled Renewable Energy Micro Grid was installed in North Thiladhunmathi Atoll Uligamu. It was a joint venture among the State Trading Organization, Maldive Gas and USAID. In this system, 2.4 kW of PV power were integrated into the wind turbine and diesel electric power systems. The details of the system are in the Proceedings of the AUPEC Conference, Perth, December 2007. This system was also modeled on HOMER.

The first large scale single PV system installed in the Maldives was the 70 kW system on the resort island known as Sonevafushi in 2009 (Sloan, Legrand, & Chen, 2009). From this experience, more and more resorts in the Maldives began to invest in PV systems.

With the change of government in 2008, renewable energy became an area of government focus. The government approached the Japanese Government for a technical /financial feasibility study to introduce grid-tied PV power in Male' and Hulhumale' islands. Following the feasibility study, the Japanese government, through JICA, implemented the first phase of the follow-on project of the study. The installed capacity of 395kWp of PV grid-connected power was derived from systems on the rooftops of five public buildings namely the President's Office, Maldives Center for Social Education, Hiriyaa School, Thaajudhdheen School and STELCO Building. The second phase included the installation of 280kWp of Solar PV grid connected systems on the roofs of Velaanaage Building, Ghiyaasudhdheen School, Kalaafaanu School, Central Administrative Building of the National University and Faculty of Health Sciences. Both phases contributed a total of 675 kWp to Male' grid. Panels were installed on the roofs of Ministry of Finance and Treasury and Hulhumale' Hospital in the third phase of the project. At the conclusion of the project, there were 740 kW installed capacity (Sun, 2014).

An important primary study on PV systems for Thinadhoo was prepared by Amara and Bloembergen (2011) for the Ministry of Housing and Environment. It was in preparation for renewable energy and energy efficiency investment plan and bidding for Thinadhoo Island. The report is noteworthy in that it is developed for a southern atoll and contains most of the considerations for installing a PV system in a medium sized island environment. The authors belong to KEMA — a well-known energy consultancy company of Netherlands.

On January 9, 2012, a 61 kW PV system on Muhyiddin School in Viligili was switched on. It was to be the first of 652 kW of PV power to be installed across six islands through a power-sharing agreement signed between State Electric Company (STELCO) and Renewable Energy Maldives (REM) (Robinson, 2012). REM also installed a sizeable PV system on another school in Male' — Billabong which became operational on 6th May 2013. (http://www.haveeru.com.mv/video/735). REM together with WIRSOL APAC GmbH has installed altogether 652 kW in six islands in the Maldives (MEE, 2012).

The government signed an agreement with Japanese representatives on 17th March 2014 to establish a 40 kW PV power systems in Dhiffushi island in Male' Atoll (Ministry of Environment and Energy, 2013).

In January 2013, the first phase of a study by AF-Mercado EMI on Solar PV Integration in Maldives commissioned for the Asian Development Bank and the Maldives Energy Authority was released. They grouped the consumers into four categories: very small or small islands (<100 kW), medium and large islands (several hundred kW including MW-scale peak), resort islands in the range of 300-800 kW peak load and Male' region. On the basis of case studies, they concluded that about 30 to 50% penetration by PV power systems is possible for medium and large islands, whereas for Male' region the corresponding figure is about 25%. Diesel cost savings would be 22–36% and 16% respectively for medium islands and Male' region (AF-Mercados EMI, 2013). The study was undertaken by Clean Energy Climate Mitigation.

The total installed PV power is a little over 2 MW in the Maldives as of 2014, with several small scale installations rated less than 10 kW making up almost half of a megawatt (MEE 2012, p 93). The energy requirements of a few islands are completely met by PV systems alone during day time. The adoption rate has accelerated as the cost of PV panels has been steadily falling. The research envisaged in the proposed study will further increase the adoption rate through greater awareness of benefits.

