Technical and Economic Assessment for Hybrid PV Mini-Grid Projects

Optimized Layout and Sizing of Off-Grid Power Plant for SKA1-Low Radio Telescope

L. Millet, J. Wüllner, M. Vetter
Team Applied Energy Storage Systems
Fraunhofer-Institut für Solare Energiesysteme
79110 Freiburg im Breisgau, Germany
e-mail: lluis.millet.biosca@ise.fraunhofer.de

A. Schinckel
CSIRO Astronomy and Space Science
PO Box 76, Epping, NSW 1710 Australia
e-mail: antony.schinckel@csiro.au

***Abstract*—Unavailability of utility power at the isolated location where the Australian component of the Square Kilometre Array (SKA1-Low) is going to be built motivates the technical and economic viability study of a standalone photovoltaics-based power plant gathered in this paper. This includes a highly conceptual power system design, analysis of load profile characteristics and particular power requirements, simulation-based sizing optimization, and a detailed economic evaluation of the system initial and operating costs.**

While the system's performance evaluation is not the main focus in this paper, consideration of system components' cooling requirements is shown to be necessary, as it considerably influences the total power requirements. From the economic analysis, it is found that economies of scale and technology price-experience curves play a major role for an accurate LCOE estimation.

Regarding the optimized layout, it has been found that distributed generation (DG) is only economical in this particular case for antennas clusters further than 10 km away from the Central Processing Facility, while the rest of inner antennas and Remote Processing Facilities should be powered from a central power plant and a reticulated transmission line system.

Keywords- Square Kilometer Array (SKA); PV-battery; PV-battery-diesel; Distributed Generation (DG); Off-Grid

I. Introduction

Solar power is expected to be soon the cheapest form of electricity in many regions [1]. However, solar power is a non-dispatchable source, which depends on weather conditions and solar irradiation, producing consequently a volatile and intermittent power.

High shares of fluctuating renewable power in utility grids or standalone hybrid mini-grids, require short- and mid-term storage to stabilize grid power and ensure power availability. Electrochemical battery storage is essential for grid stabilization, voltage and frequency control, but also for shifting potential energy excesses during some hours or even days.

Integrated PV-battery systems have a history of more than four decades, but are today attracting more interest than ever due to the rapid reduction that their components' cost has experienced over the recent years.

This paper gathers the preliminary study that was conducted at the Fraunhofer ISE for an optimized design of the standalone PV-battery-diesel system to power the SKA radio-telescope in Australia, including the highly conceptual power system design, analysis of load profile characteristics and particular power requirements, simulation-based sizing optimization, and a detailed economic evaluation of the system initial and operating costs.

The Square Kilometre Array (SKA) [2] project is an international effort to build a unique instrument able to conduct transformational science and break new ground in astronomical observations. One of the first stages of the project is the SKA1-Low, to be built at the Boolardy Station, West Australia. This low-frequency interferometer is planned to consist of over 130,000 2-metre high wideband dual-polarized antennas observing in the range 50-350 MHz.

Because of the scientific requirements, most of the antennas will be placed within a central core of around 1km diameter, but total antenna's layout will extend to a radius of about 40km, in a spatial arrangement consisting of three spiral arms with a logarithmic declining number of antennas clusters (see Figure 1). The outer clusters are connected to a small building, the so-called Remote Processing Facilities (RPFs), where basic signal data is pre-processed before

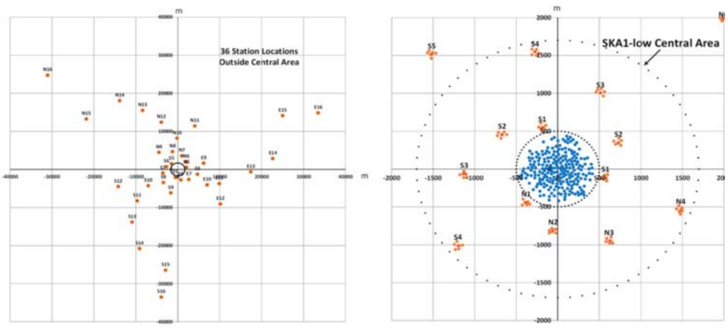

Figure 1. Configuration of SKA1-Low antennas cluster locations [1].

transferring it to the Central Processing Facility (CPF).

