ENGAGING FARM CUSTOMERS IN ACTIVE NETWORK MANAGEMENT

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ABSTRACT

The farming sector as a whole is a major customer group for electricity networks, as well as a major emitter of greenhouse gases. Moving the farming sector towards a low carbon future is a high priority. New technologies including anaerobic digestion (AD), wind and PV generation can facilitate this transition. These technologies have implications for the design and operation of the on-farm electrical network and its connection to the grid. For the farmer, a key issue can be the limitation caused by single phase supply. For the distribution network operator, problems can be caused by the connection of new kinds of loads and generation onto weak rural networks with consequent pressure on thermal ratings, voltage constraints and fault current limits.

Possible solutions to these electrical problems include installing a back-to-back converter, electrical energy storage, and demand side response. A case study is presented based on an actual farm in NE England where these solutions, together with on-farm electrical and heating microgrids and an associated control system, are being implemented.

INTRODUCTION: FARM ENERGY

In nations across the globe, the agricultural sector is a significant consumer and producer of energy. Equally significant is its contribution to potential climate change, as a major producer of greenhouse gases (GHG). This is largely because the GHG produced in agriculture includes large quantities of methane and nitrous oxide, which are around 25 times and 300 times respectively more potent than carbon dioxide [1]. One Irish study claims that livestock activity is responsible for 18% of total anthropogenic GHG emissions [2], and that the farming sector contributes between 10 and 20 tonnes of GHG per hectare (ha) to the atmosphere. The same study compared two approaches for modelling such emissions, and found that while most was due to enteric fermentation, a significant proportion was attributable to manure storage, spreading on fields, and to synthetic fertilizer production and application. These can be substantially reduced by appropriate technologies including anaerobic digestion (AD), described in the following section.

Because the agricultural sector in many countries tends to be quite conservative, there has perhaps been less emphasis on reducing its contribution to GHG emissions and national energy balances than there has been in other sectors of the economy. This means that there is still considerable scope for such reductions. A US study describes the Farm Energy Analysis tool for crop farming, which concludes that strategies such as no tillage and a legume cover crop could reduce energy use by 37% and GHG emissions by 42% [3]. However, such estimates are subject to considerable uncertainty. One UK study uses Bayesian Networks in two models to incorporate this uncertainty in calculations to derive a cost-benefit analysis of possible solutions [1].

A Canadian study concluded that tractor operations accounted for one third of farm-based CO_2 emissions [4]. A follow-up study by the same authors considered electrical energy use on farms, which accounted for 12% of total farm energy use in 1996, with no increase by 2003, although subsequent farm automation may have increased that proportion. It calculated electricity consumption on dairy farms (114-170 kWh per tonne of milk), and made similar calculations for beef, pigs, poultry, greenhouses and outdoor crops. A farm-based study from Estonia looked in detail at the energy balance for uninsulated dairy sheds, and concluded that total energy output (milk, meat and manure) was around 1.85 times energy input, including electricity, which accounted for 25% of total non-renewable energy input [6]. However, an Italian study looked at the whole food production chain from machine manufacture to supermarket shelves, and concluded that between 5 and 10 units of energy input were required for each unit of food energy output [7]. Energy depletion and climate change are the twin drivers to reduce this ratio, and under the paradigm of ‘turning electricity into food’, it described the Lebanon-based RAMSES electric tractor project, which was of particular interest in that it operated in islanded mode, based on PV generation and storage batteries.

The same study considered other kinds of farm-based renewable electricity production (wind, PV, micro-hydro and animal or plant waste), but concluded that, where there is a reliable grid supply, it will often be more economical to concentrate renewable electricity generation at a larger scale off the farm [7]. This conclusion, however, would seem to depend on financial incentives, including feed-in tariffs (FIT) for renewable generation, which vary considerably both between and within countries. One example of the latter is Canada, where provinces can adopt their own FIT regime. A study of the recently adopted regime in Nova Scotia compared it with USA and European countries, where longer-standing schemes have led to 22 GW of PV generation on barn rooftops within the German agricultural sector, as well as 12% of arable land in Germany being used for energy crops [8]. In Denmark, 64% of installed wind turbines are owned by farmers. The Nova Scotia scheme, while giving higher feed-in rates for smaller installations, does not make them available to single farms, but only to co-operatives. These features illustrate a general result, namely that the effectiveness of incentives such as FITs is a sensitive function of the precise conditions of such incentives.

