Renewable Energy Poverty: An Analysis of Islanded Renewable Energy Microgrids for Rural and Remote Communities

Captain Jake York

The University of New South Wales, Canberra

Abstract

To promote understanding of energy issues faced by rural and remote communities, this paper provides analysis of energy generation methods in Australia and abroad, as well as investigative analysis of a simulated islanded microgrid. The analysed microgrid is based on rechargeable battery distributed generators (DGs) connected through a network to several dynamic resistive loads. The design and performance of this system is analysed as load on the system is varied. Limitations of the simulation and microgrid errors are also presented.

1 Introduction

In Australia, as with many other developed countries, traditional electrical power generation is centralised within communities, with power provided from synchronous generators to consumers through large-scale distribution networks. For many reasons, a trend has emerged in Australia to move away from such power sources and towards small-scale power generation. Accordingly, Australia currently has the highest uptake of rooftop solar in the world, with one in five homes now generating its own energy (ATIC, 2017). Although the majority of the 24 million Australian residents live in capital cities (67%), large, small and very tiny communities exist across the entire country (ABS, 2017). Some of the larger communities, such as Alice Springs, function daily by relying on traditional power generation methods (sometimes supplemented by renewable power sources). However, there are many small, remote communities in the Australian outback - places like the Northern Territory (NT) and northern Western Australia (WA) - that lack the population, expertise and the demand to justify traditional power generation. In locations like these, it is not economical to provide traditional power distribution infrastructure and so renewable energy sources are an attractive alternative to stand-alone diesel generators.

This research paper will put the energy generation, distribution and storage problem for remote and rural areas in context and provide practical reasons for why barriers to renewable energy solutions exist. The paper will first discuss the issues faced by rural, remote and energy-poor communities in Australia, as well as globally. This will be followed by a discussion and analysis of a simulated microgrid to show the complexity that faces any agency attempting to practically employ renewable energy microgrid solutions on any scale.

2 Energy Issues Facing Rural and Remote Areas

Power distribution to rural and remote communities can be very difficult as large distances, prohibitive terrain and weather conditions are primary factors for consideration. In the NT and other parts of Australia, small communities can be hundreds of kilometres from the nearest town or city where power distribution is provided by large-scale networks. In many parts of the Philippines, like the western island of Palawan, transport is only possible between towns or villages via a single road that is susceptible to landslides year-round and flooding during the monsoon season (personal visit). In places like this, power lines follow the road and thus, power outages can be common.

In rural and remote communities globally, energy independence is rare, which can have significant effects on economic development and productivity. It has been established by Barnes et al. (2003) that having access to sufficient electricity-based lighting can enable populations to be productive at night, improving education levels through both time and lighting available for study. Traditional cooking solutions that rely on biomass (wood-fired) have also been linked to higher mortality rates in developing countries (Halff, Sovacool, & Rozhon, 2015). With stable, reliable and renewable energy solutions, rural and remote communities can be enabled to have sufficient opportunities to develop their populations. This is relevant for communities of upwards of hundreds of people, but also for very small communities that may not be given priority by governments.

2.1 Remote Australian Communities

The NT community of Wandigalla comprises a total of two buildings, housing a single extended family (Bushlight, 2007). In more than 180 similarly remote Australian communities, renewable energy microgrids provide all or the majority of the daily power generation needs, with any excess taken up by stand-alone diesel generators, small gas cooking equipment or conventional biomass cooking (Bushlight, 2012). Just like Wandigalla, many of these communities contain very few buildings or people and may therefore not justify funding from governments to provide meaningful energy solutions. Fortunately, the NT government has placed priority on indigenous communities as well as renewable energy, working with the Centre for Appropriate Technology (an Aboriginal and Torres Strait Islander controlled business that works with Aboriginal communities and organisations). Accordingly, the NT government provided large subsidies to over 180 of its remote communities for the purchase of renewable energy microgrids through the Bushlight program, a Centre for Appropriate Technology initiative that ran between 2002-2013. The program established and maintained renewable energy systems at the communities presented in Figure 1, as well as in northern WA, northern Queensland and parts of South Australia (Bushlight, 2012). This helped to reduce the dependence of communities on traditional energy infrastructure and allowed their focus to stay on country (as the overwhelming majority of the remote communities presented in Figure 1 are wholly indigenous).