The actual unavailability of utility power at the SKA1-Low isolated location motivates the present study, where the technical and economic viability of powering this installation with an off-grid power system based on solar photovoltaics (PV) is assessed.

Due to the high power reliability required from the telescope, which has to operate continuously 365 days a year, battery storage system and/or additional dispatchable generation sources (e.g. a small diesel generator) are foreseen to be essential to avoid power outage at any time.

Based on the power sources, two different off-grid systems are evaluated in this report: a 100% renewable energy based system (PV-battery); and a mixed system, adding a small diesel generation set to the previous configuration.

The objective of this study is to evaluate the viability of these power plant systems and their capacity to meet the power requirements of the SKA1-Low's Telescope.

Moreover, taking into account the spatial distribution of the load requirements, two common power system layouts are compared in this study: the first, consisting of a central power plant and a set of transmission power lines; and the second, which consists of a set of distributed local power generation plants. The objective of such comparison is to find the optimal distance from which the a priori advantages of a centralized power generation unit (with lower installation and O&M costs plus economies of scale effects) are no longer payed off due to distribution costs of long power transmission lines.

II. Power Plant Requirements

A. *Radio-Telescope Power Loads*

As depicted in Figure 1, the majority of the SKA1-Low's antennas are concentrated in a small core area a kilometer across, around the Central Processing Facility (CPF). However, up to 36 clusters are positioned at a further distance along the spiral arms.

In the outer clusters, each of 1536 antennas are connected to a small building, the so-called Remote Processing Facilities (RPFs), where basic signal data is pre-processed before transferring it to the Central Processing Facility. The power consumption for each of the outer antennas clusters is estimated to have an approximately constant load of around 32 kW, as detailed in the following Table 1.

Given the information provided about the antennas spatial distribution and the power requirement estimate of the RPF, the approximate nominal power load of the whole radio telescope can be plotted as a function of the radial distance from the center, or the CPF (Figure 2).

TABLE I. Power Budget of a Remote Processing Facility

Load	Power Budget
Data Processing Racks	19 kW
Racks' Cooling	7 kW
Antennas Power Load	6 kW
Total (Sum)	**32 kW**

Note, from Figure 2, that the nominal electrical power consumption from the SKA1-Low amounts to a total of about 3MW. Moreover, starting phases from HVAC chillers, large fan motors, or other devices, can produce peaks up to factor 3-5 higher the local nominal load for <30sec time periods, which have to be considered for the design of the power plant.

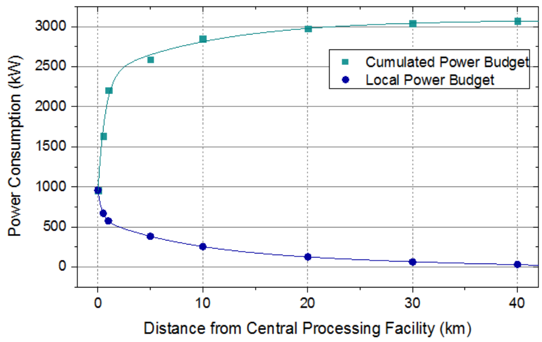

Figure 2. Spatial Distribution of SKA1-Low Power Requirements

B. *Component's cooling requirements*

Aside from the power that has to be provided to the antennas, the processing racks, and their cooling systems (Table 1), the load profile to dimension the system components should also take into consideration the cooling power required by the power plant components themselves, as most of them typically struggle when operating at extreme temperatures, including the PV inverter, the battery controller and especially the battery cells.

Optimal operation from AC/DC power converters are usually guaranteed by the manufacturers within the range of 0-45°C. In the case of the batteries, an operating range of 0-50°C is usually permitted, but hot temperatures are known to shorten cycle life, and thus increase final costs, whereas low temperatures may severely limit power capabilities [3].

Due to the climate conditions of the region near the Boolardy station (data obtained from Meekatharra Airport and Mundiwindi weather stations), no heating system is expected to be required, as temperatures in winter do not often drop to lower values than 5°C. Besides, self-heating of the system components would most probably ensure that these temperatures are never achieved at the shielded power plant containers or RPFs. However, it can be seen that there is a potential risk of achieving temperatures higher than 40-45°C in summer days. Thus, it is clear that all the electronic and storage elements that are to be located in the RPFs most probably need active cooling systems to ensure that maximum operating temperatures are not exceeded.

