Project Number & Title	**2011_14 Hybrid Generator LTI (S Reid)**
Project Originator	**Stewart Reid**
Project Manager & Dept.	**Neil McFaul Future Networks**
Project Oversight	
R&D Provider	**PNDC**
Partners (e.g. DNOs, etc)	**Off- Grid Solutions**
Business Sponsor & Dept.	

1 Project background

1.1 Scope and objectives

The use of standard diesel generator sets to provide power is generally extremely fuel inefficient.

The generator set requires to be sized for the peak load resulting in the unit running well below capacity for most of the time.

Consequently the running cost and CO2 emissions are in excess of what could be achieved with a more efficient method of generating temporary power.

This problem is widely recognised in the marine industry and has led to the development of hybrid units combining a generator with a battery/inverter unit.

The intended unit would be rated at 80A single phase, corresponding to a standard domestic supply, allowing the equipment to supply individual houses in the event of a fault or in the limited instances where SSE have failed to deliver new connections within the required timescales.

Regarding the use on the rare occasions SSE have failed to timorously provide new connections while Ofgem do have the facility to apply fines there is often a valid reason for the connection being later than anticipated and the fine can not be applied. Nevertheless the customer will be disappointed that the connection has not been made.

In these situations the provision of supply via the hybrid unit will give a non-quantifiable benefit in terms of customer satisfaction.

2 Project appraisal

Learning Objectives (All objectives set even if they were changed during the project, insert additional rows as necessary)		
No.	**Description** (as per PID)	**Extent to which achieved** Score (3-achieved, 2-partially achieved 1-not achieved) plus brief justification
1	**To investigate the suitability of a hybrid generator for fault duty and also its suitability as a temporary supply where SSE has failed to provide connections within the required timescale.**	**Score: 3** **Justification: Independently tested for domestic connection after a fault or planned outage.**
2		**Score:** **Justification:**
3		**Score:** **Justification:**

3 Methodology

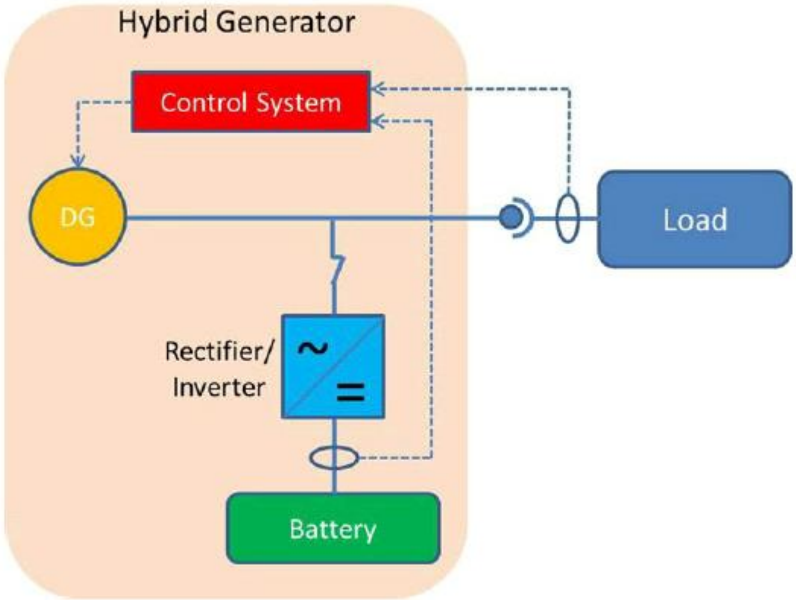
To investigate the suitability of a hybrid generator for fault duty and also its suitability as a temporary supply where SSE has failed to provide connections within the required timescale.

The hybrid generator (HG) technology is offered as a solution for off-grid power supply requirements in remote locations and can be used to provide power for residential, construction, telecom towers and disaster relief applications.

The HG is a combination of a diesel generator (DG) and a power-electronic converter with integrated battery storage. In conventional generator-only applications, the diesel generator must “load follow” and therefore operates at off-optimal conditions for the vast majority of time – the battery system alleviates this requirement.

Other benefits include low/no noise through noise insulation and operation in battery-only mode, less carbon emissions through operation of the DG at optimal conditions and use of battery, generally more efficient operation of the DG and reduced cost of ownership since the engine has to run less often.