Although the communities in remote parts of Australia have been given the opportunity to achieve energy independence, this comes at significant financial cost. The microgrid established at Wandigalla cost $254,763 (Bushlight, 2007), significantly more than a similar system that could be purchased from a retailer in a major city. In fact, all of the Bushlight systems that were installed and maintained over the 2002-2013 period were prohibitively expensive, with the average cost at $334,600. For these systems, the average maximum daily load was 29.7 kWh and average photovoltaic (PV) array size was 8.5 kWp (Bushlight, 2012).

This shows the inaccessibility of such systems due to high costs for remote areas, the reasons for which will be discussed further in subsection 2.5. First, however, further discussion will be provided on the implications this has in other parts of the world.

2.2 Global Energy Poverty

Remote communities in Australia - particularly those in the NT that had access to government subsidy - are fortunate for the fact that Australia is a developed country with the ability to invest in renewable energy opportunities. Prior to 2002, there were no large-scale initiatives to provide reliable power to small communities and as a result, many communities had intermittent or no access to power. This shows that even in an economically developed and wealthy nation, parts of the population may not share that development. Unfortunately, this situation is a

Figure 1: NT communities supported through Bushlight renewable energy microgrids. Blue communities were merely maintained by Bushlight as at 2012 (Bushlight, 2012).

microcosm of a much broader global issue. In 2010, the International Energy Agency estimated that 1.3 billion people had zero access to electricity and 2.6 billion people still completely relied on biomass for daily cooking needs (Halff, Sovacool, & Rozhon, 2015). Halff et al. (2015) note that studies in developing countries like India, Bangladesh and Kenya that have shown positive correlation between access to electricity and level of economic development, as mentioned on page 1.

Admittedly, providing access to electricity for developing populations is not a simple or inexpensive task, as demonstrated simply by the price of the Bushlight systems in Australia. However, economic consideration is not limited to factors like remoteness or isolation. Design of specific microgrid systems for specific communities is essential. To put this in further context and to understand the broader design implications, a summary of renewable energy systems is provided.

2.3 Renewable Energy Microgrids

A microgrid is a platform that integrates DGs, energy storage systems (ESS) and loads such that the power grid can ensure sustainable and reliable electricity (Gao, 2015). Detailed planning is required to determine average and maximum load expectations, as well as the envelope of how much energy may be produced by a designed system. Microgrids can be operated in one of two modes: islanded or grid-connected. In islanded mode, power generation is limited to the capacity of the DGs that are integrated in the network. In grid-connected mode, a microgrid is stabilised by the main power grid which is typically based on traditional power generation methods. The mode in which a microgrid operates may be determined by economical, ideological or geographical considerations. Often, grid-connected microgrids allow for users to draw energy from the main grid in peak consumption times and feed energy back into it during peak generation times in return for feed-in tariffs. In the case of solar power generation, peak consumption and generation times do not necessarily overlap, as private consumers have been identified to have peak power consumption periods between 7:00 am and 9:00 am, as well as between 5:00 pm and 8:00 pm daily (ActewAGL, 2018). These considerations are important for microgrids that exist near or within large-scale power distribution networks to determine whether or not to be grid-connected. Based on energy usage times, it may be more economical to include battery storage in a microgrid than to rely on feed-in tariffs to offset peak usage costs. If grid-connected, microgrids typically include control architecture to island from the main grid under specific conditions such as during grid power outages.