Of course, the detailed design of the RPFs geometry might decrease cooling needs due to passive cooling. Possible passive elements could include a cover, or deck, in order to shade the RPF container, and a proper geometrical design allowing for significant natural convection or ventilation.

The components' active cooling power requirements can be approximated as a function of external temperature, components' mass and lumped heat capacity, and the energy losses (inefficiencies) of the different system components.

Even though the efficiency figures of the solar inverters, battery converters, and lithium-ion batteries is usually very high (range usually between 95 to 98%), our estimate of the components' cooling requirements are observed to make a substantial difference to the required power from the RPFs and the antennas, adding up to 25% of power load to the original 32kW/RPF during hot, summer days, especially when the PV energy flows at maximum power both to the RPF loads and to the battery bank.

For this reason, the load profile has iteratively been set in our technical evaluation (assuming a cooling system with a COP[1] of 2) in order to adapt to the expected cooling requirements of the PV and battery system components.

III. TECHNICAL EVALUATION

A. Power System's Architecture

In utility-scale PV+[2] power plants, one of the most important layout considerations is choosing between AC and DC coupling architectures.

For this particular application, an AC coupled system is preferred, on the one hand, because of the higher maturity and availability of AC coupled products in the today's market for utility PV plants with similar size to the one dimensioned in this study, and, on the other, because the share of direct PV power consumption is observed to be high enough to make sure that the overall system's efficiency is just very slightly inferior to that of a DC-coupled system.

Regarding the PV inverter, three common possible configurations exist: micro-, string-, or central inverter. While micro-inverters are lately growing rapidly in popularity for residential solar systems, due to their higher flexibility and improved efficiency, the most popular layout for large PV power plants are string- or central inverters, because of lower capital and maintenance costs.

For this particular application in the SKA1-Low, very special attention has to be paid to the RFI and EMI that are generated by the pulse width modulation (PWM) control of the inverters, since these could cause radio-interferences affecting the quality of the telescope measurements. Most of the commercial products include EMI filters to comply with the electromagnetic interference norms: IEEE 1547, UL 1741, the CE EMC directive or the FCC Part 15. However, the interferences have to be reduced, in this case, to a much lower level than that fixed by those directives.

For this particular reason, central inverter architecture is advantageous as compared to other possible configurations. This way, all the potential electromagnetic interference generators can be contained inside or around the RPF container, facilitating the shielding and filtering efforts. Moreover, this architecture is less prone to propagate the EMI from the DC side to the solar panels, which could act as a radiation antenna and generate undesired RFI [4].

From here on, this report does not include further investigation to the issue of electromagnetic interferences. Further investigation of such potential dangers should be carried out before the installation of the PV power plant. The costs associated to EMI/RFI filtering, shielding or

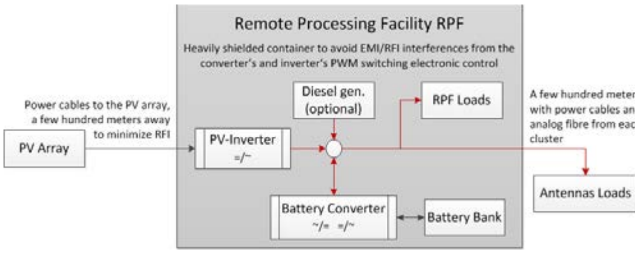

Figure 3. Schematic of the suggested AC coupled power plant's architecture for the antenna clusters, with a central inverter

cancellation are also left apart from the economical assessment that follows under Section IV, with the only exception of the transmission power cables, whose price does indeed include RFI filtering.

B. Simulation Settings

The software that has been used to optimize the components' size is the commercially available software HOMER, and the technical validation of the system performance has been conducted on Matlab, which includes more detailed PV and battery empirically-based models, which are based on testing results obtained at the Fraunhofer ISE's ServiceLab and TestLab laboratories.

Because of the objective of this study, the performance of the standalone power plant system is simulated with a time resolution of one hour, which is considered fine enough to capture the major trends and variations of the solar power availability throughout the day and along the different seasons of the year.