ANAEROBIC DIGESTORS

One technological innovation which illustrates many of the issues raised in the introduction is anaerobic digestion (AD). This is a way of processing both animal and crop farm wastes, as well as imported material, to produce a digestate which can be used as fertilizer, and biogas which can be converted to heat and electrical energy in a combined heat and power (CHP) plant. The closed nature of an AD considerably reduces GHG emissions from the input materials. ADs can be large, community-based (typically 2 MW) or small on-farm units (typically 100kW).

As with any new technology, there have been a number of initial problems to overcome, including logistic and regulatory complications in sourcing raw materials, lack of confidence in the quality of the resulting digestate, and issues relating to operation and maintenance of the AD. In the UK, only 25% of ADs installed in the 1990s are still operating [9]. The viability of AD installations is highly dependent on the FIT or other incentives available. Another UK-based study surveyed 381 farmers (average farm size 294.3ha, mostly dairying with average herd size 221 cattle, but also beef, sheep, pig and poultry farmers), of whom 40% would consider installing an on-farm AD [10]. This survey found that there were legal, technical and economic obstacles to adopting AD technology, including high capital cost, low rates of return, obtaining planning permission, and uncertainty about the technology. The conclusion was that there was potential for 3.66 GWh of annual renewable electricity generation from on-farm AD in the UK, but that this figure represented only 0.001% of UK consumption.

A US study found that take-up had been slow, with only 6% of large dairy farms having installed an AD [11]. This study described a cost-benefit model and concluded that the NPV was marginal, and highly dependent on the contract that could be negotiated with the electric power utility. However, another US study based on small dairy farms presented a more attractive business model, based on taking food industry residuals from outside the farm [12]. A Canadian study found that for medium-sized dairy farms, with 33-272 animals, daily biogas production would be between 1.19 and 3.28 m^3 per animal. With a biogas to electricity conversion efficiency of 35%, and a FIT equal to 5 times wholesale energy prices, return on investment of between 15.8% and 19.8% could be expected [13].

A European study of 27 countries (with 1.578 billion tonnes of pig and cattle manure per year) found that Denmark, Sweden, Austria and Germany had the highest take-up of AD technology [14]. In Denmark, these tended to be large community-based plants serving many farms and food industries, whereas other countries had more on-farm units. Benefits were agricultural (nutrient management), environmental (cutting emissions, increasing renewable energy generation, improved water quality, waste reduction) and health (pathogen reduction), quite apart from any economic benefits. Biogas was typically used for heat and electrical energy production in CHP plants, although in Sweden it was also used as a vehicle fuel. A Dutch study on using AD for pig manure in NW Europe concluded that co-digestion with maize silage was needed for energy efficiency [15]. A study comparing AD take up in Australia with the much higher rate in Germany concluded that, even with generous German FITs, the economic case for AD was marginal [16].

A detailed report on AD units installed in the UK repeated many of the previous points, but also instanced a new category, relating to electrical connections to farms [17]. Since this is the focus of the present paper, it is treated in a separate section.

ELECTRICAL NETWORK CONNECTION

Anaerobic Digesters can be operated just on liquid feedstock such as cattle slurry, but more often (and for greater energy production) solid feedstock such as energy crops are added. The cutting up and other pre-processing of this solid feedstock requires sizeable motors, which have to be supplied with 3-phase current. This is not a problem in the Northern European countries where take-up of AD technology has been greatest [14], as there it is normal for all customers to have access to 3-phase electricity supply. However in the UK it is estimated that around 50% of large and medium-sized farms (over 100 ha) are only supplied at single phase [18]. This situation also applies in many countries outside Northern Europe. The difficulty (time, administration and environmental constraints) and high cost of obtaining a 3-phase supply was quoted by many who had installed AD as being one of the greatest obstacles to be overcome [17]. It seems probable that many other farms have not installed AD, or indeed other electric machines driven by 3-phase motors, for this reason. It is perhaps no coincidence that the highest take-up of AD technology has been in precisely those countries where obtaining 3-phase supply is not a problem.

Not only electrical loads are limited by the single phase supply. Electrical generation may also be curtailed. In the UK, regulations concerning PV generation specify the power rating that can be connected per phase. Above the smallest size, wind turbines are manufactured for 3 phase generation, and the same would apply to CHP plant which burns the biogas produced by AD. The ability of farms to generate electrical energy to offset their own consumption, to sell to the grid as an alternative revenue stream, or to attract FITs, is severely limited by single-phase grid connection.

