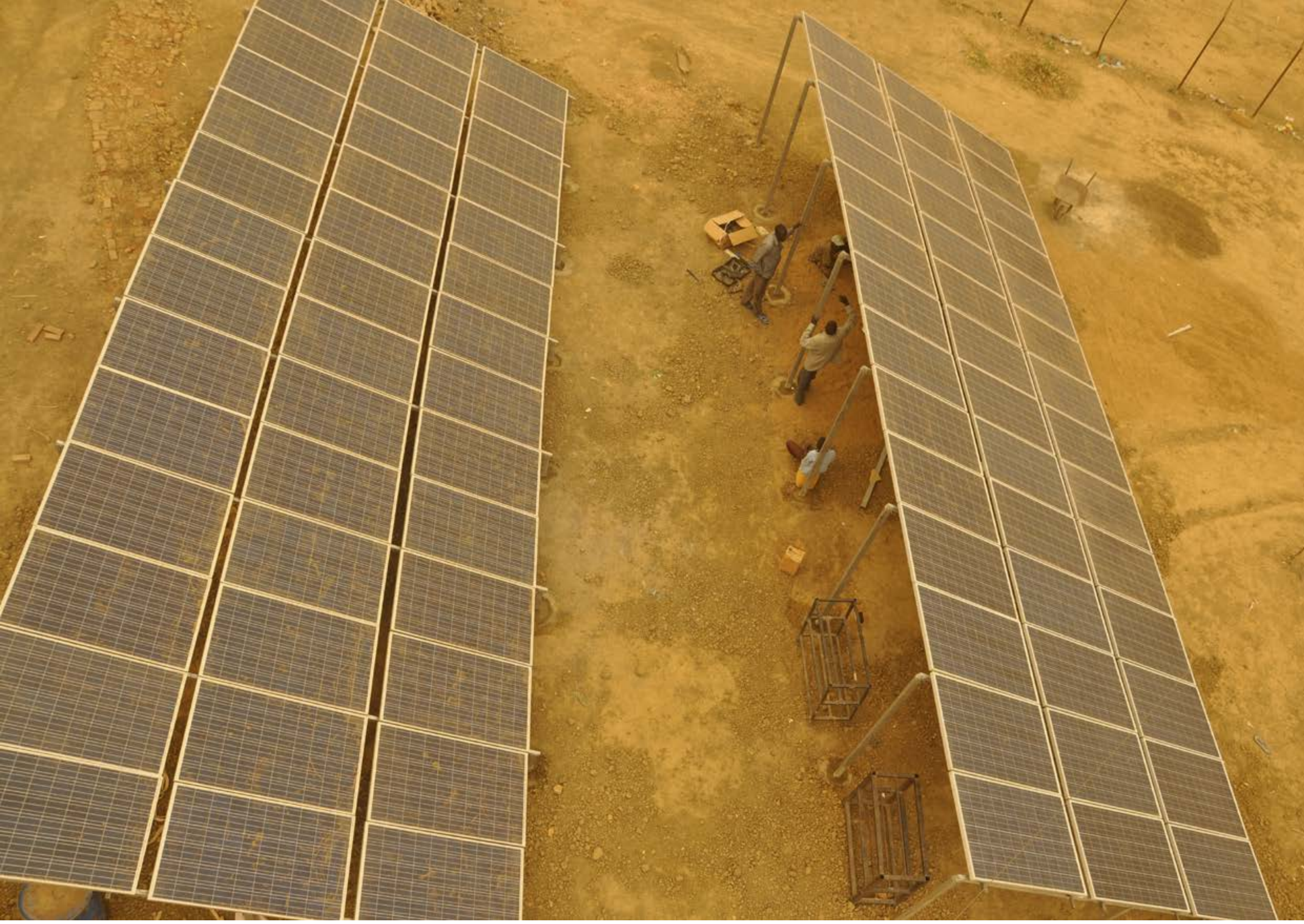

Figure 1 – Solar Panels, viewed from above

Solar Powered Transmission:

A Case Study from South Sudan

By Issa Kassimu, Natalie Chang and Ann Charles

On behalf of The Radio Community and Internews

Version 1.0, November 2016

About The Radio Community

The Radio Community (TRC) is a network of community radio stations in South Sudan that reach an estimated 2.1 million potential listeners. These include Mayardit FM in Turalei, Warrap State; Nhomlaau FM in Malualkon, Northern Bahr el Ghazal State; Singaita FM in Kapoeta, Eastern Equatoria State; Mingkaman FM in Awerial County, Lakes State; and Nile FM in Malakal, Upper Nile State (operated in partnership with Internews' Humanitarian Information Services). Stations in Leer and Nasir are currently off-air due to conflict.

About Internews

Internews is an international non-profit organization whose mission is to empower local media worldwide to give people the news and information they need, the ability to connect and the means to make their voices heard.

Internews provides communities the resources to produce local news and information with integrity and independence. With global expertise and reach, Internews trains both media professionals and citizen journalists, introduces innovative media solutions, increases coverage of vital issues and helps establish policies needed for open access to information.

Internews operates internationally, with administrative centers in California, Washington DC, and London, as well as regional hubs in Bangkok and Nairobi. Formed in 1982, Internews has worked in more than 90 countries, and currently has offices in Africa, Asia, Europe, the Middle East, Latin America and North America.

Internews Network is registered as a 501(c)3 organization in California, EIN 94-302-7961. Internews Europe is registered in England and Wales as a Charity no. 1148404 and Company no. 7891107. Internews Network and Internews Europe operate cooperatively with independent boards of directors.

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Executive Summary

Renewable forms of energy have been increasing in popularity over the last few years. Though interest is high, few radio stations are using solar power due to fears of the cost and complexity involved.

This document takes an in-depth look at the conversion to 100% solar power operation at a small community radio station called Mayardit FM in Turalei, South Sudan. Since the installation of the solar system in March 2016, the station has operated on 100% solar power (including its transmission), broadcasting up to 16 hours a day, every day of the week. To date, the system has had zero downtime.

This report was written to share learning with others who may be considering whether solar power would be suitable for their station(s). The first section describes the South Sudan context, background, and purpose of the project. The second section provides a case study of the solar power conversion at Mayardit FM, including technical specifications, user-centered design considerations, costings, and lessons learned from the first months of operation. The third section serves as a "how to" manual, which can be used by anyone interested in designing a solar system and weighing its feasibility for their own radio station.

Based on results through October 2016, the key findings are:

- The upfront, capital costs are significantly more expensive than an equivalent site using a diesel generator.
- The annual running costs are 92.8% cheaper than an equivalent diesel-powered site.
- The combined project cost over five years will save around $5,200[1] compared to a standard generator-powered site[2].
- The benefits of solar are likely to be more dramatic after 5 years, although the future cost projections are trickier to estimate[3].
- Mayardit FM has now doubled its weekday hours on air – from 8 to 16 hours per week day.
- Other stations are encouraged to consider solar power if their annual running costs are more than the equivalent solar costs and they can raise the upfront capital.
- It is possible to run a radio station and its transmitter 24/7 on solar power. However, stations at different latitudes or with access to grid electricity are also encouraged to review the equivalent costings for 12/7 and 18/7 running to see where the "tipping point" between cost of panels versus annual cash savings will come for their site.
- The site has only been fully operational for 8 months. This report should be updated in Q2 2017 to provide longer-term costings and feedback.
- Beyond financial savings, the system has resulted in significant intangible benefits, such as positive community engagement and ease of maintenance by station staff, who can now focus on programming instead of worrying about day-to-day operations. The stability of the solar system and the fuel independence it affords are already proving invaluable.
- There has been no system downtime to date.

---

[1] $96,000 for this specific project, due to donated and re-used equipment. See also the important caveats in 'A note on costings and financial savings'.

[2] For more detailed costings, see 'Review & Analysis'.

[3] Very tentative projections can be found in 'Appendix 7. Longer-term cost projections'.

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Introduction

Renewable forms of energy have been increasing in popularity over the last few years. Though interest is high, not many radio stations are using solar power due to fears of the cost and possible complexity involved.

Internews has been working in South Sudan since 2006. Under the five-year i-STREAM project (Strengthening Free and Independent Media in South Sudan) granted in October 2013 by the United States Agency for International Development (USAID), Internews supports several radio stations, including Eye Radio in Juba, Central Equatoria state, as well as community radio stations in more remote areas of South Sudan: Mayardit FM, Nhomlaau FM, Singaita FM, and Mingkaman FM. Internews has additionally established a news service in Abyei, funded by the Office of the US Special Envoy to Sudan and South Sudan.

The Internews-supported community radio stations in South Sudan are collectively referred to as The Radio Community (TRC). The stations are staffed by members of the local community, who are trained by embedded experts in journalism, production and the related skills needed to run a small radio station.

Media penetration across South Sudan is still very low. In 2015, 34% of South Sudanese reported never having accessed any kind of media or device in their lives, whether radio, mobile phone, newspapers, television, or the internet. By far, radio remains the most accessible source of information for the vast majority of people in the country. Most people in South Sudan cannot read and write; it is estimated that around 73% of the adult population is illiterate.[4] In addition, many South Sudanese cannot speak English or "Simple" Arabic, and only communicate in their local language. All of these factors mean that in some areas, TRC radio stations are the only sources of news and information for their respective communities, outside local face-to-face networks.[5]

In 2016, TRC began the process of transitioning into an independent, 100% South Sudanese owned and operated non-governmental organization. A key piece to achieving this sustainability is addressing the electricity and power issues that continually face radio stations in South Sudan. Broadcasting in South Sudan is very expensive, as there is ongoing armed conflict in addition to the challenges of remote locations and poor infrastructure. Fuel prices are high and volatile, and as there is almost no grid electricity in the country, one of the biggest costs radio stations face are those related to purchasing fuel to keep generators running.

As South Sudan is near the Equator, with good sunlight, Internews has experimented with solar power and other forms of alternative energy in the past. For a remote radio station in Kauda, in the Nuba Mountains, Internews created a system that harnessed 100% wind and solar power for a remote transmission site on a mountaintop, where there was no other way to access other energy sources. The station itself, at the bottom of the mountain, was powered 50% by solar panels and 50% backed up by a generator.[6] Though the system guaranteed some energy stability, its maintenance was intensive: one reporter would have to climb the mountain where the remote transmitter is based, to clean the solar panels, check the batteries, and ensure the security of the tower and power supply.

Since 2013, Internews Electrical Engineer Issa Kassimu has traveled throughout South Sudan designing, installing, and maintaining electrical systems for Internews-supported radio stations. When Internews received a donation of some solar-compatible batteries from United Nations Development Programme (UNDP), Issa persuaded TRC management to trial solar power on a grand scale, as he passionately believed it would bring stability to stations as well as savings benefits – essential if TRC is to be sustainable in the future.

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[4] UNICEF, 2016.

[5] Please see the 2013 and 2015 National Audience surveys commissioned by Internews and conducted by Forcier Consulting, accessible at https://internews.org/research-publications/still-listening-survey-media-landscape-accessible-areas-south-sudan-2015 (Internews and Forcier Consulting, 2013), (Internews and Forcier Consulting, 2015).

[6] For more information, see *After War, Wind Powered Radio*, at http://www.loe.org/shows/segments.html?programID=08-P13-00049&segmentID=6 (Living on Earth, 2008).

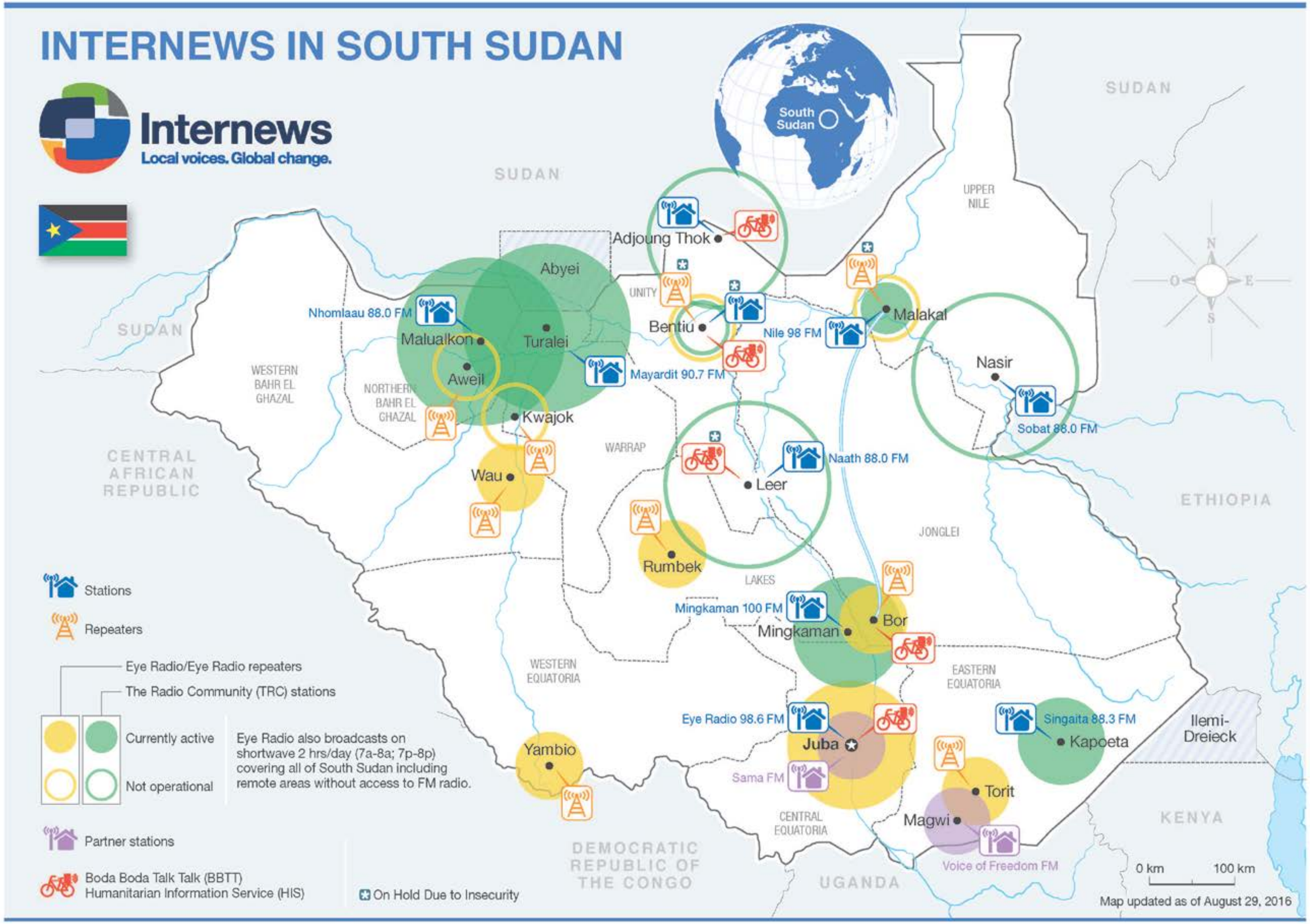


Figure 2 – Coverage Map, Internews in South Sudan

Who is this document for?

