Off-Grid Power Feasibility for Waste Water Pump Stations

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Abstract

The risk of sewage overflow in metropolitan Waste Water Pump Stations (WWPS) was investigated by the Water Corporation's Waste Water Overflow Risk Management (WORM) model. The WORM model highlighted power failure as one of the major causes of risk of overflow for metropolitan WWPS sites. For regional WWPS sites, there is significant data demonstrating the likeliness of site power failure for those situated in specific townships. Also for such regional sites, there are substantial costs associated with grid connections (53.15 cent per kWh and $5.67 daily connection fee). Overall, the Water Corporation requires a means of providing reliable and relatively low cost power to regional WWPS. This project investigated select case studies for off-grid power feasibility and determined key site based characteristics that influence such feasibility.

1. Introduction

The Waste Water Overflow Management project recently conducted by the Water Corporation highlighted power failure as a major cause of risk for overflow occurrences for Waste Water Pump Stations. For regional townships around W.A, the annual average of power outages is 3.75 at an average of 102.91 minutes each. In the recent past, townships such as Wyndham have seen an annual average of 20 or more for each customer premise. For regional grids, customers under the N2 tariff scheme (such as WC) are charged a $5.67 daily connection fee and a unit price of 53.15c for regional WWPS sites).

This project examined the possibility of reducing such operating costs by the use of off-grid solar based power systems whilst possibly improving site power reliability. A majority of off-grid power feasibility studies have been conducted using software packages such as HOMER or PVSyst. Such packages allow for consistent results and also simplify the entire process for the user. Relevant case studies include (Razak et al 2010) and (Liu et al 2011). This project made use of the HOMER simulation program for comparing various off-grid and grid connected systems to meet specific constraints (i.e power capacity shortage) whilst determining the most cost-effective solution. Also, a simulation program was written to allow for customized addition or modelling of off-grid systems (which can be utilized in future research). The program was based off the HOMER program utilizing the documentation that the program provides as well as the National Renewable Energy Laboratory (NREL) Photovoltaic (PV) system database.

1.1 HOMER Simulation overview

The HOMER simulation program will iterate between user input decision variables to find the most cost effective system based on simulation constraints, such variables include PV array size, battery storage size, generator size, wind turbine size and dispatch strategy. HOMER performs a set set of energy balance calculations for each defined time step of the year (i.e. hourly or minute interval) and ranks systems via a user specific metric such as net present cost (NPC) or unmet electrical loads.

1.1.1 PV power output

Mean monthly irradiance values are entered in conjunction with the site's latitude to develop monthly clearness indices which are then used to develop hourly Global Horizontal Irradiance (GHI) values using the method specified by Graham & Hollands 1988. Also, HOMER retrieves interval temperature data from the same database to determine the PV panel output via the equation Duffie & Beckman 1991:

$$P_{PV} = Y_{PV}\, f_{PV}\, \frac{G_T}{G_{T,STC}} [1 + \alpha_p (T_c - T_{c,STC})]$$

Where Y_{PV} is the rated capacity of the PV array, f_{PV} is the derating factor, $\frac{G_T}{G_{T,STC}}$ is the ratio between incident radiation during the time step and rated conditions and $\alpha_p(T_c - T_{c,STC})$ is represents the temperature de-rating factor.

1.1.2 Battery power input/output

HOMER uses the Modified Kinetic Battery Model as given by (Manwell & McGowan 1993). This model defines the maximum discharge and absorption of a battery cell for each individual time step whilst utilizing specific constraints. Also the model considers thermal, cycle and time de-rating on battery capacity and performance (the equations have not been listed due to the vast amount used).

1.1.3 Generator power input/output

The generator will provide power to match the electrical load or required amount to recharge the battery storage, the fuel consumption of the generator is given by:

$$F = F_0 Y_{gen} + F_1 P_{gen}$$

where F_0 is the fuel curve intercept, Y_{gen} is the rated generator capacity, F_1 is the fuel curve slope and P_{gen} is the desired output of the generator. The fuel consumption curve is used to approximate the generator efficiency, which is then used to find the actual electrical output of the generator for a given fuel usage.

1.1.4 Economics Modelling

The approximated real interest is calculated by using the equations shown below.

$$i = \frac{i' - f}{1 + f} \qquad CRF(i, N) = \frac{i(1+i)^N}{(1+i)^N - 1} \qquad C_{npc} = \frac{C_{ann,total}}{CRF(1+f)}$$

Where i' is the nominal discount rate and f is the user specific inflation rate. The real interest is then used to determine the Capital Cost Recovery Factor (CRF) for components and net present system cost (C_{npc}) for the overall system where N is the project lifetime in years and $C_{ann,total}$ total annual costs.

1.1.5 Advanced Grid Module

HOMER's advanced grid module models electrical grid costs as well as grid reliability. A user can specify the expected grid reliability and HOMER will introduce randomized outages in the simulation run. An optimal grid connected system must still satisfy the user specified constraints (such as annual capacity shortage).