A further consideration is security of electricity supply. Farms are often situated at the end of long electrical circuits, largely on overhead lines, which are vulnerable to interruptions of supply due to weather, asset deterioration, and a range of other causes [19]. Distribution network operators (DNOs), in the UK and elsewhere, are under pressure from national regulators to improve the reliability and quality of supply to their worst-served customers. This concern identifies the DNO as a key stakeholder in farm electrification and electricity supply.

The DNO are concerned not only with security of supply, but also with its quality As farms install high-power electrical equipment such as AD units, loads will increase overall, and will also increasingly fluctuate. As farms also install generation, in particular inherently variable wind and PV renewable generation, some will become net producers of electrical energy at certain times of day. The long, overhead, often low-rated medium voltage feeders supplying these farms will have to carry increased loads, possibly with reversed power flow. This could lead to infringements of thermal ratings, of voltage constraints, and of fault current limits [20]. These non-linear loads on such weak networks could also lead to deterioration of power quality for other customers on the same feeder.

POSSIBLE SOLUTIONS

The traditional solution to the electrical problems described in the previous section is capital investment in electrical infrastructure. For the farm, this would be the provision of a 3 phase supply, involving the construction of possibly several km of new overhead line, at a cost of several £100k, not to mention the time and environmental disruption. For the DNO, increasing loads could require the reinforcement of whole rural networks, at a cost of several million pounds, with even greater delays and disruption. It is worth finding alternative, smarter solutions that can at least postpone, if not altogether replace, such intrusive and costly capital expenditure.

An alternative on-farm solution is to install a back-to-back converter, which can convert single phase incoming supply to a 3 phase supply through an intermediate dc busbar. Such converters are available at ratings up to approximately 15kW, but have to be custom manufactured to order at higher ratings. The custom nature of the converter gives the opportunity for additional functionality including the possibility of reverse power flow, and access to the dc busbar for the connection of PV generation and electrical energy storage (EES).

EES can also form part of the solution. An AD consumes electrical power intermittently, with large motors running for typically 1-2 minutes at a time every hour or so, probably with power factor well below unity. Its rate of biogas production will also vary, both hourly and seasonally. Generation on the farm, whether by biogas-burning CHP or by renewables such as wind or PV, will also be irregular. There is usually a strong financial incentive to consume as much of this generated energy as possible on the farm, rather than selling it to the grid at one time and buying it back a few hours later. EES can achieve this, as well as absorbing or providing peaks of both generation and demand that would otherwise overload the grid. The Customer Led Network Revolution smart grid project shows how EES deep down in electricity networks can spread peaks, enabling reinforcement to be deferred while increasing amounts of smart load and renewable generation [21].

EES can also work well in conjunction with demand side response (DSR) schemes. Where the DNO expects the network to become overloaded at a certain time (this expectation could be informed by weather forecasts, load predictions, or planned outages for maintenance), a request for load reduction or generation curtailment between specified times can be made. More immediately, an unexpected surge in demand can be met by immediate, possibly automatic disconnection of contracted load. Farm customers are particularly suitable for inclusion in DSR schemes because their loads are relatively large and can often be easily deferred (for example, the operation of AD motors for dry materials preparation), and because their location at the end of weak rural feeders makes such curtailment particularly necessary. For the DNO, having DSR schemes in place gives confidence to defer network reinforcement, and the availability of EES makes it more likely that requested DSR will be immediately effective [22]. For the farm, EES means that DSR requests can be obeyed without actually having to curtail load (or to increase it at times of excess generation) immediately.

CASE STUDY

Cockle Park Farm is a fairly typical 262 ha mixed farm located in the North East of England. It has a dairy herd of 180 Holstein Frisian cows, a pig unit of 120 sows, around 800 sheep, greenhouses, and around 150 ha of arable crops. Although a commercial working farm, it is also used for research by Newcastle University, and a number of low carbon initiatives have already been implemented and tested, including biodiesel production and use in vehicles and for electrical energy generation.

In 2010, the first on-farm AD in the region was installed and commissioned. However, because the farm has only single phase power supply, the 3 phase AD was powered by a 3 phase diesel generator, which is not only costly in rental and fuel, but also diminishes its low carbon justification. Connection of 3 phase supply would require 10 km of new overhead or underground circuits, at a cost of several 100k euros. The less costly alternative was to commission and install a 100kVA back-to-back converter as described in the previous section, and this solution has been adopted, as shown in Figure 1, which also shows detail of the on-farm microgrid.