PV Power Systems

There are usually two types of PV systems: grid-tied and off-grid systems. Off-grid systems are independent of the utility power grid. Typically, off-grid or stand-alone systems have a number of PV panels producing DC. The DC may be used to charge batteries or may directly power other appliances. Often, for household appliances, an inverter is used to convert the DC into AC at the appliance voltage. When the panels are not producing power (typically at night) the inverter may be run from the batteries. There is no inter-connection between the PV system and the grid or the network of electrical transmission lines connecting generating stations to consumers in a given area. The absence of interconnection is the distinguishing feature between an off-grid PV system and grid-tied system (Al-Adwan, 2013). In contrast, a grid-tied or grid-connected PV system usually has no batteries and the PV system is connected to the grid through an inverter. Grid interconnection has the advantage of better utilization of generated power. For one thing, batteries which are a major cost of an off-grid system, is not essential. When sun is available, excess power generated is fed into the grid at an agreed tariff. At night or when PV power is not available the owner of the system consumes power from the grid. Figure 3 shows a general block diagram of a grid-tied PV power system.
Grid interconnection requires the grid owner, in the case of the Hithadhoo Campus, FENAKA, to agree to quality of power generated. Safety issues are involved as well. The technical requirements for grid connection are determined by the Maldives Energy Authority (MEA). Their specifications are in the published document, entitled "Guidelines on Technical Requirements for Photovoltaic Grid – connection." This document specifies issues regarding frequency limits, voltage fluctuations, islanding detection, and other attributes of the system (Maldives Energy Authority, 2013).

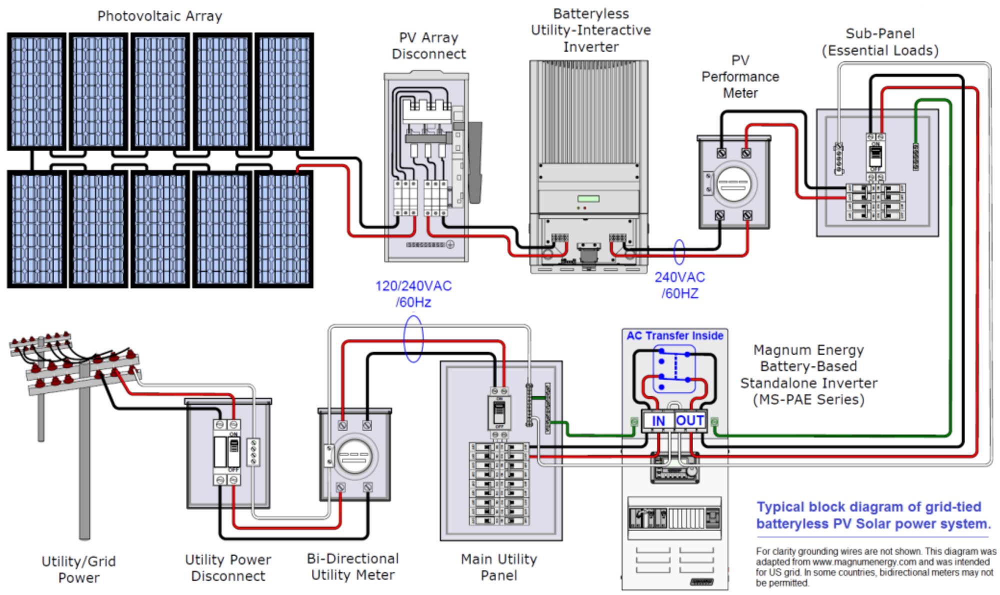

Figure 3. Typical block diagram of grid-tied batteryless PV system.

Kaundinya, Balachandra and Ravindranath (2009) reviewed 102 studies of grid-tied versus stand-alone electric energy systems. They found that most studies are context dependent and context specific precluding the findings of the economic-financial assessment objective. However, Eltawil and Zhao (2010) reviewed literature on technical and potential problems of grid-tied PV power systems and noted that grid connected PV power systems have become the dominant technology for PV electricity accounting for over 75% of all installed PV power systems by 2005.