The work to establish the feasibility looked at this combination of Battery, Generator and demand profile. The scope preclude to a mobile containerised units that can be transported via road and sea and contain a full step-up hybrid system.



This topology allows for the selection of either the Diesel Generator or the DC Battery to deliver an output at the optimum Load.

The Project finding on Fuel efficiency and Generator life extension.

The Hybrid generator set has been tested against a standard generator to compare fuel efficiency and whole life cost returns.

Back Ground – Fuel Efficiency

For a comparison between the standard generator and Hybrid, we need to compare the running operational cost of the two units. This means testing the two units which optimise both of the qualities and weakness to get an overall comparison.

Standard Generator: This generator has an efficiency profile where the KW produced will be directly proportional to the amount of Litres/hr used.

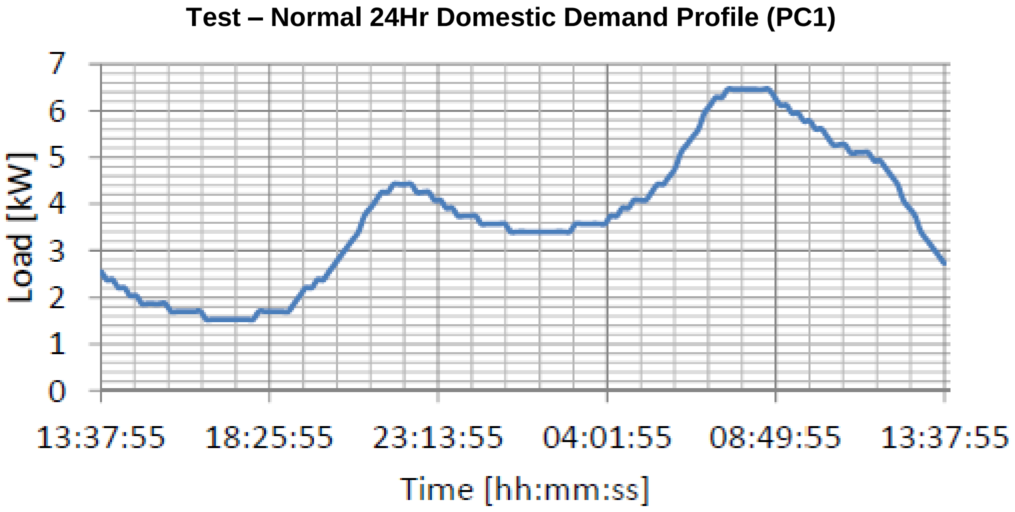
Hybrid Generator: Similar to the standard generator this unit will combine the two strengths of the battery technology and the generator efficiency.

Demand Profile: The demand profile for a standard unit requires the standard generator to operate at close to 95% loading rate. The 95% loading means the standard generator produces the most KW for the least amount of diesel used per hour (L/Hr). As a domestic house demand cycles, this 95% loading rate is compromised at different times of the day. Therefore the standard generator operates at low load ratings for long periods of the day and is not as efficient*.

The hybrid generator will also want operate at the 95% loading rate when the demand is high on the generator function, and similarly operate in battery function when the demand is low. The battery will only have a set amount of stored energy. This stored energy will last longer with lower demand levels. The inefficient time for operating the hybrid will be in the charging of the battery and not supplying a domestic load. The charging of the battery can be more efficient when used in loading of the generator. This period of charging moves the over all domestic load + battery load up toward the standard generators efficiency point.

By developing a demand profiles that have a Maximum and Minimum demand profile for the standard generator over a 24hr period and then comparing this too the Hybrid. These two types will show the Maximum and Minimum fuel saved. This will give a good benchmark for testing against a domestic profile and what the avg savings on operational expenses will be.

