Design of a Battery Energy Storage System for Critical Infrastructure

Ilija Babic
School of Electrical, Computer and Telecommunications Engineering
University of Wollongong
Wollongong, Australia
ib916@uowmail.edu.au

Sean Elphick
Australian Power Quality & Reliability Centre
University of Wollongong
Wollongong, Australia
sean_elphick@uow.edu.au

Jonathan Knott
Australian Power Quality & Reliability Centre
University of Wollongong
Wollongong, Australia
jknott@uow.edu.au

Adam.Drenoyanis
Shoalhaven Water
Nowra, Australia
Adam.Drenoyanis@shoalhaven.nsw.gov.au

Andrew Truran
Shoalhaven Water
Nowra, Australia
Andrew.Truran@shoalhaven.nsw.gov.au

***Abstract*— This paper describes the process for designing a battery energy storage system (BESS) to provide backup electricity supply to critical infrastructure, in this case a sewage pumping station. Three key criteria are considered in the design process; the characteristics of the load, the reliability of the electricity supply and the amount of energy used by the load. An understanding of each of these considerations has been achieved through a combination of laboratory experimentation, field measurements and analysis of reliability and energy consumption data. Using the presented design process, a case study design is undertaken for an actual sewage pumping station located in NSW, Australia. Evaluation of the site clearly showed the influence that the pump motor starting transient has on the sizing of the BESS and analysis indicates that changing the pump starting technology will result in an order of magnitude difference in the cost of the BESS.**

Keywords—battery energy storage system, sewage pumping station, BESS

I. INTRODUCTION

Historically, backup electricity was supplied to critical infrastructure through the use of standby generators [1], [2]. These generators typically utilise fuel sources such as diesel or natural gas. Apart from the noise and pollution produced when operating, these generators can also be relatively expensive to purchase and maintain compared to the value of having them available to provide electricity when the primary electricity supply (typically a grid connection) is not available [3].

Battery technology has advanced and prices have decreased to the point it has become increasingly viable for Battery Energy Storage Systems (BESS) to be used as an alternative to traditional generators for backup electricity [4]. Batteries are now commercially available that are both cost-effective and reliable, and can be configured for many different applications. It is also possible to further increase the reliability of batteries by combining them into a hybrid battery storage system (BSS) incorporating fuel cells and capacitors [5], [6], however, these solutions typically have a much higher cost than BESS.

Reliability of distributed infrastructure, such as telecommunications towers and water pumping stations, is crucial for maintaining access to critical services such as phone reception and fresh water [7]. Despite this, many pumping stations rely on traditional generators for back-up electricity supply due to the infrequent nature of electricity outages.

Sewage Pumping Stations (SPS) play a critical role in sanitation and general comfort of modern societies – ensuring wastewater can be moved to sewage treatment plants through a relatively closed system. These SPS typically consist of storage vessels – known as wet wells – that collect sewage from surrounding customers, and a pumping scheme that can pump sewage from the wet well on to the next destination in the sewage network – either another SPS or a sewage treatment plant. Wet wells are sized to provide some amount of buffering in the sewage system – which can be used to mitigate the risk of overflows in the event of an electricity outage – however this is highly dependent on the volume of sewage inflow and is not an appropriate backup plan. For this reason, BESS have emerged as a potential solution to improve SPS reliability and ensure that electricity supply outages can be managed remotely.

The City of Shoalhaven is in the south eastern coastal region of New South Wales, approximately 200 km south of Sydney and has a population of just over 100,000. Shoalhaven Water is responsible for providing fresh and wastewater services to the city, and does so through a network including more than 230 SPS [8], which require backup electricity in case of electricity supply outages. The current method used by Shoalhaven Water to mitigate electricity supply outages is to transport a generator to site when required. This mitigation method involves hours of labour and requires staff to be on call (often during periods of inclement weather). When dealing with distributed infrastructure such as SPS or freshwater pumping stations, the reliability of the electricity supply is crucial. In terms of freshwater supply, outages can have devastating effects both socially and economically. These natural disasters typically occur in tandem with and/or can cause electricity outages due to the severe weather circumstances, often influencing grid capabilities. In the case of SPS, loss of supply can lead to overflow and release of effluent leading to significant environmental damage, community health impacts and in some cases commensurate commercial impacts (for example, damage to oyster leases in the Shoalhaven River).

