ASSESSMENT OF THE AFFECT OF DIFFERENT ENERGY MIXES ON HIGHLY DISTRIBUTED LOCAL ENERGY NETWORKS

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ABSTRACT

With a strong focus on achieving a sustainable and reliable energy network, the future of the UK energy system can perhaps lie with a flexible, decentralised network. The energy system will be expected to deliver sustainability and security through the widespread use of distributed energy resources (DERs), thereby contributing to the national and international ambition of a low carbon future.

This paper will present the method of Energy Hubs for the modelling of a decentralised energy network and subsequent optimisation of costs and use of technologies. Different scenarios will be presented, with the results demonstrating what the effects are of different energy mixes at the low voltage level. This setting will also utilise the Supergen Highly Distributed energy Future (HiDEF) 'Cell concept' and combine it with the energy hub ideology. Applying this combined model to represent a decentralised energy network will demonstrate higher degrees of control within the system that are required and enable the investigation of the effects of different energy mixes in the future.

INTRODUCTION

The future of the UK energy system as a highly decentralised network is an idea that is fast gaining momentum in research. Such a topology will enable the system to function as a sustainable and reliable energy network. The power system will be expected to deliver these assurances through the widespread use of DERs, thereby contributing to the national and international ambition of a low carbon future.

It is anticipated that changes in behaviour with regards to energy use (e.g. driven by smart meters) and through the widespread deployment of small scale distributed generation the nature of the electrical system will change. One approach to the management of this will be to consider the power (and energy) system(s) in smaller parts, leading to the concept of smart grids [1]. Within the HiDEF project a 'Cell' concept [2] has been formulated that segregates the energy system into a number of elements to form smaller 'local' decentralised energy networks, where each cell has its own demand, generation, network and storage. The advantage being that once cells are established, the control problem surrounding DER integration is greatly reduced.

A specific aspect of HiDEF is to model energy systems to maximise the benefits of decentralised energy. It is this topic that provides the impetus for this paper and associated ongoing research. Thusly, this paper presents a model of the UK energy network that challenges the current 'fit-and-forget' approach that currently exists with the integration of DERs, as the current top-down topology does not facilitate and maximize the benefits of bidirectional power flows that DERs create. This paper does so by recognising the obtainable benefits that distributed generation can bestow upon the power system. Recent research in the area of DER integration has developed the method of energy hubs to formally model flows within an energy network. Energy hubs are able to deal with multiple energy carriers and the nature of this concept allows the network to be represented in a modular construction that could align well with the 'Cell concept'. The subsequent optimisation of energy systems through the placement of DERs within a 'cell' is also achievable using this method.

RELATED WORK

There is a large area of research focussed around the concept of energy hubs. Andersson et al [3][4] examined the energy hub as a means of considering the combination of electricity and other energy carriers in a power system. This work also investigated how newer technologies such as fuel cells could be taken into account. Hemmes [5] also looked at the energy hub, expanding the methodology by focussing on by-products and how the concept of trigeneration systems could be integrated into larger power systems. This led to the development of multi-source multi-product systems that this paper will build upon; a multi-source multi-product system being one with multiple inputs / energy carriers and multiple outputs.

Similarly, distributed energy resources have been a key research focal point; in particular exploration into how they may be integrated into the current network. [6] is a comprehensive study on the costs and benefits that may arise from the use of distributed resources. Furthermore, in work carried out by Alarcon-Rodriguez et al [7], the optimal placement of DERs within the distribution network was studied, along with attempts at characterising the advantages and disadvantages of using such distributed generation. Similarly, [8] all investigate approaches for optimising the size and placement of distributed generation within the distribution network.

