A BALANCED SCORECARD APPROACH FOR THE ENHANCEMENT OF DISTRIBUTED RENEWABLE PENETRATION LIMIT IN ISOLATED NETWORKS

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ABSTRACT

Currently Horizon Power is operating 30 isolated power systems ranging from hundreds of KW to tens of MW in generating capacity using multiple fossil fuel based units. These generation systems are expensive to run and have a large carbon footprint. Integrating renewable energy generation into these power systems is thus desirable.

This paper presents a balanced scorecard approach to the development of enabling strategies to enhance the integration of decentralised renewable systems into the Horizon Power's isolated grids. The balanced scorecard considers technical, economic, social and environmental perspectives. The technical evaluations include the impacts of renewable generation on the quality of supply including supply reliability and power quality. Particular considerations were given to the power station spinning reserve requirements and rising voltage in LV networks. The socio-economic and environmental evaluations have been undertaken based on Horizon Power experiences, policies and practices.

INTRODUCTION

Horizon Power is a vertically integrated, state owned electricity utility responsible for regional and remote towns in Western Australia. Horizon Power's service area is vast (Fig 1), approximately 2.3 millions square kilometers, with approximately 43,000 customers. This necessitates innovative solution to the supply of reliable and economical power supply to customers in the area.

Our service area includes two interconnected networks – the North West Interconnected System (NWIS) in the Pilbara (Karratha, Roeburne, Point Samson, Port Hedland and South Hedland) and a smaller regional network (powered by a hydro power plant) connecting the towns of Kununurra, Wyndham and Lake Argyle, as well as isolated systems which power towns. Currently Horizon Power is operating 30 isolated power systems ranging from 200kW to 30MW in generating capacity. These multiple units fossil fuel based generation systems are expensive to run and have a large carbon footprint. Integrating renewable energy generation into these power systems is thus desirable considering its values in economic, environment and social benefits**.**

Horizon Power has, since 1990s, gained vast experiences operating a number of centralised systems with high penetration of renewable energy sources (in excess of 80%). These include energy storage and sophisticated integration control systems such as wind/diesel/flywheel and solar PV/diesel/flywheel hybrid power stations. The recent net "Feed in Tariffs" (FiT) incentive by the State government and the Renewable Energy Certificates (RECS) financial subsidy by the Federal government are the two major drivers of a significant increase in decentralised renewable energy installations in customer premises. High penetration level of this un-controlled solar PV generation, which is desirable, can deteriorate power quality, stability and reliability of the power supply.

Due to the above drivers and constraints, Horizon Power is experiencing difficulties in balancing customer expectations, system operations and government policy particularly in our small and isolated systems. Customers expect a reliable power supply together with installation of PV or other renewable energy systems on their premises. High penetration of renewable energy systems can have adverse impacts on system network and power station operations and production costs as the network load becomes an unknown to the system operators. While being too conservative about renewable energy systems interconnections to the networks may be a public relation disaster, not being so may result in high cost remedy.

