Engineering the GB Electricity System

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Abstract

In order to have an electricity system that provides a secure and sustainable supply at an affordable price is a fundamental national objective. Measures to also reduce CO_2 emissions from the system tend to have a negative effect on the achievement of these objectives. A best practice engineering approach is needed to satisfactorily balance these requirements. The paper explains the need for such an approach, discusses its main features and puts forward ideas about how new arrangements for the Electricity System may be introduced.

Introduction

Between 1926 and 1990 the GB Electricity System[a] was managed by government bodies that were, in general, very effective in providing security of supply at affordable cost. Now it seems that few people are confident that current market arrangements achieve these objectives.

The major additional issue for the System now is to reduce CO_2 emissions. We argue that is that while market competition might in principle at least, keep prices down, it does not address security of supply and will not independently reduce emissions. The UK and the Scottish Governments are imposing requirements on the System to meet objectives for emissions reduction without assessing the true cost of these interventions. Also their electricity planning arrangements do not involve proper assessment for security of supply (see later section on Security of Supply).

The fundamental argument of this paper is that the absence of an engineered system approach to planning for electricity is leading towards a situation where none of the basic objectives of security, sustainability and affordable cost to the consumer will be satisfactorily met.

The Department of Energy and Climate Change (DECC) has produced an Energy Pathways Calculator[1] that can be used to assess the effects of different means of reducing CO_2 emissions. This is used to help people to understand the issues involved, but is not sufficiently robust for providing information to support planning decisions.

[a]The GB Electricity System referred to here comprises the generation plant and transmission facilities that provide electricity in England, Scotland and Wales. It is privately owned but is subject to a degree of government planning.

The Engineered Approach

The GB Electricity System is a large technical entity, and planning for it is, in effect, a re-design or partial re-design of the System. The core objective in engineering design is to reduce the risk of unsatisfactory outcomes to as low a level as practical. For the Electricity System these risks include: electricity blackouts, reductions in CO_2 emissions being less than expected, negative effects on the economy, avoidable cost increases resulting in increased fuel poverty. It should be noted that electricity blackouts caused the US Government to adopt many of its electricity industry reliability measures and to make them statutory requirements.

If strategies for risk reduction are not adopted, then there will be a high likelihood that the system will not be fit for purpose. The consequences of this will be highly detrimental to society.

Techniques used in engineering design include:

- Careful definition of requirements taking account of all relevant issues.
- The consideration of a range of options that may satisfy the requirements.
- Use of predictive models, data analysis and other numerical techniques that allow the potential performance of options to be estimated.
- Adoption of a systems approach including consideration of the effect on the system of changes to its parts. For example the integration costs discussed in Section 4.2 are due to system effects that tend to be ignored. Consideration of the system in the longer term is also a feature of the systems approach.
- Pervasive scrutiny of all inputs and outputs to processes to seek to eliminate faults.
- Collaboration with a wide range of disciplines.

- Careful analysis of the options against the requirements leading to choice of a solution that provides the most suitable balance to the competing requirements.

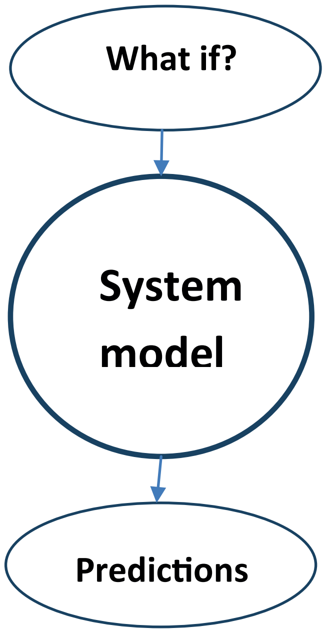

Figure 1 System model

At the core of the methodology is a system model that simulates the behaviour of the generators and transmission system. This would have economic and technical components and would be the engine for assessing the effect of changes to the System - Figure 1. Features of this model are discussed in the section on Government Planning which follows.

The model would also be used as resource in the continuing assessment of the performance of the System - another feature of a properly engineered system.