This paper proposes a novel methodology for sizing a BESS to provide backup electricity for SPS facilities, demonstrating the capacity to improve the reliability of this infrastructure and to reduce the overall costs associated with traditional methods of securing electricity supply. Case studies on SPS sites operated by Shoalhaven Water are highlighted to demonstrate the deployment of this methodology.

The key parameters required for undertaking a BESS design for a SPS are:

- An accurate understanding of the electrical loads at the SPS, including the transient characteristics of large loads (i.e. pumps);
- Understanding of the electricity consumption characteristics of the SPS loads;
- Understanding of the electricity network reliability at the SPS;

Each of the above is examined in detail in this paper using a combination of laboratory and field assessments. As such the paper provides a framework for the design process for a BESS to be implemented for backup electricity supply. The final sections of the paper utilise all of the learnings in a case study design of a BESS for an actual SPS site operated by Shoalhaven Water.

II. Electrical Loads and Transient Behaviour

Sewage Pumping Stations typically contain an array of electrical plant, the largest of which is two or more pumps that are operated in a duty/standby configuration to provide redundancy for pumping operations. As the pumps are typically the largest plant – the remainder being communications/control equipment, lighting, ventilation or other small loads – the steady-state and transient behaviour of the pumps is critical to accurately assess when designing an appropriate BESS for electricity supply resilience. This is particularly critical for pump starting transients, which can vary significantly depending on the motor starting technology employed – substantially impacting the peak power requirement for the BESS. BESS are typically limited in the power they are able to supply, as high rate discharging significantly impacts the life of battery cells almost universally across available technologies. As such, the peak power requirement can be the defining factor in developing an appropriate BESS for backup and resilience applications.

A. Evaluation of Motor Starting Characteristics

Understanding of the electrical loads at the SPS, in particular, the starting transients of pumping loads has been achieved through a combination of laboratory performance evaluation and captured field data from Shoalhaven Water sites in order to understand the transient electricity consumption characteristics of each pump starter technology currently utilised. Through analysis of this data, the maximum and continuous electricity consumption requirements have been identified and are utilised to appropriately size the battery and inverter. These requirements have been determined in a similar manner to the SPS design for Sydney Water described in [9]. However, the pump load characteristics investigated in this paper differ to those examined in that study due to the varying pump starter types, pump ratings and geographical differences between the sites. Throughout this section of the paper, the inrush current transients captured are presented as rms current values based on 10 cycle measurements.

1) Laboratory Evaluation of Motor Starting Technologies

In order to gain a better insight into the transient inrush current of each pump motor starting technology in a controlled environment laboratory experiments were devised. It is well known that there is a large inrush current upon starting a direct online motor. However, various motor starting technologies can mitigate this inrush current and, as such, the inrush current will vary depending on the motor starter type. The magnitude of the motor inrush starting current is of particular interest for this study as the peak rating of any BESS must be adequately sized to support the inrush starting current of the motor. Shoalhaven Water currently use four motor starting technologies. These are direct-on-line (DOL), variable speed drive (VSD), soft starter and star-delta starter. Laboratory assessment was undertaken of DOL, VSD and soft starter motor starts. Performance of star-delta starters was not able to be undertaken in the laboratory due to unavailability of a suitable star-delta starter.

a) Experimental Setup

The method for laboratory evaluation of the three starter types involved connecting a simple induction motor to a power supply either directly for the case of DOL or through a starter. The power source utilised was an AMETEK MX45 programmable power source. This power source was chosen for its stable output waveform which was used to simulate network voltage conditions. A Hioki PW3198 power monitoring device was used to capture the inrush current, as well as to monitor the voltage and load power during testing. The motor used was a standard 5.5 kilowatt three-phase induction motor. Load on the motor was provided by a DC motor, configured to operate as a generator connected to a variable resistor, which was connected to the shaft of the induction motor. In this configuration, total motor load could be controlled by varying the resistance connected to the DC generator. For each starter type tests were undertaken at three motor loading levels.

b) Results

Direct-On-Line (DOL) Starter

The single line diagram for the DOL motor case is shown in Fig. 1. The only difference between the following experiments is the connection of a VSD, or soft starter and contactor between the power source and motor, respectively.