2. Methodology

Due to the large number of regional WWPS sites, only a select few were chosen for investigation. Each chosen site had significant operational differences including, pump size and electrical load profile, temporal region and grid power reliability. The methodology for investigating site feasibility is shown in the flow chart below.

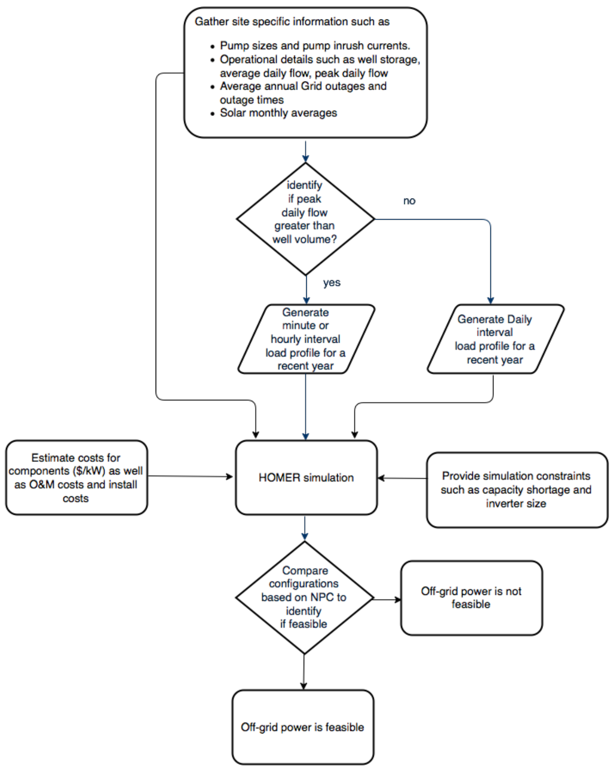

Figure 1 Flow chart for methodology

Load profiles were generated by multiplying the pump running time by the pumps rated input power (kW) and making an assumption for auxiliary site power use. In each case the yearly profile was compared to the annual usage and scaled up by the same percentage change as seen in daily run hours annual average. Cost estimates of components (including inverters, batteries, PV panels) were derived from previous WC PV installations and estimate quotes from installers. Generator cost inputs were estimates were made from historical data from regional sites. In each investigation the following configurations were simulated and defined as types:

- Type 1: Grid connected with no backup battery supply (current operation).
- Type 2: Off-grid PV/Battery with some unmet loads (comparable to grid connection).
- Type 3: Grid connected with PV/Battery backup system to mitigate power outages.
- Type 4: Off-grid PV/Battery/Genset system with no allowable unmet loads
- Type 5: Grid connected with Genset backup system to mitigate power outages.

For each configuration that utilized a battery system it was assumed that 3 phase inverters were required and also a soft starter or variable speed drive for each pump.

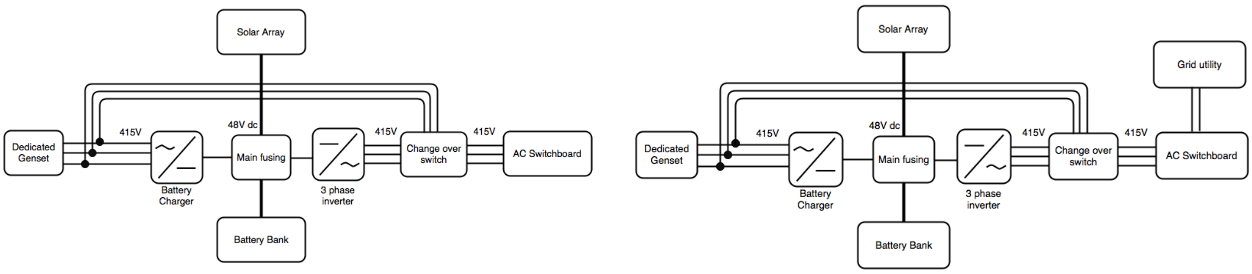

Figure 2 Off-grid and Grid connected systems simulated for a three phase AC load

In each case the results were produced from simulations using 10-minute time steps. This presented no significant difference to the overall results when compared to the hourly time interval simulations but it more accurately represented the high discharge/charge cycles of the simulated batteries. The following capital cost assumptions were used as inputs to the HOMER simulation program.

	PV	Inverter	Battery Storage	Generator	System electrical install costs
Capital Cost	$1500 per kW	$1000 per kW	$800 per kWh	$333 per kW	$3000 per kW
Annual Maintenance Costs	$20 per kW	$40 per kW	$8 per kWh	$3000 per Generator	$500 for site
Description of inclusions	Fixed PV racking and maximum power point trackers for each string.	3 phase inverter with smart controller switch and remote control capabilities.	Lithium Ion batteries with charge controller	Diesel Generator	kW for inverter size. Assuming a dual pump system, including pump drive replacement and overal electrical system install.