Government Planning And The Electricity Market

The present situation is that:

1. The potential for the market to deliver its expected outcomes has been greatly weakened by government targets for CO_2 emission reduction and the introduction of subsidised renewable generation.
2. The recent agreement to construct a nuclear power plant involves a guaranteed price to the generator.
3. Competitive arrangements will not ensure that a security of supply standard is satisfied - see section on Security of Supply.

Therefore the competitive nature of the market for GB electricity generation is in decline and the market does not address the very important issue of security of supply. Central planning for the Electricity System is therefore essential. Such planning should seek to control the inherent risks. We assert that it is only by adopting engineering techniques of the type listed in the section on the Engineered Approach that this can be achieved.

System Requirements

Many of the important characteristics of the GB Electricity System can only be understood if it is recognised as a single, large, technical entity. Important whole system features include: the balancing mechanism that allows a deficiency in one part to be counteracted by extra generation from another part, and stability issues.

In planning an electricity supply system, it is essential to address all the issues that will be affected by the planning decisions. The prime engineering and economic requirements are that a fit for purpose system will meet demand at minimum cost. Other issues to be considered include: emissions reduction, reduction in the use of fossil fuels, user requirements (such as charging for electric cars), health and safety, environmental impact, effect on landscape, etc.

Security of Supply

The overarching objective in planning for an electricity system is that the risk of demand not being met is contained. This is best achieved by defining a standard such as: ‘That demand will fail to be met in not more than four winters in 100 years’. The logical approach is to treat the achievement of this standard as non-negotiable, and to calculate the risk on a probability basis. Any proposed mix of generation and transmission devised for the system, must satisfy the standard. Alternative arrangements need to be explored seeking to keep the cost to a minimum and to meet further objectives such as reduction in CO_2 emissions and reduction in dependency on fossil fuel.

No energy market mechanism exists that will independently address security of supply in this way. It also appears that present government planning does not follow such a procedure. We very strongly recommended that assessment of security of supply is based on an agreed probability based standard.

Calculations to assess security of supply need to include the probable availability of plant and of fuel. Methods are available to do this.

Cost

The costs referred to here are those that the generators, transmission owners and distributors need to pay. The prices that customers will pay will be greater than these costs.

In making cost comparisons between the types of plant to be installed on the system, it is essential to include all the costs that are to be borne by the customers by each plant programme. Recently, it has been common practice to calculate a 'levelised cost' for each type of plant, usually based on the costs borne by the generator. Whilst this may be appropriate for the guidance of long-term policy, it has major shortcomings (discussed below) for planning the system to optimise cost. Total System Cost Analysis should be used as the planning tool.

Levelised Cost

The levelised cost of a type of generation is the sum of the discounted costs with regard to time of individual contributions, divided by the energy output also discounted with regard to time. The discount rate used should be the average weighted cost of capital. This gives a cost in £/MWh. The calculations should include all the costs to be borne by the ultimate customer – not just those to be borne by the Generator.

The incorporation of intermittent energy in the system from renewable sources adds costs that are paid for by customers through charges that are levied by the National Grid. They do not appear as an item on energy bills to customers but they have to be paid and should be attributed to the source of generation in levelised cost calculations. These charges are called extra system costs or integration costs. The latter term is used here.

Integration Costs

To provide for a proper cost comparison, the following integration costs need to be included in the levelised cost calculations:

- Cost of extra backup generation: Since wind generation in GB will have a long-term load factor in the range 25-30% compared to that of thermal generation of about 88%, there will be a requirement for 'back-up' generation to make it comparable with thermal plant in its contribution to security of supply. This requirement may be as much as 92MW of extra gas generation for every 100MW of wind generation. The extra capital and fixed operational costs of this generation should be for the account of wind generation.
- Cost of transmission reinforcement needed to connect to the remote sites of renewable generation. Placing increasing generation in the north of the country adds significantly to the need for reinforcement all the way south to the 'centre' of the system north of London. These extra reinforcements would not be required for a programme of only thermal generators distributed throughout GB, so the extra capital costs should logically be charged to wind generation and other remote renewables. Placing generation in the north of the system will add to the existing north to south flow of power resulting in extra losses. The revenue costs of these losses could be significant and should also be charged to wind generation and other remote renewables.
- Cost of System Balancing: Since the levelised cost approach looks only at an individual type of generator it does not consider the interactive effects between generators on the system. Therefore, it does not consider the effect of 'must run' generation such as wind on the load factors of other generators, thus reducing their efficiency and increasing maintenance costs. Also, in an operational timescale, to provide frequency control to accommodate the variability of wind, there will be extra costs for short-term response and reserve facilities. These costs should again be for the account of wind generation.