Solar Irradiation

The energy available for PV power systems comes directly from the Sun. The solar irradiance is defined as the amount of radiant energy incident on one square metre of Earth's surface. The National Renewable Energy Laboratories of the US has computed solar irradiation for Maldives using satellite data (Renner, George, Marion, Heimiller, & Gueymard, 2003). They conclusion suggests that Maldives has sufficient solar resources for PV:

The study shows that ample resources exist throughout the year for virtually all locations in Sri Lanka and the Maldives for PV applications, such as solar home systems and remote power applications. In the Maldives in particular, the high levels of solar resource throughout the entire country make it well suited for off-grid, island-based photovoltaic applications as an alternate to, or supplement to, diesel power generators. Because of the general high level of cloudiness and humidity associated with tropical settings such as this, the resources for concentrating solar power are generally less than adequate, except for certain times of the year. (p.16)

However, the values of irradiance found by Renner et al. (2003) were noted to be about 15% higher than what was measured at Hulhule between 2003 and 2005. Hulhule is the island where the main international airport is located. The ground level measurements gave an average of 5.03 kWh/m^2/day according to Sark et al. (2006). The most recent data available are available from JICA (2009) and may be taken as the most reliable data of daily insolation for Male'. The data they used for their study are given in Table 3. Amara et al. (2011) gives horizontal irradiation data for the island of Thinadhoo in their report (page 27). However, the data were obtained from Retscreen® International Clean Energy Project Analysis Software and not measured on ground. Their average irradiation (horizontal component) for the island is 5.87 kWh/m^2/day which appears to be higher than the measured value at Hulhule or Male'.

Table 3

Horizontal Plane Solar Irradiation for Male' in kWh/m^2/day

Month	*irradiance*	*Month*	*irradiance*
January	5.23	July	4.51
February	5.61	August	5.60
March	5.99	September	4.56
April	5.24	October	6.06
May	4.86	November	4.00
June	5.06	December	5.10

Average: 5.15 Source: JICA (2009, p. A-6-10)

Grid-tied PV power system components

PV panels

Scarcity of land dictates that any PV system in the Maldives must be space intensive. Since PV solar array takes most of the horizontal area, this is where considerations of space must be focused on. In this regard, from the point of view of area conservation, panels using highly efficient PV cells are desirable. There are many types of PV solar cells available, but the most common are made of silicon. The three main types of silicon cells are monocrystalline, polycrystalline and amorphous. The efficiencies obtained in laboratory settings are reported every six months in the journal *Progress in Photovoltaics.* Al-Adwan (2013) outlines how efficiencies of commercial cells are evaluated. The efficiencies of commercial PV cells are summarized by JICA (2009) as is shown in Table 4. The price appears to be installed price per Watt.

Table 4

Comparison of Silicon Solar Cells

Attribute	*Monocrystalline*	*Polycrystalline*	*Amorphous*
Size	10— 12.5 cm	15.5 cm	140 cm x 110 cm
Efficiency	15–20%	12–17%	8–12%
Price	US$5–6/Watt	US$4/Watt	US$4–5/Watt

JICA (2009) recommends crystalline silicon type for Maldives because the required space is smaller and their installations in the Maldives feature all monocrystalline cells.

An important feature PV panels is that the panel voltage decreases as the current drawn from it increases. The literature provided by the manufacturer of the panel often includes the current and voltage curve of the panel. Figure 2 shows such a curve. When the current is zero, the open circuit voltage is 37 V. As more current is drawn, the voltage tends to drop until it becomes zero at short-circuit. The short-circuit voltage is 8.34 A. As power is current multiplied by voltage, there is an optimum voltage at which the panel produces maximum power. This point is known as maximum power point and is labelled in Figure 4. In typical systems, it is the task of a DC to DC converter to operate the PV array at the optimum voltage for maximum power. This function is called Maximum Power Point Tracking (MPPT) and the necessary DC to DC converter is often incorporated in the inverter box. There are single-chip controllers for MPPT. For example, Texas Instruments SM72442 is a programmable single chip MPPT controller providing driving signals for a 4-switch buck-boost converter.