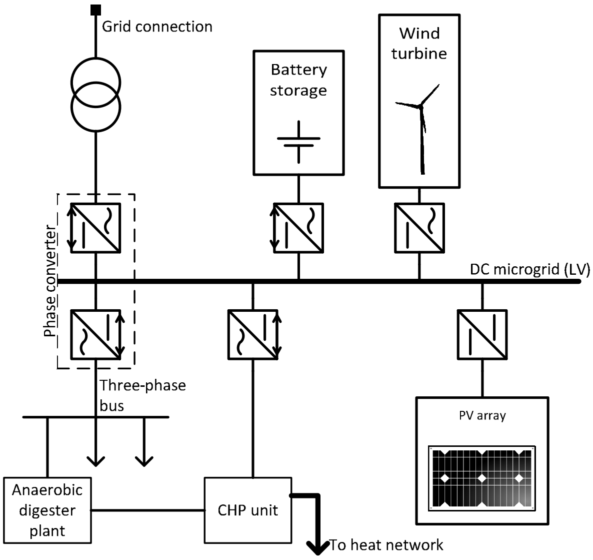

Figure 1 – Schematic of on-farm microgrid

In the longer term, the goal is to move the farm towards becoming a carbon neutral test site, in a way which would be affordable by and transferrable to other farms which are not themselves research establishments. A second goal is to manage the farm's electrical connection in such a way as to benefit the DNO and the surrounding network and its customers, by incorporating an appropriate DSR scheme. Stages in the plan to achieve these goals are as follows:

- The design, installation and operation of a 100kVA back-to-back converter able to accommodate reverse power flows, and with an accessible dc busbar.
- This will enable the AD to operate at full capacity (with seasonal peaks), using mixed solid and liquid feedstock from Cockle Park and from neighbouring farm sources, producing both stored biogas and digestate for use on-farm as a fertiliser.
- Installation and connection to the dc busbar of on site PV generation located on the roofs of existing animal sheds.
- Installation of a biogas-fuelled CHP plant producing both heat and electrical energy for use on-farm and for export to the grid whenever there is a surplus.
- A hot water grid around the farm to make optimal use of CHP-produced heat, displacing the use of diesel oil and electricity for space heating of housing and animal sheds.
- Installation of 100 kWh of EES, connected to the dc busbar, enabling the export of energy which then has to be re-imported a few hours later at much higher cost to be minimized.
- A demand reduction scheme (DSR) implemented in conjunction with the DNO, which will enable the farm load to be managed in response to need to keep within thermal limits and to support voltage constraints on the weak rural 20kV feeder which connects the farm to the grid.
- Installation of electrical smart grids (dc, ac single phase and ac 3 phase) around the farm, together with associated control systems which enable all the above interventions to be balanced safely and effectively so as to minimize farm energy costs (or maximize revenue) and to reduce GG emissions.

CONCLUSIONS

In most countries, the agricultural sector is a major consumer of energy and producer of greenhouse gases. However, it also has the potential to become a significant producer of energy, in particular renewables, and to significantly reduce its rate of greenhouse gas emission by using technologies such as anaerobic digestion (AD). Besides the environmental benefits that such changes would bring, there are also potential economic benefits. For the farmer, the possibility of an alternative revenue stream from energy production and sales could reduce heavy reliance on being part of the supermarket supply chain. There is also the potential for reduced carbon footprint of agricultural produce, which is of importance not only to the farms themselves, but also to their industry and retailer customers. Engaging with the distribution network operator (DNO) could bring further benefits, for the farmer through taking part in a demand side response scheme (DSR), and for the DNO because implementing such a scheme could enable costly capital investment in network reinforcement to be deferred by several years, and possibly avoided altogether.

These principles of active agricultural energy management are illustrated with reference to a case study based on a mixed farm in NE England. Technologies being implemented and used to meet emissions, energy, and economic targets include AD, a back-to-back converter, PV and CHP generation, electrical energy storage, a DSR scheme, and on-farm smart grids with associated control systems. The goal is to make the farm into a carbon neutral test site, in a way which would be affordable by and transferrable to other farms. As this challenging project develops, it is intended to disseminate the results more widely within the Power Systems community.

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