Levelised Cost Estimates

Studies were carried out in 2011 to estimate levelised costs for various types of plant on a probabilistic basis[2]. Endeavours were made to include estimates of the system integration costs described above. (The costs of transmission losses were not included. These require studies involving considerable computing power and access to large amounts of data not available to us.) The results are summarised in Figure 2.

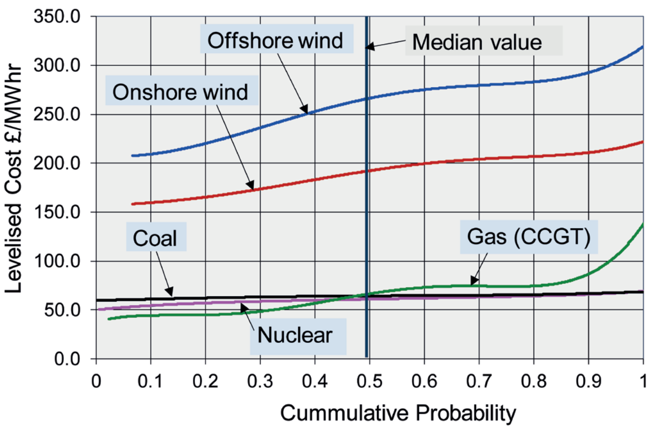

Figure 2 Levelised cost estimates for various type of generation.

The meaning of the values on the horizontal axis on this diagram is as follows. A 0.1 value of cumulative probability means that there is a 10% chance that the corresponding vertical axis value will be less than that given - and, conversely, a 90% chance that the value will be greater than that given. The 0.5 value of cumulative probability is the median value that gives an even chance that it will be greater or smaller than that quoted. The slope of the line is a measure of uncertainty - the steeper the slope the greater the uncertainty.

Figure 3 shows the median values of levelised cost from Figure 2 as a column chart. This diagram also shows the estimations of integration costs for wind generation. These are likely to be low to negligible with low proportions of wind in the system (possibly less than 5%) but as this proportion increases they may increase disproportionately. The values used to calculate the integration costs shown on Figures 2 and 3 were obtained from published sources[3,4] and are based on 28GW of wind on the system (50% onshore, 50% offshore). This corresponds to the Government prediction for 28 GW of renewables in the System in 2020[5].

The values with the integration cost deducted shown on Figure 3 (£112/MWhr for onshore wind and £192/MWhr for offshore wind) are in line with estimates by others[3,4]. No other estimates that include the integration costs for wind in the GB system are known to us so we are unable to make comparisons.

From the values given in in Figures 2 and 3 the following observations can be made:

- Figure 2 shows the levelised cost estimates for nuclear, , CCGT (i.e. gas), and coal being grouped together in the range broadly £50 – 100/MWhr. However, wind generation costs are significantly higher: on-shore being in the range £150 – 220/MWhr; off-shore being in the range £200 – 320/MWhr.
- The value of levelised cost for nuclear (£61/MWhr median) seems low in comparison with the strike price (£92/MWhr) recently negotiated for a new Hinkley Point reactor. The latter is a guaranteed price and not the cost of production averaged over the lifetime of the facility - as is the case for the levelised cost value.
- Despite the high level of uncertainty about the values for integration costs they do not appear to be unrealistic. Lowering the load factor and decreasing the operating efficiency of expensive thermal plant (needed to maintain security of supply etc.) will not come cheap.
- The need for more accurate predictions of cost is evident.

