Feed-in Tariffs and Community Aggregated Trading of Microgeneration Sourced Electricity.

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ABSTRACT

A number of countries internationally have now introduced feed-in tariffs where domestic customers are either paid to generate their own electricity or defer import, In this paper, a community based case study is investigated to compare the effects of different pricing approaches on customers. The case study envisages a situation where domestic customers with micro-generators receive a feed in tariff and the community as a whole is free to participate within the regular market clearing process and the spot market. This enables shortfalls in production to be bridged for extended periods of time. A comparison is offered therefore between the per-unit cost of electricity using both approaches.

INTRODUCTION

In the future, the way in which electrical networks are designed and operated will change from the present day status. These changes will be the result of social, societal and technological developments which may be revolutionary or evolutionary. A number of scenarios for the development of electrical networks are presented in *"Electricity network scenarios for the United Kingdom in 2050"* [1]. A revolutionary approach to network management going forward is dividing the network into localised adjacent mini / micro networks known as cells.

The Cell Concept

The cell concept may be considered to be an amalgamation of, and extension upon, the existing entities of smart-grids and micro-grids.

A succinct definition of a smart grid is offered by the European Technology Platform as *"electricity networks that can intelligently integrate the behaviour and actions of all users connected to it - generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies"* [2].

A micro-grid may be considered to be *"a cluster of micro-sources, storage systems and loads which presents itself to the grid as a single entity that can respond to certain control signals"* [3].

The cell concept incorporates both of these entities. Additionally the cell possesses generation at one or more of the three orders of magnitude – micro or domestic, small and large or conventional generation.

Cells may either be competitive or collaborative. Considering first the competitive scenario, this may be considered analogous to national electricity trading, where countries have a large scale interconnector (such as the link between the UK and France). Under such a scenario, cell operators may collaborate if and when it its beneficial to do so, but need not when rewards for doing so are lacking.

Collaborative cells offer a less dramatic step change in energy policy than competitive cells. Under such a scenario, the control of the system would remain global with the control delegated to local level.

Additionally, a key difference between a cell and a micro-grid-smart-grid hybrid is the presence of an energy storage media, which has the potential to allow for many desirable operations such as frequency regulation, voltage regulation and controlled discharging [5].

Feed-In Tariffs

Feed-in tariffs (FIT) allow qualifying generators to receive financial rewards for either avoiding electrical imports or exporting their output. Previously, such generation was treated as spill to the grid and their was typically no remuneration to the producer. The introduction of FITs sees domestic customers incentivised to invest in microgeneration technologies, as the cost can be offset over a number of years of income.

An alternative approach for the selling of electricity to the grid would be for a community aggregation scheme to be formed, whereby a number of customers possessing micro-generation technology act together in order to strengthen their market position. Aggregation of generation is something that is visible in electricity markets. The wide spread deployment of energy storage media, such as electric vehicles and associated batteries, elevates an aggregate of micro-generation into a stronger position within the market.

Electrical storage media allows the aggregate controller to participate in two desirable avenues. Firstly, the option to either sell the energy at the current price offering or store the energy until a better price is offered is presented. Secondly, as the energy may now be stored the opportunity for participation in forward bilaterial contracts is now created.

FITs are a collection of schemes, present in many nations globally, including the UK and most of continental Europe, whereby a small or micro-scale generator receives a guaranteed price per kWh generated.

Feed-in legislation was initially conceived as a driver to reduce the subsidies awarded to conventional fossil fuel based generation technologies, which in 2006 was

estimated to be in the range of US $100-200 million [4]. Due to the legal complexity of reducing these subsidies, FITs have effectively increased the level of subsidisation awarded to renewable energy technologies rather than reducing the funding received by conventional generators [4].
The UK introduced feed-in tariffs through The Energy Act 2008. This system is similar to many contemporary schemes worldwide and provides a renewable based generator with 13p per kWh of **avoided import**. This allows the generator to consume the energy they have generated, whilst still receiving remuneration for this. Additionally, 3p per kWh is received for any energy exported back to the grid, incentivising the participation of domestic and other small scale generators.

Community Aggregation Electricity Sales

Community aggregation schemes (CA) are schemes by which multiple micro-generators act as a singular body in preference to acting individually. By acting as a single entity, the opportunity exists for the aggregator to be set-up as a low cost generator, providing either a constant output or being deployed exclusively during peak demand periods to negate the necessity for more expensive plant to be switched on during these times – thus reducing the market clearing price (MCP) paid.

COST COMPARISON

In order to compare the per unit cost of electricity using UK FITs and CA methodologies, a 5 bus test cell was established, characterised by Figure 1 and Tables 1 and 2. Although smaller than the *"many sources, many loads"*, of the cell, the model shown in Figure 1 enables transparency of results and aids understanding.