For many rural and remote communities in Australia and globally, being grid-connected is not an option as infrastructure does not exist to connect to. In terms of physical area, Australia is the sixth largest nation in the world. As such, the reality for our remote communities is that they must rely on their own renewable power generation mechanisms or on intermittent fuel supplies for diesel generators, gas cooking appliances or biomass. For communities with solar power generation, given the offset of power consumption and generation times, renewable energy solutions must include energy storage. Without energy storage, power from solar sources is limited to daylight hours which is affected even further by the time of year, position of the sun relative to the PV panels and cloud cover.

2.4 Existing Research Scope

There has been much research into renewable energy in recent years. A large amount of this research is verified through simulation and in some cases, through practical execution in renewable energy laboratory settings (Pascual, Barricarte, Sanchis, & Marroyo, 2015). However, despite the availability of simulation tools to design microgrids (such as Matlab and HOMER), it is clear that there is no single model that has been applied to renewable energy microgrids as a baseline that can be modified to suit specific parameters. The design of microgrids can be varied in multiple respects, which can include:

- DGs such as:
  - PV arrays,
  - wind turbines,
  - micro hydro turbines, and
  - biomass.
- ESS such as:
  - batteries,
  - flywheels, and
  - capacitors.
- inverters and converters,
- loads, and
- control architecture.

This is by no means an exhaustive list. In experimental design, researchers have different goals and design microgrids in order to optimise one or several aspects. Microgrid specifications are also never standardised. In practice, service providers design microgrids that are specifically tailored to end-user requirements, rather than applying a general solution to a given problem and making adjustments after application as required.

Although this paper also considers a specific microgrid design, the intent of the microgrid analysis is to highlight the many different areas that must be considered by engineers when they design for a given purpose as well as to identify areas for further consideration.

2.5 Design Considerations

Despite the many different microgrid designs, a popular framework exists, which has been developed by Guerrero et al. (2011). This framework provides overarching guidance as to the levels of control that should be designed into a microgrid, which are presented in Figure 2 (overpage).

Tertiary control relates to control of power flow when a microgrid is connected to a main grid. Secondary control can include a mechanism to disconnect from a main grid (if grid-connected), but mainly is concerned with maintaining electrical levels within required values for safe operation. Primary control can include virtual impedance control and is concerned with maintaining system stability and damping through emulation of physical behaviours.

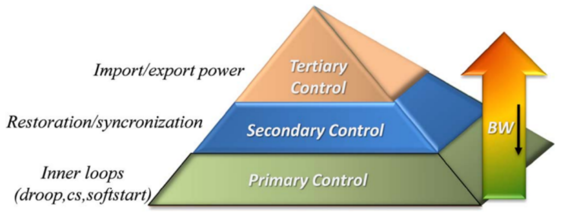

Figure 2: Levels of control in a microgrid (Guerrero, Vasquez, Matas, Vicuna, & Castilla, 2011).

Lastly, inner loop control - the lowest level of control - is concerned with current and voltage regulation to maintain local system stability.

As mentioned above, there is a large amount of literature available on the design of renewable energy microgrids. However, this literature is commonly targeted at specific aspects of design to improve performance, rather than the design of a general model. Particular areas of research that are presented in this section will also be discussed in reference to the example microgrid that is analysed in section 3.

2.5.1 Autonomy

Autonomous performance of control tasks is absolutely necessary in a renewable energy microgrid. The assumption here is that microgrids are operated and relied upon by non-technical users, which would be true in the case of Australian remote communities or rural, energy-poor communities in developing countries. Zaheeruddin (2015) proposed a control algorithm to maintain power balance in a grid-connected microgrid. The control algorithm is based on data collection from connected sources and loads to maintain balance, but this is underpinned by reliance on the main grid when demand exceeds local power generation. Ganesan et al. (2017) also proposed microgrid control architecture that maintained optimum efficiencies in a microgrid. Their design was based on feedback sensing of loads and generating sources, as well as state of charge (SOC) of ESS. The microgrid network they analysed was based on several different load types, which were classified as critical or non-critical.