***Demand profile for domestic loads can very. This can lead to domestic demands during the day to very from profile to profile.**


Test – Normal 24Hr Domestic Demand Profile (PC1)
Load [kW]
0
1
2
3
4
5
6
7
13:37:55
18:25:55
23:13:55
04:01:55
08:49:55
13:37:55
Time [hh:mm:ss]

4 Project outcomes

Outputs:

Mode	Average Energy Produced [kWh]	Average Fuel Consumed [L]	Fuel Efficiency [kWh/L]	Generator Run Time [Hours]
Gen + Inv	90.3	36	2.5	9
Gen only	90.3	60.5	1.49	24

Graph 1 Hybrid Vrs Normal running totals

From the graph we can see that a typical generator consumes 24.5 Litres more and operates 16hrs longer. Depending upon the demand curve, these times and fuel consumptions can vary. We have just shown a very typical graph that a domestic user would expect during a 24hour period.

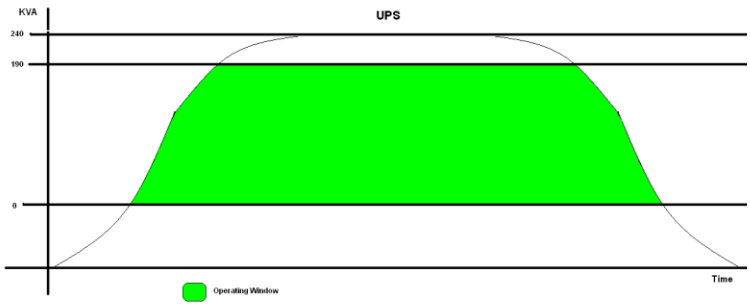
Determining these values has helped to benchmark them against RIIO-ED1. We are looking at minimum running hours of 16Hrs, a minimum utilisation of 60% at a fuel savings of 24 Litres. This will allow us to breakeven in the overall costs of the additional units. The graph below shows the cost/benefits per year. As these are very simplistic costs benefits, not all cost savings can be attributed.

		Litres Saved												
	2071.68	1	5	8	10	20	25	30	35	40	45	50	55	60
Utilisation	10.0%	£326	£428	£504	£556	£811	£939	£1,067	£1,194	£1,322	£1,450	£1,578	£1,705	£1,833
	15.0%	£338	£492	£607	£683	£1,067	£1,258	£1,450	£1,641	£1,833	£2,025	£2,216	£2,408	£2,600
	20.0%	£651	£856	£1,009	£1,111	£1,622	£1,878	£2,133	£2,389	£2,644	£2,900	£3,155	£3,411	£3,666
	25.0%	£664	£919	£1,111	£1,239	£1,878	£2,197	£2,516	£2,836	£3,155	£3,474	£3,794	£4,113	£4,433
	30.0%	£827	£1,133	£1,363	£1,517	£2,283	£2,666	£3,050	£3,433	£3,816	£4,199	£4,583	£4,966	£5,349
	35.0%	£989	£1,347	£1,615	£1,794	£2,689	£3,136	£3,583	£4,030	£4,477	£4,924	£5,371	£5,818	£6,266
	40.0%	£1,152	£1,561	£1,868	£2,072	£3,094	£3,605	£4,116	£4,627	£5,138	£5,649	£6,160	£6,671	£7,182
	45.0%	£1,315	£1,775	£2,120	£2,350	£3,500	£4,074	£4,649	£5,224	£5,799	£6,374	£6,949	£7,524	£8,099
	50.0%	£1,328	£1,839	£2,222	£2,478	£3,755	£4,394	£5,033	£5,671	£6,310	£6,949	£7,588	£8,226	£8,865
	55.0%	£1,491	£2,053	£2,474	£2,755	£4,161	£4,863	£5,566	£6,268	£6,971	£7,674	£8,376	£9,079	£9,782
	60.0%	£1,653	£2,267	£2,726	£3,033	£4,566	£5,333	£6,099	£6,866	£7,632	£8,399	£9,165	£9,932	£10,698
	65.0%	£1,816	£2,480	£2,979	£3,311	£4,972	£5,802	£6,632	£7,463	£8,293	£9,123	£9,954	£10,784	£11,615
	70.0%	£1,979	£2,694	£3,231	£3,589	£5,377	£6,271	£7,166	£8,060	£8,954	£9,848	£10,743	£11,637	£12,531
	75.0%	£1,992	£2,758	£3,333	£3,716	£5,633	£6,591	£7,549	£8,507	£9,465	£10,423	£11,381	£12,339	£13,298
	80.0%	£2,304	£3,122	£3,735	£4,144	£6,188	£7,210	£8,232	£9,254	£10,276	£11,298	£12,320	£13,342	£14,364
	85.0%	£2,317	£3,186	£3,837	£4,272	£6,444	£7,529	£8,615	£9,701	£10,787	£11,873	£12,959	£14,045	£15,131
	90.0%	£2,480	£3,400	£4,090	£4,550	£6,849	£7,999	£9,149	£10,298	£11,448	£12,598	£13,748	£14,897	£16,047
	95.0%	£2,643	£3,614	£4,342	£4,827	£7,255	£8,468	£9,682	£10,895	£12,109	£13,323	£14,536	£15,750	£16,964
	100.0%	£2,806	£3,828	£4,594	£5,105	£7,660	£8,938	£10,215	£11,493	£12,770	£14,048	£15,325	£16,603	£17,880