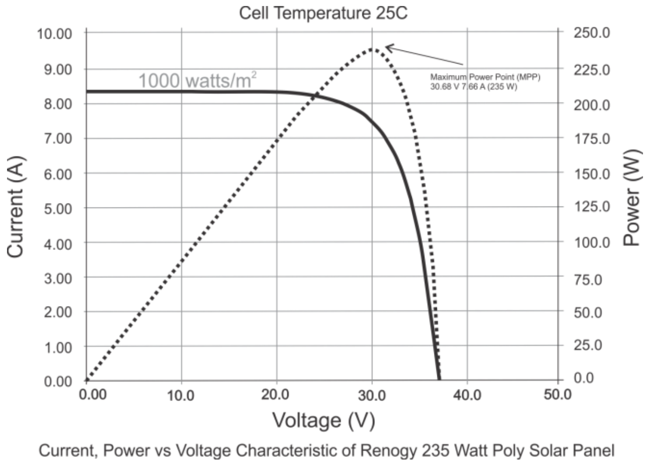

Figure 4. Characteristic Voltage Curve for a commercial panel (Renogy 235 Watt).

Grid-tie inverters

Most household appliances and other loads operate on 230 V alternating current (AC), and PV solar panels produce direct current (DC). Therefore, to utilize solar energy effectively, a power inverter is required. An inverter changed direct current into alternating current. The alternating current has to be produced at the voltage and grid frequency. In the Maldives, for general household use, electric power is supplied at 230V AC and 50 Hz. With regard to the waveform of AC produced by the inverter, there are essentially two types of inverters: square wave inverters and sine wave inverters. Square wave inverters are usually not suitable for many household appliances. As grid current is a sinusoidal, sine wave inverters are required for grid connection. Sine waves are generated by using Pulse Width Modulation (PWM) techniques using semiconductor switches. The semiconductor “switches”, usually MOSFETs or IGBTs, generate high-frequency high-voltage rectangular pulses, which are, next applied to low-pass LC filter. The LC filter produces the moving average of these rectangles. The required 50 Hz (or 60 Hz as the case is for US) sine wave is produced by suitably modulating the duty cycle and periodically changing the polarity of the pulses. Microcontrollers for processing the necessary signals are available as a single piece. The energy fed into the grid has to be in phase (synchronous) with grid power. If the power of the PV system is high, three phase inverters are normally used.

The efficiency of the inverter is a major feature of the efficiency of the whole PV power system and much research has taken place about the design of inverters. There are many designs of inverters principally aimed at increasing efficiency and reliability. For example, Mekhilef, Ahmed, and Younis (2008) described a general design for a 3 kW three phase grid-tie inverter. A diagram of their inverter, typical of grid-tie inverters, is depicted in Figure 5. The design of Mekhilef et al. (2008) uses an analog to digital converter (ADC) to track maximum power point. The digital values are used by the microcomputer to generate the modulation index which is used as input to pulse width modulation (PMW) generator to get the required sine waveform.

Transformers were used to isolate the PV power system from the grid. Transformers ensure that dangerous DC faults are not transmitted to the grid. DC in the grid may saturate distribution transformers and render traditional house meters unusable.

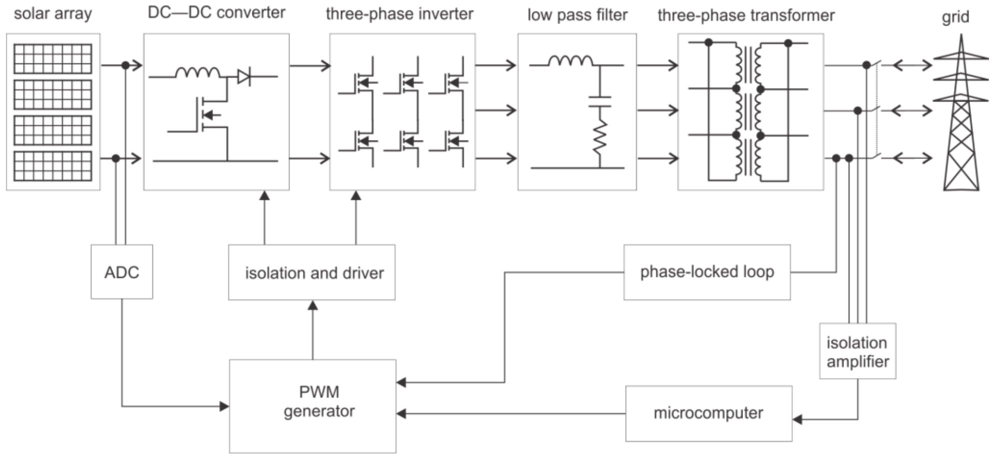

Figure 5. A system level diagram of a grid-tie inverter with associated cabling. In many inverters, the microcomputer's role is taken over by microcontrollers. The transformer is useful in isolation but wastes energy.