Despite autonomous control of microgrids being a popular focus for research, it is a concept that underpins all electricity distribution systems and has been for some time. Almost 40 years ago, automatic control of national power systems was a well entrenched phenomenon (Venikov, 1982). Based on inertia within power generation systems, automatic power regulation in large networks is conducted under both normal and emergency conditions with minimal human involvement. The microgrid analysed by Ganesan et al. (2017) was forced to consider this problem differently to large power systems. An islanded microgrid cannot necessarily generate power constantly and while there is no generation, there is limited power demand that can be met by ESS. When power demand exceeds generation (be it from a generating source or ESS), voltage breakdown occurs rapidly. This is characterised by the power setpoint phenomenon (Van Cutsem & Vournas, 2003). It is for this reason that microgrids are designed individually - to tailor generation and storage to specific load requirements and provide an envelope of available power within which the anticipated load will be contained.

2.5.2 Inverter Operation

Inverters, which are used to convert DC signals to AC signals, are necessary for microgrid design as PV arrays generate DC power but grid power signals are relayed in AC. Solar inverters often incorporate maximum power point tracking and anti-islanding protection when microgrids are grid-connected. They can also be used to reduce electromagnetic and harmonic distortion in power devices. Shen et al. (2013) developed and prototyped a five-level inverter with the goal to generate phase-corrected current that can be injected into the main grid. Anani et al. (2012) also designed an inverter to synchronise signals with the main grid using a digital phase-locked-loop. Perlekar and Ward (2012) have provided analysis of industry inverters when tested in a laboratory environment. Their work was focussed on efficiency of inverters and how loss can be attributed under steady-state conditions.

2.5.3 Efficiency, Demand Management and Prediction

In microgrids, it is desirable to achieve maximum possible output from DGs as well as most efficient use of storage solutions. Especially in islanded microgrids, efficient resource usage allows for greater flexibility in demand and increases in microgrid performance when not generating. Network instabilities can cause voltage breakdown and damage system components if not handled effectively by control architecture. For this reason, management of loads and demand to keep the system within safe operating conditions is crucial. Pogaku et al. (2007) presented an early paper that modelled a microgrid under transient conditions and analysed its stability. Their model also provided feedback which was able to support controller design to improve that stability. Hossain et al. (2014) designed a control scheme for a combined solar and wind generating microgrid that was robust to large system disturbances such as disconnecting from the main grid. Their controller performed well in simulation when reacting to load variations similar to those applied to the microgrid discussed in section 3.

Demand forecasting is possible through use of historical data and persistence modelling as well as numerical weather predictions. Pascual et al. (2015) propose a dynamic control strategy that takes forecasting and ESS SOC feedback to minimise unnecessary grid-tied power fluctuations. This reduces ESS SOC losses and increases the overall robustness of a microgrid network. Their work was also able to be verified in a practical renewable energy microgrid laboratory.

2.5.4 Differences

The above research is varied in a number of ways as the authors all have different goals and systems that they wish to test. To place the lack of general modelling for microgrids into context, a snapshot of the various differences is presented in Tables 1 and 2.

Author(s)	Goal	Generating capacity
Hossain et al.	Power sharing	6.5 MW
Ganesan et al.	Intelligent energy management	100 kW
Pascual et al.	Demand forecasting	12 kW
Perlekar & Ward	Steady-state inverter analysis	Nil
Pogaku et al.	Autonomous operation	6 kW
Shen et al.	Five-level inverter testing	1.2 kW
Zaheeruddin	Controller design	78 kW

Table 1: Differences in literature (1)

Author(s)	ESS	Load	Grid connected
Hossain et al.	0.6 MWh	0.9 MW	Yes
Ganesan et al.	50 kWh	400 kW	Yes
Pascual et al.	35 kWh	1.27 kW	Yes
Perlekar & Ward	10 kWh	Variable	No
Pogaku et al.	Nil	13.1 kW	Yes
Shen et al.	Unspecified	Unspecified	No
Zaheeruddin	200 kWh	80 kWh	No

Table 2: Differences in literature (2)

As shown in the tables, no two systems feature the same design specifications, which makes it even more difficult to consider a standard case for modelling. In line with this, a specific microgrid was considered for further analysis.