This document is aimed at two primary audiences:

1. Internal Internews and TRC staff, to review the project and its impact in detail, both in the immediate and longer-term.
2. Broadcast engineers and managers at other radio stations, for general information and learning, and also as a guide for stations beginning to evaluate whether solar-powered transmission is the right step for them. We hope sharing this information is useful for stations in every country, although there may be particular resonance for smaller broadcasters in the East Africa region. If you are an engineer interested in how to put a solar-powered system together, you may wish to skip straight to the 'Manual for Solar System Design & Sizing' section, first. You may also find the case study from 'Turalei Solar Project Design' onwards particularly helpful.

Due to reasons of commercial confidentiality, in-depth costings are not available in this document. We can accept no liability for the information provided.

However, we are very interested to hear from other stations to find out whether the information we have shared has been useful to them. Feedback and updates are welcome via the Contacts section.

A note on costings and financial savings

The economic situation in South Sudan is fluctuating constantly. Prices increase daily, and inflation changes rapidly.[7] Local goods are usually bought and paid for in SSP (South Sudanese Pounds) while international orders are placed in USD (United States Dollars). USD is frequently used as a "second currency" in the country itself.

There used to be a fixed exchange rate set by the government, which I/NGOs had to follow. This was very different from the equivalent "black market" rates. The official exchange rate was abolished in December 2015, and the South Sudanese Pound was allowed to trade freely in the market against the US dollar and other currencies to compete with the black market.[8]

Therefore, when reading monthly spending in this document, it is important to bear in mind that the costs incurred from month to month may increase dramatically, without the consumption or activity at the station having changed. In order to give a more accurate picture of the benefits realized in the project, calculations include a power usage rate for comparison as well as financial amount.

A note on terminology

The station on which this report focuses is called "Mayardit FM." It is physically located in a town called Turalei, which is also based in a county called Turalei. Depending on the source, Turalei town is either in Warrap or Twic State. There is ongoing debate about which state is officially recognized. In this document, Turalei and Mayardit FM are used interchangeably to refer to the site on which the radio station and its transmission equipment and solar panels are based (unless stated otherwise).

Further explanation of acronyms and abbreviations in this document can be found in "Appendix 1: Acronyms and Abbreviations List" below.

[7] An anecdotal example: the unofficial exchange rate in October 2014 meant that $100 USD bought 450 SSP. By March 2016, $100 bought 4000 SSP. In October 2016, $100 bought 7000 SSP.

[8] (Sudan Tribune, 2015)

South Sudan: The Power Problem

Figure 3 – Entrance to Mayardit FM

Mayardit FM, an Internews-supported community radio station in Turalei, has long struggled with inconsistent power. "I heard they were out of power for three days, so I came straight here," said Internews Electrical Engineer Issa Kassimu in March 2016, recalling his last trip to the station to repair and service the generator. He concluded that the station's generator had to be replaced, and so did the backup batteries, which were depleted from many days of insufficient charging.

Such power challenges are typical for radio stations across South Sudan, whether in urban Juba or remote locations. As there is almost no grid electricity in the country, all Internews-supported radio stations that compose The Radio Community (TRC) are run on 15-20 KVA generators. Such equipment is expensive to procure and difficult to maintain. The full procurement costs of a generator can reach USD$20,000, including logistics and transport. The hot, dry, and dusty conditions shorten the generators' life spans. Poor quality fuel also increases wear and tear. In the remote locations where TRC stations are located, it is hard to find spare parts and oil in local markets.

The harsh conditions also mean that the generators require a great deal of maintenance. Radio stations face extreme weather: temperatures hover around 40 degrees Celsius (104 degrees Fahrenheit) at some parts of the year, leading to overheated equipment. The equipment is also quickly damaged by dust caused by the dry conditions in South Sudan. The rainy season brings different problems, as the dirt-track roads become muddy and impassable for months at a time, meaning repairs, spare parts, and servicing can be delayed for long periods. Transporting equipment to sites can be costly and difficult, as it can only be done during the dry season, or must fit onto small planes. Some roads are unsafe to use due to the risk of armed raids.

Figure 4 – Solar panels with Mayardit FM in the background

It is also hard to find qualified and reliable maintenance engineers, and low

Figure 5 – Mayardit FM staff push the new 20kV backup generator into place

educational standards mean it is difficult to train local staff to maintain technical equipment. Station staff are relatively new to working in radio in the first place, and there are not many broadcast and electrical engineers in the country.

TRC stations do not have engineers on site – they rely on remote support and visits from Juba at roughly quarterly intervals. If a piece of equipment breaks and the team on the ground cannot mend it, the station can be off-air for days at a time, compounded by logistical challenges. A flight has to be booked three days in advance, and it can take a whole day to travel to a station from the nearest airport or airstrip. Ongoing conflict in different regions also serves as an impediment to free movement.

High, fluctuating fuel costs and poor fuel quality pose many problems too. Diesel is imported into South Sudan, and it is hard to transport and in short supply in remote areas. In areas like Turalei, diesel is supplied by informal traders who lack proper storage or retail facilities. The fuel is sold in the open and stored in unsealed barrels and jerry cans. Diesel can become contaminated and is sometimes mixed with other petroleum fuels. Traders do not use standard measuring containers, and often customers are overcharged for the quantity of fuel purchased. The cost of fuel means stations can only afford to be on air for limited hours.

As part of i-STREAM, Internews has been investigating whether solar power, which is abundant throughout the year in South Sudan, can be the solution for these power challenges. The hopes for a solar powered system are many:

- Lower fuel costs and reliance on intermittent fuel supplies. It is expected that the stations may still need to rely on a backup generator – but with much reduced fuel costs and generator running time.
- Increase broadcast hours.
- Lower maintenance costs, through less reliance on generators, and installation of battery monitoring software to ensure correct battery usage and recharge, regular solar panel cleaning, and electrical circuit tests.
- Simplified and streamlined operating, monitoring and maintenance that local staff can sustain independently without technical expertise or specialist parts.

Internews Solar Power Pilot Projects

In 2015 and 2016, Internews supported the installation of three smaller-scale solar power projects in South Sudan: two as part of capacity building grants for two small local organizations, and one for the Internews-supported news and information service in Abyei. Issa Kassimu did the consultation, design, and installation of all three systems.

These solar systems have proven to be a great success, functioning without any need for technical support or repair to date. A full comparison of the technical equipment used at these sites can be found in "Appendix 3: Turalei equipment vs. other Internews solar sites."

Voice of Freedom Magi (VOF): A hybrid solar system, which relies on a generator to charge the batteries when there is no sunlight in the morning and in the evening. However, in the presence of sunshine, the solar panels charge the batteries and provide electricity. The generator charges the batteries from 0:600-07:30, solar charges the batteries from 07:30-18:30, then the generator runs from 18:30-20:30.

Community Needs Initiative South Sudan (CNISS): An off-grid system, where the batteries are entirely charged by the solar panels. There is no alternative power source; there is no generator.

Internews Abyei News Service: A hybrid system, similar to Voice of Freedom Magwi, combining the use of solar panels and the generator to power operations.

(For more information, see "Appendix 8. The Abyei Hybrid Solar Project".)

In the fall of 2015, Issa proposed the largest and most ambitious solar experiment to date: to install a photovoltaic solar system that would produce 37,440 kWh per year for Mayardit FM. This would require the installation of 84 solar panels (250W each) and 48 solar batteries (2V, 1643 AH each) to support 16 hours of broadcast and 24 hours of power per day.[9] The station's diesel generator would remain only as a backup power source. By far, this would be the biggest solar project Internews had ever tried, with the goal to power one station exclusively via solar energy.

While all TRC stations stand to benefit from solar, Mayardit was selected because it had enough space on site to set up the solar panels and construct a battery control room. Turalei was also considered a stable location, with the radio station having the acceptance of local authorities and the community.

[9] For a full list of equipment, please see "Appendix 2. List of equipment used at the Turalei site."

Mayardit FM

Mayardit 90.7 FM broadcasts a range of news and programs which vary in content and focus, including education, health, agriculture, and other important issues, as well as music, sports and entertainment. Formats range from news and feature magazine programs, to talk shows and special coverage. In February 2016, Mayardit also began broadcasting Internews-supported program *Abyei This Weekend*, a two-and-a-half hour weekend show supporting information access for communities in the disputed region of Abyei. According to data gathered for the 2015 National Audience Survey, current Mayardit FM listeners are likely to be Dinka speakers who are under 39, have no education or only some primary education, and find it difficult to get by on their household's current income.[10]

Frequency	Mayardit 90.7 FM
Location	Turalei, Warrap State
Coverage Area	Approximately 100km radius, with roughly 167,226 potential listeners[11]
Broadcast Language	Dinka
Hours on air[12]	0600-1000, 1800-2200 (Mon-Fri), 4 hours each (Sat-Sun)
Hours on air[13]	0600-2200 (Mon-Sun)
Transmitter power	2000W
On air since	November 2009

Figure 6 – Mayardit FM Profile

[10] Internews and Forcier Consulting, 2015.

[11] Exact statistics for local populations in South Sudan are not known as there is no official census and people may move to different locations at short notice due to instability. This number is a rough estimate based on data collected during the 2013 National Audience Survey, overlaid with known coverage areas.

[12] Before project began

[13] After project completed

Figure 7 – Mayardit FM staff in the studio

"Before, we had problems with fuel because sometimes we ran out of it and the station had to shut down. Sometimes there was a mechanical problem with the generator, and we had to shut down. During the rainy season, the price of fuel traditionally shoots up, or we just can't move fuel from where it's stored to where we need it."
- Aguer Atem Barac, Acting Editor, Mayardit FM

As is typical for TRC stations, Mayardit FM has long struggled with consistent power. In addition to the problems with generator maintenance and fuel, Issa found that the backup batteries were not getting enough charge – just 3-4 hours in the morning, and 3-4 hours in the afternoon. This depleted the life span of the batteries, and they needed to be replaced often.

In September 2015, Issa completed a solar power feasibility study and sent it to TRC senior management. Over the next few months, he continued to advocate for the project, combating skepticism of its high costs and probability of success. By December, Issa was given the green light.

Turalei Solar Project Design

Internews' solar power trials (outlined in "Internews Solar Power Pilot Projects" above) had all been "hybrid" models – the solar panels were intended to take turns with the generator as the power source for the batteries – or small-scale off- grid systems.

It was decided that the Turalei project should be designed using solar power only, with the intention that a diesel generator is never required.

A diesel generator has been included as part of the emergency power-planning on site (should there be a catastrophic failure with the solar equipment), but it requires a manual switchover and is not assumed to be part of usual day-to-day operation.

As a compromise, it was agreed that air conditioning may have to be removed from the site and fans used instead if the A/C load proved to be too high. To date, this has not been required.[14] The A/C is only used for the hotter parts of the day.

Solar Project Goals

The objectives for the project were:

1. Install the donated solar batteries and the other procured equipment to replace the use of the diesel generator.
2. Build a new building to house the solar equipment.
3. Use solar to power the whole site, including office, studios and transmitter.
4. Ensure the equipment is reliable and easy to maintain (compared with the previous set-up).
5. Ensure community acceptance – both staff at the site and listeners living in the local area.
6. Increase the hours broadcast by Mayardit FM each day without increasing overall station running costs.

System Principles

The design principles applied for the new system were:

- Low maintenance for staff. The system should not need high levels of maintenance. Servicing the generator is costly and more specialist repairs require an engineer to be flown in. The new system needed to be easy to understand and not require complex maintenance.
- 15 year target use before replacement.
- Emergency back-up to be done by diesel generator – this will be manually switched.
- Air Conditioning to be switched off. This was agreed with the station staff, as A/C units are resource-heavy. Fans will be used instead. The first month of real use has shown that it *is* possible to run the A/C units during the hottest part of the day without affecting output. They will therefore be retained, with a possible addition of automatic switches so that they are not left running overnight by accident.
- The site must be able to broadcast for 16 hours per day.
- Non-broadcast power (e.g. office, accommodation) to be available 24 hours per day.

[14] It is possible to design a system to run A/C with solar power but it is more expensive, the load will be higher and therefore more panels required.