CELL CONCEPT

The HiDEF [9] cell concept was developed to help compartmentalise the energy network as a means of analysing and mitigating network connection constraints on local generation. The segregation of the network into cells diminishes the control problem faced when installing high levels of DERs. This is because by utilising the resources within the cells, they can perform management tasks and provide services. A cell is an area of the network containing a number of DERs which can be manipulated according to specified objectives. Objectives are classified as having either internal or external scope. An objective with internal scope may be internal constraint mitigation; that being the guarantee of good voltage regulation or evasion of thermal constraints, ensure. An objective considered to have external scope would be to provide adequate support for system frequency through controlling net generation export and net demand.

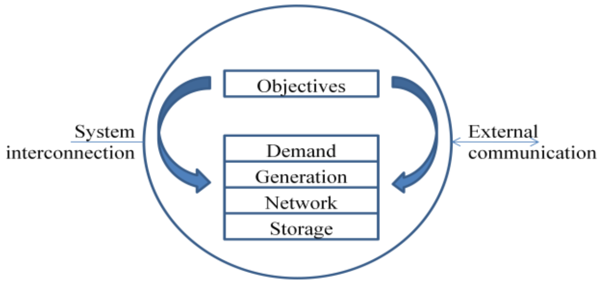

Figure 1: Fundamental interactions within a cell

The demarcation of cells is based on the network structure and each cell is expected to contain a mixture of DERs and technologies. As such, cells can be formed at different system levels, broadly speaking at the low, medium and high voltages of the electrical network. Cells are hierarchical and the size of them can vary, depending upon the scale of constraints and objectives, with a number of smaller cells able to be grouped together to form a larger cell. It is this flexibility within the model that makes the cell concept unique.

METHOD

Energy Hubs

In this work the decentralised energy system will be modelled through the use of energy hubs, originally developed by Andersson and Geidl [3][4]. Energy hubs act as a 'black box', grouping together components within a small section of the network. Each of these sections will contain a certain mix of micro-generation technologies, such as micro-CHP, solar photovoltaic panels and wind turbines. Wind turbines in particular will need to be used extensively in order for the country to meet government renewable energy targets and therefore it is important to incorporate wind energy into the hub model. An extension of this basic hub is to include storage capabilities. Electric vehicles are envisaged to form part of the make-up of future electrical systems as both loads and potential storage devices. As such, it is important to consider their storage potential within the model. The inputs to an energy hub consist of different energy carriers (electricity, natural gas, wind etc.). The hub model then takes these inputs and performs a series of conversions by utilising the components inside, to meet certain levels of output. Thus, energy hubs present two problems that need to be solved; optimising flow between hubs and optimising the configuration within the hub itself.

The inputs and outputs of a single hub are grouped together to become vectors P and L respectively. A coupling matrix C is performed on each of the inputs P to give the desired outputs. The coupling matrix consists of coupling factors, determined by converter efficiencies and hub topologies. A single energy carrier within the hub is therefore modelled thusly

$$[L] = [C][P] \tag{1}$$

It is, as previously mentioned, important to incorporate storage into the model. As this model progresses storage will be incorporated however, at this time, it has not been taken into consideration.

Hub Network Model

The general methodology behind energy hubs as described in the previous section is utilised to form the model for this research. The current energy hub model is a three hub model as shown in Figure 2.

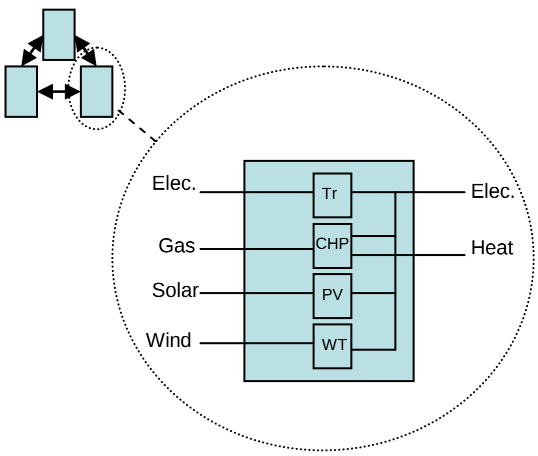

Figure 2: depiction of network and individual hub

Each of the hubs consists of an electricity transformer and technologies for micro-generation, namely micro-CHP, PV solar panels, and a micro-wind turbine. The previous section detailed that energy hubs present two distinct optimisation problems – optimal power flow between hubs and optimal layout of technologies within a hub. This particular application involves finding the optimal use of existing technologies to find the minimum cost for generating the demand level present within a hub. Currently storage capabilities have not been taken into consideration.