However, in US in 2005, and in many other countries the requirement to galvanically isolate the PV system has been removed. To ensure safety, ground current detection and other methods are used to identify possible fault conditions. Transformerless grid-tie inverters have the advantages of higher efficiency, (typically 1 to 2% higher than equivalent systems with transformers), less cost, less volume, less weight and less complexity (Gu, Dominic, Lai, Chen, LaBelle, & Chen; 2013). A typical transformerless configuration is shown in Figure 6. The dotted line shows the digital signal processing part, the heart of which is a microcontroller. Gu et al (2013) have demonstrated inverters with efficiencies greater than 99% using superjunction MOSFETS, zero voltage crossing and zero current crossing switching.

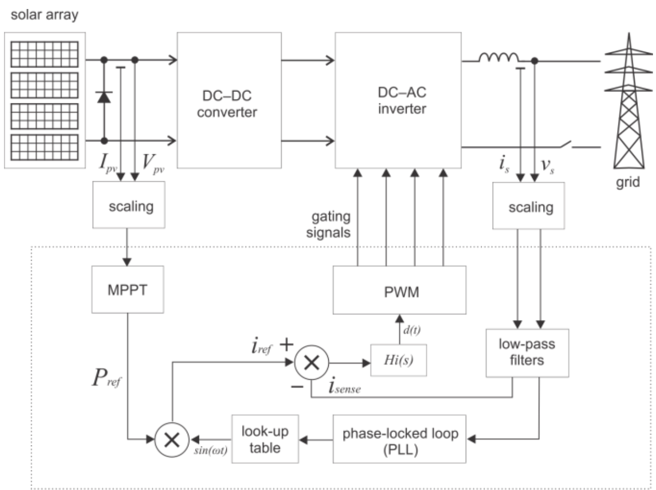

Figure 6. A transformerless grid-tied PV system After Gu et al (2013).

A new trend in grid-tie inverters is the use of microinverters instead of one large central or string inverters. A PV system using microinverters is shown in Figure 7. In a grid-tied microinverter configuration, each PV panel has a small inverter which changes the DC produced by the panel into grid-compatible AC. The outputs of all the microinverters are connected to the grid. The microinverter does all the processing that a large central or string inverter does, including MPPT and ensuring that the output is compatible with grid requirements. The claimed advantages of microinverters include redundancy; if the string or central inverter breaks down, the whole system breaks down. But with microinverters, a non-functional panel or microinverter will only lead to the loss of power produced by that panel. This advantage is particularly apparent when shade or dirt on one panel reduces the output of that string of panels. Another advantage is that each panel can be oriented to give it the best sun—a feature difficult to implement in an array. Yet, another advantage of microinverters is that MPPT has to be done for one panel, not for the whole PV array. MPPT performed at each panel by a microinverter will yield better overall system results than MPPT done for the whole PV array. Replacing a faulty panel or microinverter is straightforward, whereas for a central large one, the costs and the difficulties would be more. The system is also expandable as one has to add new panels and microinverters to increase yield. Other advantages include that the main connections are at grid voltage not at 300– 600 V DC as the case is with central inverter systems. The grid voltage is safer and the normal residual current circuit breakers will protect the system and the workers in the event of a ground fault. Microinverters are now available with over 25 years of warranty indicative of its reliability and less downtime.