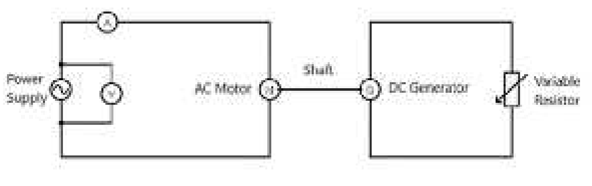

Fig. 1. Single Line Diagram of Experimental Setup for Motor with DOL Starter

The inrush current transient captured for the DOL start can be seen in Fig. 2. The peak value of the inrush current found is approximately 70 A. Since the motor current is rated at 10.5 A the magnitude of the inrush is almost seven times the rating. This is within the theoretical range, which is between five and ten times the rated current. The inrush current is present for approximately 40 ms, after which the current stabilises.

It can also be seen motor loading has little impact on the inrush current, with only minor variations in the value of the peak current detected. This demonstrates that varying the load has little effect on the inrush current for a DOL starter. The magnitude of the current has been shown to peak at approximately 70 A for the motor, which is close to seven times the rated current.

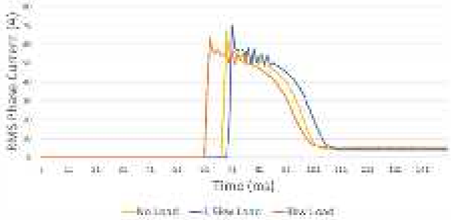

Fig. 2. Laboratory Measurement of DOL Starter Inrush Current Transient for Varying Loads

VARIABLE SPEED DRIVE (VSD)

The VSD used for testing was a Siemens 3 kW Micromaster 420.The inrush current transient for the VSD for varying loads is shown in Fig. 3. Unfortunately, due to the power monitoring equipment resolution, the entire transient was unable to be captured. While the motor is running with no load, there is a transient waveform which has a peak larger than the running current. However, the magnitude of the peak is approximately 8 A. This is lower than the rated current of 10.5 A and demonstrates the effectiveness of the VSD in limiting the starting current. It is noted that the duration of the transient starting current is much than the DOL, with close to 110 ms recorded (not including initial uncaptured data).

With varying loads applied, the starting current is shown to increase to a peak of 10 A and 10.5 A respectively. Yet again this demonstrates that the peak inrush current does not exceed the rated current when a VSD is used.

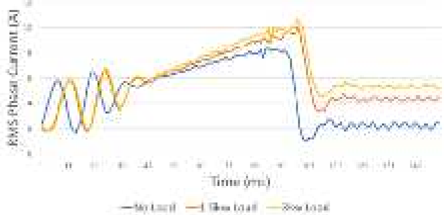

Fig. 3. Laboratory Measurement of VSD Inrush Current Transient for Varying Loads

SOFT STARTER

The soft starter used was a Sure-Start three-phase soft starter. The inrush current transient captured while starting a motor with a soft starter can be seen in Fig. 4. The peak inrush current is constant for varying motor loads and has a waveform similar to that obtained for the DOL starter. However, the soft starter lowers the peak of the inrush to a value just below 50 A (down from approximately 70 A for the DOL case). This demonstrates that the soft starter limits the current to the motor upon start up, in comparison to a DOL starter. The inrush current is limited to approximately five times the rated current.

The inrush current transient was also found to have a longer duration than the DOL starter inrush, with the soft starter taking approximately 60 ms to reach the stable running current at no load. The inrush duration was also found to be 10 ms longer for the 3 kW load. This demonstrates that the limited current being supplied by the soft starter requires a longer period to reach stability.

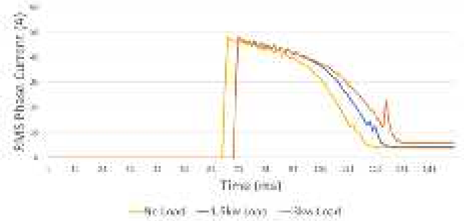

Fig. 4. Laboratory Measurement of Soft Starter Inrush Current Transient for Varying Loads

B. *Field Measurements*

1) *Measurement Procedure*

The purpose of the field measurements which were undertaken was to verify that motors in the field have performance which agrees with the experimental results obtained in the laboratory and to obtain data for star-delta motors starters which could not be evaluated in the laboratory. Field measurements were undertaken at the sites listed in TABLE I. As can be seen each site utilises a different motor starting technology. A Hioki PW3198 power quality analyser was used to capture the inrush current by setting an appropriate inrush current trigger in order to capture thirty seconds of current data on motor start. Each motor start was captured multiple times to ensure accuracy of results.