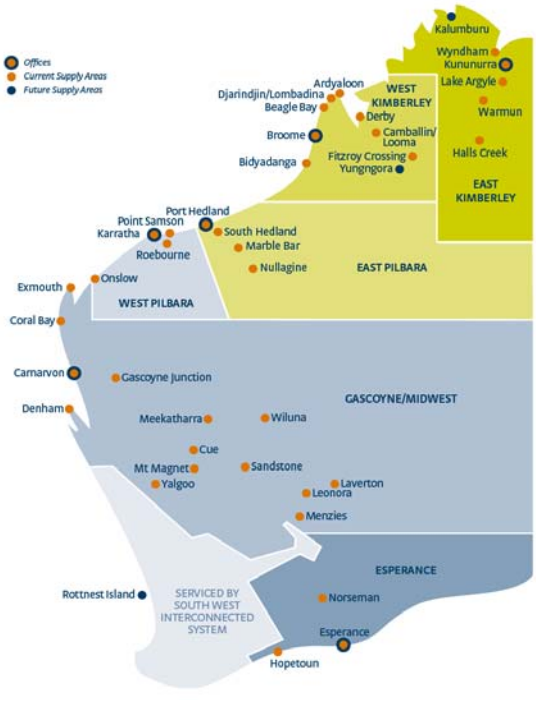

Fig 1 Horizon Power's Service Area

This paper addresses these issues and is organised as follows. Firstly, an overview of Horizon Power's isolated power systems and the operational philosophy to meet the statutory power quality and reliability performance standards; and the environment, social and economic operational constraints is given. Secondly, the regulatory framework i.e. a brief on the governments' policies and financial incentives to promote renewable energy is provided. Thirdly, the existing connection requirements and issues relating to distributed renewable energy systems are described. Fourthly, the enabling strategies to enhance the penetration limit are then investigated. Finally a balanced scorecard approach is introduced and applied to a study case and the obtained results are presented and discussed.

ISOLATED SYSTEMS OVERVIEW

Horizon Power's isolated power systems comprise multiple units of gas and/or diesel engine driven generators supplying Aboriginal communities and remote towns via medium voltage distribution networks. The inland remote outback is usually in arid climate, an extreme and harsh environment to operate a power system.

Generation Policy

Horizon Power has practiced outsourcing the generation business to independent power producers (IPP) under long term (up to 20 years) power purchase agreement which restricted Horizon Power to generate electricity to 10% of the total energy demand. Horizon Power has recently tended towards the "build, own and operate" generation business model to better serve the corporate strategy in creating lasting value for social, environmental and economic benefits.

Energy Mix

The overall energy mix comprises mainly gas (85%) and diesel (15%). Renewable energy remains very low at less than 0.5%. These are provided by hybrid wind/diesel or gas systems and solar PV/diesel/flywheel generating systems. The mix is dominated by gas fired power plants powering the NWIS and 5 large towns. However, there are 23 small power stations running on diesel fuel.

Cost of Energy

The average cost of energy (to serve customers) is 31.2 cents/kWh. This includes generation, distribution, overhead and depreciation costs. The cost ranges from 0.28c/kWh for the NWIS to 1.68 AUD/kWh for Coral Bay, a remote town. The cost of energy for small diesel plants can be as high as 1.65 AUD/kWh, depending on the cost of transporting fuel to remote sites and operation and maintenance costs.

CO_2 Emission

Horizon Power's CO_2 emission has been monitored in terms of the emission per kWh sent out, (kg CO_2 e/kWh). This indicator has decreased from 0.71 to 0.68 in the past year. This is largely due to completion of the high energy efficiency gas fired plant at Karratha and the renewable power plants at Marble Bar and Nullagine.

Performance Standard

Horizon Power's isolated systems are required to provide a main grid quality power supply 24 hours a day. The system operation is regulated by performance standards shown in Table 1 with the key performance indicators (KPIs).

Table 1 A Summary of Performance Standard

Parameter	SAIFI	SAIDI
Unit	Outage/yr/customer	Min/yr/customer
Target	6.6	290
KPI	2.43	162

REGULATORY FRAMEWORK

Renewable Energy Policy

The Australian Government has established the Renewable Energy Target (RET) to encourage additional generation of electricity from renewable energy sources to meet the Government's commitment to achieving a 20% share of renewables in Australia's electricity supply in 2020. The RET legislation places a legal liability on wholesale purchasers of electricity to proportionally contribute to an additional 45,000 GWh of renewable energy per year by 2020. It also sets the frame work for both the supply and the demand of 'Renewable Energy Certificates' (RECs) via a REC market [1]. The State Government provides additional incentives in 'Renewable Energy Buy-back Scheme' (REBS) and the net 'Feed-in Tariff' (FiT) introduced in August 2010 [2]. As a result of these policies, Horizon Power is facing an unprecedented surge in the PV installations that may exceed the following limits.

Network (Power Quality) Limit

In LV networks the voltage at the point of PV connection rises above the network voltage during power injection into the network. This creates the power quality issue such as rising system voltage in low voltage (LV) networks [3]. This voltage rise may exceed the permissible +/-6 % system limits.

Power Station (Reliability) Limit

Step load capability of generating units is the limiting factor related to system spinning reserve and power supply reliability issues. When faults occur in a network with high penetration of PV, the PV inverter may be disconnected by the under/over voltage protection functions. The loss of this PV equates to an additional step load seen by the generating units. Generally, generation dispatch with sufficient spinning reserve will help balance the load and system stability and reliability can be maintained. With a high penetration level of renewable energy, the dispatching is more difficult as the actual network load is unknown to the operator.