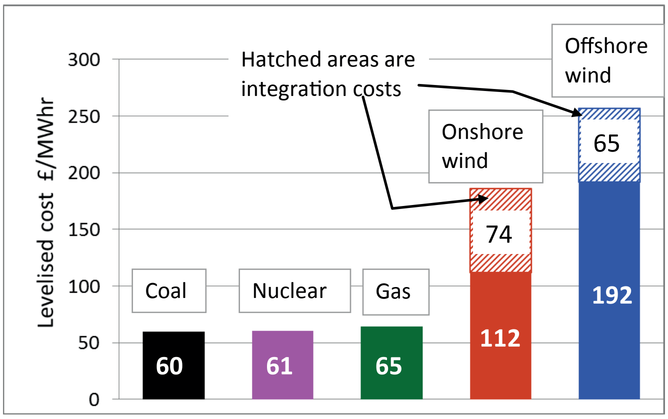

Figure 3 Median values of levelised cost.

Total System Cost

A validation analysis[2] of the levelised costs shown on Figures 2 and 3 makes the following statement: “Because of the limitations of the levelised cost approach and uncertainty about the data, the cost predictions presented will tend to give only broad indication of trends rather than accurate predictions.” The shortcomings of the levelised cost approach can be largely overcome by using a Total System Cost model that makes use of a model of the electricity system discussed in earlier.

All the costs (both capital and revenue) for both generation and transmission that will be paid by customers would therefore be taken into account. Various generation plant programmes (that satisfy the standard of security of supply) can then be compared on the basis of both cost (present valued) and CO_2 emissions. Only when such information is available can Government, industry and the public have a real debate about the efficacy of subsidising particular types of generation in order to satisfy targets for reductions in emissions.

Taking each major item of cost in turn:

- The calculation of generation capital would allow for incidence of expenditure so that Interest During Construction (IDC) is calculated. It would include all de-commissioning costs. The follow-on programme of generation commissioning would be adjusted to ensure that the standard of security of supply would be met.
- Generation revenue – Salaries, Other Works Costs (OWC) and fuel costs. Fuel costs (and usage) are possibly the most difficult items to estimate, and it is suggested that software, similar to that known as GOAL (Generation Optimization and Loading) that was used at the time of the Pool (from privatisation to the introduction of NETA (the New Electricity Trading Arrangement)) be considered for this purpose. This program

was used to minimize the cost of generation on a daily basis taking into account start up costs, loading rates, part load running efficiency and the constraints on load factor caused by the shape of the load demand curve. The program would compute the fossil fuel station running needed to accommodate the intermittent nature of wind generation so as to ensure proper frequency control. The program would need modification to accommodate the stochastic and non-dispatchable nature of wind generation. A levelised cost approach cannot accommodate these features. With wind generation, further checks would be required to ensure that proper voltage control could be exercised, and that the system had sufficient synchronous inertia.

- Transmission capital – For each generation programme, a transmission reinforcement programme would be identified so as to ensure that Transmission Security Standards were not breached.
- Transmission revenue - For each generation programme, the cost of transmission losses would be calculated.

Adding the present value (PV) of all the costs above would allow for the comparison of total system costs of different generation plant programmes. Also, by comparing the amounts of fossil fuels used, the amount of carbon emissions saved by the inclusion of wind and other renewable sources in the system would be estimated.

The studies could be done on a probabilistic basis.

System Emissions

The use of thermal generators to control the Grid to cater for intermittent renewable energy results in reduction in their operating efficiency and hence causes extra carbon dioxide emissions. These are system emissions. In order to assess the efficacy of any mix of generation types it is essential that the system model can predict such emissions.

The Electricity Market

The Present Context

While renewable energy is traded on the market, the payments that generators receive are supplemented via extra payments such as from Renewable Obligations Certificates (ROCs) and Feed-in tariffs (FiFTs). The competitive market for renewables is therefore very weak although new contracts for differences may provide some competition.

A recent agreement to build a nuclear power station at Hinkley Point is based on an agreed price structure for the energy that will be generated. If this is to be the normal strategy for new nuclear then then market competition for nuclear energy will decline.

As the amount of intermittent renewable energy in the system increases, gas and coal plant will require to be either(a) constrained off to allow the renewable generation to take priority in dispatch or (b) brought in at short notice as response or reserve plant The generating companies will find that they cannot run their coal and gas plants profitably and will seek price guarantees. They will also look for guarantees to cover the cost of carbon tax.

We are therefore moving towards a situation where the market in energy will not exist and prices for all types of generation will be guaranteed.