- The site to have enough physical space to house the solar panels on the ground. The number of panels required is too heavy for roof-mounting.
- The site to have enough physical space to construct an indoor area to house the charge controllers. These need to remain under cover.
- The system will have a 20% contingency for power headroom in its design. This is to allow for personal equipment which may be needed, emergency broadcasts and growth over time.
- The sunlight will be directed to power the batteries *first*. Once the batteries are full, the sunlight will be directed straight to powering the station directly. As soon as the sun power is lost, the batteries will automatically kick in. Therefore, the priority is keeping the batteries topped-up.
- The system was designed for one day of autonomy, meaning that the batteries are sized to hold enough power to support operations for one day (24 hours) without sunshine. It is rare for there to be no sunshine in South Sudan, so one day of autonomy was considered adequate.[15]

Block Diagrams

The following diagrams provide a visualization of how the Turalei system has been designed. In summary:

- Energy from the sun is captured by the solar panels. Energy is prioritized to the batteries first.
- Once the batteries are full, the solar energy is automatically switched to run the radio station directly.
- If there is a drop in sunlight, the station automatically switches back to being run on the batteries.
- When the light returns, the system prioritizes recharging the batteries and the cycle repeats again.
- In an emergency, it is still possible to power the station using the old system of a diesel generator with an AVR (Automatic Voltage Regulator). However, as this is not anticipated as being a common occurrence, this has been designed as a manual switchover. It is possible for you to design your system differently.

[15] It is possible to design a system with a longer reserve for places which have less natural light, but this will mean you need more batteries, which will cost more.

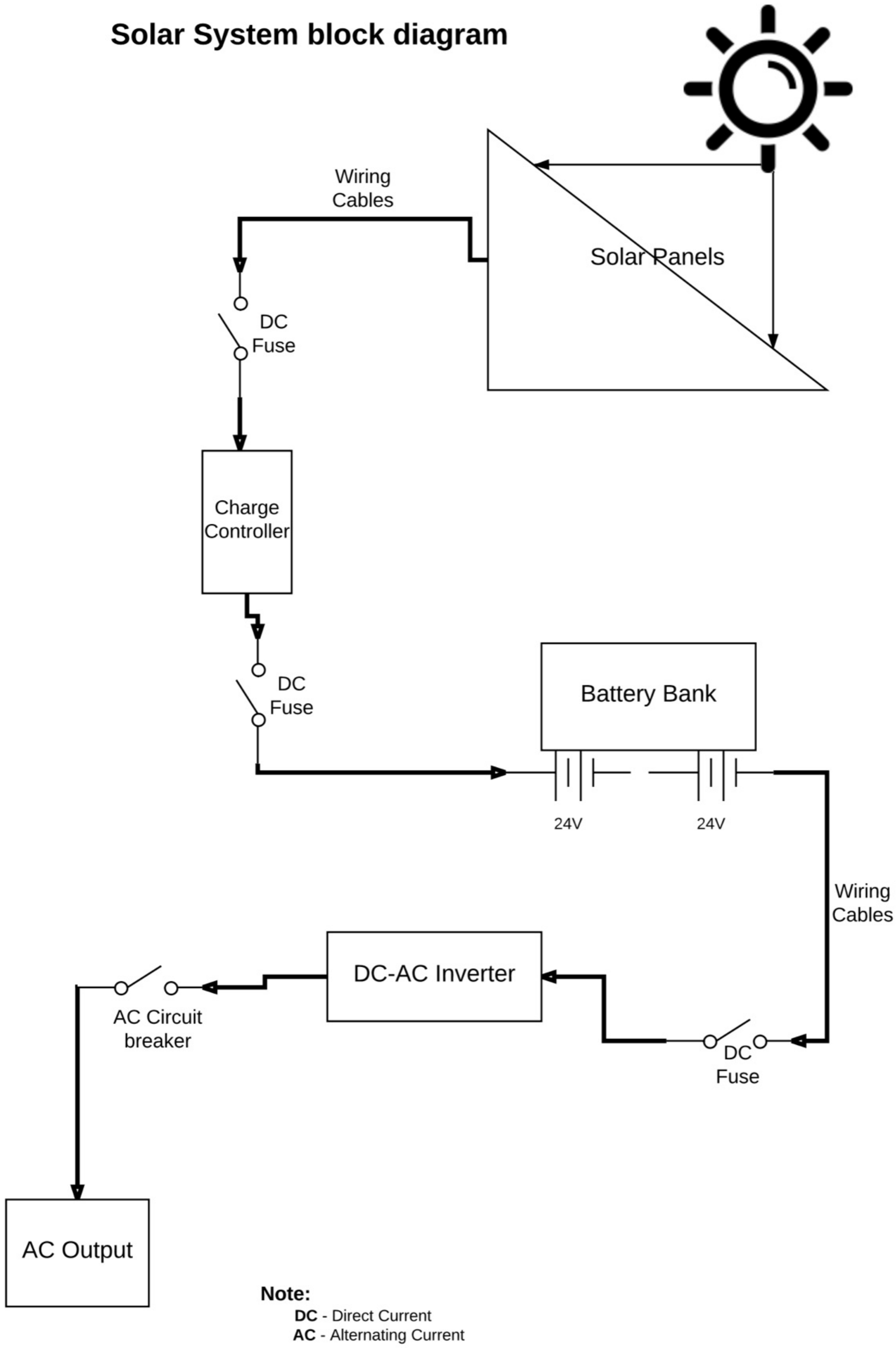
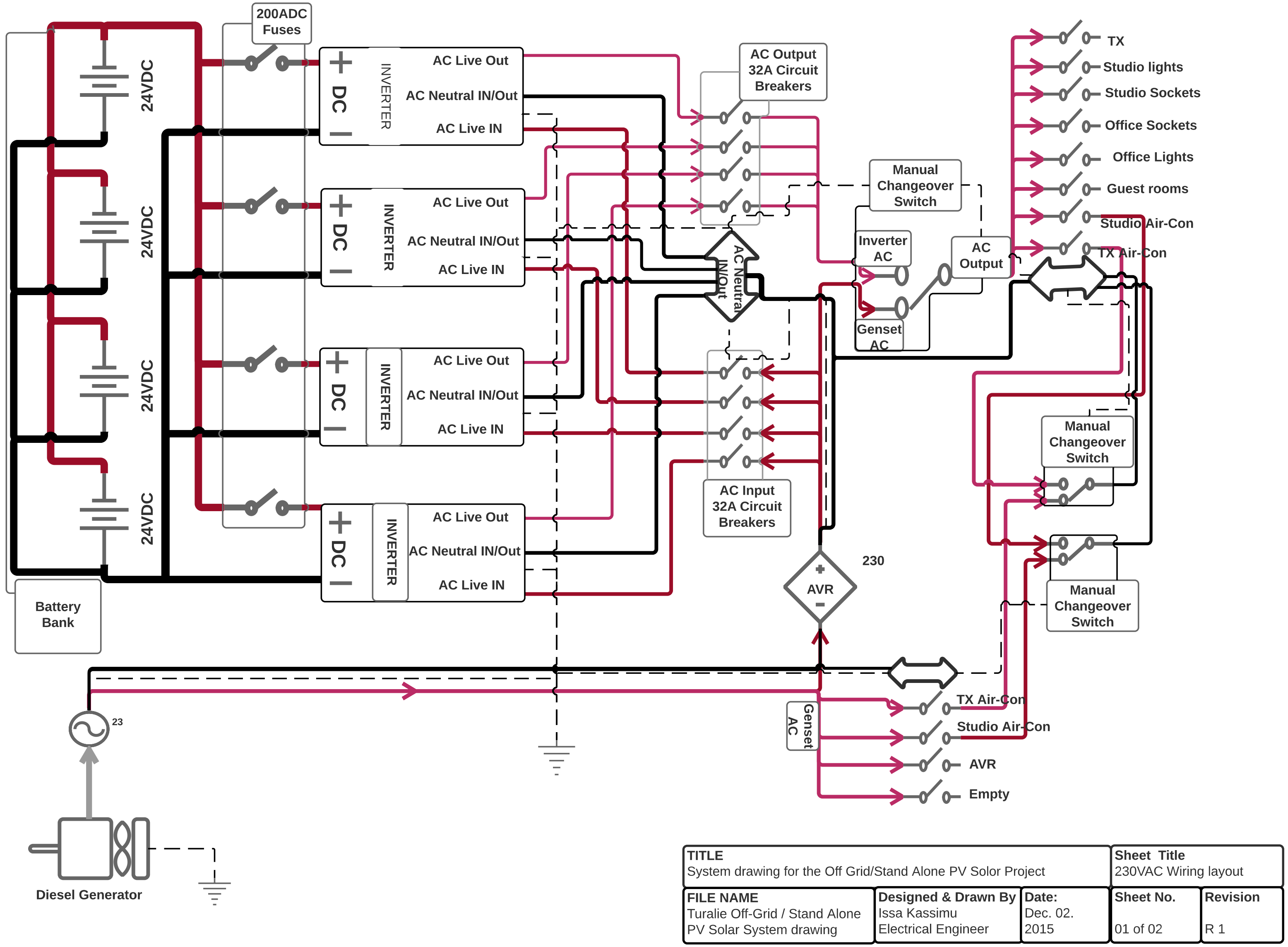


Figure 8 - High-level system diagram

Figure 9 – Detailed Turalei Block Diagram



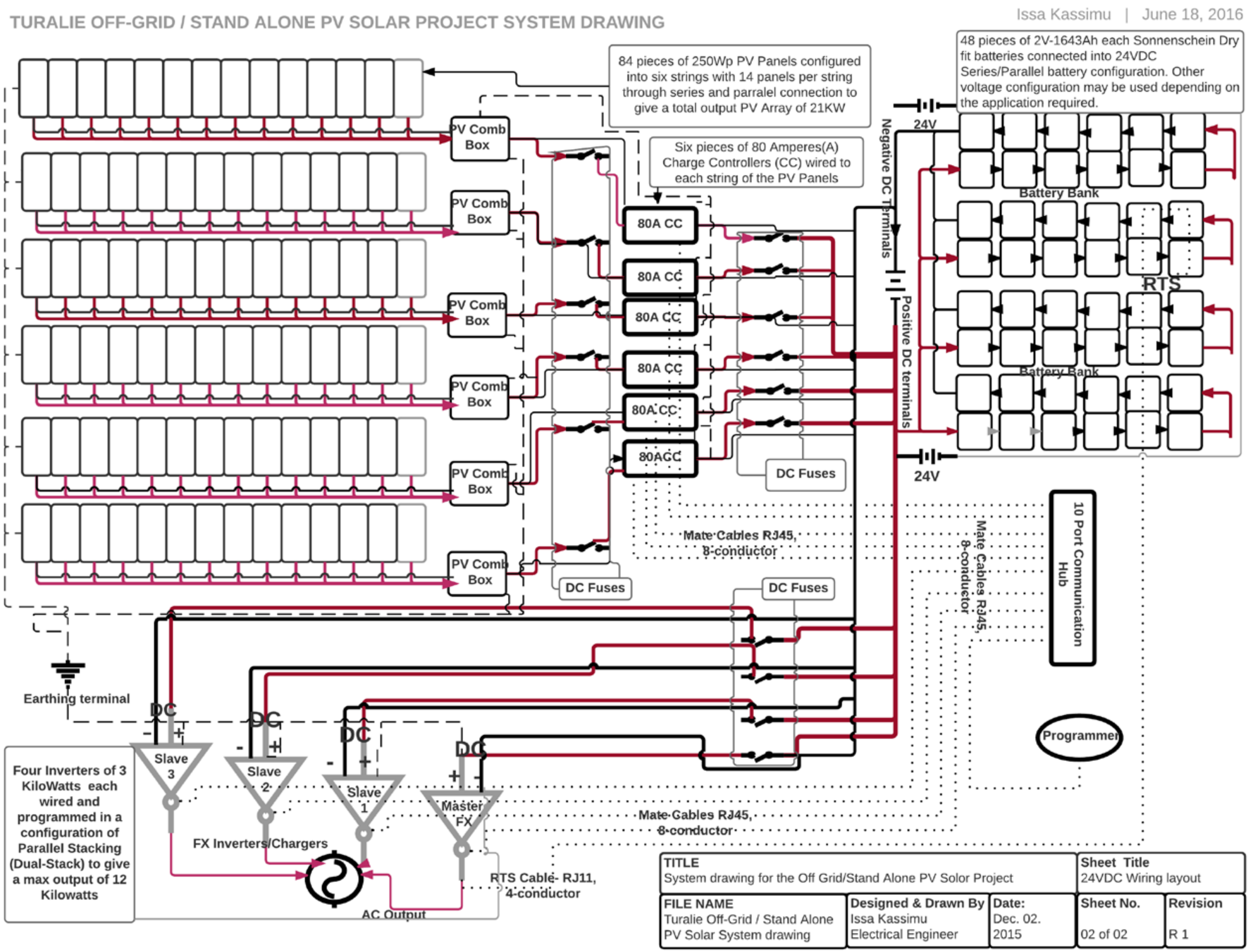

TURALIE OFF-GRID / STAND ALONE PV SOLAR PROJECT SYSTEM DRAWING
Issa Kassimu | June 18, 2016
84 pieces of 250Wp PV Panels configured into six strings with 14 panels per string through series and parralel connection to give a total output PV Array of 21KW
48 pieces of 2V-1643Ah each Sonnenschein Dry fit batteries connected into 24VDC Series/Parallel battery configuration. Other voltage configuration may be used depending on the application required.
Six pieces of 80 Amperes(A) Charge Controllers (CC) wired to each string of the PV Panels
PV Comb Box
80A CC
DC Fuses
24V
Negative DC Terminals
Positive DC terminals
Battery Bank
RTS
Mate Cables RJ45, 8-conductor
10 Port Communication Hub
Programmer
Earthing terminal
DC
Slave 3
Slave 2
Slave 1
Master FX
FX Inverters/Chargers
AC Output
RTS Cable- RJ11, 4-conductor
Four Inverters of 3 KiloWatts each wired and programmed in a configuration of Parallel Stacking (Dual-Stack) to give a max output of 12 Kilowatts
TITLE
System drawing for the Off Grid/Stand Alone PV Solor Project
Sheet Title
24VDC Wiring layout
FILE NAME
Turalie Off-Grid / Stand Alone PV Solar System drawing
Designed & Drawn By
Issa Kassimu
Electrical Engineer
Date:
Dec. 02. 2015
Sheet No.
02 of 02
Revision
R 1

Figure 10 – Pre-Solar vs. Post-Solar System Comparison

<table>
<tr><th></th><th>Pre-Solar</th><th>Post-Solar</th></tr>
<tr><td>Station, Transmitter Tower, Transmitter, Compound, Equipment

(No Change)</td><td colspan="2">• A station building with a main office, manager’s office, main studio, transmitter room and reception / lounge room in one main building.
• A 72 meter transmitter tower in the grounds outside.
• A 2000 W transmitter, with an approximate coverage of 100 KM.
• Accommodation, washroom and kitchen buildings for staff and international trainers who stay on-site. The accommodation block had sockets for fans and electrical equipment.
• Inside the offices were 15 laptops in almost-continuous use as well as a printer, router for the wireless network and fans. There was also a refrigerator, vacuum cleaner and other office equipment.
• The studio contained broadcast equipment, three computers and an air-conditioning unit.</td></tr>
<tr><td>New Construction</td><td></td><td>• 84 Photovoltaic solar panels
• Building to house the solar control equipment</td></tr>
<tr><td>Generator</td><td>13.5 KVA generator</td><td>20 KVA back-up generator—for manual switchover in case of prolonged Photovoltaic failure[16]</td></tr>
<tr><td>Broadcasting</td><td>0600-1000 and 1800-2200 Monday to Friday (8 hours), with 4 hours each on Saturdays and Sundays. 48 hours per week. The non-broadcast power is in use 24 hours a day.</td><td>0600-2200, Monday to Sunday, (16 hours per day). This means that the station is broadcasting for 112 hours per week (64 hours per week more hours on air). The non-broadcast power is in use 24 hours a day.</td></tr>
<tr><td>Power Load Notes</td><td>Air conditioning used all the time in the studio and transmitter room.</td><td>Air conditioning unit only for the hottest parts of the day. [17]</td></tr>
<tr><td>Power Load</td><td>11.7 KW[18]</td><td>9.2 KW[19]</td></tr>
<tr><td>Power Consumption</td><td>82 kilowatt hour</td><td>103 kilowatt hour</td></tr>
</table>

[16] The bigger generator was purchased to accommodate future expansion at the station.