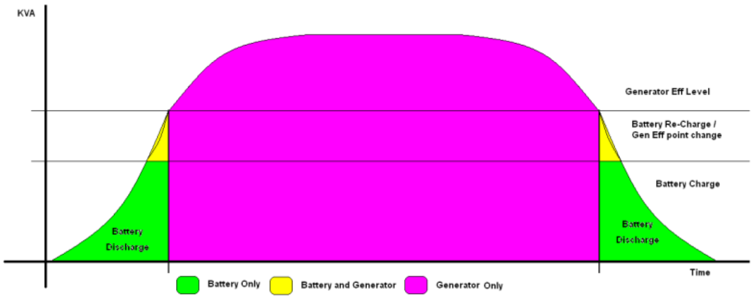
There are additional *Co_2* cost benefits and additional broader measures improvements in any of our customers discomfort from the silent running feature.

The design of the unit is to have a Hybrid 16KVA 240v generator supply a domestic house. The design of the unit has the LV of the 30KVA Generator supplying an LV bus bar. The LV bus bar supplies the input AC supply to the Rectifier/Inverter unit. The Rectifier/Inverter unit connects directly to the battery connection. The Rectifier/Inverter unit converters the DC back to a steady state AC output supply that meets ER G5/4-1.

The steady state supply output helps the unit comply with G54 requirements. The system was tested by establishing test criteria to understand the output information at LV.



The topology of this unit has design limits built in, they have benefits in flexibility switching between the Generator and Battery. This selection allows for the control of the battery being switched in/out at set points on the demand graph. It also helps to switch in/out the battery to help make the efficiency point of the generator more controllable.



This battery currently requires a total of 2hrs to recharge. The efficiency of this battery type inherently has a low internal resistance which helps the re-charge time. It should also be noted as deterioration and number of cycles, this charge time will increase.

By testing at the LV state we were able to identify improvements to the system in running controls to improve efficiency between the controlling of the Generating and Battery operating at optimum times and demand conditions.

The control switching between the Generation and the Battery is depended upon the demand profile and Generator efficiency profile; by optimise this condition we can switch on/off the Generator/Battery.

Economical: The unit to be viable as an alternative power supply; it shouldn't cost more in Whole Life cost than a normal generator.

The unit has been tested at LV to establish criteria in developing a demand load test and comparison between the hybrid unit and a normal generator. By simulating the demand conditions, we are able to benchmark the two types against each other in a controlled natural environment.

The Units have been tested with the following results: Generator only produces 1.45 KwHr and the Hybrid produces 2.5 KwHr. This test has been developed over a common demand profile where both the units have been subjected to 24hr runs.

The Battery load inherently super imposes its demand unto the normal domestic load. This increase in demand by the battery is a good thing, when the generator is running below its efficiency point. The unit has a controllable current charge. This allows for more flexibility in charging the battery and controlling demand the total load subject to the generator.