TABLE I SPS Pump Specifications

SPS Site	Pump Rating (kW)	Rated Current (A)	Starter Type
Site 1	2.4	4.7	DOL
Site 2	22	40	VSD
Site 3	13.5	26	Soft Starter
Site 4	5.9	11	Star-Delta

2) *Measurement Outcomes*

The inrush current transients for all sites field measurements are shown in Fig 5 at the end of this section.

a) Site 1 (DOL)

The peak magnitude of the inrush current is 30 A, or approximately 6.4 times the rated current of 4.7 A. This is slightly lower than the experimentally determined results of a DOL start, however still within the theoretical range of between five and ten times the rated current. The duration of the inrush is 25 ms, which is also lower than the experimentally determined inrush duration of 40 ms. Despite these slight differences, the characteristics of the pump inrush current are similar in nature to those found in the laboratory. Therefore, it can be said that for a pump operating with a DOL starter the inrush current will be approximately 6 to 7 times larger than the rated current.

b) Site 2 (VSD)

The peak inrush current slightly exceeds the operating current and but doesn't exceed the rated current of 40 A. This agrees well with the results captured experimentally, which identified a peak current equal to or below the rated current and slightly higher than the running current. It is however interesting to note that the entire transient waveform was captured, and the duration of the transient can be seen to be approximately 12.5 seconds. This is determined as the time taken from the initial spike until the current is operating at running current. Therefore, the current is limited to the rated current when using a VSD, however the inrush current transient is significantly longer than that of the other starter methods available. This ‘ramp’ time is programmable within the VSD.

c) Site 3 (Soft Starter)

The current peaks at a value of approximately 60 A, which is more than three times larger than the running current. Interestingly, the peak current is less than three times the rated current of 26 A, which a significant variation on the laboratory result which showed a peak current of 5 times rated. This suggests that the soft starter deployed by Shoalhaven Water has a higher current limiting capability than the device evaluated in the laboratory. Another key finding from the measurements is that the duration of the transient is 170 ms, which is significantly longer than the duration of the transient found in the laboratory.

d) Site 4 (Star-Delta Starter)

The key feature of the inrush current is the two current spikes due to the changeover between star and delta configuration. It is noted that the initial inrush current is initially limited to 21 A, however the second inrush spike exceeds this value and reaches almost 39 A. This correlates to a value close to 3.5 times the rated current. It is also interesting to note that the overall duration of the transient is almost 400 ms, which is more than double the duration of the soft starter transient.

Fig. 5. Shows the inrush current transients for each starter type normalised against the rated current for each pump.

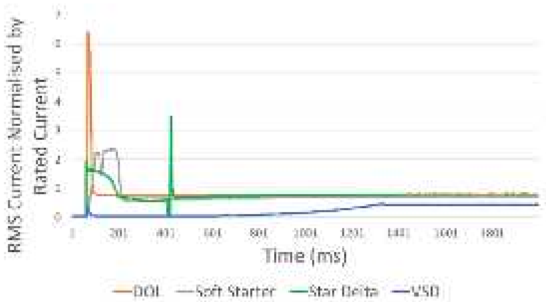

Fig. 5. Normalised Inrush Current Transient for Each Starter Type

III. Evaluation of SPS Site Electricity Consumption

Determining a suitable size for a BESS also relies heavily on understanding the load energy consumption profile of the site. When determining the capacity required for a given outage time, it is vital to understand the potential energy consumption within that time frame. Two important aspects when analysing SPS electricity consumption trends are the average and maximum daily consumption. The average daily consumption provides a good insight into the typical consumption characteristics during normal operation. Meanwhile, the maximum daily consumption can be used to identify worst case scenario consumption. The electricity consumption data over the past year, for the sites being examined in this paper, is shown in TABLE II.

TABLE II SPS Average and Maximum Daily Electricity Consumption

Site	Average Daily Consumption (kWh)	Maximum Daily Consumption (kWh)
Site 1	2.7	31.5
Site 2	19.8	530.8
Site 3	11.9	256.4
Site 4	9.5	92.7

The key finding from the consumption data is there is a huge contrast between the average daily consumption and the maximum daily consumption. Sites 1 and 4 have maximum consumptions within the range of 9-12 times larger than the average consumption, while sites 2 and 3 have maximum consumptions that are approximately 22 times larger than the average consumption. These maximums can be explained by peak wet weather events and due to stormwater ingress into the wastewater collection system.