As mentioned in Section I, two different hybrid power plant system configurations have been considered: a PV-battery-diesel hybrid system, and purely renewables-based PV-battery system.

For the electrical storage, a lithium-ion battery storage system has been selected for the present application. While lead-acid batteries had been the standard choice for standalone PV systems among the past 20-30 years, because of its simplicity, safety, widespread and low cost, Li-Ion is actually the most popular technology, mainly because of their price reduction as a result of economies of scale effects, and because of their better cycle life with respect to lead-acid. Besides, other storage technologies have been discarded because of their lacking technological maturity, such as NaS or VRF batteries, or because of the site topography, which does not support, e.g., pumped hydro storage.

The load profile the power plant has been optimized with corresponds to that of a single Remote Processing Facility and the associated 6 clusters of 1536 antennas, and has iteratively been adjusted to meet the components' cooling requirements during summer months, as mentioned in Section II.B.

In order to obtain the optimal components' size, the total project cost has been minimized, based on the retail price, expected lifetime, and approximated O&M costs of each of the system components that are detailed in Table II. In addition to the component costs, which were estimated from market analysis and other project's experience, the initial installation has roughly been estimated with a cost of 200€/kWp, which includes mounting of PV structures, hardware and racking electronic components installation,

[1] COP stands for Coefficient of Performance

[2] The notation "PV+" refers to PV plants which include battery storage

and battery, battery converter and solar inverter's installation.

These installation costs, as well as the base prices gathered in Table II, are representative prices for 2017, but might be considerably different to the real prices that can be expected for a power plant to be installed in a very remote area, such as in this particular case. Therefore, these base prices are reviewed in next Section IV, where a deeper economic analysis is conducted to obtain better project cost estimates.

TABLE II. CAPITAL AND O&M BASE COSTS OF POWER PLANT COMPONENTS

Component	Inputs for price estimation of HRES components		
	Capital costs	*Lifetime*	*O&M costs*
PV Modules	500 €/kWp	25 years	13 €/(kWp.year)
PV Inverter	90 €/kW	15 years	3 €/(kW.year)
PV BOS	90 €/kWp	25 years	5 €/(kWp.year)
Li-Ion Battery	450 €/kWh	10 years ~3,000 cycles	5 €/(kWh.year)
BMS	130 €/kWp + 50 €/kW	10 years ~3,000 cycles	5 €/(kWh.year)
Battery Converter	170 €/kW	15 years	3 €/(kW.year)
Diesel (optional)	500 €/kW	15,000 runtime hours	0.03 €/h + 1.1€/L (fuel)

The horizon to evaluate the project costs has been set to 25 years. Regarding macro- and microeconomic environment, a nominal discount rate, d_n, of 6% has been assumed, since this can be considered a reasonable cost of capital for utilities in Australia in the actuality[3], and an inflation rate, e, of 2%[4]. As a result, the real discount rate, d_r, is obtained by

$$d_r = \frac{(1-d_n)}{(1-e)} - 1 \qquad (1)$$

Regarding system performance constraints, the battery bank has been restrained to operate within a 90%DOD range, and the minimum operating time of the diesel generator was set to 30 minutes.

C. Optimal Components' Size for PV-Battery-Diesel

The simulation-based optimized size of the PV-battery-diesel power plant components are gathered in the following Table III.

Note that the optimized system has a very high renewable fraction, f_{ren}, which is computed as:

$$f_{ren}(\%) = \frac{Energy_{(Renewables \to AC,Load)}}{Energy_{(AC,Load)}}.100 \qquad (2)$$

As depicted in this table, the levelized cost of electricity (LCOE) for the hybrid power system is of approximately 0.245€/kWh, and the total project cost is of 1.169 M€ for a 25-year horizon. The costs contribution of each of the system components is shown in Figure 4.

[3] The discount rate has been determined from the WACC (cost of capital) estimations from the Australian Energy Regulator, AER (https://www.aer.gov.au/, accessed Jan 2018).

[4] The inflation rate is assumed constant at the actual through project horizon. Inflation is estimated from Consumer Price Index from the Reserve Bank of Australia (https://www.rba.gov.au/, accessed Feb 2018).