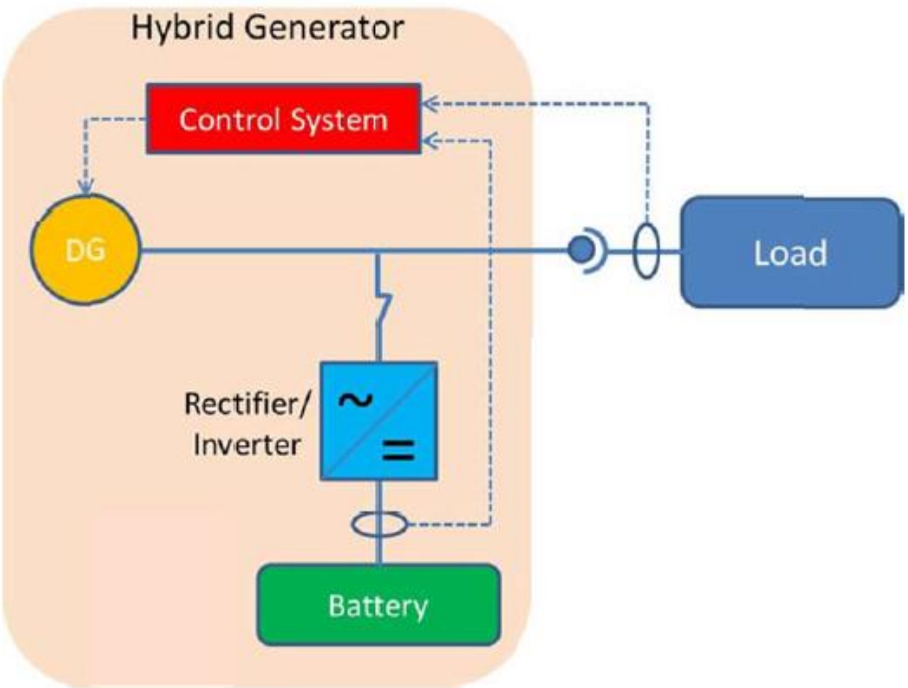
On a typical domestic profile this will see the battery demand and domestic load increase towards the generators efficiency point where the battery load will become a burden and cause the generator to work harder. At this point we would want to off load the battery, but due to its capacity, state of charge and the load, the battery will have limited operating time. By controlling the charging current, this allows for a faster charge time.

4.1 Undertake a study to establish the capability of the generator/battery combination to meet the inrush currents and provide suitable fault clearance capability.

The study to look at the capability of the generator and battery combination with this design technology can be seen in the KWHR output. The balance is needed between demand, generation, state of charge and battery capacity. This balance also has a financial implication and payback.

This system has been designed as a uni-directional connection point. The unit has been designed to connect to a domestic house, just like the normal generators.

From this project we have been able to determine the efficiency of the unit by balancing the discharge time of the battery with the generator efficiency point. The generator efficiency can be improved by increasing the capacity of the battery. By increasing the capacity of the battery this causes an increase in capital expense and therefore increases the payback time.



5 Project outputs

The outputs of this project have been to comply with the ER G5/4-1 .
The University of Strathclyde Power Networks Demonstration Centre Project report.

6 Lessons learned

The lessons learned have been the multiple technologies interacting has a balance between control, capacity of the network, battery type, battery capacity, UPS topology and a financial cost.

6.1 Commercial

For the unit to be commercially viable and have a benefit, it has to compete with a standard single generator being deployed and reduce the amount of fuel consumed. We have covered that the unit does operate efficiently compared to a normal generating unit. The cost of this unit is 2 time the price of a standard generator than therefore the utilisation, co2 savings and fuel saved is the way in which these unit pay for this additional cost.
The suite of generator is sized to provide peak load conditions; this provides the unit operating at 50% load at all operating times. This then allows for the unit to be efficient.

6.2 Environment

The hybrid unit had hoped to reduce the run time of the generator and therefore reduce the $C0_2$ output. This has shown a run time of the battery lasting 16 hrs. The reduction of $C0_2$ can be seen as 24.5 litres of fuel is not burnt in a 24hr period.
The unit running on hybrid mode (23:00-07:00) helps to reduce the decibel noise that would present with a standard generator.

6.3 Financial

The Whole life cost of running a hybrid has to be more efficient than a standard generator supplied. A standard generator against a hybrid generator requires the hybrid to be more efficient to return on investing in the battery and control modules. We can see the normal generator produces 1.5kwhr and the hybrid has shown to produce 2.5kwhr. The total fuel saved through our tested amounts to 25 litres and a reduction of running hours. This then offsets the maintenance cost of the generator. All these factors combine to produce a savings during the amount of times it is used. Current deployment runs at 25% and with RIIO-ED1 plans this is to increase to reduce CI and CML's.