[17] To save power, the teams now use fans where possible. See ‘Overview of the system principles’ and Lessons for Future Projects for more information on air conditioning use.

[18] Note that the load before the solar system is higher as it included the two A/Cs. Please see “Appendix 4. Power Estimation Sheets” for power load and power consumption calculations.

[19] Thus far, the actual power load is roughly 5.2 KW (taken from the MATE monitor), suggesting that the solar system can sustain additional power demands such as the two A/Cs.

Solar Project Timeline

The project began in September 2015. It was scheduled to finish in April 2016 – a total of six months. The timing was chosen to fall outside of the rainy season, which would make transport of equipment prohibitive. This document will be updated after one year from the end of the project (April 2016) so that lessons and figures after a longer period of use can be captured.

Stage 1: Feasibility and Design (August – December 2015)

In August 2015, Issa met with Mayardit FM staff to calculate power allowances and load for his feasibility study. By September, he completed the feasibility study and circulated it with Internews senior management. For the next few months, Issa conducted internal advocacy for the project, particularly combatting skepticism of its high costs and probability of success. By December, Issa was given the green light to proceed.

Stage 2: Procurement and Logistics (December 2015 – March 2016)

From December through March, Issa procured equipment from a vendor in Juba, rather than a vendor outside of South Sudan, so that follow ups would be possible if equipment was found to be defective. In February, the materials began processing in Juba in preparation for transport to the field. Internews' Operations department catalogued and tagged all equipment, and also gained authorizations and clearance from the South Sudanese government and National Security Service to take the materials to site. Transportation of equipment to Turalei from Juba took eight days. By the time of arrival, Issa noticed slight damage to the equipment due to poor packing combined with the bumpy road conditions.

Stage 3: Installation (March 7-27, 2016)

Installation of the system was an intensive, three-week effort requiring the combined work of a small team of casual day laborers managed by Issa. The team constructed a new room adjacent to the radio station to house the solar batteries, charge controllers, inverters. The team also dug tunnels in the ground to conceal the electrical cables, and holes to a minimum depth of 70cm to hold the panel mounting stands in place. The team then had to cut and solder the mounting stands to their appropriate heights before mounting the 84 solar panels. Issa mixed a custom mix of gravel and cement to hold the stands firmly in the ground. For a more detailed, daily description of the installation tasks, please see Appendix 4: Turalei Solar Work Plan.

Stage 4: Operation (March 28, 2016 – ongoing)

Since March 28, 2016, the system has operated without any downtime. The remaining tasks include installing a motion-activated light for security purposes during night time. There may also be cosmetic improvements to the space, such as adding gravel around and under the panels to prevent it from becoming muddy during the rainy season. Issa also plans to do continuous maintenance and capacity building for staff to monitor and adjust the system on their own.

Figure 11 - Panels waiting to be mounted

Figure 12 – Installing the mounting stands

Figure 13 – Mounting the panels

Figure 14 – Issa in the control room

Review & Analysis

Overall assessment to date/summary[20]

This section give much more in-depth information on how the project at Turalei was run and its outcomes.

- The power load for the old site set-up was roughly 11.7KW.[21] The power consumption was 82KWH.
- The rough cost of running the site in March 2016 (pre-solar; generator powered) was around $29,000 a year[22] (please see the note in 'A note on costings and financial savings' above).This included the cost of diesel, spare parts, and maintenance.
- As calculated in the feasibility study, the power load for the new site set-up is 9.2KW. The power consumption is 103KWH.
- The rough cost of running the site in May 2016 (fully solar-powered) is $2,100 a year[23] (please see the note in 'A note on costings and financial savings' above). This is spent on spare parts and maintenance.
- The annual running costs are around 92.8% cheaper using solar compared with the generator.
- The total project costs for Generator and Solar power over five years are around $194,000 and $189,000 respectively. The solar system cost includes a backup generator.
- There is therefore around a $5,200 saving using solar over five years (assuming the project had been started from scratch).
- The solar system becomes cost-effective after year 5.
- The actual savings for the solar system at this site are likely to be higher over five years ($96,000 approx.), as the station used solar batteries donated by UNDP and re-used equipment.
- The savings in the solar system are likely to be greater in the longer term (5-20 years period), although the costs are harder to project.[24]
- It would be helpful if a station considering solar has a donor who can pay for upfront costs.
- The initial installation has gone to plan and is running successfully. The only difference is that the team is using the A/C for much of the day – it was initially planned that this would not happen. Despite the extra load, the whole system has continued to run smoothly.
- The station staff and local community have seen the solar system as a positive change. The solar system protects against volatile fuel prices as well as inflation. The ease of operation and maintenance for station staff is also a priceless benefit. Fewer station shutdowns enable the staff to focus on fulfilling their mandate of providing information and a platform for dialogue to local communities. The stability of the station also makes it more attractive to advertisers and NGOs who want to sponsor programming.

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[20] All figures are rounded. Full details for this site can be found in the supporting spreadsheet, 'Turalei solar project cost benefit analysis' (may not be available externally).

[21] Note that the overall load before the solar system is higher as it included the two A/Cs.

[22] Not including capital set-up costs. See (Internews, 2016)

[23] Not including capital set-up costs. See (Internews, 2016)

[24] We have provided very rough estimates of costs for 15 years in 'Appendix 7. Longer-term cost projections'.

Cost Analysis

We calculated the costs in the following way:

1) Imagined that we were building a traditional generator-run site in Turalei from scratch
2) Compared those costs with the equivalent costs for building a new solar-run site at Turalei

We then compared the initial equipment and set-up ('Capital') costs for each option, as well as estimating annual running costs for each method of running the site.

We ran a calculation based on how much each system would cost overall over a five year period. It should be noted that the solar system is designed to be in place for at least 15 years (and possibly up to 25), so any savings / loss may be greater. For simplicity, we chose not to factor in the longer-term costs or possible equipment replacement at a later date after five years.

Finally, we calculated a separate figure which took account of the donated equipment, so we could have a more accurate comparison of the costs and benefits of this specific site for internal evaluation.

Note should be taken of the existing caveats in 'A note on costings and financial savings' above. The exchange rate is volatile and prices in South Sudan are high for the region. The financial picture at your station may be very different! Therefore, readers should take figures provided as a guideline, and not assume they are precise predictions.

For simplicity's sake, we also chose not to add complex projection modelling or inflation calculations to our five year costs – the market in South Sudan is too unstable for this to be valuable.[25]

Monthly costs

Monthly costs for the pre-solar system include fuel, spare parts, and maintenance (labor and travel). Monthly costs for the post-solar system include spare parts and maintenance (labor and travel).

The monthly costs pre-solar were hard to break down as fuel is not bought every single month and some bills included costs for the use of the station's motor vehicle as well as fuel for the generators. Where the records for motor vehicle and generator fuel were combined, we estimated a fair ratio (50% to the vehicle, 50% to the generator) and used the generator part as the basis for our estimate. We then took an average of the costs over a four-month period and scaled them up to give an indication of figures over a whole year.

The monthly costs post-solar are also an estimate, as the system has not been in place for very long. July 2016 also brought an increase of violence to South Sudan's capital, Juba,[26] which resulted in the killing of a TRC journalist[27] and an emergency evacuation of many Internews staff members (including the Electrical Engineer), with the result that routine trips from Juba to Turalei were suspended.

With these caveats in mind, the figures do show an enormous saving in the monthly running costs between generator-run and solar-powered. The pre-solar annual running costs are approximately $29,100, compared with $2,100 per annum post-solar. **This means that solar-powered stations could be an attractive option for organizations which can have the initial set-up costs funded by a donor.**

[25] Stations considering doing their own generator vs. solar analysis would be advised to compare litres of fuel and/or units of energy used as well as $ amounts to ensure a fair comparison for the situation in their country.

[26] (Burke, 2016)

[27] (Internews, 2016)

Capital (initial set up) costs

An important factor in the total project cost is the initial equipment and set-up effort required.

We found that the initial set-up costs for the generator method were significantly cheaper than the solar-powered method: approximately $48,100 v. $178,200, respectively. (The solar system capital costs include a back-up generator).

In the real-life case of Turalei, the initial solar set-up cost was closer to $87,400 due to equipment which was able to be re-used on site and supplies which had been donated.

Stations which do not have access to the large injection of start-up capital required for solar may find it easier to continue with the generator method.

Combined project costs

The combined project cost (for five years) for the generator method was approximately $194,000.

The combined project cost (for five years) for the solar-power method was approximately $188,700.

Therefore, the saving (over five years) is approximately $5,300.

Solar systems are designed to be in place for 15 years, so this saving will improve over time (although there might need to be replacement parts bought as equipment wears out).

For the specific site at Turalei, the saving (over five years) will be closer to $96,000, due to the re-use of capital equipment mentioned above.

Although these figures are estimates only, **on balance, a solar-powered system is more cost-effective over time than a generator-powered one**. At sites which expect to have the same base for many years, solar would be a good choice, so long as the initial capital costs could be covered.

In the specific case of Internews's real project at Turalei, the estimated saving over five years should be counted as a financial success, especially as it adds protection against volatile fuel prices (the sun being essentially free) as well as inflation. The ease of operation and maintenance for station staff – as well as the stability offered by solar – is also a priceless benefit. Increased on-air reliability enable the staff to focus on fulfilling their mandate of providing information and a platform for dialogue to local communities. The stability of the station also makes it more attractive to advertisers and NGOs who want to sponsor programming.

General section remarks

1. The batteries for the solar project at Turalei were donated. We have included the cost in this analysis so that a true comparison can be made for similar projects in the future.
2. Costs are fluctuating so a comparison of the power output achieved may be more accurate than direct prices, as they vary from month-to-month due to the exchange rate.
3. Our analysis shows that the solar system will begin to pay for itself after five years. Comparative savings after this point are likely to be higher than their generator equivalent. An estimate of the costs over 15 years has been provided in 'Appendix 6. Longer-term cost projections' below. The figures quoted there should be treated with even more caution than the ones in this section, however.
4. Figures have been rounded in the report text.

It is recommended that this report is updated after one year when the first 'actual' figures are known.