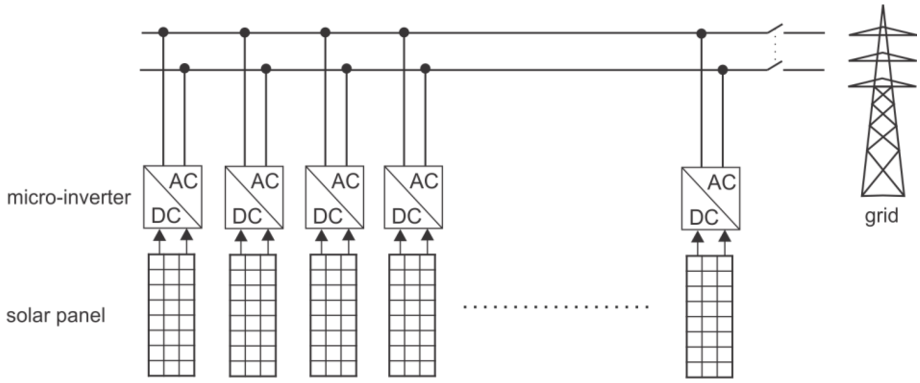

Figure 7. A grid-tied PV system based on microinverters has a higher redundancy than systems based on string inverters.

The advantages of microinverters appear to suggest that they would become more common. However, more than 99% of the PV solar systems installed worldwide are of the central inverter type (Novak, 2012). Harb, Kedia, ZAhang, Balog(2013) reported a comparative study of a microinverter and string inverter grid-connected 6 kW PV system. They used the reliability, availability, safety, failure, and cost of both configurations. They found out that the microinverter system gave an economic advantage as it was available more often; particularly when the high costs of replacing the string inverter was considered. The microinverter was found to offer safety advantages (particularly lack of arching) which were not monetized earlier.

Grid-tie requirements

Recognizing the important role of PV power to mitigate global warming and reduce costs, most jurisdictions now allow customers to feed power into the grid. The quality control of grid power is paramount especially with the evolution of "smart grid" whereby among other possibilities, many producers may feed power into the grid. Power companies have stipulated technical requirements for grid connection. The overall authority is maintained by the relevant national body. In Australia, the requirements are given in Australian Standards AS 4777 and AS 5033. In the US the National Electric Code (NEC) Sections 690 and 705 give the technical requirements for interconnection and installation of PV systems. The requirements are long and much of the requirements pertain to safety. There are commonalities among various standards across the jurisdictions. For example, the total harmonic distortion of the grid-connected power waveform must be less than 5%. De-islanding is a requirement in all codes. Islanding is the feeding of power from the PV system into the grid while the grid is off-line causing hazardous conditions for workers and equipment. Usually de-islanding circuits are built into the inverter. These disconnect inverter output from grid in the event of loss of grid power. At the same time, the inverter will not energise any circuit de-energised by the grid.

For Maldives, JICA (2009) recommended guidelines for technical requirements for grid connection. There are different guidelines based on the power capacity of the PV system: namely, for less than 50 kW, less than 2 MW and less than 10 MW, etc. The guidelines were based on those of the Natural Resources and Energy Agency of Japan. For systems of capacity less than 50 kW, the JICA (2009, p. 8-18) seems to have been adopted in the Maldives. In summary, the guidelines of the Maldives Energy Authority (2013), the relevant body for standard setting in electric matters, are as follows:

(a) The frequency shall be 50 Hz. {Unlike the standards of other countries, no allowable deviation was stated}
(b) Depending on the PV system's output power, the breaker capacity and interconnection voltages are given as in the Table 5.

Table 5
PV System Categories by Breaker Capacity and Voltage

Category	*Rated output of PV System*	*Breaker capacity*	*Interconnection voltage*
1	< 7	40 A	LV (1Φ 230V)
2	7 – 35	63 A	LV (3Φ 400V)
3	35 - 175	315 A	LV (3Φ 400V)
4	175 >	—	MV (3Φ 11kV)