3 Microgrid Analysis

A simulated microgrid was analysed to develop further understanding of the levels of control required. Areas in which the simulation does not meet analysis expectations or requires improvement were also investigated. A brief description of the microgrid will be provided, then each level of control will be discussed separately. Following that, the faults identified in the microgrid simulation will be quantified and potential solutions will be briefly discussed.

3.1 Simulation Overview

The microgrid analysed in this section has been developed by Macana and Pota (2017), the design of which is based on control architecture developed by Pogaku et al. (2007). The system integrates three DGs based on rechargeable batteries through circuit breakers to resistive loads. System specifications are given in Table 3 and the system itself is displayed in Figure 3(overpage).

Specification	Value
Renewable sources	Nil
Goal	Transient stability
DG amount	3
DG type	Rechargeable battery
Battery capacity	1.3 kWh each
Battery initial SOC	80%
Load type	Resistive only
Load size	3 x 250 Ω in parallel

Table 3: Microgrid system specifications

The system is broken into four sub-parts in Figure 3:

- the top-level view of DGs and loads,
- the setup of one DG,
- the setup of the battery DC-DC converter, and
- the setup of each DG controller.

As the DGs are connected to several loads through circuit breakers, the simulation can model transient behaviour of a microgrid when loads are connected or disconnected. The second and third DGs are also connected via circuit breakers so the behaviour of the microgrid can also be modelled as more or less power is available. In islanded mode, the connected DGs supply all required power to the loads while maintaining necessary voltage and frequency levels.

The DGs are connected to the loads via a common bus, but each DG is modelled separately within its own reference frame. Each model has its own power sharing controller, output filter, as well as voltage and current controllers. These can be observed in the last element of Figure 3.

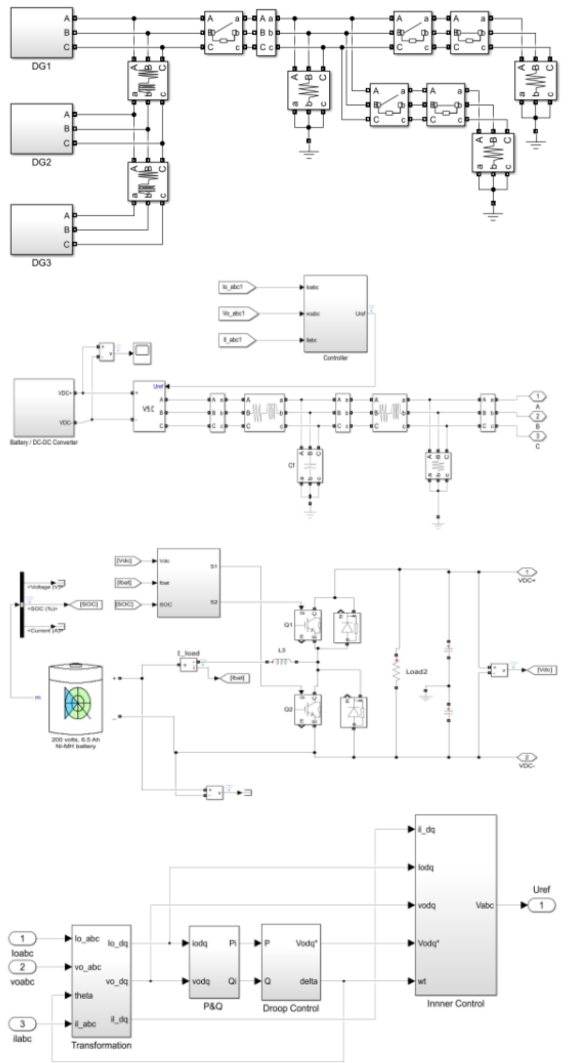

Figure 3: Simulated microgrid for analysis

Effectively, the DG controller is a voltage source inverter that can be used to interface a DG with the other DGs in the microgrid when they are connected.