Initial cost-benefit analysis summary sheet

TURALEI / MAYARDIT FM SITE COSTS (POWER ESTIMATES)			
Item	**Pre Solar**	**Post Solar**	**Notes**
General costs	N/A	N/A	Staff, stationery, general equipment etc. - out of scope for this report.
Capital costs - buildings, transmitter, studio equipment etc.	N/A	N/A	Out of scope for this report, except building used to shelter solar equipment (included in capital costs)
Capital costs	$48,100.00	$178,182.00	Assumes all equipment bought new. Turalei solar system capital costs actually lower (see below).
Annual running costs	$29,168.75	$2,100.00	
Power total (annual aggregate)	$38.788.75	$37,736.40	Capital cost divided by five and added to annual running costs.
Power total (5 years)	$193,943.75	$188,682.00	Capital cost added to 5x running cost. Assumes no inflation for calculation purposes.
Overall saving / loss post solar		**$5,261.75**	**Assumes system in use for 5 years, no inflation, and no project contingency added.**
INCOME			
Solar battery units - donated by UNDP - cash equivalent		($77,760.00)	
Equipment already used at Turalei - cash equivalent		($13,000.00)	Not required to buy new for this project.
Actual overall saving / loss post solar for Turalei project		**$96,021.75**	**Cost of donated batteries and existing equipment included.**

Figure 15 - Cost-benefit analysis summary sheet

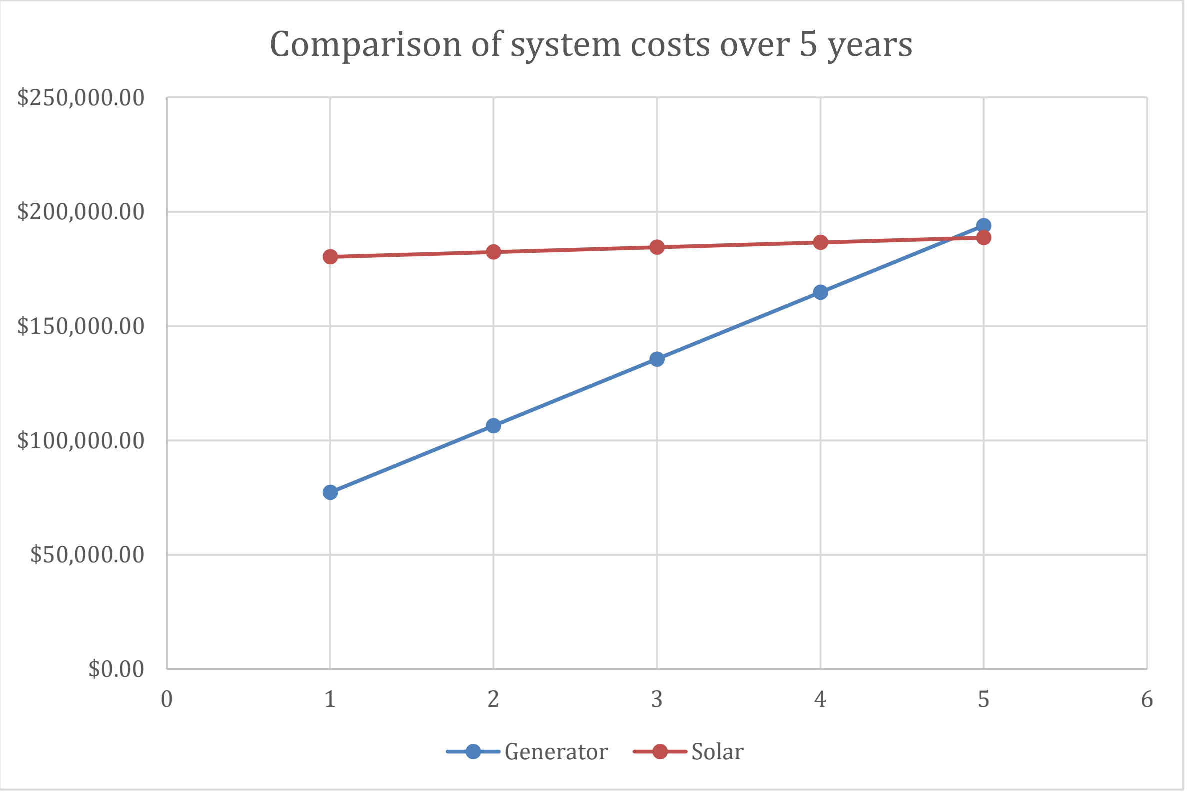

Figure 16 – Comparison of system costs over five years

System uptime/downtime data

A common concern when moving to solar is how reliable the system will be. Here are the downtime statistics for use so far:

Month (2016)	Hours system down	Notes	Month (2016)	Hours system down	Notes	Month (2017)	Hours system down	Notes
May	0		Sept	0		Jan		
June	0		Oct	0		Feb		
July	0		Nov			March		
Aug	0		Dec			April		

Figure 17 - Solar Uptime stats

The Mayardit FM Operations Officer has also been manually filling out a simple daily performance log sheet. This log sheet is shared with Issa and used as a basis for further discussion as needed. (See "Appendix 5: Daily Performance Log Sheet").

Maintenance and Longevity

The system is designed to be as simple to operate as possible. For example, the panels are cleaned automatically when it rains. Simple checks are done by station staff with more advanced support available from an Electrical Engineer (Issa) by phone or in person where required.

Maintenance routine

Daily

- Check to see if the panels are clean and clean if required.
- Check the batteries to see if they are dusty and clean if required.
- Check the status of the battery panels (i.e. fully charged, charging, not charging) and report findings if required.

Weekly

- Cross check on the daily maintenance
- Prepare weekly performance report for site manager
- Carry out thorough cleaning around the site and on the equipment

Monthly

- Test/ take reading for battery voltages
- Inspect equipment to confirm its normal operation

Yearly

- Test/Check the grounding/Earth connection
- Tighten/check bolts and nuts

In Emergency

- Contact your engineer or the supplier

Social Acceptance, User Experience, and Human-Centered Design

The design of Mayardit's system is intentionally "standalone" to require minimal technical maintenance, guaranteeing a much-improved user experience and human-centered design than previous diesel-powered operations. As designed, the system can run for 24 hours without sunshine. The system is also designed to prevent catastrophic damage or overload. In case of excessive solar power that the charge controllers can't handle, the fuse will blow.
The MATE system, a central configuration portal that coordinates system operation and prevents different components from conflicting, also protects against battery drainage by shutting down the system at a low voltage cut-off point.[28]

"This system is complex, but not for the user," Issa says. Aside from cleaning the panels and battery room, the equipment should require little active maintenance from staff. To spot check the system performance, Issa has trained the Operations Officer to read the values and report back the data. (See "Appendix 5: Daily Performance Log Sheet").

> *"The staff should think of it as their system, not as Issa's system."*
> - Issa Kassimu, Electrical Engineer

For Mayardit FM staff, this means a lot of attention previously spent on maintaining simple operations and power supply can now go to programming. "We're more self-reliant, we simply get our power from the sun and that means we can focus more on producing news and programming which is important for our audiences. It also means we can extend the number of hours each day that we broadcast and for us, that's a challenge because we have more airtime to fill, we want to make the quality of this as good as it can be. For our audiences, it's great, because it means we can reach them for longer periods and buildup our audience. We are here to serve their needs and the system helps us to do that," says News & Program Editor Aguer Atem Barac.

Paradoxically, the minimal attention required by the system may mean that staff become less vigilant about energy expenditure, and possibly overload the system by using too much energy (I.e. leaving the air conditioner running, leaving the fans and lights on at night, etc.) Issa emphasizes that staff stewardship of the system is the determining factor in its success. Monitoring the solar batteries – which requires reading the three status lights – is crucial for decision making about whether to flip the switch to the backup generator. "Users need to own the system and see it as their responsibility to maintain. I want them to feel like this system depends on their judgment," Issa adds.

> *"Since the solar system was installed, we haven't had [power] problems. The system is simple and we regularly check the batteries and it allows us to move on with our production and serve our audience. It's simple and very reliable and also reduces our running costs – we don't have to spend money on this budget, which helps us."*
> - Aguer Atem Barac, News & Program Editor, Mayardit FM

To date, the system has had zero downtime, as the power load calculations accommodate staff members' energy consumption habits, plus an additional buffer. As a key component of the feasibility study, Issa conducted interviews with station staff to understand their power consumption

[28] Please see System Components for more information on the MATE.

behaviors and daily routines, knowing that they had their own gadgets, such as laptops and cell phones, in addition to the equipment they required to do their work.

"The staff are the clients [not Internews senior management]. They are the ones using the equipment, and so they need to provide the information." Questions like, "How many hours do you think the printer would be on in a day? How many laptops do you use? How many hours will you charge them?" all fed into the calculations. In the end, Issa incorporated a 15-20% additional allowance for power into the feasibility study. With this allowance, Issa was confident that the system could support additional power loads, such as air conditioning for the studio, and additional fans for the office.

However, such projections are reliant on user behavior. As Issa emphasizes, the success of the system depends on energy load and consumption, as well as battery maintenance. "My biggest concern is that staff will leave the air conditioner running." As staff become accustomed to the additional energy allowance, Issa worries that they will pay less attention to leaving equipment running over night, forgetting to turn things off when they leave the office. "I am trying to figure out how to convey the message of conservation."

Community

Measuring 1.6 x 1m each (and 14 x 18m in total area occupied), the solar panels are clearly visible to anyone who walks along the perimeter of Mayardit FM. The installation took eight days to complete, and during this period, the activity attracted the curiosity of many members of the community. "People asked a lot of questions," Issa says, "but the community has a very positive perception."

Since the install, Mayardit has been broadcasting for 16 hours – twice the length before the change to solar. This extended broadcast time has already garnered positive appreciation from listeners. "The coming of the solar system has helped a lot, so if you want to listen to any song you can tune into Mayardit radio and listen to it and when it was running on a generator, it was just a short time on air, and it forced us to buy memory cards to record and listen to it," says Makuach Nyuol Yor, a male listener in his 20's. "If possible, we also want Mayardit to use this power to work until midnight."

> *"We really love the solar system because it is the first time to have direct power from sun in this community and it is even surprising to us because it is the first time for some of our people to see a big solar system like this in their lives."*
> - Makuach Nyuol Yor, a male listener in his 20's

Some listeners have also expressed their wish to get some power from such a large system. "One thing we request as a community is if we can also somehow get electricity from this system, because we can see that the panels are very large," says Nyamec Beny Kur, a female listener in her 30's.

While the panels are clearly visible, concerns about potential theft or damage are minimal. "Stealing the panels would not be easy. One panel would take about 30-40 minutes to take down," Issa remarks. Each panel is secured by four bolts to the mounting stands, and weighs 19 kilograms. Mayardit also has a night guard who patrols the property, who would take note of suspicious activity. With time, they may install greater security precautions, such as a stronger fence, razor wire, and a motion-activated light that can turn on in the dark for security purposes. Unless the panels experience a direct and targeted attack (i.e. someone throws rocks at them), they are sturdy and durable.

Lessons for Future Projects

Here are some things we've learned along the way which we hope will help others doing similar projects.

Project Planning

- It is strongly recommended that future projects calculate the cost of installing a generator or grid electricity-powered system for comparison to solar system costs at their site, so that a full understanding of the cost benefits can be understood and the two methods compared before the project is started. The annual running costs may be lower, but overall project savings may not be realized until the medium-term.
- While a cost-benefit analysis should be conducted at the outset of the project to determine its financial feasibility, keep in mind that there are significant savings/benefits that may not show up on a balance sheet. In the Turalei example, staff have saved significant time and attention that was previously consumed by procuring fuel and maintaining the generator, and can now concentrate on delivering programs.
- An environmental cost-benefit analysis is also worth conducting during the planning phase. Carbon footprint calculations were not calculated for this project, as the focus was on more economic and long-term equipment stability factors. However, it is likely that significant emissions savings have been made and future projects are encouraged to include this aspect in their figures. (However, noise pollution savings are certain; the generator no longer disturbs the school next door, so students can finally learn in peace.)
- The Turalei system was deliberately designed on the assumption that Air Conditioning (A/C) would not be used on the site, including in the studios and transmitter room. The intention was to save money, as fewer solar panels would be required (A/C uses a lot of power). However, fans do not work in the studio as there is no ventilation (there are no windows and doors should not be left open for reasons of sound-deadening while on air). Staff and equipment get too warm without A/C, and it has been discovered that it is possible to keep the units running without overloading the system. When the batteries are full and there is abundant sunshine, the staff also turn on the A/C in the transmitter room. The lesson is to make sure that A/C **is** included in your design, especially in the studios, as it will be needed even if you would rather that it is not!

Installation

- Solar equipment is heavy – so sites requiring air transport might be prohibitively expensive (and even if the flights are cheap, small planes may not be large enough to store the equipment in the hold).
- Recruitment – it was difficult to find people who have technical expertise to assist in installation. Even the Mayardit FM staff don't necessarily have the technical background. The team wanted to get another technical person to assist, but people were asking $100/day, and wanted to be flown in, fed, and accommodated, which would have stretched the budget too far.
- There is a lack of parts and equipment locally – Issa had to call Juba for things like bulbs and cables. He had been wanting to install lights in the control/battery room, and had waited on the arrival of a cable for a week.

- Procuring other materials – gravel and sand were also hard to obtain in Turalei. Issa improvised by making a custom mixture (needed to secure mounting stands in ground)
- Transportation of equipment took eight days, and was not necessarily secure or safe. The batteries were slightly damaged, indicating they had been bumping around during transport.

Technical

- You will definitely need to run A/C (see above)!
- Night-time use will require more battery back-up, as more power is taken from the reserves when there is no daylight.
- The solar control equipment has the option to export usage data. However, the version bought in this project cannot do it automatically or remotely. Staff on site are not as confident with the computer programming required to access the information. If monitoring the amount of power used is important for your records, consider a model which allows remote / automatic access.

Miscellaneous

- If you are able to technically extend the amount of time your station is on-air, you also need to make sure you are ready editorially and programmatically to cover the extra content required.
- The community was happy to accept the installation but would have liked to have been able to access the electrical supply as well. This was out-of-scope of the project, however mitigating this aspect in communicating your project could be helpful in community engagement. It may be worth incorporating a low power usage but high impact public service component to your project, such as phone charging or public internet.
- Make sure your on-site staff realize the importance of routine checks and that the batteries must not be allowed to completely drain (to save system damage). Build checks into the system (like the MATE battery voltage cut off point) to reduce damage caused by human error.

Manual for Solar System Design & Sizing

Introduction

Solar photovoltaic system or **solar power system** is one type of **renewable energy system** which uses photovoltaic (PV) modules to convert sunlight into electricity. The electricity generated can be either stored or used directly, fed back into grid line or combined with one or more other electricity generators or more renewable energy source. Solar PV system is a very reliable and clean source of electricity that can suit a wide range of applications such as residence, radio stations, industry, agriculture, livestock, etc.

To design your own solar power system, you essentially must answer three questions:

1. **What is the load?**

Calculate the power required to run the equipment in the radio station, including the transmitter, studio, and office. Don't forget the personal gadgets and electronics of the staff.

2. **How many hours of power do you want to support? How many days in a week?**

Determine how many hours of broadcast, versus how many hours of station power you desire.

3. **Where is it?**

Based on the latitude of the location, the panels should be adjusted to face the right direction, and mounted at the optimum angle.[29] Additionally, different locations will have different allotments in terms of space (whether the panels should rest on the ground, or on the roof), and whether the space under the panels could be used for another purpose.

Major system components[30]

Solar PV system includes different components that should be selected according to your system type, site location and applications. The major components for solar PV system are solar charge controller, inverter, battery bank, auxiliary energy sources and loads (appliances).