Table 1 Assumed component costs

3. Results and Discussion

The following tables shows the optimal (with the lowest net present cost) system configurations, including component sizes for each type of system investigated.

System type	PV (kW)	Gen (kVA)	Batteries (1.2kWh each)	Grid	Inverter (kW)	Net Present Cost ($)	NPC Ranking	Initial Capital ($)	Unmet load (kWh/yr)	Grid Usage (kWh)
1	0	0	0	Yes	0	51,359	1	0	13.8	3753
2	32	0	40	No	8	121,282	3	100,400	31.2	0
3	4	0	8	Yes	8	92,538	2	52,400	0	702
4	4	6	6	No	8	124,767	4	83,300	0	117
5	0	48	0	Yes	0	143,312	5	20,000	0	3753

Table 2 Site investigation HOMER results for Wyndham SPS 1

System type	PV (kW)	Gen (kVA)	Batteries (1.2kWh each)	Grid	Inverter (kW)	Net Present Cost ($)	NPC Ranking	Initial Capital ($)	Unmet load (kWh/yr)	Grid Usage (kWh)
1	0	0	0	Yes	0	42,521	1	0	3.85	2095
2	5	0	8	No	10	76,743	2	56,500	1.01	0
3	5	0	7	Yes	10	97,273	4	54,500	0	3.01
4	5	0	10	No	10	78,743	3	58,500	0	0
5	0	30	0	Yes	0	121,366	5	10,000	0	2092

Table 3 Site investigation HOMER results for Carnarvon SPS6

System type	PV (kW)	Gen (kVA)	Batteries (1.2kWh each)	Grid	Inverter (kW)	Net Present Cost ($)	NPC Ranking	Initial Capital ($)	Unmet load (kWh/yr)	Grid Usage (kWh)
1	0	0	0	Yes	0	37,386	1	0	1.29	1362
2	8	0	10	No	5	72,638	4	52,000	2	0
3	0	0	2	Yes	5	60,256	2	17,000	0	1364
4	4	4	6	No	5	75,225	5	36,333	0	0
5	0	24	0	Yes	0	68,042	3	8000	0	1360

Table 4 Site investigation HOMER results for Esperance MH0242

The simulation results in each table show there is no off-grid power system that produces a lower NPC value (or a higher NPC ranking) than a grid only system. This can mainly be attributed to the associated costs of installing a battery/inverter system for off-grid power. Battery storage was required due to the continuous diurnal operation of WWPS sites with peak power demand occurring during morning and evening times. Inverter costs were assumed to be significant due to the requirements of installing new drives or starters for the existing pumps to handle the significant inrush currents for induction motor starting. Table 2 shows that for sites such as Carnarvon, an off-grid power system can be an economically viable (via NPC ranking) option for meeting all electrical loads during yearly operation (assuming there is no major component failure within a components expected lifetime). This could be credited to the Carnarvon site having a relatively low variation of daily site run hours (as shown in table 4 below), being in a high irradiance region and also due to the sites past grid unreliability.

Wyndham SPS1 has extremely large variations in daily site run hours and would therefore require a battery generator system to meet the demand. For the Esperance site, the grid power reliability values meant that to improve grid reliability only a generator or relatively small battery backup system would be required to makeup for the relatively minor amount of outage time and such systems would be cheaper than an entire off-grid installation. The limitations of these results is that they assumed a linear scale of component costs with size aswell as the gradient of this scaling (i.e $1.5 per kW for PV panels). The estimates chosen were conservative to allow to replicate surplus budget allocation as normally practice during project installments. Also the results assume that components would not fail before their expected lifetime (a situation that could significantly increase overall costs).

WWPS site	Max daily Site run hours	St Dev Daily run hours	Average Daily Run hours	Worst month solar irradiances	Average annual outage time sum (hr)
Wyndham SPS 1	24	2.54	3.04	5.02 (June)	16.6
Carnarvon SPS6	3.4	0.24	1.011	3.73 (June)	11.3
Esperance MH0242	5.9	0.73	0.37	2.52 (June)	1.98

Table 5 Main factors for Off-Grid power feasibility as a means of improving WWPS reliability

4. Conclusions and Future Work

Overall the current results demonstrate off-grid power systems to not be a viable option for reducing WC's regional operational costs for WWPS sites. In terms of improving site reliability, an off-grid system may be used as a more cost effective method to reduce outage times as seen by the Carnarvon case study. Future work will include revising and/or validating component costs with additional solar installers. Additionally, a specific design for the most feasible and reliable off-grid system will be produced which may be applicable to future off-grid power applications not only specific to WWPS operations. Furthermore, the simulation program will be further developed to use cost inputs to rank configurations. Currently the program only matches the minimum amount of PV panels and solar batteries to meet to specified user demand.

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