TABLE III. SUMMARY OF THE SIZING OPTIMIZATION RESULTS

Component	Size / Others
PV Modules	226 kWp
PV Inverter	120 kW
Battery	533 kWh
Battery Converter	73 kW
Diesel	42 kW
Initial Capital	524,900 €
Avg. O&M	40,900 €/y
NPC	1,169 M€
LCOE	0.246 €/kWh
Ren. Fraction	95.6 %

Note that the diesel generator capacity is higher than the nominal load required by the RPF. This is justified by system energy losses and cooling requirements that add up to 8 kW to the nominal RPF power budget.

With regard to the capabilities of the power system to cover possible high peak loads, it should be noted that peaks up to 73kW could always be rapidly and in a sustained manner covered by the battery system. Moreover, as most of the battery converters admit up to a factor of 3-5 of their nominal power for short time periods, peaks up to 200-300kW could be covered for a few seconds or even some minutes.

It is important to mention that the size of the optimal components that ensure continuous power to a single RPF can be linearly scaled up in order to estimate the components' size of the central power plant, located near the CPF, which would power many more antennas clusters, assuming that power transmission losses do not represent a considerable efficiency decrease of the power system.

D. Optimal Components' Size for PV-Battery

In the case of the purely renewable energy based PV-battery power plant, the sizing optimization simulation has been run under the constraint of a set of annual capacity shortage values. When the capacity shortage is set to the default 0%, the designed power system is required to meet the totality of the load. However, logically, in order to ensure meeting the load during consecutive non-sunny days or weeks, the battery bank and/or the PV modules have to be extremely oversized, as shown in Figure 5.

The results in Figure 6 show that, if a small percentage of the load is allowed to be unmet, the all-renewables system components' size can be drastically decreased and that, under the climate conditions at the Boolardy Station, just a 2-3% capacity shortage allows the PV-battery system to be price-competitive with the mixed PV-battery-diesel system presented above.

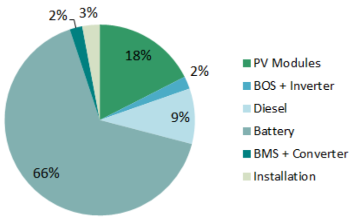

Figure 4. Contribution of each of the main system components' cost to the aggregated Net Present Cost (NPC) for PV-Battery-Diesel system with Li-Ion batteries.

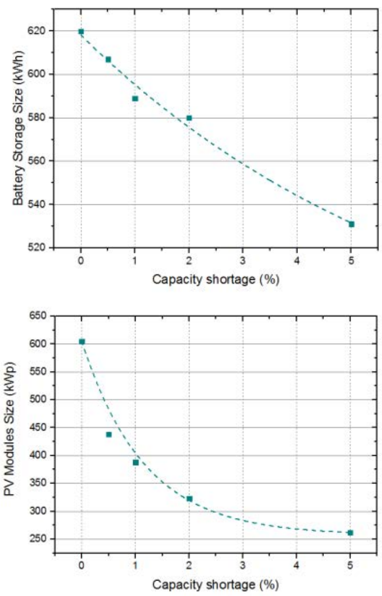

Figure 5. Optimized size of the battery bank (a) and PV modules (b) vs. the permitted system's capacity shortage.

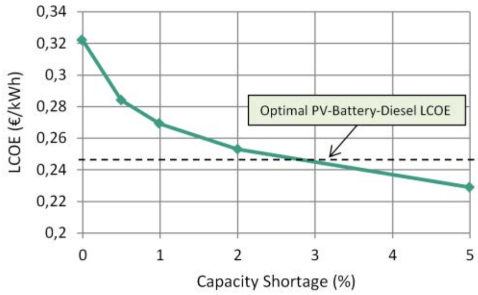

Figure 6. Levelized cost of electricity, LCOE (€/kWh), of the optimized PV-Battery system vs.capacity shortage (%)

E. Transmission Power Line

A reticulated power distribution power line from a central power plant, near the CPF, could also provide the power requirements to each of the RPF stations, as well as to the antennas located in the central area.

The power transmission lines would consist of a heavily shielded underground cable that would operate at medium voltage (i.e., 11kV). Each of the RPFs would require a step-down transformer, as the antennas and other RPF loads need to be powered at LV, e.g., 400V. The estimated cost of the transmission power line can be computed from the base costs gathered in Table IV. The life expectancy of all transmission line components has been set to 50 years.