3.1.1 Transformation

Each DG controller contains a transformation and PQ block. The setup of these blocks is contained in Figure 4. The task of these blocks is to transform the incoming three-phase voltage signal to a single rotating direct-quadrature-zero (DQZ) frame for simplification of following calculations. Simscape Power Systems contains system blocks that can achieve this routinely, so potential error is minimised.

3.1.2 Droop Control

The droop controller (in Figure 5) of each DG sets the magnitude and frequency of the DG output voltage, buffering it against perturbations caused by changes in load or generation. The simplest way to describe this is similar to the way a governor acts

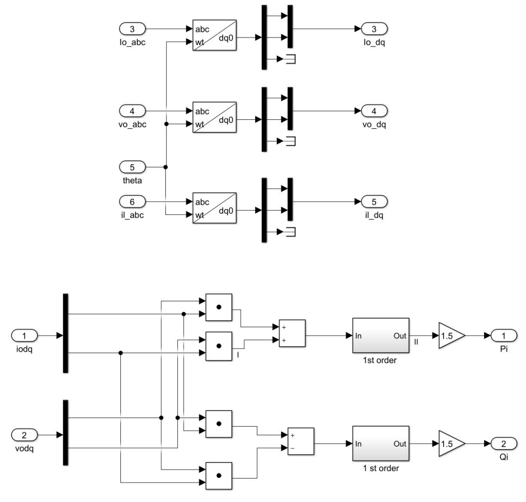

Figure 4: Transformation and PQ controllers

in a synchronous generator, where in this case, the reference frequency is decreased when load on the system is increased. In the lower branch of Figure 5, the frequency is scaled by the droop gain mp, which is set to $9.4 * 10^{-5}$, and subtracted from the nominal frequency (50 Hz). This causes artificial droop in the DG frequency when sharing real power between DGs. Reactive power is also shared by introducing a voltage magnitude droop characteristic (top branch of Figure 5). Here, Vn is the nominal setpoint voltage for the reference frame and is equal to $220 * \sqrt{2}$ [V]. Vn and wn are calculated using the original model by Pogaku et al. (2007).

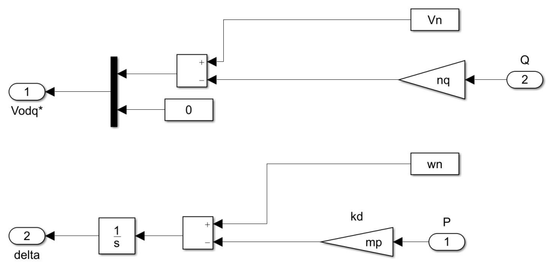

Figure 5: Droop controller

3.1.3 Inner Control

Inner control in the system is achieved through separate voltage and current controllers. These controllers are designed to reject high frequency disturbances and provide damping for the filter system in Figure 3. The droop controller signal and the reference input are fed to the voltage controller. After processing by the voltage controller, the output and a current signal are passed to the current controller. The layouts of these controllers are presented in Figures 7 and 8 respectively. As can be seen in the figures, each controller has dual inputs: reference and feedback. These are passed into standard PI controllers. In the voltage controller, the output is a reference current for the current controller.