$$\min f(x) = \sum_{i=1}^{n} Ct.x_i \quad (2)$$

$$s.t. \quad C_p x - D = 0 \quad (2a)$$

$$Ax - D(1\text{-}R) \leq 0 \quad (2b)$$

Where

$\mathbf{x_i}$ is the i^{th} energy carrier
$\mathbf{Ct_i}$ is the cost of the i^{th} energy carriers
$\mathbf{C_p}$ is the coupling matrix
D is demand
A signifies non-renewable energy carriers
R is the minimum percentage of renewable energy.

The model minimises the cost of generation based on specific technologies and costs. In each hub, if there is not enough potential supply to meet demand, the model assesses if there is enough supply across the network to meet this shortfall. If so, the energy is transported from one hub to another at an augmented cost. If supply is insufficient across the whole network, the model will cut demand until supply and demand can be balanced. This process is depicted in Figure 3. Demand has been prioritised as follows, with priority number 6 being the first to be cut should this be necessary:

1. Cold appliances
2. Wet appliances
3. Lighting
4. Cooking appliances
5. Consumer electronics
6. Domestic ICT

Built into the model is a minimum percentage requirement for renewable technologies to ensure renewable energy targets can be met.

SCENARIOS – POSSIBLE FUTURES

The Department for the Environment and Climate Change (DECC) has developed a series of pathways for the UK energy network to take in the future [10]. The output from which is predicted demand and supply over the time frame of 2010 to 2050. The four general futures have been adopted in this research
The pathway analysis looks at all demand and supply across a series of sub-sections. As this research focuses on the low voltage level network, i.e. domestic energy use and micro-generation, the following aspects of the analysis have been considered.

- Domestic heat supplied with electricity
- Dominant non-electric heat source

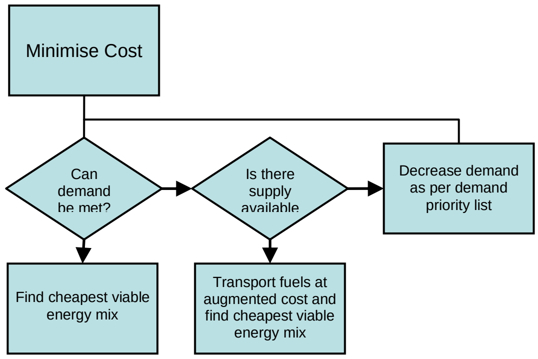

Figure 3: representation of model functionality

- Energy demand for domestic lights and appliances
- Energy use for domestic cooking
- Distributed solar photovoltaic panels
- Micro-wind

The four scenarios for this research are categorised by four 'levels of effort' as prescribed by the DECC. Scenario 1 represents no change in recent trends, i.e. this scenario acts as a 'business as usual' control case study, Scenario 2 represents a little effort across all sectors that is highly achievable in working towards a low carbon future, Scenario 3 requires significant change in attitudes and effort and finally, Scenario 4 represents a heroic effort and change in attitude.

The initial scenarios to be studied are outlined in Table 1.

EXPECTED RESULTS

With the ever increasing inclusion of highly decentralised renewable technologies it is no longer possible to ignore the impact that they have on the energy network. It is essential to understand the issues that will arise in order to retain a reliable and secure network in the future.
Using energy hubs as a means of modelling cells will provide the necessary analytical tool for the assessment of different energy mixes on highly distributed local energy networks. The scenarios present a broad spectrum of possible futures, which, combined with energy hub methodology, present the opportunity to accommodate any renewable technologies and accurately assess the impact the chosen scenario has on total costs.
The cell methodology discussed in this paper will provide optimal levels for the integration of renewable micro generation into the UK energy network.