Consequently, the 5-Bus Test Cell has 4 conventional generators, situated at bus 1, and only one aggregator situated at bus 2. Branches connecting each bus are sufficiently capacious that constraints caused by network congestion need not be considered. In Figure 1 A2 at bus B2 represents both the aggregator during the CA analysis and the location of recipients of the feed-in tariff, which for simplicity has been aggregated and considered to a single negative load fixed at one point.

The value of the aggregator / negative load is variable from 0 to 1 % of the peak load at the host bus, and as such is representative of an imminently feasible community based renewable energy scheme.

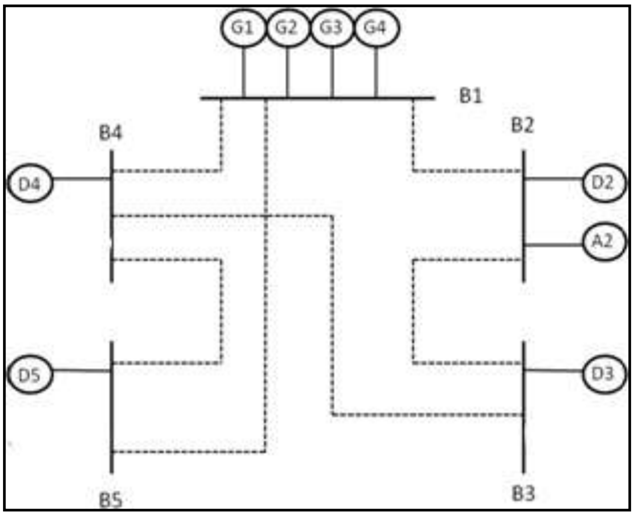

Figure 1 - 5 Bus Test Cell.

Table 1 - Daily Demand Profiles For Each Bus.

Hour	D2 (MW)	D3 (MW)	D4 (MW)	D5 (MW)
0	**300**	500	250	250
1	**276.8**	500	230.66	230.66
2	**261.47**	500	217.89	217.89
3	**253.73**	500	211.44	211.44
4	**246.13**	500	205.11	205.11
5	**249.93**	500	208.28	208.28
6	**253.73**	500	211.44	211.4
7	**269.2**	500	244.33	244.33
8	**307.6**	500	256.33	256.33
9	**338.4**	500	282	282
10	**346.13**	500	288.44	288.44
11	**349.93**	500	291.61	291.61
12	**346.13**	500	288.44	288.44
13	**338.4**	500	282	282
14	**334.6**	500	278.83	278.83
15	**334**	500	278.83	278.83
16	**349.93**	500	291.61	291.61
17	**384.53**	500	320.44	320.44
18	**369.2**	500	307.67	307.67
19	**365.26**	500	304.39	304.39
20	**361.47**	500	301.22	301.22
21	**353.73**	500	294.78	294.78
22	**334.6**	500	278.83	278.83
23	**311.53**	500	259.61	259.61

Table 2 - Generator Data.

GenID	F (£/h)	A (£/MWh)	B (£/MWh^2)	C_{MAX} (MW)
G1	4.0	8.0	0.005	625
G2	4.0	8.0	0.005	625
G3	3.32	27.34	0.006	600
G4	3.32	27.34	0.006	600
A2	4.0	4.0	0.01	Variable

Simulation Approach

Simulations for this work were performed using the AMES software package developed by the University of Iowa. This software offers an agent-based modelling capability of participants within an electricity market. [6]
In order to make use of the learning capacity that each agent possesses simulations may be run over a number of days, thus allowing each agent to submit its best available strategy, learnt over a number of consecutive days. For this work, a period of 50 day was simulated to establish the results taken from the final day's simulation.
For the analysis of the CA method, a cheap generator occupying a prominent position within the economic dispatch portfolio is included. The maximum output capacity of this generator is variable between 0 and 1 % of the peak demand at the bus in steps of 0.1 %.Only operation costs are considered within this study.

Feed-In Tariffs

In order to obtain a per-unit cost of electricity using the feed-in tariff scheme, the following simulation methodology was employed. Levels of qualifying FIT generation technologies with output corresponding to 0 to 1 % of peak demand at the host bus were considered in 0.1 % steps. At each of these steps, a cost per unit price of electricity was calculated in accordance with equation 1 and table 3 with the FIT paying 0 to 200 % of the market clearing price (*MCP*) in 10 % steps. The cost per kWh using FIT remuneration is given mathematically by

$$C = \frac{(D \times MCP) + (IA \times \%MCP)}{D + IA} \quad (1)$$

Table 3 - Costs parameters

Symbol	Meaning	Units
C	Cost	p/kWh
D	Demand at bus	kWh
IA	Import Avoided	kWh
%MCP	% of MCP	p/kWh

RESULTS

A number of interesting results were observed from the simulations. Firstly, introducing an amount of FIT qualifying generation into a cell with a small number of large traditional generators has the power to influence the overall cell wide price, albeit the increases observed were in the sub 0.1% range.
Secondly, if the recompense associated with FITs is negated, or if the price paid each to each FIT qualifying generator is zero, the cell wide MCP is lower than for the corresponding level of CA generation sold on the free market as shown in Figure 2.
While having zero recompense for domestic and other micro-generation schemes is technologically feasible, having no incentive to purchase expensive domestic generation equipment would greatly decrease the levels of uptake of such schemes.