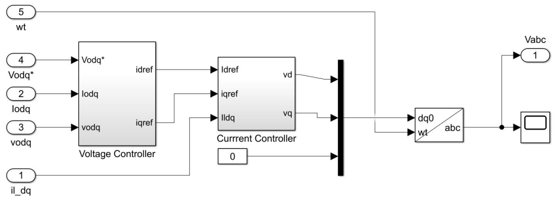

Figure 6: Inner controller

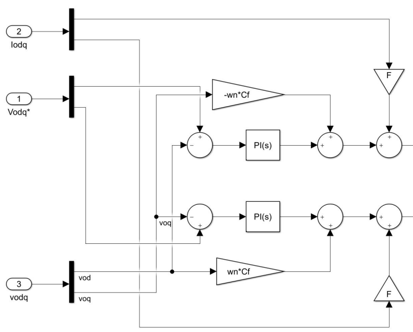

Figure 7: Voltage controller

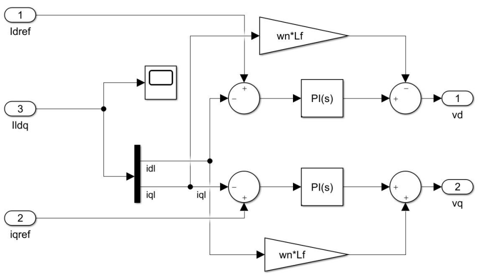

Figure 8: Current controller

In the current controller, the outputs are voltages in the DQZ reference frame, which are then passed to the DG filter through a common reference frame so that the DG can be connected in parallel with other DGs.

3.2 Simulation Faults

Several faults were encountered when analysing and running the Simulink model of the microgrid. As mentioned, the microgrid is originally based on control architecture developed and quantified in detail by Pogaku et al. (2007). The simulation is run with a simulation step size of 10^{-4} using the fixed step-size solver *ode*1, which uses Euler's method of integration to numerically solve the system. Of the fixed-step solvers, this is the least computationally complex.

The simulation is designed to analyse transient behaviour of the system and is therefore expected to run over a matter of real-time seconds. If run for longer, the transient behaviour is still able to be analysed in the expected time frame but simulations become extremely lengthy. A simulation of 60 real-time seconds ($60 * 10^4$ simulation steps) took more than an hour running on a PC with a 7th generation i7 processor and 16 gB of RAM. The reason this becomes an issue is because although transient behaviour of the system is the goal, a system that is based on batteries as a source is difficult to analyse in detail when battery SOC changes on a scale of 10^{-4}.

With the exception of reference to the original design by Pogaku et al. (2007), the system in Simulink is largely undocumented. This resulted in examination of the system which was not able to test its robustness fully. As a result, anomalous conditions occurred when running simulations.

The system was only able to be tested on resistive loads. If any reactive loads were added to the system, the Simulink solver presented errors and would not continue.

When not connected to any other sources or DGs, at the start of the simulation, the battery in DG1 charges. As no other sources are present in the circuit, this is not a physically realisable condition (by not obeying the law of conservation of energy) and was caused by an error in the model setup. For a significant period of analysis, this condition was not able to be solved either by the author of this paper or by Macana. A short-term solution to remove DG controllers from the simulation was agreed upon. However, by doing this, the system became susceptible to disturbances that the controllers were specifically designed for and thus, the analysis possible on the system was shallow.

As shown in Figure 8, there are two summing blocks that produce the outputs of the current controller. According to the original design by Pogaku et al. (2007), these summing blocks should be identical. The *vd* branch is incorrect in this case and needed to be amended to reflect the other block (two plusses). The same error was present in all DGs; it is also not known if similar errors persisted in other controllers due to the lack of documentation.

4 Conclusion

Renewable energy penetration is becoming increasingly common in Australia. For remote communities, microgrids are considered to be a justifiable alternative to expensive distribution networks from major population centres. However, in reality, the design and practical employment of a renewable energy microgrid is an extremely complicated and involved process prone to both major and minor errors. Further work is required if standardised, scaleable microgrids are to be used to combat global energy poverty and if remote and rural communities in Australia are to truly become independent. Currently, microgrid design is limited by its variability and that no two researchers have considered the same problem. A model that can be scaled and amended to suit specific purposes without major reconsideration would increase the availability and decrease the enormous costs associated with design and implementation of renewable energy microgrids.

5 References

ActewAGL (2017). *Time of use rates for electricity meters.* www.abs.gov.au/ausstats/abs@.nsf/mf/3218.0.