- **PV module** – converts sunlight into DC electricity.
- **Solar charge controller** – regulates the voltage and current coming from the PV panels going to battery and prevents battery overcharging and prolongs the battery life.
- **Inverter** – converts DC output of PV panels or wind turbine into a clean AC current for AC appliances
- **Battery** – stores energy for supplying to electrical appliances when there is a demand.
- **Load** – is electrical appliances that connected to solar PV system such as lights, radio, TV, computer, refrigerator, etc.
- **Auxiliary energy sources** - is a diesel generator or other renewable energy sources.
- **Mate system controller and display** - displays and configures the system and its components like the charge controllers and Inverter

[29] The optimum angle at the equator is 15 degrees. When not at the equator, add your latitude to 15 to calculate your optimum angle. For example, Turalei's latitude is 9. Therefore, the panels were mounted at 24 degrees.

[30] Links to specific items of equipment are for illustration purposes only, and do not suggest endorsement by Internews.

- Coordinates system operation, maximizes performance, prevents multiple products from conflicting
- Permits important adjustments of the power system like the "low battery voltage cut off/cut in point", which prevents the battery bank from being over depleted
- Instantly displays any FX or Charge Controller errors as well as the specific component affected for easier troubleshooting.

- **HUB Communications Manager -** allows multiple Outback devices to connect and integrate at one point via CAT5e cable WITH RJ45 modular jacks.

Solar PV system sizing

- **Note**: to help with your calculations, we have provided a free, publically accessible spreadsheet. Please see the supporting document, 'Solar Power calculator,'[31] which can be used alongside this section if required.

1. Determine power consumption demands

The first step in designing a solar PV system is to find out the total power and energy consumption of all loads that need to be supplied by the solar PV system as follows:

1.1 Calculate total Watt-hours per day for each appliance used.

Add the Watt-hours needed for all appliances together to get the total Watt-hours per day which must be delivered to the appliances.

1.2 Calculate total Watt-hours per day needed from the PV modules.

Multiply the total appliances Watt-hours per day times 1.3 (the energy lost in the system) to get the total Watt-hours per day which must be provided by the panels.

2. Size the PV modules

PV modules of different size will produce different amount of power. To find out the sizing of PV module, calculate the total watt-peak rating. The peak watt (Wp) produced depends on size of the PV module and climate of site location. We have to consider "panel generation factor" which is different in each site location. For South Sudan, the panel generation factor is approximately 6.31.To determine the sizing of PV modules, calculate as follows:

2.1 Calculate the total Watt-peak rating needed for PV modules

Divide the total Watt-hours per day needed from the PV modules (from item 1.2) by 6.31 to get the total Watt-peak rating needed for the PV panels to operate the appliances.

2.2 Calculate the number of PV panels for the system

Divide the answer obtained in item 2.1 by the rated output Watt-peak of the PV modules available to you. Increase any fractional part of result to the next highest full number and that will be the number of PV modules required.

The Result of the calculation is the minimum number of PV panels. If more PV modules are installed, the system will perform better and battery life will be improved. If fewer PV modules are used, the system may not work at all during cloudy periods and battery life will be shortened.

[31] The spreadsheet can be viewed here: http://bit.ly/2g1YCo9. (Internews, 2016)

3. Inverter sizing

An inverter is used in the system where AC power output is needed. The input rating of the inverter should never be lower than the total watt of appliances. The inverter must have the same nominal voltage as your battery.

For stand-alone systems, the inverter must be large enough to handle the total amount of Watts you will be using at one time. The inverter size should be 25-30% bigger than total Watts of appliances. In case of appliance type is motor or compressor then inverter size should be minimum 3 times the capacity of those appliances and must be added to the inverter capacity to handle surge current during starting.

For grid tie systems or grid connected systems, the input rating of the inverter should be same as PV array rating to allow for safe and efficient operation.

4. Battery sizing

The battery type recommended for using in solar PV system is deep cycle battery. Deep cycle battery is specifically designed to be discharged to low energy level and rapid recharged or cycle charged and discharged day after day for years. The battery should be large enough to store sufficient energy to operate the appliances at night and on cloudy days. To find out the size of battery, calculate as follows:

4.1 Calculate total Watt-hours per day used by appliances.
4.2 Divide the total Watt-hours per day used by 0.85 for battery loss.
4.3 Divide the answer obtained in item 4.2 by 0.6 for depth of discharge.
4.4 Divide the answer obtained in item 4.3 by the nominal battery voltage.
4.5 Multiply the answer obtained in item 4.4 with days of autonomy (the number of days that you need the system to operate when there is no power produced by PV panels) to get the required Ampere-hour capacity of deep-cycle battery.

$$\text{Battery Capacity (Ah)} = \frac{\text{Total Watt-hours per day used by appliances}}{(0.85 \times 0.6 \times \text{nominal battery voltage})} \times \text{Days of autonomy}$$

5. Solar charge controller sizing

The solar charge controller is typically rated against Amperage and Voltage capacities. Select the solar charge controller to match the voltage of PV array and batteries and then identify which type of solar charge controller is right for your application. Make sure that solar charge controller has enough capacity to handle the current from PV array.

For the **series charge controller** type, the sizing of controller depends on the total PV input current which is delivered to the controller and also depends on PV panel configuration (series or parallel configuration).

According to standard practice, the sizing of solar charge controller is to take the short circuit current (Isc) of the PV array, and multiply it by 1.3

Solar charge controller rating = Total short circuit current of PV array x 1.3

Remark: For MPPT charge controller sizing will be different. (See Basics of MPPT Charge Controller)

Example with Calculations

Example: A house has the following electrical appliance usage:

- One 18 Watt fluorescent lamp with electronic ballast used 4 hours per day.
- One 60 Watt fan used for 2 hours per day.
- One 75 Watt refrigerator that runs 24 hours per day with compressor run 12 hours and off 12 hours.

The system will be powered by 12 Vdc, 110 Wp PV module.

1. Determine power consumption demands

Total appliance use = (18 W x 4 hours) + (60 W x 2 hours) + (75 W x 24 x 0.5 hours)

= 1,092 Wh/day

Total PV panels energy needed = 1,092 x 1.3

= 1,419.6 Wh/day.

2. Size the PV panel

2.1 Total Wp of PV panel capacity needed = 1,419.6 / 6.31

= 224.9 Wp

2.2 Number of PV panels needed =224.9 / 110

= 2.04 modules

Actual requirement = 2 modules
So this system should be powered by at least 2 modules of 110 Wp PV module.

3. Inverter sizing

Total Watt of all appliances = 18 + 60 + 75 = 153 W
For safety, the inverter should be considered 25-30% bigger size.
The inverter size should be about 190 W or greater.

4. Battery sizing

Total appliances use = (18 W x 4 hours) + (60 W x 2 hours) + (75 W x 12 hours)
Nominal battery voltage = 12 V
Days of autonomy = 1 days

Battery capacity = [(18 W x 4 hours) + (60 W x 2 hours) + (75 W x 12 hours)] x 1
(0.85 x 0.6 x 12)

Total Ampere-hours required 178 Ah
So the battery should be rated 12 V 600 Ah for 1 day autonomy.

5. Solar charge controller sizing

PV module specification

Pm = 110 Wp

Vm = 16.7 Vdc

Im = 6.6 A

Voc = 20.7 A

Isc = 7.5 A

Solar charge controller rating = (2 strings x 7.5 A) x 1.3 = 19.5 A

So the solar charge controller should be rated 20 A at 12 V or greater.

Frequently Asked Questions

- **What happens at night?**

The system can still work so long as the battery bank has enough capacity. The battery bank will be the main source of power and their reserves will run down, as they cannot be charged by the solar panels due to the absence of sunlight.

- **What if it is raining?**

The rain can actually be good for your solar system! It cleans the panels, which enables more efficient energy conversion. Sometimes, there may not be sufficient charging due to the absence of sunlight while it is raining. In this case, the batteries will be the sole source of power.

- **What if I need more power in the future?**

Based on your additional calculated power demand, you can be in position to upgrade your system by adding more components, such as additional solar panels and batteries.

- **Will the system work for 24 hours?**

The system is supposed to work for the number of hours it is designed to work for, for example if it's designed to work for 24 hours, yes it can work for that 24 hours. The duration depends on the load on the system, as well as whether the system has the opportunity to recharge from sunlight.

- **What happens if the load is greater than the system is designed for?**

If the load is greater than the system is designed for, it will work for a shorter amount of time than planned. If the load is lighter than designed for, the system will work for a longer amount of time than planned.

- **How many panels do I need?**

The number of panels you need can only be determined by the system size and design you have. We have provided a method to calculate this in the 'Solar PV system sizing' section above.

- **Will it work in my location?**

Yes, it will work! Although the design and the size may vary. A location that has abundant sunshine near the equator, like South Sudan, will require fewer panels. A location far from the equator with variable sunshine, like Iceland, will require a larger system.

- **Is solar power cheaper compared to running on a generator?**

It is cheap in the long run, but expensive in the installation stages. Costs vary, so you will need to do your own estimate to find out if it is a cost-effective for your location. Bear in mind that solar equipment is usually expected to last longer than generator equivalents, and brings benefits beyond cost savings, such as ease of operation, maintenance, and less reliance on volatile fuel prices and availability.

- **Is the system hard to maintain?**

No, the system is easy to maintain! Usually, any solar system is a "standalone" system that runs on its own. You don't need to turn on the sunshine!

- **How often has your system been off-air?**

As of October 2016, the system has had no unplanned time off air.

- **Can the equipment be removed and re-installed at another location?**

Definitely yes, as long as you can remove and reinstall the equipment without damaging it.

- **How long can a solar system be expected to last?**

It depends on the manufacturer's warranty on the equipment, the conditions in your location, and your maintenance routine. For example, the solar panels installed at Mayardit FM have a warranty of 25 years. It is important to conduct consistent maintenance to achieve the lifespan, such as cleaning the panels, inspecting for loose connections at the terminals, and ensuring no damage occurs. In addition, the batteries must be monitored so that they are never depleted, otherwise they will need to be replaced (see question below).

- **Will any parts need replacing? How long will the batteries last?**

The battery lifespan is estimated at 15-25 years. However, batteries can be spoiled in a very short period of time if not monitored properly by the user. You must not drain the battery completely or it will have to be replaced.

The solar panels should last for as long as the manufacturer's guarantee. The only effect on this would be if there was direct damage, e.g. rocks being thrown onto them. Dust will affect the system performance (reduces sunlight absorbed) but not the panel longevity themselves.

- **What is the most vulnerable part of the system?**

The batteries; if they are depleted completely, there is no way they can be charged again. In this case, they must be replaced.

- **What is the most challenging aspect of installing a solar system?**

The design of the system.

Appendix 1: Acronyms & Abbreviations

Acronym (A-Z)	Full meaning	Definition
A/C	Air Conditioning	Method of cooling a building in hot weather. More power-intensive (and effective) than a fan.
AC	Alternating Current	A type of electricity where the flow changes direction. 'Mains' power (including from a generator) is usually AC.
AVR	Automatic Voltage Regulator	Piece of equipment used to smooth power spikes cause by diesel generators to save damage to sensitive electronic equipment.
CNISS	Community Needs Initiative South Sudan	NGO which has received support from Internews.
DC	Direct Current	A type of electricity where the flow stays in the same direction. Battery power is usually DC.
INGO	International Non-Governmental Organization	A Non-Governmental Organization which has its headquarters in a different country, or works across several countries. Internews, WaterAid and Oxfam are all examples of INGOs.
Internews	Not an acronym	INGO specializing in developing strong, independent media around the world.
i-STREAM	Strengthening Independent Media in South Sudan	Internews's five-year program supported by USAID.
MATE	Not an acronym	Short for 'Outback MATE,' a brand and model of solar system controller.

Mayardit FM	Not an acronym	Mayardit FM is the name of the TRC station which is based in Turalei and broadcasts to much of the region. It is named after a type of bird commonly found there.
NGO	Non-Governmental Organization	A Non-Governmental Organization which is based in the same country it serves. TRC is working towards becoming an NGO.
PV	Photovoltaic	E.g. 'Solar PV'. A method of transferring sunlight into electrons, for use as a source of electrical power.
SSP	South Sudanese Pound(s)	National currency of South Sudan.
TRC	The Radio Community	Network of community stations run by Internews in South Sudan.
Turalei	Not an acronym	Turalei is a town in the northern part of South Sudan. Mayardit FM is based there.
UNDP	United Nations Development Programme [sic]	UN Agency supporting sustainable development.
USAID	United States Agency for International Development	United States Government agency primarily responsible for administering civilian foreign aid.
USD	United States Dollar(s)	Currency used in the United States of America and commonly traded in South Sudan.
VOF	Voice of Freedom Magwi	NGO which has received support from Internews.