Horizon Power's Connection Requirements

Network

Connections of decentralized renewable energy systems via grid connected inverters to Horizon Power networks must at least comply with [4], summarized below.

- Maximum system capacity is 10kVA for 240V single phase and 30kVA for 415V three phase systems.
- The maximum distributed generation that can be connected to a distribution transformer is limited to 20% of the transformer rating.

Power Station

Gas and diesel engines have a step load capability limited to approximately 20% to 30% of the unit rating respectively. Horizon Power practices N-1 operating philosophy for spinning reserve requirement to ensure system stability due to a loss of a single generating unit. The renewable penetration limit is defined as the minimum of the following three criteria;

- 50% of the smallest generator capacity installed at the power plant.
- 30% of instantaneous network load at the time of peak renewable generation.
- 10% or 15% of the annual peak demand for gas or diesel generation respectively (based on load factor and step load capability of the generating units).

A BALANCED SCORECARD APPROACH

The balanced scorecard approach described in [5] has been adopted for the evaluation of the enhancement options. The four perspectives considered are technical, environment, economic, and social (customer satisfaction). Horizon Power has identified possible enabling strategies for the enhancement of the PV penetration limit as detailed below.

Enabling Strategies - Network Solutions

1. Employing the industry best practices in LV design that take into considerations line/cable size/capacity and length from service mains to inverters; PV inverter capacity and future PV expansion.
2. Limiting maximum PV capacity to, for example, *3kVA or lower* for single phase systems.
3. Employing inverters with fault-ride-through (FRT), voltage/reactive power control and active power reduction capabilities. This involves the inverter manufacturers and the installers.
4. Extending smart grid and AMI capabilities to customer demand response to enhance system stability e.g. distributed under frequency load shedding (UFLS) at appliance level i.e. deferrable load such as air conditioner compressor, fridge, pool pump etc.

Enabling Strategies – Power Station Solutions

1. Practising generation dispatching with extra spinning reserve only for cloudy days based on weather forecast. It is possible to utilise a short term overload capability of the generating units as an emergency spinning reserve by modifying the governor controller as suggested by [6].
2. Implementing advanced functions in power station design e.g. under frequency roll off (UFRO) function, or over sizing units for higher step load capability.
3. Incorporating state of the art short term energy storage systems (i.e. in ~ 5kWh range; 500kW, 30s) to provide the additional spinning reserve using flywheel, or super capacitors, or Zinc Bromine (ZnBr) battery etc. High cost is a barrier.

The Scorecard

The scorecard for the enabling strategies is qualitatively evaluated as detailed below. The results are indicative and should be subject to an annual review as research, development and commercialisation of the enabling technologies can be quite dynamic.

The technical assessment considers the reliability, uptake time (to become fully effective), availability of the enabling technology, and implementation complexity. On the economic assessment the key topics considered include capital, operating and maintenance and life cycle costs. The environmental assessment considers mainly green house gas emission. Finally the customer engagement, satisfaction, and equity are considered in the social assessment.

A CASE STUDY – CARNARVON

The existing Carnarvon power plant has gas engines operating as a base load generation, supplemented during peak load by diesel engine generation. The forecast low and peak demand are 3MW and 12MW respectively. Diesel engine is dispatched when the demand reaches approximately 8MW. A staged expansion work is in progress to eventually relocate the existing station to a new power station located 7 kms away. The future power plant has been designed to have a number of similar capacity (1.8MW) gas and diesel units installed. The generator control with an under frequency roll off (UFRO) feature has been specified. Six 22kV feeders deliver power to over 2,600 customers as shown in Fig 2 .

The Current Situation

Horizon Power is facing formidable tasks in accommodating increasing PV installations highlighted by the following drivers and constraints.

- The renewable penetration limit for the Carnarvon power system is currently set at 900kW.
- The application to connect solar PV systems to the grid is at present approximately 1,350kW from 140 applications.
- The RECs capital subsidy for a $50,000, 10kW PV system connecting to the Carnarvon power grid is approximately $42,000.
- The existing REBS offers an 18c/kWh for the net export.
- The new FiT scheme offers additional 40c/kWh for the net feed-in (i.e. the net export).