Since optical fiber cabling for data communication needs to be installed either way, from each of the telescope RPFs to the CPF, the trenching cost that is shown in this Table corresponds only to the incremental cost that the power line excavation would represent, as compared to a simpler installation of the optical fiber communication cabling.

TABLE IV. ESTIMATED COSTS OF POWER TRANSMISSION LINE

Item / Component	Price
11 kV Shielded Cable	51,000 €/km
Trenching/Installation	19,000 €/km
Step-down Transformer	63,000 €/RPF

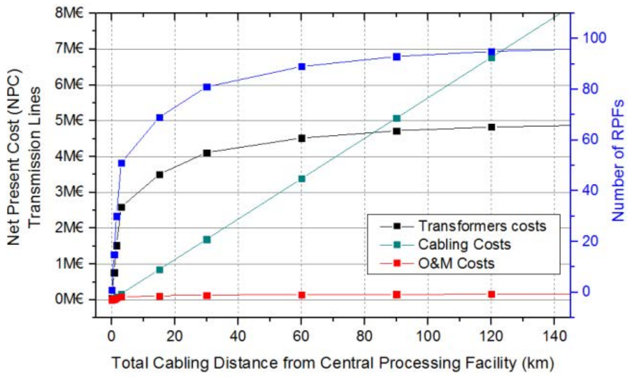

Figure 7. Net present cost of power transmission line components as a function of the total cabling distance from the CPF.

IV. ECONOMIC ANALYSIS

The economic analysis of an investment in a renewable energy technologies project, which is meant to provide sufficient information to make a judgement or a decision, requires the analysis of each year of the life of the investment. It is necessary to take into account the relevant direct costs, indirect and overhead costs, taxes, and returns on investment, as well as any externalities, such as environmental impacts [5].

The levelized cost of electricity (LCOE) is one of the most used indicators in energy projects, as it allows for the comparison of different technologies (e.g., wind, solar, gas) of unequal life spans, project size, different capital cost, risk, return rates and production capacities. It is computed as

$$LCOE = \frac{NPC}{\sum_{t=1}^{n}\left(\frac{E_t}{(1+d_r)^t}\right)} \quad (3)$$

with

$$NPC = \sum_{t=1}^{n}\left(\frac{C_t}{(1+d_r)^t}\right) \quad (4)$$

where C_t comprises all investments, O&M, and fuel costs at the period (year) t, E_t is the total AC energy served to the loads, and d_r is the real discount rate.

The economic analysis performed in this section tries to give deeper insight on the effects that some of the most important factors have to the cash-flow and the LCOE estimations of this project. The investigated factors are: the economies of scale effects, the price-experience curves, and the locality effects.

A. Economies of Scale

Economies of scale play a major role for the correct cost estimation of a central (bigger) power plant, in order to compare those costs with those of a set of decentralized smaller local power plants.

The effects of scale economy for the PV system components are estimated from an average of the data provided in [6] and [7] using 2017 prices, while for the battery system, the data provided in [8] is used.

B. Technology Price-Experience Curves

Aside from the scale effects, the system components' costs are expected to keep decreasing considerably in the short and mid-term, as it monotonically did during the last few years. The expected price decrease is accounted for in

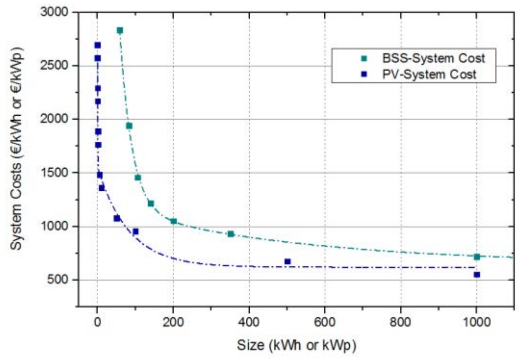

Figure 8. Economies of scale effects for photovoltaic (PV) and battery storage systems (BSS).

the cash flows that arise from components' replacements that are foreseen during the project life.

The PV and battery price decrease prognosis is approximated in this study with the so-called price experience curve, which relates the components' market price to the cumulated amount of worldwide installed manufacturing capacity. With the forecasts from [9] and [10], for market evolution and prediction of batteries manufacturing capacity increase, it can be foreseen that the price of lithium-ion battery systems is going to decrease up to 60-65% by 2050.