6.4 Legal and regulatory

ER G5/4-1 and G83 complies.

6.5 Management (incl. project management)

The unit in its development did take 3 phases. The Mark 1 had harmonic problems with the 16kv generator assisting the 16kva battery pack combining to make 30kva. Having both the linear and non-linear components combining causes the distortions and failing on harmonist. Mark 2 had a larger alternator and reduces charging current. This passed the harmonics trials but the combination of both units limited the time to deliver 30kva. The mark 3 had the generator to increase to 30kva and a 16kva battery. This allows for high demand periods to have stability and low demand uses the battery to offset in fuel.

6.6 Network

The unit is ready to be deployed into the field.

6.7 Safety

The big difference of this unit is the fact that the output to the network can run in silent mode. Standard generation has an engine running and can been heard. In this situation the hybrid can still be outputting to the network and run silent. Hazards signs and additional guarding may be needed.

6.8 Security

This unit can operate in a silent mode; additional guarding and signage may be required.

6.9 Social

N/A

6.10 Technical

The hybrid unit has been designed to be towed to the current UK licence. This overall product can be designed to suit different needs and style. The software development has been proven and developed.

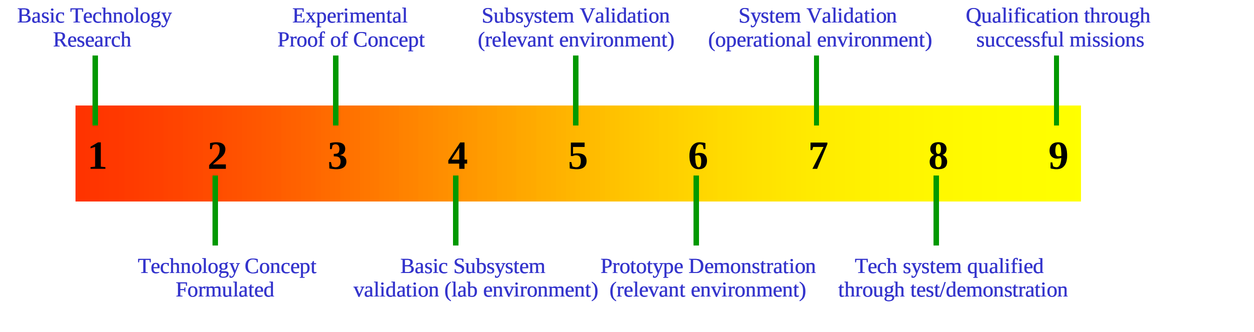
Control: The control function of the unit has been tested and software has been built to operate with the different situations that the unit would meet and optimise its running arrangement to meet the efficiencies required.

Transport: The unit has the transport signs applied for both the road and sea passage.

Change in Technology Readiness Level (TRL)

Please indicate TRL at outset and and end of project

Technology Readiness Levels



1	2	3	4	5	6	7	8	9
						OUTSET	**END**	

7 Project costs

Please complete table, insert rows as necessary. Under each year, enter main expenditure categories.

Internal Project Costs		
Year	**Budget**	**Actual**
2013/14	20000	20000
2014/15	15000	20000
Total	**35000**	**40000**
External Project Costs		
Year	**Budget**	**Actual**
2013/14	95000	95000
2014/15	86000	111000
Total	**181K**	**206K**

7.1 Cost savings/overruns

List source of any discrepancies > +/-10% between budget and actual costs and detail how and why these occurred

8 Potential for transfer to business as usual (BAU)

8.1 BAU conversion assessment (indicate assessment with an X)

Confirmed potential for BAU	X	Confirmed 19/12/14
Unconfirmed potential for BAU		
No potential for BAU		

8.2 Justification of BAU conversion assessment

Explain why the assessment has been made – this should be based on what benefits the project has delivered compared to expected benefits originally claimed as justification for the project in the PID

Business adopting this unit as BAU. Training and roll out to follow.

9 Implications and recommendations for future work

State what the implications of the project are for the business and stakeholders – what needs to be done next? i.e. what steps need to be taken for BAU conversion or further research?

Program to learn domestic pattern and adjust position to optimise its efficiency automatically.