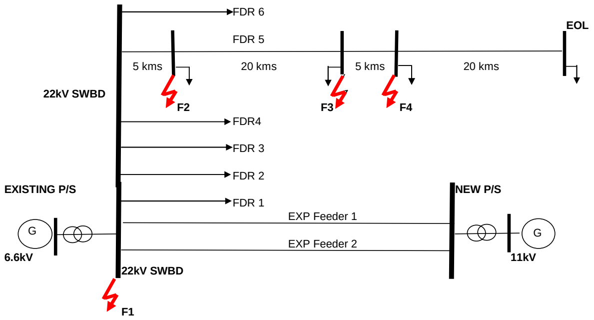

Fig 2 Single Line Diagram of the power systems

System Simulation Studies

Transient stability studies investigated the effect of inverter FRT on the power station behaviours following a permanent fault close to the 22kV switchboard. The fault was cleared in 300ms and followed by a re-close after ~70s. The system load was 7.5MW with 3MW PV installed.

The simulation results are given in Fig 3 depicting system responses with and without PV inverter FRT feature (the 'blue' and 'red' curves respectively). Without the inverter FRT, it is assumed that all PV inverter were disconnected and the system frequency collapses to below 10Hz.

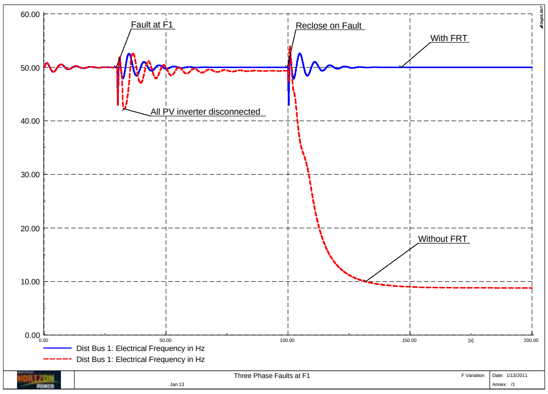

Fig 3 Transient stability study results

The fault studies were undertaken to determine the effect of fault location on the behaviours of the Carnarvon power system. A case study is based on a selected 50 km feeder (FDR 5). The voltage and frequency variations following 300ms three phase faults at F1 to F4 are summarised in Table 2.

Table 2 Summary of frequency and voltage excursions

Fault Location	Km from SWBD	Frequency (Hz)		SWBD V(p.u.)		EoL V(p.u.)	
		Max	Min	Max	Min	Max	Min
F1	0	55.9	43.7	1.136	0	1.075	0
F2	5	55.0	44.8	1.124	0.250	1.064	0
F3	25	52.8	40.0	1.107	0.625	1.048	0
F4	30	52.6	40.5	1.097	0.652	1.032	0

The results indicated that faults 25 km away from the power station can result in frequency dip as low as 40Hz i.e. lower than those of close in faults. Faults close to the power station can result in over voltage in areas near to the switchboard. And both conditions may cause disconnection of the PV inverters in the affected areas.

The Balanced Scorecard

Network Solutions

The strategies 1 and 2 score very well on quality control during connection approval process, customer equity and cost. They are currently practiced. The strategies 3 and 4 score poorly on the availability and complexity of enabling technologies, up take time and participation of other stakeholders e.g. installer, manufacturers and customers.

Power Station Solutions

The short term energy storage solution is not recommended due to high cost. Future breakthrough in cost effective energy storage technology may change the ranking of this solution. Operating the power station with extra spinning reserve may need change to the current practice and will increase energy production cost. Utilisation of the UFRO is applicable only to a new power station control design.

Discussions

Though the probability of total PV disconnection due to network faults may be lower than first perceived, a conservative approach is taken until it is confirmed by field experience. The obvious solution at present is to limit the kW capacity of each customer PV installation to 1.5kW.

CONCLUSION

This paper applies the balanced scorecard approach for the enhancement of PV penetration into isolated networks. Several network and power station strategies for enhancing the penetration level were identified. Further studies and field monitoring are being undertaken to gain more confidence on the probability of various uncertainties of the system responses thereby enabling higher penetration level of distributed renewable energy systems.

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