IV. Evaluation of SPS Site Reliability

A key consideration when sizing a BESS is the reliability requirements of the load. For a SPS, a BESS should be ideally sized to provide sufficient energy to ride out the worst-case outage scenario. This eliminates the need for a generator to be brought on site during outages. However, due to the costs associated with increasing the size of a BESS this may not necessarily the best solution from a financial perspective. For this reason, varying levels of reliability must be determined for each site based upon the recorded electricity outages in order to determine a suitable BESS size.

The reliability of each SPS site has been determined by analysing the average electricity outage time as well as the maximum electricity outage time. The data, which can be seen in TABLE III, has been collected over a two-year period from April 2018 to April 2020.

TABLE III - SPS Outage Statistics

Site	Outages per year	Max outage time (minutes)	Average outage time (minutes)
Site 1 (DOL)	5	262	96
Site 2 (VSD)	1	22	22
Site 3 (Soft Starter)	3	139	83
Site 4 (Star-Delta)	4	222	95

V. Design of BESS: Case Study

A. Site Selection

The site selected for the case study was chosen based on two main criteria. These were the reliability of the system as well as the size. Since the goal of the case study was to develop an actual proposal for Shoalhaven Water, it was important to select a site which would benefit greatly from a BESS. The size of the system was also important, as a site with a smaller pump rating will require a smaller BESS and hence be more cost effective for a trial. Based on these criteria, selecting from the sites monitored in this paper, it is clear that Site 1 is the best choice for the case study due to the high number of outages and low electricity consumption.

B. Sizing Methodology

Sizing of the BESS system involves consideration of the following:

- The peak power rating required to service the pump starting transient which is determined by pump starter type
- The overall energy storage requirement which is determined by the outage duration and energy consumption for each site

1) Peak Power Rating

The first step of the proposed sizing methodology is to determine the peak power rating of the inverter and battery which is a function of the magnitude of the inrush current. While the duration of the inrush current is short, any system must be rated to accommodate the inrush current. For site 1 the maximum inrush current transient recorded was 36 A.

As noted, the inrush current is significantly greater than the load rated and running current. Hence, the peak power rating of the system is determined on short term phenomena. From an engineering design perspective, it is possible to either proceed with the aforementioned maximum current or alternatively use a different motor starting technique. This decision needs to be considered from a cost-benefit and technology availability perspective. In order to demonstrate the options available, the inrush current magnitude has also calculated for two additional hypothetical cases, one in which a Soft starter is utilised and another for a VSD. The inrush for these cases was determined by using approximations based upon the data obtained experimentally and through measurements. For a soft starter an approximation of 3.5 times the rated current was used, while for the VSD the inrush was estimated to be limited to the rated current, as shown in TABLE IV.

TABLE IV Inrush Current for each Pump Starter Type

Starter Type	Inrush current (A)
DOL	36
Soft Starter	16.45
VSD	4.7

The theoretical maximum rating for each starter type was then calculated by multiplying the inrush current with the rated voltage of 415 volts. The values calculated and measured can be seen in TABLE V. From the figures in TABLE IV and TABLE V it can clearly be seen that using a VSD for motor starting as opposed to a DOL results in an order of magnitude reduction in the peak power rating of the BESS.

TABLE V Maximum Theoretical and Measured Power Consumption of each Pump Starter Type

Starter Type	Maximum Short-Term Theoretical Power Consumption (kVA)	Maximum Short-Term Measured Power Consumption (kVA)
DOL	25.9	23
Soft Starter	11.8	n/a
VSD	2.4	n/a

C. Energy Storage Requirements

The third step in the design process is to calculate the storage required based upon varying resilience levels and outage lengths. Determination of an appropriate resilience is again an engineering design decision. In order to illustrate the impact of considering different levels of resilience, energy storage requirements for resilience levels of 95%, 99%, 99.99% and 100%, based on outage durations of four, six, eight, ten and twelve hours, have been evaluated. The results are shown in TABLE VI. The values in TABLE VI are predicated on the BESS system being able to maintain continuous supply for a specified outage time.