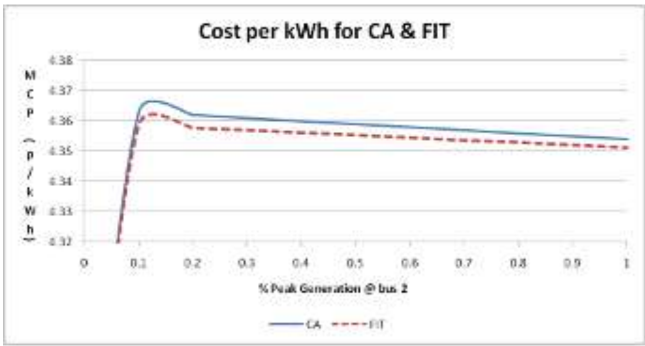

Figure 2 - Cost comparison without FIT recompense.

Key to the successful wide-spread endorsement of FIT schemes is the financial rewards that make them attractive. For each level of peak generation percentage at bus 2, 20 different levels of FIT recompense were considered ranging from 0 to 200 % of the MCP in 10 % steps, in accordance with equation 1. This data was compared against the corresponding values offered by the CA scheme and curves plotted for each.
From these curves, the equilibrium points where the cost per unit equals the MCP experienced using the CA scheme were calculated. As may be noted from Figure 3, increasing the amount of FIT qualifying generation reduces the percentage of MCP that may be paid to each FIT qualifying generator before the MCP is more expensive.
If such a premium is paid for FIT qualifying generation then the FIT scheme will very quickly become less financially viable that CA schemes of equal capacity.

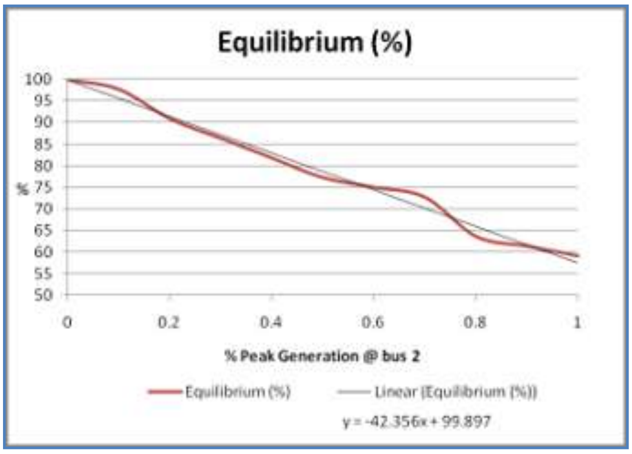

Figure 3 **- Cost equilibrium points.**

DISCUSSIONS

As shown in Figure 2, adding "small participants" to the generation portfolio has actually increased the overall cost of electricity. This is before any recompense is paid for the FIT schemes or before any capital costs are considered.

This highlights that current market operations at the wholesale level may not be well suited to being downscaled into a cell and in fact may not fit congruously with a portfolio containing large numbers of smaller generators rather than the traditional model of having fewer large generators.

Additionally, the boundaries and contents of a cell must be considered carefully. Adjacent cells need not be equivalent, given that nearly every country in the world has geographically diverse regions – urban, suburban & rural to name three – then it seems absurd to adopt a "*one size fits all*" approach to the sizing and contents of a cell.

At present, the cell is a concept and while in theory, it possesses the potential to achieve a number of desirable outcomes such as allowing for *"multiple sources-multiple loads"* to become the new electrical network paradigm. In order to achieve this vision, a number of key design issues need to be decided upon as soon as possible, for example:

Cell Size

At present, the cell as consider here is simply a scaled down version of a national electricity delivery network, with a few additional desirable features included. The scaling of the cell will greatly influence the design of electrical power markets within. For example, a typical domestic street could be a cell – with no traditional generation, or a whole city could be a cell – with many traditional generators. The end result is two very distinct cells requiring different approaches to their management.

Cell Boundaries

The situation of boundaries will greatly impact upon the characteristics of a cell from a markets perspective. For example, a rural cell could appear completely different electrically and economically, if a large wind-farm is situated within its borders, rather than outwith.

CONCLUSIONS & FUTURE WORK

Community aggregation schemes offer a viable alternative to each individual domestic/micro-generator within a cell receiving remuneration through FIT schemes, and in operational expenses alone, may be cheaper than the FIT method.

FIT schemes, if widely adopted, may prove to be very expensive. The ultimate goal of FITs is mitigating carbon emissions, to which economic viability will be subservient. Markets and schemes that have been configured for use on a nationwide level require at best refinement, and possibly a complete reassessment of their suitability to operate at the cell level. As such, much scope exists for future study in regard of market design.

The cost of deploying large amounts of micro-generation and energy storage media could be considered in future studies.

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