Assessment of Tradable Short-Term Transmission Access Rights to Integrate Renewable Generation

Mohamed Shaaban
Dept. of Electronic and Electrical Engineering
University of Strathclyde, Glasgow, UK
m.shaaban@eee.strath.ac.uk

Keith Bell
Dept. of Electronic and Electrical Engineering
University of Strathclyde, Glasgow, UK
keith.bell@eee.strath.ac.uk

***Abstract*-Current regulatory practices in Great Britain (GB) grant future transmission access rights to constrained transmission areas subject to the completion of the associated transmission network reinforcements. This, however, may introduce substantial delays for generators to have access to the system and is of particular concern for wind farms wanting to connect in the north, remote from the main demand centres in the south. This paper examines the trading of transmission access rights, between conventional generators and new entrant renewables, as a possible short term remedy. An approach, using contingency analysis and sensitivity calculations, is described to determine the best candidate locations for the trading of transmission access rights between different generators. The approach is then implemented on a 250 node model representing a significant part of the GB system and results are elaborated.**

***Index Terms*—transmission development, access rights, integration of renewables.**

I. Introduction

The British government is committed to diversifying its generation mix and to contributing to the European Union's ambitious target of 20% of its energy utilisation from renewable resources by 2020. To foster the deployment of renewable generation across the GB system, a Renewables Obligation (RO) policy has been enacted which requires all licensed electricity suppliers to source a definite, and annually increasing, proportion of their electricity from renewable energy sources [1, 2]. The level is 9.1% in 2008/9 rising to 15.4% by 2015/16. Individual electricity suppliers that have not managed to obtain the required amount of renewable energy on their own must buy Renewable Obligation Certificates (ROCs) from other generators or through auctions to make up the shortfall [2].

As the strategic siting of renewable generation is dictated by the availability of the key environmental conditions required, there is a growing concern that the constrained characteristics exhibited by the transmission network in parts of the GB system may hinder the accommodation of renewables into the system. The standard access arrangements currently grant new generators firm rights for use of the transmission system. However if the new connection entails non-compliance with the security criteria of the system, reinforcement has to be completed first before any access right is granted. While the necessary reinforcements are identified and carried out by the appropriate transmission owner, there is no obligation on the transmission owner or the system operator to abide by any particular time frame for the provision of transmission access [2]. Where reinforcements take time to complete, this has the consequence of postponing the introduction of renewable generation into the system, arguably provides a disincentive to investment in new generation capacity and can be seen as delaying the achievement of the government's committed renewable goals.

This paper discusses a short-term resolution to this problem through the relinquishing of transmission access rights at some location(s) to allow new renewable generators, in another location, to get connected to the system. An approach is presented that enables the determination of the best possible locations to share the access rights between generators.

II. Access Right Arrangements in the GB Transmission System

The transmission system plays a pivotal role in providing non-discriminatory open access to connect physically dispersed supply and demand as well as facilitating the accommodation of new generation regardless of its location. Access to the GB transmission system is granted through contractual arrangements with the GB system operator (GBSO). Each generator has to buy the appropriate transmission access right which reflects the maximum power the generator can export across the GB transmission system away from the connection site [3]. A transmission right is a property right that allows its holder to access a portion of the transmission capacity [4]. In Britain, the volume of such rights must be consistent with the design criteria of the security and quality of supply standard (SQSS) [5].

The main security criterion in the GB SQSS stipulates that all equipment loadings shall not exceed its operating limits following 'N-D' fault outages where N-D signifies the outage of a single transmission circuit or a double circuit. To satisfy the various criteria set out by the SQSS, the GBSO and transmission owners may need to conduct major transmission reinforcements to allow new generation capacity to get connected.

Due to the specific disposition of generation and demand in the GB system, where much of the generation is located towards the northern part whereas the bulk of demand exists in the southern parts, the power flows broadly from north to south. As a consequence, there is insufficient transmission capacity to accommodate all the new generation, mainly wind, that has applied for new rights in Scotland. This has resulted in a number of transmission reinforcements being required to maintain compliance with the SQSS. Because such constraints could result in delaying the connection dates of new generation projects, the GBSO has identified the opportunities to connect new generation without an associated need for major transmission reinforcement as shown in Fig. 1 [3]. Categorised in five groups where 'very low' indicates a constrained network condition that needs major transmission reinforcement before connection whereas 'very high' indicates abundant network transmission capacity, the GBSO endeavours to provide guidance to prospective new projects on the ease of gaining transmission access.