The learning rate of PV technologies, including manufacturing and also their installation, O&M, and other related activities (as shown in Figure 8), has been estimated with the detailed forecasts that were published in [1] on 2015, by averaging the prognostics from the most optimistic and ambitious with the most conservative scenarios.

C. *Locality Effects*

As described in the introduction, the SKA1-Low radio-telescope is going to be built at a very remote location, at a distance of around 10-hour drive from Perth's harbour, and about 3 to 6-hour drive from the nearest medium-size villages.

There are not many Australian manufacturers of PV, inverters, or batteries, and the system components might most probably be necessarily imported. Nonetheless, this should not affect severely the components price estimation since Australia is, since 2014, a participant of the Environmental Goods Agreement (EGA). This agreement enables the inexpensive trading of environmental goods, such as solar panels or wind turbines, between all member participants, which include the major battery and PV modules producers –such as China, US, Singapore, or South Korea.

On the other hand, however, installation, fuel, and O&M costs are expected to be considerably affected by the denominated "locality" effects, scaling up to factor 2-2.5 from normal market prices.

In this study, these costs' scaling factor have been expressed as an heuristic function that relates the costs' scaling factor to the number of locations at which a power plant is installed, to give a better estimate for the comparison of a central vs. a decentralized power plant layout.

V. OPTIMIZED POWER PLANT LAYOUT

Taking the effects of economies of scale, locality, and price-experience curves into account, the LCOE for the optimized PV-battery-diesel power plant system can be computed as a function of the number of RPFs (or antennas clusters) that it powers.

As a result, and since the costs increase due to locality effects have a much greater impact than cost reductions attributed to price-experience curve effects, the LCOE for the optimized PV-battery-diesel power plant system of a single RPF increases by 24.2%, from the 0.246 €/kWh shown in Table 5 up to 0.307 €/kWh.

Figure 9 shows also that economies of scale and locality effects make a considerable difference to the estimate of the central power plant costs with respect to the cost of a remote power plant near an RPF. For example, if the central power plant is sized big enough to service all SKA1-Low power requirements, the total LCOE descends down to 0.290 €/kWh, because of reduced cost of higher capacity system components –solar inverter, battery converter, battery pack– and reduced transportation costs –affecting installation, O&M, and fuel final costs.

From this analysis, it is found that the optimal power plant layout would consist of a central power plant which would cover all antennas that are at a lower radial distance from the CPF than ~10km (where the radial distance has been obtained by dividing the total cabling distance, 30km, by the number of spiral arms, 3), whereas the 15-18 outermost antennas clusters –and RPFs– should optimally be powered from local PV-Battery-Diesel power plants.

However, as it has been observed that the particular effects of location (which affect installation, transport and O&M costs) have a great influence on the final LCOE, and given that their contribution has only been roughly estimated in this study, a sensitivity analysis is included in following Figure 10 to capture how the optimized power plant layout would change as a result of +/-10% higher or lower LCOE values for local plant production.

It can be observed that, with increasing energy production costs, the number of RPFs that should be powered from the central power plant also increases, because a longer cabling distance is still cheaper than local power generation.

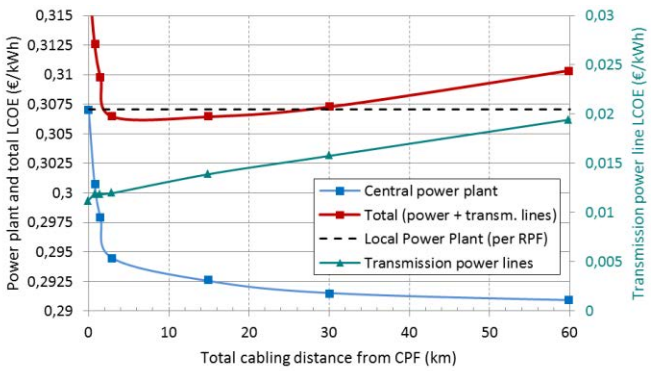

Figure 9. Comparison of the levelized cost of electricity (LCOE) for a central power plant with transmission power lines vs. a decentralized layout, with local power plants at each RPF.