A problem with the electricity market has been that only energy has been traded whereas there is a need also for trading to promote competition for the provision of capacity. The Market Reform Bill recently passed by Parliament seeks to generate such competition. It remains to be seen whether the provisions made will be effective. Promoting competition for the provision of generation capacity may result in an increased level of investment in plant but will not guarantee that the risk to security of supply is acceptable.

Central Tendering And Dispatch

In this section we outline an alternative strategy that would maintain competition but could satisfy a standard of security of supply.

A planning arrangement could be put in place to decide on the new generation plant required to ensure a specified level of security of supply and plant mix. This would be delivered by competitive tender based on both capital and revenue costs, and by including the costs of the necessary transmission plant to ensure that the standards of security for the Transmission System will be met. The generation plant could then be centrally scheduled and dispatched optimally in merit order. With this arrangement, a single corporate body should not hold the licenses for both Generation and Supply.

This solution would require the establishment of a central authority – possibly a Standing Commission of Parliament - which would assess the requirement for new generation plant in future years, and arrange and assess the tender offers. The offers would be assessed using a Total System Cost Analysis. Successful tender offers would be the basis for long-term contracts with indexing for revenue costs such as fuel, materials and salaries on an agreed basis. The essentials of the contracts would be the delivery of energy to the system at an agreed indexed price, and power at a percentage of the installed capacity at times of peak demand to calculate the capacity payment based on tendered capital cost. The delivery of the power at peaks would be obligatory so Generators would have to pay for their own back-up.

With regard to back-up, there is an added complexity for intermittent generation. To ensure that the costs of intermittency are included in the tender offer, the tenders and resultant contracts would be structured such that intermittent generators would, in principle, carry the costs of their own back-up. That said it may be at this point that Government subsidy mechanism does enter into the equation as a result of the debate with industry and the public as previously mentioned. This would allow direct comparison of cost and CO_2 emissions for different plant programmes.

The need for bilateral contracts with the System Operator for ancillary services such as response and reserve, reactive power, 'black start' etc. would continue.

Introducing Engineering Methodology To Electricity Planning

There is an acceptance in the engineering community that a systems engineering approach is needed for planning of the electricity system. For example, an April 2014 report[6] by the Royal Academy of Engineering on Wind Energy stated that: "without careful strategic planning incorporating all these elements as a system, the challenges will not be met" Also The Institution of Engineering and Technology recently issued a report[7] that recommended that "DECC should work with industry to establish a System Architect role to achieve a whole systems approach"

An engineering approach (as is implied by these statements and described in an earlier section of this paper of this paper) should be a standard feature of electricity planning. While a permanently constituted body should be appointed to implement such an approach, the urgency of the present situation leads us to recommend that, in the first instance, an *ad hoc* group be established and charged with the following objective: 'Make recommendations as to what would be the most suitable mix of plant and transmission to contain the latent risks in relation to the development of the GB Electricity System - taking account of all relevant issues'.

Conditions that need to pertain in relation to commissioning of this project include:

1. Those who manage the project must have, as a group, the relevant range of high level competence. A multidisciplinary team needs to be assembled with a core of professional engineers since the problem is dominantly technical.
2. All involved in the project must focus, and be free to focus, on the fundamental objectives.
3. The work must be transparent from a technical and a public perspective. It must be possible for independent checks to be made on the methodology, the data, the implementation, and the conclusions. Those involved should welcome ideas from any source that might help to improve the quality of the outcomes.

Funds should be allocated to the project to allow parties that have special expertise and data to assist with the study.

The results of the project would (a) provide information as to whether or not the electricity market is achieving what it is expected of it and (b) inform the development of government policy for the Electricity System. This statement is particularly applicable to Scotland where the proportion of renewable energy targeted for the electricity system is much higher than in England and Wales.

Conclusion

Planning for an electricity system is fundamentally an engineering problem. Proven methods of controlling the risk to security of supply (i.e. the probability that generation will be unable to meet demand) are available. There exist methods of estimating the cost of different generation mixes that can give more accurate results than those in present use. It is possible to make realistic estimates of CO_2 emissions taking account of all relevant issues.

In the absence of the use of such techniques the risk that planning decisions will prove to be unsatisfactory is unnecessarily high.

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