For the 100% resilience case, the energy storage required was calculated by multiplying the motor power rating with the outage length (in hours). Therefore, the results for 100% resilience can be described as the maximum theoretical power consumption during an outage of a specified length. The energy storage requirements for the remaining three resilience cases were calculated by determining a running average of the measured historical hourly consumption data for the site. The running average was determined for each outage length by varying the window size of the historical consumption data.

TABLE VI Energy Storage Requirements for differing Resilience Levels and Outage Times

Outage (hrs)	Storage Required (kWh)			
	100% Resilience	99.99% Resilience	99% Resilience	95% Resilience
4	9.6	8.7	1.7	1
6	14.4	13	2.3	1.4
8	19.2	17.3	2.9	1.8
10	24	21	3.5	2.2
12	28.8	23.6	4.3	2.5

In TABLE VI it can be observed that there is a very large jump in the required energy storage between 99% and 99.99% resilience. As such, the most effective engineering design may be to allow for 99% resilience and accept the fact that there will be a small percentage of occasions where the system may not have adequate storage.

D. BESS Costing Models

Costing models have been developed for each of the proposed solutions as well as for the current scenario with no BESS. The key considerations for each of the systems are the cost of parts and the cost of installation.

1) Current method (No BESS)

The cost of the present situation with no BESS has been determined using pricing estimates along with the reliability data from TABLE III. A formula has been developed to estimate the cost per outage based upon three factors:

Cost per outage = (Call-out cost) + (Number of workers) * (Cost of labour per hour) * (hours) + (Generator fueling/maintenance costs)

For this formula, an estimated call-out cost of $1,000 AUD, generator fueling/maintenance cost of $100 AUD have been used. It is also assumed that three workers are required for 5 hours per outage (based upon average outage time of 96 minutes as well as travel time) at a rate of $100 per hour. This results in an overall cost of $11,800 AUD per year.

2) Proposed BESS

The price for each of the proposed solutions has been developed utilising the peak power requirements (assuming a discharge rate of 1 C at peak power) from TABLE V to determine the overall system rating and associated costs. From TABLE II, for Site 1, the maximum outage duration is 4.4 hours. Therefore, when considering the storage requirements, the value of minimum capacity required has been selected as 3 kilowatt-hours. This is because it provides 99% resilience for an outage duration of 8 hours, which is significantly greater than the current maximum recorded outage. It is important to note that for the DOL and soft starter run pumps the power requirements of the battery and inverter are much larger than the capacity required. Due to lack of commercially available systems with such a large discrepancy between the two values, the battery for these two systems has been priced according to a larger system capable of handling the necessary power requirements. The prices for the proposed systems can be seen in TABLE VII.

TABLE VII BESS Costing for Site 1 for each Starter Type

Component	DOL Price ($)	Soft Starter Price ($)	VSD Price ($)
Contactors	550	188	86
Battery	23,000	11,000	3,000
Inverter	9,000	9,000	3,000
Starter	n/a	868	3,070
Installation	6,600	6,600	6,600
Total	39,150	27,656	15,756

The price of the components has been sourced from retail prices found online. Battery price has been estimated assuming that for one kilowatt hour of battery storage it costs $1000 AUD. Installation cost has also been estimated using the below formula:

$$\text{Installation cost} = (\text{hourly cost of labour}) * (\text{number of workers}) * (\text{hours}) + (\text{equipment costs})$$

For this scenario it is assumed that two workers are required for eight hours with an hourly rate of $100 AUD each, and that the cost of equipment is approximately $5,000 AUD. This brings the total installation cost to $6,600 AUD, which is used in TABLE VII. From a cost perspective, the most suitable option is to install a VSD when implementing a BESS. Installing a VSD reduces the system cost significantly due to the lower power requirements lowering the battery and inverter costs.

VI. Discussion and Conclusion

This paper discusses an innovative process for designing a BESS to provide backup electricity supply to critical infrastructure, in this case a sewage pumping station. Three key criteria are considered in the design process; the characteristics of the load, the reliability of the electricity supply and the amount of energy used by the load.