Appendix 2: List of equipment used at the Turalei Site

S/NO.	Item description	UOM	Quantity	Rate($)	Amount($)
1	**21,362 Watts peak PV array Installation requirement**				
2	250W Polycrystalline silicon panels- African or Canadian or Macro	pcs	84	400	33600
3	Pre-fabricated panels mounting stands to cover a total area of 14mX12m as per the design	Units	1	3500	3500
4	40x40mm Perforated steel angle lines (Mounting frames)	pcs	80	25	2000
5	Roofing bolts with hex nuts & washers Size 1/4x3/4	pcs	420	1	420
6	4X16mm flexible cable(EA cables with multiple strands)	Meters	150	22	3300
7	4X35mm cable (EA cables with multiple hard strands)	Meters	10	45	450
8	Cable lugs-35mm	pcs	24	2	48
9	Standard Strip connectors - 60A	Bars	20	10	200
10	Cable ties- Medium size	Packets	24	12	288
11	Insulating taps- red, black, yellow and blue	pcs	48	0.5	24

12	35mm Conduit pipes and accessories (bends, couplers, circular boxes and solvent glue.	Pcs	50	10	500
13	PVC junction boxes.	Pcs	90	10	900
14	Outback FLEXmax 80A Solar Charge Controller	pcs	6	1500	9000
15	Flexible conduits.	Roll	1	100	100
16	Expand screw nails- 12mm	Packets	6	10	60
17	**101665 Ah total battery capacity installation requirement**				
18	2V, 1643Ah Sonnenschein dry fit batteries (Price in Germany /UK	pcs	60	1620	97200
19	Jumper cables - 120mm	Meters	70	40	2800
20	Cable lugs-120mm	Pcs	50	10	500
21	Battery room/shade- 4Mx3M	Units	1	6000	6000
22	11902 Watts AC Inverter output installation requirement				0
23	3,000VA - 24V Outback Inverter/Charger	pcs	4	3000	12000
24	Outback Hub-10 communication manager	Pcs	1	800	800
25	Outback MATE system display and controller	Pcs	2	500	1000
26	200A Catritrage fuses with holders	Pcs	10	50	500

27	Jumper cables - 90mm	meters	30	30	900
28	Cable lugs-90mm	Pcs	24	8	192
29	Raw bolts - 8M	Pcs	20	3	60
30	Hanger consumer unit 12 ways complete with circuit breakers	Unit	1	200	200
31	Earth rode-pure copper	pcs	4	65	260
32	Earth wire-1x25mm	meters	40	8	320
33	**Other Operational requirement during installation process**				
34	Transportation of the equipment to the site.(Turalie)	Trip	1	5000	5000
35	Labour for assistant electricians (skilled personnel)	EA	2	2000	4000
36	Labour for casual Labour at site (un-skilled)	EA	2	500	1000
37	Estimated total($)				187122

Appendix 3: Turalei Equipment vs. other Internews solar sites

Necessary Equipment							
	PV Panels				Charge Controllers		
	Power (Wattage)	# of panels	Brand	Mount	Rating (Amperes)	No.	Brand
VOF	250	24	Macro	Rooftop	80	2	Flamx outbacks
CNISS	250	8	Macro	Rooftop	80	1	Flamx outbacks
Abyei	250	6	Macro	Rooftop	80	1	Flamx outbacks
Turalei	250	84	Canadian	Ground	80	6	Flamx outbacks
	Inverters/Chargers				Storage Batteries (Ampere hours, AH)		
	Power (Watts)	No.	DC Input/AC output	Brand	Voltage / AH	No.	Brand
VOF	3000	2	24 V/230 V	FX outbacks	12 / 200	20	Ritar
CNISS	3000	1	24 V/230 V	FX outbacks	12 / 200	8	Ritar
Abyei	3000	1	48 V/230 V	FX outbacks	12 / 200	8	Gaston
Turalei	3000	3	24 V/230 V	FX outbacks	2 / 1643	48	Dry fit Sonnenschein

Auxiliary Equipment					
	Mate display/programme		Communication hub		
	No.	Brand	No.	No. of ports	Brand
VOF	1	Outbacks	1	4	Outbacks
CNISS	n/a	n/a	n/a	n/a	n/a
Abyei	n/a	n/a	n/a	n/a	n/a
Turalei	1	Outbacks	1	10	Outbacks

Note: This does not include other equipment, including but not limited to: jumper cables, distribution panels, fuses/circuit breakers, changeover switches, cable lugs, combination boxes/junction boxes, perforated steel angle line, strip connectors, bar connectors, automatic voltage regulator/stabilizer (AVR, needed for hybrid systems), earth rode, or lighting arrestors.

Appendix 4. Power Estimation Sheets

Pre-Solar System: Electrical power estimation sheet for Turalei Radio Station based on 8 hours operational time

S/No.	Appliance	Quantity	Wattage (W)	Hours from 6am-6pm	Hours from 6pm-6am	Hours per day	Days per week	Watt hours/day	% of total
1	printer laser jet p2055dn	1	720	2	0	2	7	1440	1.8
3	Dell Monitor	3	384	4	4	8	7	3072	3.7
4	Dell CPU	3	1320	4	4	8	7	10560	12.8
6	Bulbs	40	8	2	12	14	7	112	0.1
7	Fridges	3	70	4	4	8	7	560	0.7
9	Scanner	1	240	2	0	2	7	480	0.6
10	Internet router	1	18	12	12	24	7	432	0.5
11	Internet modem	1	384	12	12	24	7	9216	11.2
12	Ceiling fans(office)	6	75	6	4	10	7	750	0.9
13	Wall fans(Accommodation)	7	65	4	8	12	7	780	0.9
16	Dell Laptops	15	90	6	2	8	7	720	0.9
17	Motorola VHF Radios	3	144	2	2	4	7	576	0.7
18	Air blower	1	600	2	0	2	7	1200	1.5
19	Vacuum cleaner	1	1500	2	0	2	7	3000	3.6
20	Backup transmitter BW 1000W	1		12	4	16	7	0	0.0
21	Big transmitter RVR Elettronica TEX2000 light	1	3000	4	4	8	7	24000	29.2

22	RM-1 Stereo rack monitor Fostex	1	50	4	4	8	7	400	0.5
23	Tascam Stereo Tuner	1	8	4	4	8	7	64	0.1
24	Digital utility processor(Inovonics)	1	50	4	4	8	7	400	0.5
25	Tascam AM/FM stereo tuner	1	10	4	4	8	7	80	0.1
26	Tascam cassette player	1	30	4	4	8	7	240	0.3
27	Tascam CD player	1	30	4	4	8	7	240	0.3
28	Telephone hybrid	1	10	4	4	8	7	80	0.1
29	Mixture Soundcraft RM100	1	300	4	4	8	7	2400	2.9
30	LED Security lights	8	50	1	12	13	7	650	0.8
31	Air conditioners	2	2600	4	4	8		20800	25.3
	Totals		**11756**					**82252**	**100.0**

11.7KW 82KWH

Post-Solar System: Electrical power estimation sheet for Turalei Radio Station based on 16 hours operational time

S/No.	Appliance	Quantity	Wattage (W)	Hours from 6am-6pm	Hours from 6pm-6am	Hours per day	Days per week	Watt hours/day	% of total
1	printer laser jet p2055dn	1	720	2	0	2	7	1440	1.4
3	Dell Monitor	3	384	12	4	16	7	6144	5.9
4	Dell CPU	3	1320	12	4	16	7	21120	20.4
6	Bulbs	40	8	2	12	14	7	112	0.1
7	Fridges	3	70	12	4	16	7	1120	1.1
9	Scanner	1	240	2	0	2	7	480	0.5
10	Internet router	1	18	12	12	24	7	432	0.4
11	Internet modem	1	384	12	12	24	7	9216	8.9
12	Ceiling fans(office)	6	75	6	4	10	7	750	0.7
13	Wall fans(Accommodation)	7	65	4	8	12	7	780	0.8
16	Dell Laptops	15	90	6	2	8	7	720	0.7
17	Motorola VHF Radios	3	144	2	2	4	7	576	0.6
18	Air blower	1	600	2	0	2	7	1200	1.2
19	vacuum cleaner	1	1500	2	0	2	7	3000	2.9
20	Backup transmitter BW 1000W	1		12	4	16	7	0	0.0
21	Big transmitter RVR Elettronica TEX2000 light	1	3000	12	4	16	7	48000	46.3
22	RM-1 Stereo rack monitor Fostex	1	50	12	4	16	7	800	0.8
23	Tascam Stereo Tuner	1	8	12	4	16	7	128	0.1

24	Digital utility processor(Inovonics)	1	50	12	4	16	7	800	0.8
25	Tascam AM/FM stereo tuner	1	10	12	4	16	7	160	0.2
26	Tascam cassette player	1	30	12	4	16	7	480	0.5
27	Tascam CD player	1	30	12	4	16	7	480	0.5
28	Telephone hybrid	1	10	12	4	16	7	160	0.2
29	Mixture Soundcraft RM100	1	300	12	4	16	7	4800	4.6
30	LED Security lights	8	50	12	4	16	7	800	0.8
	Totals		**9156**					**103698**	**100.0**
			9KW					103KWH	

Appendix 5. Turalei Solar Work Plan

Turalie and Agok PV Solar Project daily activities work plan			
Date	**Specific Tasks**	**Completion date**	**Comments**
7-Mar-16	Travelling from Juba to Agok then Turalei	7-Mar-16	
	Assessment of the reported faulty 13.5KVA FG Wilson generator	7-Mar-16	Needs an overhaul and replacement of worn out parts.
	Mobilization of causal laborers to move the generators and batteries appropriately for installation		Required many men as the generators are heavy to be fitted or moved with bare human hands instead of a mechanized lift and also the dry fit batteries are very heavy as well for just one or two people to carry
8-Mar-16	Re-arrangement of the generators and Installation of the new 20KVA Caterpillar generator	8-Mar-16	
	Disconnection and removal of the old existing 200Ah batteries to create space for 12 pieces of new dry fit 1643Ah Sonnenschein batteries to be connected as temporary power backup		
	Site clearance for the PV Solar steel stands layout		
9-Mar-16	Setting up the PV Solar steel stands structural layout at the site.	9-Mar-16	Needed a personnel with a basic masonry skill to help adjust and confirm the required readings on the opposite side although I have to work it out with minimum team support. Working under severe sun heat required enough refreshment like water, and other soft drinks for the team but due to budget limitation this was not factored in.
10-Mar-16	Pegging the set PV Solar steel stands structural layout points	10-Mar-16	
	Excavating the pegged PV Solar steel stands structural layout points to a minimum depth of 70cm	11-Mar-16	Difficulty in excavating the hard ground under the severe sun heat

11-Mar-16	Fitting the PV Solar structural steel stands into the excavated holes, adjusted to the initial layout point and firmly reinforced with a proportional mixture of cement, sand, aggregate and water(Concrete)	13-Mar-16	Lack of technical knowledge from the hired team on basic masonry work, So I have to set and adjust all the structural steel stands personally. Working under severe sun heat has affected work progress as the team needed frequent breaks to re-hydrate themselves.
12-Mar-16	Fitting the PV Solar structural steel stands into the excavated holes, adjusted to the initial layout point and firmly reinforced with a proportional mixture of cement, sand, aggregate and water(Concrete)		
13-Mar-16	Fitting the PV Solar structural steel stands into the excavated holes, adjusted to the initial layout point and firmly reinforced with a proportional mixture of cement, sand, aggregate and water(Concrete)		
14-Mar-16	Putting up the PV Solar structural steel supporting rails (Rafters) and carefully adjusting them to the required tilt angel with the structural steel stands and firmly tight with bolts and nuts.	16-Mar-16	Lack of technical knowledge from the hired team on how to use basic hand tools and machines like drills, pliers, spanners, spirit levels etc. so I have to set and mount most the all the structural steel Rafters, Purlins and PV Solar panels personally or supervise every work they execute. Working under severe sun heat has also affected the process of the tasks as the team lacked the required refreshments like adequate water and other soft drinks as a result of limited facilitation support for such harsh and hazardous work environment.
	Putting up the PV Solar structural steel perforated mounting lines (Purlins)) and firmly tight with bolts and nuts on the supporting rails (Rafters) at the appropriate spacing.		
	Mounting up the 84 pieces of 250 watts PV Solar panels and firmly tight onto the perforated steel angle line with bolts and nuts		
15-Mar-16	Putting up the PV Solar structural steel supporting rails (Rafters) and carefully adjusting them to the required tilt angel with the structural steel stands and firmly tight with bolts and nuts.		
	Putting up the PV Solar structural steel perforated mounting lines (Purlins)) and firmly tight with bolts and nuts on the supporting rails (Rafters) at the appropriate spacing.		
	Mounting up the 84 pieces of 250 watts PV Solar panels and firmly tight onto the perforated steel angle line with bolts and nuts		
16-Mar-16	Putting up the PV Solar structural steel supporting rails (Rafters) and carefully adjusting them to the required tilt angel with the structural steel stands and firmly tight with bolts and nuts.		

	Putting up the PV Solar structural steel perforated mounting lines (Purlins)) and firmly tight with bolts and nuts on the supporting rails (Rafters) at the appropriate spacing. Mounting up the 84 pieces of 250 watts PV Solar panels and firmly tight onto the perforated steel angle line with bolts and nuts		
17-Mar-16	Travelled from Turalei to Agok Designing the roof top lay out for the six pieces 250W panels	17-Mar-16	The space on the required roof face side is small though the design finally accommodate all the six 250 watts panels.
18-Mar-16	Installing the perforated angle steel lines on the roof as per the design	18-Mar-16	The iron sheets are of week gauge, working on the roof was a bit challenging as the only safe sports are the timber purlins which where places far apart. Nail sports left as a report of fixing the perforated steel angle lines might cause some water linkages during raining season, it has to be sealed off.
19-Mar-16	Mounting up the 6 pieces of 250 watts PV Solar panels on the roof and firmly tight onto the perforated steel angle line with bolts and nuts Mounting up the 80A Outback's charge controller	19-Mar-16	Very challenging to work at roof height under severe sun heat as every things get hot for un gloved hand to handle.
20-Mar-16	Termination, Configuration and connection of the PV Solar panels to the Outback's charge controller Connecting the PV Solar outputs to the battery bank Testing and commissioning the installation	20-Mar-16	The existing batteries had deteriorated due to excessive discharge and limited recharge thus where unable to store the power from the PV solar panels effectively.
21-Mar-16	Travelled from Agok to Turalei		
21-Mar-16	Mounting the six 80A Outbacks Solar Charge Controller with their DC fuse boards and excavating the cable trench from the PV Solar plant to the control room	21-Mar-16	The building wall was not strong enough to handle wall plugs and fasteners

22-Mar-16	Termination, connection and configuration of the PV solar panels	24-Mar-16	Required a skilled personnel to help taking readings but there was lack of that technical knowledge from the hired team on the actual required electrical installations and regulations part two basics, so I got to do this entire task personally
23-Mar-16	Termination, connection and configuration of the PV solar panels		
24-Mar-16	Termination, connection and configuration of the PV solar panels		
25-Mar-16	Carrying the heavy new dry fit 1643Ah Sonnenschein batteries into the control room and assembling them for configuration to the required voltage set up	26-Mar-16	The batteries are very heavy so this task really required many men and done carefully at enough working space. Configuration and connection of the entire battery bank required an assist to help me as this task involves taking reading at either of the sides and done with a lot of attention though I had to work late in the day complete this task.
	Mounting battery output DC fuse boards, Connection and configuration of the battery bank		
26-Mar-16	Carrying the heavy new dry fit 1643Ah Sonnenschein batteries into the control room and assembling them for configuration to the required voltage set up		
	Mounting battery output DC fuse boards, Connection and configuration of the battery bank		
27-Mar-16	Mounting the FX Invertors/Chargers, Power communication hub, mate display, AC input/output distribution panel, Load distribution panel and changeover switches	27-Mar-16	
	Completing the DC connection from the battery bank through the fuses to the six 80A Outbacks charge controllers and the four 3000VA FX Inverters/Chargers		
	Completing Earthing/grounding for the entire installation work		
28-Mar-16	Completing the AC power connection from the four FX Inverters through their distribution panel/breaker to the changeover switch and load distribution panel	28-Mar-16	
	Connecting the Outbacks Mate display, Communication hub inputs and programming the FX Inverters/Charger.		
	Double cross checking installation work		
	Collecting tools and clearing up the site.		
	Testing and commissioning the system		

	Recording System performance, operation and collecting date for brief technical analysis		
29-Mar-16	Brief Orientation to system users		
	Travelling from Turalei to Agok		
	Replacing the faulty Agok batteries with ones taken from Turalei		
	Collecting tools and clearing up the site.		
30-Mar-16	Travelling from Agok to Juba		

Appendix 6. Daily System Performance Log Sheet

Turalie's Off Grid PV System Performance daily log sheet.