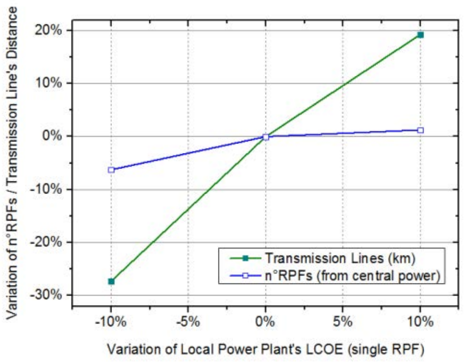

Figure 10. Sensitivity analysis from optimal transmission lines distance (km) and number of RPFs powered from central power plant with respect to local power plant project's LCOE variation.

Of course, in order to obtain a better estimate of the exact optimal cabling distance, the exact spatial distribution of the antennas should be taken into account. Besides, a more detailed estimation of the LCOE could be pursued by, i.e., improving the economies of scale and locality effects estimations, which could be based on provider's component prices and transportation costs in Australia, or by considering all financial aspects that influence the real discount rate –such as the percentage of equity and/or debt, tax rates, inflation forecasts, etc.

Finally, given that continuous power availability is important for this application, a further study including risks and grid failure analysis, with a deeper consideration of power system's robustness and reliability, should also be conducted to evaluate some potential disadvantages of centralized power generation that were not included in this report.

CONCLUSIONS

In this paper, the findings from the preliminary techno-economic assessment for sizing and layout design of a renewable's based power plant at the SKA1-Low radio-telescope have been summarized.

In this work, the system architecture has been discussed and optimized components' sizing and power plant layout has been suggested, based on the particular power requirements of the telescope and with consideration of the particular topography and location of the site.

Besides, economies of scale and experience curve effects have been introduced in the cash-flow analysis. It has been observed that their effects are noticeable, showing that they ought to be taken into consideration to provide accurate project costs estimations.

From the presented results, it can be concluded that a local PV-battery-diesel power plant should be installed at those RPFs which are at a further distance than ~10 km from the CPF, which are presumably 5-6 RPFs per spiral arm, and the rest of inner antennas and RPFs should be powered from a central power plant with a set of reticulated transmission lines.

REFERENCES

[1] J. Mayer, S. Philipps, N. Hussein, T. Schlegl, C. Senkpiel, "Current and Future Cost of Photovoltaics", Agora Energiewende, Fraunhofer Institut for Solar Energy Systems, ISE (2015).

[2] M. G. Labate, R. Braun, P. Dewdey, M. Waterson, J. Wagg, "SKA1-LOW: Design and Scientific Objectives", 32nd URSI GASS, Montreal (2017).

[3] L. Millet, "Development of an Empirically-based Numerical Model for the BTMS Design of an EV's Lithium-Ion Battery Pack", Master thesis, Universitat Politècnica de Catalunya (UPC), Fraunhofer Institut for Solar Energy System, ISE (2017).

[4] N. Henze, T. Degner, "Radio Interference of Photovoltaic Power Systems", International Wroclaw Symposium and Exhibition on EMC (2002).

[5] W. Short, D.J. Packey, T. Holt, "A Manual for the Economic Evaluation of Energy Efficiency and Renewable Energy Technologies", National Renewable Energy Laboratory (1995).

[6] N. Hussein, M. Abokersh, C. Kost, T. Schlegl, "Electricity Cost from Renewable Energy Technologies in Egypt", Fraunhofer Institute for Solar Energy Systems, ISE (2016).

[7] R. Fu, D. Feldman, R. Margolis, M. Woodhouse, K. Artani, , "U.S. Solar Photovoltaic System Cost Benchmark: Q1 2017", National Renewable Energy Laboratory, NREL (2017).

[8] J. McLaren, P. Gagnon, K. Anderson, E. Elgqvist, R. Fu, T. Remo, , "Battery Storage Market: Commercial Scale, Lithium-Ion Projects in the U.S.", National Renewable Energy Laboratory, NREL (2016).

[9] C. Curry, , "Lithium-ion Battery Costs and Market", Bloomberg New energy Finance, BNEF (2017).

[10] International Renewable Energy Agency, IRENA, "Battery Storage for Renewables: Market Status and Technology Outlook" (2015).