Under current arrangements, new generators apply to the GBSO for firm access rights to the transmission system at a particular location of their choosing. (Firm rights here mean an entitlement to some compensatory payment in the event of a restriction of physical access capability on the transmission system; non-firm rights may also be applied for). However, if a new connection at that location would be non-compliant with the SQSS criteria, the issue is referred to the relevant transmission owner to carry out the necessary transmission reinforcements prior to granting access rights. The GBSO is bound to make an offer to the new connection outlining the required reinforcement and quoting a likely completion date. If major reinforcements are required, this can lead to significant delays to a generator's connection relative to the date it sought, not least because of planning consents issues for the transmission connection works [2].

A number of measures have been proposed to facilitate earlier connection either by providing appropriate market signals regarding the rationing of transmission capacity (through transmission access auctions) or through sharing of capacity via trading of rights in the short term [2]. Such trading might take place between conventional generation and a wind farm with rights being acquired from the conventional generator when wind conditions are good or the conventional generator is on a planned outage, or being returned back to the conventional generator when wind conditions are poor.

This paper is concerned with the last of the above proposed measures and presents an analytical approach that might permit generators holding or seeking rights or the GBSO to identify the most promising access rights transactions.

III. Calculation Approach

The problem at hand can be stated as: find the best possible generator locations(s) to trade their transmission access rights, or at least part of them, on a short-term basis with an entrant renewable generator such that the system N-D security criterion is not compromised.

In most areas of the GB system, DC power flow analysis is usually adequate to investigate this problem as it captures the essence of the underlying structure of active power injection and the associated MW flows in lines and transformers. The DC power flow formulation is [6]

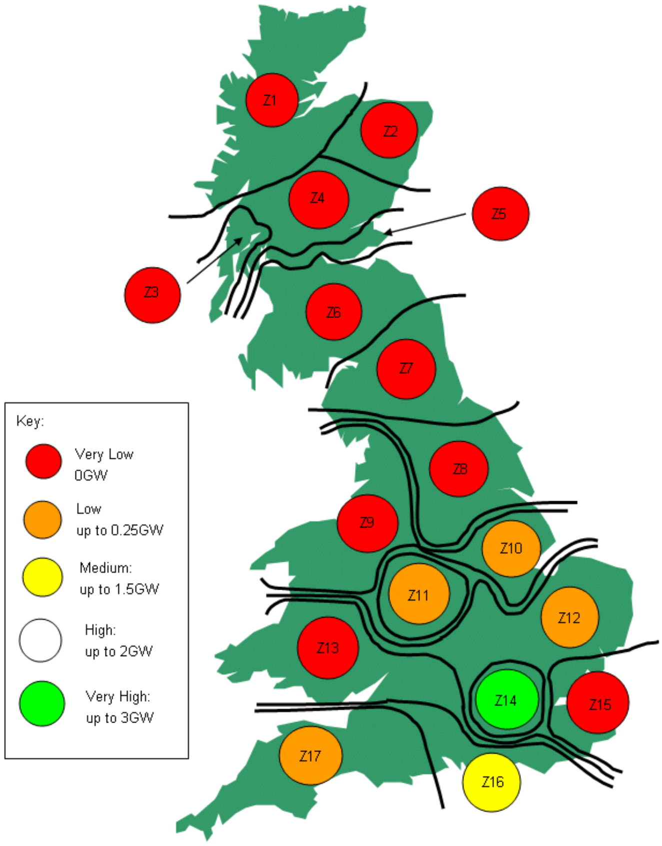

Fig. 1. GB generation connection opportunities [3]

$$\boldsymbol{P} = \boldsymbol{B\theta} \tag{1}$$

where $\boldsymbol{P}$ is the active power injection vector, $\boldsymbol{\theta}$ is the bus voltage angles, and $\boldsymbol{B}$ is given as

$$B_{ij} = -\frac{1}{x_{ij}}, \qquad B_{ii} = \sum_{j \neq i}^{L} \frac{1}{x_{ij}}$$

where x_{ij} is the reactance of line ij and L is the number of network transmission lines. The active power flow in line ij can be expressed as

$$P_{ij} = \frac{1}{x_{ij}}\left(\theta_i - \theta_j\right) \tag{2}$$

Equation (2) can be expressed in a vectorised form as [7]

$$\boldsymbol{P}_L = \boldsymbol{DAXP} \tag{3}$$

where $\boldsymbol{P}_L$ is an $L \times 1$ vector of branch MW flows, $\boldsymbol{D}$ is an $L \times L$ diagonal matrix whose elements are branch susceptances, $\boldsymbol{A}$ is the branch-node incidence matrix, and $\boldsymbol{X}$ is the nodal impedance matrix and is equal to $\boldsymbol{B}^{-1}$. The incidence matrix $\boldsymbol{A}$ is actually mapping the injection domain into the branch MW flow domain, therefore

$$\boldsymbol{P} = \boldsymbol{A}^T \boldsymbol{P}_L \tag{4}$$

Under conditions in which generation and demand are balanced and the network is heavily loaded, we are interested in determining the magnitude of change in line MW flows $\boldsymbol{\Delta P}_L$ with respect to the change in the active power injection vector $\boldsymbol{\Delta P}$. A particular 'generator shift factor' (GSF) can be defined as [6]

$$GSF_i^{mn} = \frac{\Delta P_{mn}}{\Delta P_i} \tag{5}$$

where ΔP_{mn} is incremental change in branch *mn* MW flow, and ΔP_i is the change in bus *i* MW injection (which will be taken up by the renewable entrant generator in this case). A negative *GSF* indicates that a particular injection reduces the flow in line *mn* and vice versa. Indeed generator nodes are the prime interest in applying (5) in this study.