Date	0600hrs			1000hrs			1400hrs			1700hrs			2000hrs			2200hrs			Weather Condition		
	Full(G)	OK(Y)	Low(R)	Full(G)	OK(Y)	Low(R)	Full(G)	OK(Y)	Low(R)	Full(G)	OK(Y)	Low(R)	Full(G)	OK(Y)	Low(R)	Full(G)	OK(Y)	Low(R)	Sunny	Cloudy	Rainny
01-Aug-16		✓			✓			✓			✓			✓			✓				✓
02-Aug-16		✓		✓			✓			✓				✓			✓		✓	✓	
03-Aug-16		✓		✓			✓			✓				✓			✓			✓	
04-Aug-16		✓		✓			✓			✓				✓			✓			✓	
05-Aug-16		✓		✓			✓				✓			✓			✓		✓	✓	
06-Aug-16		✓			✓		✓				✓			✓			✓				✓
07-Aug-16		✓		✓			✓			✓				✓			✓			✓	
08-Aug-16		✓		✓			✓				✓			✓			✓				✓
09-Aug-16		✓		✓			✓			✓				✓			✓		✓		
10-Aug-16		✓			✓		✓			✓				✓			✓				✓
11-Aug-16		✓		✓			✓			✓				✓			✓		✓		
12-Aug-16		✓		✓			✓			✓				✓			✓		✓		
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17-Aug-16		✓		✓			✓			✓				✓			✓		✓		
18-Aug-16		✓		✓			✓			✓				✓			✓		✓		
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23-Aug-16		✓		✓			✓				✓			✓			✓				✓
24-Aug-16		✓		✓			✓			✓				✓			✓		✓		
25-Aug-16		✓		✓			✓			✓				✓			✓		✓		
26-Aug-16		✓		✓			✓			✓				✓			✓		✓		
27-Aug-16		✓			✓		✓			✓				✓			✓				✓
28-Aug-16		✓		✓			✓			✓				✓			✓		✓		
29-Aug-16		✓		✓			✓			✓				✓			✓		✓		
30-Aug-16		✓		✓			✓			✓									✓		
31-Aug-16			✓	✓			✓				✓									✓	

Appendix 7. Longer-term cost projections

As outlined in the '[Review & Analysis](#)' section, the systems have been compared on a standard project cycle of 5 years.

Solar systems are designed to be in use for longer than this (15-25 years), and the savings tend to increase over time.

We have therefore prepared some **very rough** calculations to show how savings *might* appear with longer use.

There are some very important additional caveats:

- The prices in this list are based on estimates from 2015/16. Future costs have been assumed to be identical.
- No account has been made for inflation.
- No contingency has been added.
- Costs in South Sudan fluctuate all the time. Solar mitigates against fuel price increases, but the situation may be very different in your country. Please do not make important decisions based on these figures!

There are some assumptions:

- Prices will be identical every year.
- The station will not be run 24/7 and therefore the generators and ancillary equipment would need replacing every 5 years[32].
- The backup generators for the solar system would also need replacing every 5 years. Even if they hadn't been used, they could still suffer damage and deterioration in South Sudan's harsh conditions.
- Equipment replacement has been assumed to run on even lifecycles. This is rarely the case in real life (equipment either breaks early or carries on for longer than planned!)

[32] Generator lifespans vary. Typical life expectancy is 20,000 hours (so it depends on how frequently you use it). If you used the generator for 24 hours a day, your expected lifespan would be: 20,000/24 = 833 days (less than 3 years). Generator lifespan also depends on cleaning and maintenance.

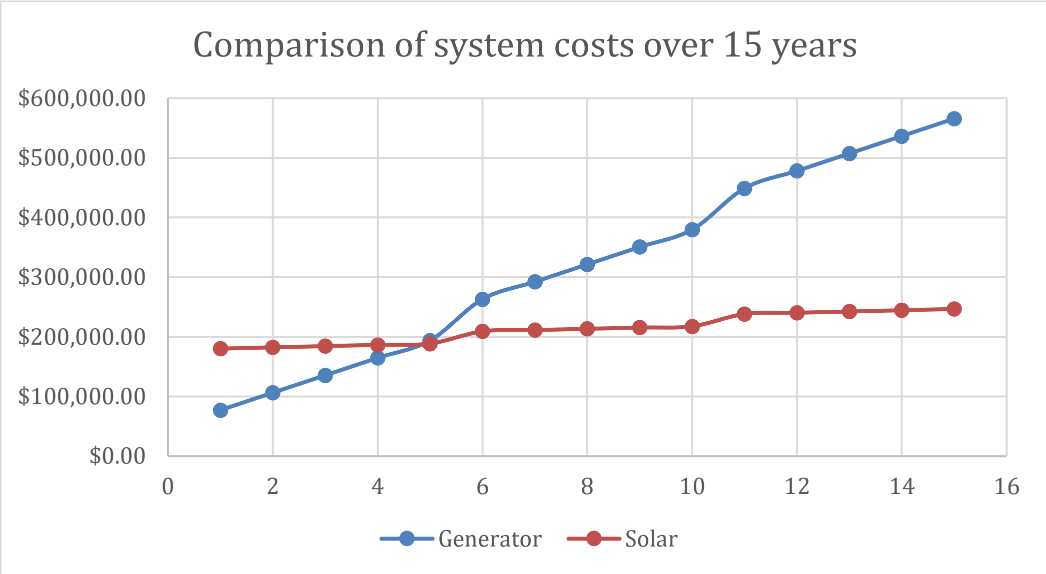

Figure 18 - Comparison of system costs over 15 years

With these very heavy caveats in mind, it can be seen that the solar system *may* become more cost effective as time goes on. This is because the generator system will need quite expensive items of equipment to be replaced every five years (e.g. generator, AVR) whereas the solar equipment does not need to be replaced so early. In addition, the lower annual running costs for solar mean that, after the five year point, the projected costs do not rise as steeply.

As the solar system has not been installed for even a year at this point, it remains to be seen how these very rough projections will relate to real life. The further into the future costs are projected, the less confidence there can be.

It should also be noted that the solar equipment is more expensive to buy. Although it is not expected that it will need to be replaced for many years, if there is accidental or malicious damage to the equipment, those costs would need to be bourne by the host station.

For the purpose of this chart, the cost of the donated equipment was not taken into account.

The full calculations can be seen in the supporting spreadsheets, '*Turalei system yearly costs comparison*'[33] and '*Turalei solar project cost benefit analysis_15 year estimate*[34]' (may not be available externally).

[33] (Internews, 2016)

[34] (Internews, 2016)

Appendix 8. The Abyei Hybrid Solar Project

As not all stations have the resources needed to implement a solar system of the same scale as Turalei, this Appendix showcases a cheaper, hybrid solar system that still relies on generator/fuel power but reaps substantial cost savings and benefits.

With funding from the US Special Envoy to Sudan and South Sudan's office through July 2016, Internews has been supporting a news service in the Abyei Administrative Area (disputed territory between Sudan and South Sudan). The team is now transitioning into an independent community based organization.

The team has an office in Agok, which is near to the border with South Sudan.

They do not broadcast live from this office, but instead travel to Turalei once a week to present the *Abyei This Week* program. They also prepare pre-recorded shows which are broadcast on a number of stations in South Sudan.

To prepare the team for longer term financial and operational independence[35], in March 2016 the Abyei office was converted from running on generator power to running a hybrid system, where solar energy is used for some of the time and diesel for the rest. The installation was completed around the same time as Turalei's solar system.

This Appendix contains background information prepared for Internews management in early 2016 to make the case for a limited solar installation.

It should be noted that **as the Abyei office does not have a transmitter, the overall power consumption is far lower than at the Turalei site**.

Project justification

SOLAR POWER can greatly supplement the use of the electrical generator, reducing projected diesel usage in the Abyei Compound to 50 litres a month in dry season (until end of April). In rainy season (May, June, July) it can reduce projected usage to 150litres per month[36]. This reduction in fuel use alongside the reuse of existing infrastructure (solar batteries etc.) during installation to save costs, will make a solar panel array cost effective for the Information Access in Abyei project. In addition, the project will have the bonus of legacy sustainability (solar can provide 100% of power in dry season during the day, reducing fuel use to zero in dry season during work hours) and it will provide a secondary power supply to back up the generator.

Project Objectives

- The installation should pay for itself within the remaining five months of the project.
- There should be enough solar panels to provide full electrical power during the day in dry season, and for at least half the day in rainy season.

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[35] See the 'Internews Solar Power Pilot Projects' section above.

[36] This figure is based on the generator only needing to be run every two days for two and a half hours at a time (or roughly 40 hours a month) during the dry season. In rainy season it needs to be run for four hours every day. The generator uses roughly 1.5 litres of diesel per hour, so the figures allow for a margin of error to allow for unexpected extra use (e.g. forgetting to switch it off on time).

- Reuse of as much existing infrastructure as possible (e.g. roof mounting, use of existing solar batteries, 12 volt system etc.)
- After the solar installation, the generator would only be run in the evening for battery top up purposes:
    - Dry season 2.5 hours on alternate days
    - Wet season 4 hours a day, daily
- Generator diesel usage was estimated at 1.5litres an hour once running sweetly. Considerably more is consumed during start up by the engine.
- Therefore, even with the new lower exchange rates in dry season with the generator running at 1.5 litres per hour for a well-run generator it would still save about $400 a month.

Costings

No solar, diesel costs per month (assuming the use of 400ltrs of diesel per month):

- Locally bought diesel: $2,125 per month with diesel at 500ssp per 20ltr jerry can
- Tanker delivery diesel: $960 per month using Dalbit at $2.40 per litre delivered by tanker (unreliable deliveries dates, 8 week fluctuations)

No solar, projected costs for diesel with 5 months remaining in project (March-July 2016):

- Locally bought diesel: $10,625
- Tanker delivery diesel: $4,800

Solar Equipment cost: $4942 (see Figure 19 on following page)

With Solar, Dry Season diesel costs per month (50 litres):

- Locally bought diesel: $265
- Tanker delivery diesel: $120

With Solar, Wet Season diesel costs per month: (150 litres):

- Locally bought diesel: $795
- Tanker delivery diesel: $360

A note on how the figures were calculated

When these calculations were made the USD to SSP exchange rate used for project expenses was roughly 1USD = 4.6SSP.

In December 2015, the South Sudan central bank suddenly abandoned its fixed exchange rate to let the SSP trade freely in the market with other world currencies and compete with the black market[37].

Therefore, the official rate Internews was using also subsequently dropped to 1USD = 29SSP, which meant that locally bought diesel was now roughly 4 times cheaper (it's only 4 times as the price of diesel had also risen, though not as steeply, to 600SSP/650SSP per 20ltr jerry can).

As the currency rate change happened towards the end of the project (after the dry season had finished) it didn't really affect the cost effectiveness of the Abyei solar project overall.

This is a good illustration of how the fluctuating prices of SSP can have a dramatic effect on project costs!

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37 (Sudan Tribune, 2015)

	General Installation Material Estimates for Solar Installation in Abyei				
S/NO.	Item description	UOM	Quantity	Rate($)	Amount($)
1	Polycrystalline silicon panels- Canadian with; Pmax 255W, Voc 37V, Isc 9A and power tolerance of 0 - +5W	pcs	6	470	2820
3	60x60mm Perforated steel angle lines (Mounting frames)	pcs	8	35	280
4	Roofing bolts with hex nuts & washers Size 1/4x3/4	pcs	64	0.5	32
5	4X10mm flexible cable(EA cables with multiple strands)	Metres	10	20	200
6	1X35mm cable (EA cables with multiple hard strands)	Metres	4	10	40
7	Cable lugs-35mm	pcs	4	1	4
8	Standard Strip connectors - 60A	Bars	1	7	7
9	Cable ties- Medium size	Packets	1	10	10
10	Insulating taps- red,black,yellow and blue	pcs	4	1	4
14	Outback FLEXmax 80A Solar Charge Controller	pcs	1	1500	1500
16	Expand screw nails- 12mm	Packets	1	45	45
24	**Estimated total($)**				**4942**

Figure 19 - Abyei Solar System Equipment List

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