	Level 1	**Level 2**	**Level 3**	**Level 4**
Demand	*20%*	*Stable*	*-40%*	*-60%*
Demand mix				
Heating	*10% electric*	*20% electric*	*50% electric*	*90% electric*
Cooking	*63% electric*	*100% electric*	*100% electric*	*100% electric*
Solar PV	*Negligible*	*4m^2/person*	*5.4m^2/person*	*9.5m^2/person*
Micro-wind	*Negligible*	*40% of homes*	*All homes*	*All homes*
Micro-CHP	*Negligible*	*20% of homes*	*46& of homes*	*60% of homes*

Table 1: table of possible futures

CONCLUSION AND FURTHER WORK

This paper has outlined a method by which a decentralised energy system can be modelled. It has described that energy hubs are an appropriate modelling method to represent cells and how they can be manipulated to replicate the flexibility within them. Although the concept of energy hubs has been researched previously, it is a novel approach for modelling cells within the energy network.

Using such an approach to analyse the impact of different energy mixes will lead to a greater understanding of how the network will behave in the future. With ambitious government targets for increased renewable generation and reduced carbon emissions, the importance of microgeneration cannot be overlooked. It is only by modelling the network at the low voltage level that the characteristics of small scale supply and demand can be represented accurately. It is imperative that the implications of changing the generation mix in the network are fully understood and this analysis will provide greater insight into how costs will be affected by such a change in generation. In addition to costs, such a model is able to include further technical constraints such as voltage and thermal regulations, and line losses.

Storage, in the form of electric vehicles, fuel cells and so on, will also provide a pivotal role in assessing the affect of different energy mixes and help to maximise to potential of unpredictable energy sources such as wind and solar energy.

REFERENCES

[1] N Jenkins, “The Smart Grid Concept”, Smart Grids Symposium, Glasgow, April 2010. Available at http://www.supergen-hidef.org/content/sites/supergen-hidef.org/files/The%20Smart%20Grid%20Concept%20-%20Nick%20Jenkins.pdf

[2] Supergen III: Highly Distributed Power Systems, “System Level Concept Definition”, November 2008

[3] M Geidl, G Koeppel, P Favre-Perrod, B Klöckl, G Andersson, K Fröhlich, “The Energy Hub – A Powerful Concept for Future Energy Systems”, Third Annual Carnegie Mellon Conference on the Electricity Industry, March 2007

[4] M Geidl, G Andersson, “A Modelling and Optimization Approach for Multiple Energy Carrier Power Flow”, in Proc. IEEE Power Eng. Soc. PowerTech, St. Petersburg, 2005, Russian Federation

[5] K Hemmes, “Towards multi-source multi-product energy systems”in Proc. 2nd Eur. Hydrogen Energy Conf., Zaragoza, Spain, 2005

[6] DTI, Meeting the Energy Challenge, “A White Paper on Energy”, London: Department of Trade and Industry, May 2007. Available at http://www.reckon.co.uk/item/85c7aef5

[7] Alarcon-Rodriguez, A.; Haesen, E.; Ault, G.; Driesen, J.; Belmans, R.; , "Multi-objective planning framework for stochastic and controllable distributed energy resources," Renewable Power Generation, IET , vol.3, no.2, pp.227-238, June 2009

[8] Arturo Alarcon-Rodriguez, Graham Ault, Stuart Galloway, Multi-objective planning of distributed energy resources: A review of the state-of-the-art, Renewable and Sustainable Energy Reviews, Volume 14, Issue 5, June 2010, Pages 1353-1366

[9] Supergen HiDEF Website, www.supergen-hidef.org

[10] Department for the Environment and Climate Change, “2050 Pathways Analysis”. Available at http://www.decc.gov.uk/assets/decc/What%20we%20do/A%20low%20carbon%20UK/2050/216-2050-pathways-analysis-report.pdf