From a design perspective it is clear that changing the motor starting technology in order to reduce the peak rating of the proposed BESS makes good financial sense and should be considered provided that there are no other technical limitations. It has been shown that the peak rating is directly proportional to the cost of the BESS, and that the starter type implemented dictates the peak rating of the motor. The peak inrush current, which is directly proportional to the peak power, of each starter type has been verified through the results found both experimentally and through measurements taken on site. It was found that the DOL starter is the least effective at limiting the peak inrush, the soft starter was somewhat effective, and the VSD was the most effective. These results are in accordance with the theoretical performance of each of the starter types.

The reliability of the proposed BESS with a VSD starter was based upon the assumption that the 99% resilience case would be sufficient along with a maximum outage time of eight hours. The financial implications of increasing the resilience from 99% to 99.99% also led to the lower resilience being selected, as it requires comparatively significantly less energy storage. However, for the proposed BESS with a DOL or soft starter, the minimum required storage was limited by the system size required to provide peak electricity consumption. This meant the DOL starter BESS had to be sized for the 99.99% resilience case for an outage up to ten hours, and similarly, the soft starter BESS was sized for the 99.99% resilience case for an outage up to 4 hours. These solutions are more reliable; however, they bring much higher costs associated with the increased system size.

From a simple payback perspective, payback periods range from a little over three years for the largest system down to slightly more than one year if the starter technology can be upgraded. The trade-off found is between system reliability and cost. Increasing the reliability from 99% to 99.99% resilience requires five to six times more energy storage, which significantly increases the cost of the BESS and associated payback period. It is important to also consider the risks associated with a lower reliability, as it lowers the chances of the BESS providing sufficient backup electricity to an SPS during an abnormal electricity outage.

Severe weather events are a large contributor to electricity outages. Site reliability is entirely dependent on the electricity outage data obtained, and it can therefore be said that the impact of severe weather events on this data is significant. Since the data utilised in this paper has been collected over a two-year period, it can be said that the data is not an accurate representation of every possible electricity outage event that has occurred or will occur. Therefore, the proposed BESS may not be effective for every potential electricity outage. This is simply due to the unpredictable nature of extreme weather events. However, a BESS will reduce the cost of backup electricity generation by potentially removing or limiting the need for a generator to be brought on site.

References

[1] T. A. Nguyen, M. L. Crow, and A. C. Elmore, "Optimal sizing of a vanadium redox battery system for microgrid systems", *IEEE Transactions on Sustainable Energy*, 6(3):729–737, 2015.

[2] C. Singh and A. D. Patton, "Reliability evaluation of emergency and standby power systems". *IEEE Transactions on Industry Applications*, IA-21(2):476–480, 1985.

[3] A. Grama, D. Petreus, R. Etz, and T. Patarau, "Fuel consumption reduction of a diesel-electric power generator. In 2015", *38th International Spring Seminar on Electronics Technology (ISSE)*, pages 381–384, 2015.

[4] D. Rastler, "Electric Energy Storage Technology Options: A White Paper Primer on Applications, Costs, and Benefits", Technical report, EPRI, 2010.

[5] M. J. Vasallo, J. M. Andujar, C. Garcia, and J. J. Brey., "A methodology for sizing backup fuel-cell/battery hybrid power systems", *IEEE Transactions on Industrial Electronics*, 57(6):1964–1975, 2010.

[6] A. Lahyani, P. Venet, and A. Troudi. "Design of power sharing system between supercapacitors and battery in an uninterruptible power supply", *In 2011 IEEE 33rd International Telecommunications Energy Conference (INTELEC)*, pages 1–7, 2011.

[7] B. Bidoggia, G. Spiazzi, S. Buso, T. Lequeu, and L. Ventura, "Design of a fuel cell based backup system for telecoms applications", *In INTELEC 2008 - 2008 IEEE 30th International Telecommunications Energy Conference*, pages 1–8, 2008.

[8] Adam Drenoyanis, Raad Raad, Ivan Wady, and Carmel Krogh, "Implementation of an iot based radar sensor network for wastewater management", *Sensors*, 19(2):254, Jan 2019. ISSN1424-8220. doi:10.3390/s19020254. URLhttp://dx.doi.org/10.3390/s19020254.

[9] J. Knott, D. Sutanto, K. M. Muttaqi, D. Robinson, S. Elphick, S. X. Dou, H. Bustamante and R. Muller., "Development of novel sodium-ion batteries for operation of sewage pumping stations: Determining energy requirements", *Ozwater*, pages 1–8, 2018.