Anani, N., Al-Kharji Alali, O., Al-Qutayri, M., & Al-Araji, S. (2012). *Synchronization of a Renewable Energy Inverter With the Grid.* Manchester, UK: Journal of Renewable and Sustainable Energy.

Australian Bureau of Statistics (2017). *Regional Population Growth, Australia, 2016-17.* https://www.actewagl.com.au/Help-and-advice/How-to-read-your-meters/Time-of-use-rates.aspx.

Australian Trade and Investment Commission (ATIC) (2017). *Microgrids, Smart Grids and Energy Storage Solutions.* Canberra, Australia: Australian Government.

Barnes, D., Peskin, H., & Fitzgerald, K. (2003). *The Benefits of Rural Electrification in India: Implications for Education, Household Lighting, and Irrigation.* Washington, USA: World Bank.

Bushlight (2007). *Light and Life in the Bush - Wandigalla.* Alice Springs, Australia: Centre for Appropriate Technology.

Bushlight (2012). *Overview of the Bushlight Repair & Maintenance Program – September 2012.* Alice Springs, Australia: Centre for Appropriate Technology.

Halff, A., Sovacool, B., & Rozhon, J. (2015). *Energy Poverty: Global Challenges and Local Solutions.* London, UK: Oxford Scholarship Online.

Hossain, M., Pota, H., Mahmud, A., & Aldeen, M. (2014). *Robust Control for Power Sharing in Microgrids With Low-Inertia Wind and PV Generators.* Gold Coast, Australia: IEEE Transactions on Sustainable Energy, Volume 6, Issue 3.

Ganesan, S., Padmanaban, S., Varadarajan, R., Subramaniam, U., & Mihet-Popa, L. (2017). *Study and Analysis of an Intelligent Microgrid Management Solution with Distributed Energy Sources.* Vellore, India: MDPI.

Gao, D. (2015). *Energy Storage for Sustainable Microgrid.* Denver, USA: Elsevier.

Guerrero, J., Vasquez, J., Matas, J., Vicuna, L., & Castilla, M. (2011). *Hierarchical Control of Droop-Controlled AC and DC Microgrids - A General Approach Towards Standardization.* Barcelona, Spain: IEEE Transactions on Industrial Electronics, Volume 58, Issue 1.

Macana, C., & Pota, H. (2017). *Adaptive Synchronous Reference Frame Virtual Impedance Controller for Accurate Power Sharing in Islanded AC-Microgrids: A Faster Alternative to the Conventional Droop Control.* Canberra, Australia: 2017 IEEE Energy Conversion Congress and Exposition.

Pascual, J., Barricarte, J., Sanchis, P., & Marroyo, L. (2015). *Energy Management Strategy for a Renewable-Based Residential Microgrid With Generation and Demand Forecasting.* Pamplona, Spain: Applied Energy Volume 158, Issue 12.

Perlekar, T. & Ward, J. (2012). *Steady-State Analysis of a Renewable Energy Inverter.* Boston, USA: 2011 North American Power Symposium.

Pogaku, N., Prodanovic, M., & Green, T. (2007). *Modeling, Analysis and Testing of Autonomous Operation of an Inverter-Based Microgrid.* London, UK: IEEE Transactions on Power Electronics, Volume 22, Issue 2.

Shen, J., Jou, H., Wu, J., & Wu, K. (2013). *Five-Level Inverter for Renewable Power Generation System.* Kaohsiung, Taiwan: IEEE Transactions on Energy Conversion, Volume 28, Issue 2.

Van Cutsem, T. & Vournas, C. (2003). *Voltage Stability of Electric Power Systems.* Dordrecht, The Netherlands: Kluwer Academic Publishers.

Venikov, V. (1982). *Electric Power Systems: Automatic Power System Control.* Moscow, Russia: Mir Publishers.

Zaheeruddin, M. (2015). *Renewable Energy Management Through Microgrid Central Controller Design: An Approach to Integrate Solar, Wind and Biomass with Battery.* New Delhi, India: Energy Reports, Volume 1.