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Experiences in modelling the performance of generating plant for frequency response studies on the British transmission grid

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Abstract

Significant changes to the generation mix on the British transmission system have occurred in the past 10 years, and this trend is expected to continue in the future with an increase in renewable generation. This change, in conjunction with market changes, has driven the need to establish suitable generator models for thermal plant used in dynamic response studies. These studies are presently used to quantify the dynamic requirement that secures the transmission system against large instantaneous losses of power. This paper provides an account of the experiences gained in modelling the performance of generators based in Great Britain. Established governor models to represent the behaviour of traditional coal and oil fired plant already exist and comments are made on their performance against system incidents. Models of combined cycle units using traditional open cycle gas turbine models have shown poor correspondence with monitored grid data in simulations. A gas and steam turbine governor model to represent combined cycle plant was developed, and is presented, with results from validation trials against recorded test data. Improvements in simulating grid frequency have been demonstrated using the developed models in a full network simulation of a recent generator loss event.

Keywords: Power system control; Dynamic simulation; Frequency reserve; Frequency response; Combined cycle gas turbines; CCGT

1. Introduction

The energy mix of the electricity grid in Great Britain has changed greatly over the last decade, with an increasing proportion of combined cycle gas turbine (CCGT) units now being utilised for ancillary services, such as frequency response. Historically, the provision of frequency response has been dominated by coal fired stations that have proven to be very reliable, but a large number of these units will be retired in the coming decade. With these changes in plant mix and an increase in the proportions of renewable generation expected by 2010 [1], a firm understanding behind the collective dynamic behaviour of generator response is required. The balancing market in Britain has now been liberalised, and there is a growing requirement to optimise the response held on the system in order to reduce the financial impacts of what may become a more volatile market.

Changes in the system frequency of a synchronous AC transmission system are a direct result of the imbalance between the electrical load and the power supplied by system connected generators [2]. Any short-term imbalance of energy will result in an instantaneous change in system frequency as the disturbance is initially offset by the kinetic energy of rotating plant. The power system in Great Britain is linked with Ireland and France through dc interconnectors, these connections do not offer synchronous ties with the external systems. As such, the national grid is operated as an isolated island system and the adequate provision of energy and response at all times is essential to ensure the network is not jeopardised. Significant loss of generating plant without adequate system response can produce extreme frequency excursions outside the working range of plant. This can lead to demand disconnection as the frequency drops below 48.8 Hz and may even cause disconnection of plant if the deviation infringes 47.5–47 Hz, which in an already delicate operating situation may lead to system collapse.

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Deviations from the nominal frequency are managed through scheduling frequency response, this reserve is composed of demand management and dynamic response held on synchronised generators. To schedule the necessary levels of response needed to meet frequency obligations, a frequency response requirement is employed to prevent a breach of limits under large imbalances of power. Studies have shown that the frequency response requirement is influenced by the interactions between the generator performance, the transmission system characteristics and load behaviour [3]. The frequency response requirement is formulated through modelling the performance of these components in simulated loss scenarios. It is essential that these models depict the true dynamic behaviour of plant to establish a frequency response scheme that does not compromise the overall security of the system. This paper highlights the experiences that have been gained through the reconstruction of various system incidents in order to validate a proposed model to calculate the system frequency response requirement.

2. Requirements for frequency response

The transmission system in England, Wales and Scotland is managed by National Grid and this network can experience a national demand that ranges between 20 and 60 GW. As system operator, National Grid performs many tasks during the day-to-day running of the transmission system. Among these tasks the real time balancing of the system is crucial to maintain system frequency at 50 Hz. Under instantaneous gains or losses of power, such as a generating station trips, the system can experience large frequency swings. The British grid must cope with conditions whereby the largest potential dimensioning fault on the system can reach 1320 MW. In order to recover any large imbalance of generation or demand National Grid became a world leader to pioneer a process to calculate, monitor and contract for a reserve held for frequency response [4].

To limit the effect of extreme losses the Transmission System Security and Quality of Supply Standard [5] defines control tolerances that are applied to the network to contain grid frequency. National Grid operates under its own limits of ±0.2 Hz which are imposed on the system under normal operation, and these limits should contain step changes in power up to 300 MW. For a step change in power up to 1 GW, the system frequency is controlled within a deviation of ±0.5 Hz. For significant losses greater than 1000 MW but below 1320 MW the system frequency may drop to 49.2 Hz for no longer than 1 min, before returning to 49.5 Hz.

In order to match the dynamic changes in demand a proportion of this frequency response must be held on spinning units. These synchronised generators are deloaded to provide headroom to operate under governor action. The response may also be partly held by non-dynamic measures, which includes frequency triggered demand management and hydro-generation on frequency sensitive relays. The total frequency response held on the system is optimised every 20 min according to the total network demand and the largest dimensioning fault on the system. This process is significantly different from other network operators [6,7] who can constrain their individual instantaneous disturbance reserves by dividing the requirement between

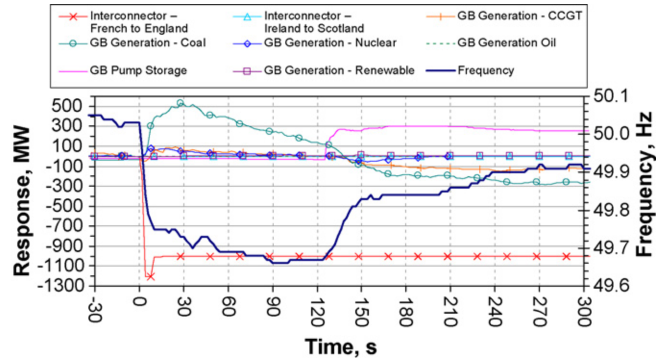

Fig. 1. Frequency response on the GB grid to a 1000 MW bipole trip at a national demand of 42318 MW.

neighbouring interconnected countries. Under these conditions response is commonly establish at a discrete level and not optimised against system conditions as the potential risk is a sustained quantity.

Around seventy percent of the system generators operate as base load plant, with the remaining units providing the frequency response requirement. The concept of a frequency response requirement is complicated by an artificial distinction to define the required system response over two time scales. A primary response requirement is defined to arrest the initial drop in frequency, and is deliverable 10 s after an incident has occurred. This response must be sustained where necessary for a further 20 s. The secondary response requirement is deliverable subsequent to primary time scales and can be required for up to 30 min. The secondary response requirement recovers the frequency to the appropriate limits. To recover the levels of frequency response subject to further incidents, the control room dispatches standing reserve that has been pre-scheduled on warm or fast starting units. Fig. 1 shows a breakdown of system generation following a loss of 1000 MW and the associated delivery of response. The reduction in generating plant output in Fig. 1, even at low frequencies, can be attributed to changes in system loads and some increase in open cycle gas turbine output over the monitored timescales.

Generators that contribute in the balancing mechanism have a portfolio of response contracts that are derived through compliance tests. These contracts quantify the delivery of response expected at set frequency deviations and set load levels over secondary and/or primary time scales. The control room maintains the system frequency response requirement by dispatching balancing units until the sum of contracted primary and secondary response levels equals the optimised response holding level. To ensure the response holding process remains robust supplementary feedback from event monitoring is conducted. This includes in depth analysis of plant performance for all events outside 49.8 or 50.2 Hz for more than 2 min.

3. The frequency response model

Unlike similar techniques used to establish a response requirement [8,9] the method proposed by National Grid involves the utilisation of a full transmission system model