(c) For metering, the guidelines call for two (buying and selling) meters with protection for reverse rotation installed.
(d) With reverse power, the power factor at the receiving point shall be 85% or more seen from the grid side and should ***not*** be the leading power factor. Without reverse power, generating facilities must have a power factor of 95% or more.
When PV systems are connected to a grid, the voltage for low voltage customers shall be kept within 230 ± 5.75 V for 230 V lines and 400 V ± 10 V for 400 V three phase lines. When there is a danger of deviation from the normal line voltages for low voltage consumers due to reverse power, steps must be taken automatically to adjust voltage by using reactive power control function or output control function. If this is not possible, distribution line capacity must be increased.
(e) The following protection relays are mandatory: Over-voltage relay (OVR), Under-voltage relay (UVR), Over-frequency relay (OFR), under-frequency relay (UFR). If there is a possibility of reverse power, then a reverse power relay (RPR) must be installed at the point where such conditions can be detected. UFR, OFR and RPR shall be installed for each phase. Under and over-voltage relays shall be installed for all three phases.
(f) Self-synchronizing inverters shall be used to limit instantaneous voltage fluctuations to the lower limit of 207V on single phase lines. If external synchronizing inverters are used, the voltage fluctuations must be kept within 10% of the normal voltage; else, current limiting reactors shall be used to limit voltage.
(g) The following breakers shall be installed at the point of connection between PV systems power and grid parallel-off point: (i) power receiving breaker, (ii) PV system output breaker, (iii) Generator communication breaker, (iv) Bus communication breaker.
(h) One from *each* of the following active **and** passive methods of anti-islanding systems shall be used: Active (frequency shift type, active power fluctuation type, reactive power fluctuation type and load fluctuation type), Passive (power phase jump detection type, 3rd harmonic voltage rise detection type, frequency rate change detection type).
(i) If automatic recovery is enabled in the inverter, this function shall become active only after "receiving" voltage is confirmed to prevent the expansion of damage by unnecessary parallel-in.
(j) If PV system may cause overload to the grid (and hence substation transformers), the PV system must automatically limit the load or suppress feeding power into the grid.

The above technical requirements are similar to those in other countries as may be verified for NEC codes.

Evaluations of Grid-tied Systems

A number of meta-analyses of grid-tied systems have been reported. For example, the International Energy Agency published a report of the issues faced with Australian, Austrian, British, Canadian, Dutch, German, Japanese, Spanish, Swedish, Swiss and US PV systems, including the German "1000 roofs programme", the Japanese programme for residential PV and "German Sun at school programme" (IEA, 2002). The study found inverter failures, over-rated power of modules, partial shading of the array, soiling, and faulty connections on the dc side were the main problems of PV systems. The report suggested the following maintenance regime: inspect arrays annually, clean arrays regularly and perform monthly check on power production. The study also noted that amorphous solar cells degraded most. The main cause of inverter damage was from surge voltages from the grid. The report also suggested using cage clamps for connections, providing drainage for all condensation in all outdoor boxes, always introducing wires from the bottom among other workmanship-related advice.

A more recent review of grid-connected PV systems was carried out by Eltawil and Zhao (2010) to summarize the technical and potential problems. Eltawil and Zhao (2010) noted that inverters were the weakest link in the reliability of the PV system, corroborating the findings of IEA (2002). They recommended that the inverter be over-sized by 60% to 100% in comparison to the PV system to increase the reliability of the inverter. The inverter should be operated at unity power factor. At high penetration levels, variable power factors were not recommended. They concluded that the effects of harmonics and active methods of anti-islanding and distributed generation need further research.

With regard to the type of inverter used in grid-connection, it appears that the transformerlss ones are better in terms of system efficiency. Díez-Mediavilla, Dieste-Velasco, Rodríguez-Amigo, García-Calderón, & Alonso-Tristán (2013) reported a comparative evaluation of two 100 kW grid-tied systems which differ only in the inverter used. They both were in the same geographical area, used the same type of PV panels, support systems and wiring. One facility used an inverter with an integrated transformer. The other inverter was transformerless. Their results, based on the case study, indicated that the transformerless inverter system performed better than the isolated system by a factor of 1.2% which in economic terms represented more than 2000 euros per year.

The review indicates that grid-tied PV systems are promising, reliable, and satisfactory for the Maldives. Long-term performance studies for Maldives are almost non-existent for the country. Emerging popularity of microinverters and technically advanced inverters are likely to increase the penetration of PV systems. In large islands, the penetration will be limited due to effects of clouds, shading and other intermittent causes. In June 2014, Germany produced more than 50% of its electricity from PV systems for the first time setting a record in PV penetration ("Germany produces half of energy with solar," 2014).

10. REFERENCES

The university requires all cited references be listed in APA format. Always use recent references (less than 10 years old) unless the work cited is seminal or highly relevant or illustrative of the point being made in the text.

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