From the above equations, when subject to security constraints, the change in generation dispatch $\boldsymbol{\Delta P}$, often realised by a generation decrease at one location balanced by a generation increase in another location, determines the amount of transmission access right which can be relinquished fully or partly from one generator to a new renewable generator.

To account for the N-D contingency criterion, we employ the same approach used in long-term network planning. The objective here, however, is to find the feasible quasi-optimal power injections into the system under a given contingency configuration, whereas in network planning the focus is to consider options for building new transmission capacity based on different contingency scenarios for a given generation dispatch that is to be accommodated securely [8].

Under a credible contingency condition of an outage of branch *ij*, the new nodal impedance matrix $\boldsymbol{X^n}$ is calculated as

$$\boldsymbol{X^n} = \left[\boldsymbol{B} - \frac{1}{x_{ij}} \boldsymbol{a}_{ij} \boldsymbol{a}_{ij}^T \right]^{-1} \tag{6}$$

where $\boldsymbol{a}_{ij}$ is the transpose of the row corresponding to line *ij* in the incidence matrix $\boldsymbol{A}$. Since matrix inversion can be computationally onerous particularly in the case of practical systems with many cases of credible contingencies, an approximation to the above formula can be used [7]:

$$\boldsymbol{X^n} \approx \boldsymbol{X} + \frac{1}{x_{ij}} \boldsymbol{X} \boldsymbol{a}_{ij} \boldsymbol{a}_{ij}^T \boldsymbol{X} \tag{7}$$

Replacing $\boldsymbol{X}$ by $\boldsymbol{X^n}$ in (3) and removing the susceptance element corresponding to line *ij* from the matrix $\boldsymbol{D}$ would render the same analysis valid for contingency conditions. Assuming constant power injections in both the pre-contingency and post-contingency system conditions, the changes in branch MW flows are attributed exclusively to the change in network topology by

$$\Delta \boldsymbol{P}_L = \boldsymbol{D} \boldsymbol{A} \Delta \boldsymbol{X} \boldsymbol{P} \tag{9}$$

For a given initial dispatch of power (related to the level of demand and the access rights held by generators at each location), the above equations can be used to obtain the set of incremental MW power injections which satisfy the intact system as well as contingency conditions. These injections determine, explicitly, the amount of MW transmission capacity access rights which can be given up at one location of the system to be acquired by the renewable generation at another location without breaching any of the system operating limits including the N-D security criteria. The above transmission access rights can be shared between the two (or more) generation locations on a short-term trading basis. This trading, depending on site merits, could accelerate the incorporation of renewable generation into the system precluding, at least temporarily, the need for transmission upgrades.

IV. Case Study

The approach described has been applied to a case study on the GB network. Zone 14, as shown in Fig. 1, covers central London, a heavily importing zone, whereas zone 15 (called the Thames Estuary) currently has considerable generation and high exports but limited capacity to accommodate more. The developers of a major new 1000 MW offshore wind farm – "London Array" – have applied for connection within the Thames Estuary area in 2010 [3]. Under favourable wind conditions and when other generation in the zone is also operating, the resultant increased export from zone 15 would significantly exceed the nominal boundary capability, particularly under off-peak demand conditions, and would seem to require significant network reinforcement before the "London Array" could be integrated into the network [3]. We postulate the scenario of the network reinforcement not being completed in due time and wish to explore what trading of access rights might permit the "London Array" to nonetheless operate without breach of system security criteria.

In order to demonstrate the main issues associated with accommodation of generation connections in zones 14 and 15, a model of the GB system has been constructed that represents these zones in detail while employing an equivalent for the rest of the system. The resulting model is composed of 250 buses, 54 generators, and 406 transmission lines/transformers with a total load of 14029 MW. The detailed network connection of zones 14 and 15 is depicted in Fig. 2. The red links are for the 275 kV network (mostly inside zone 14 and much of it comprising underground cables) whereas the blue ones are at 400 kV. The encircled dots indicate major generator locations. The "London Array" would be connected in zone 15 at a new substation between Canterbury North and Kemsley. It is required to find the

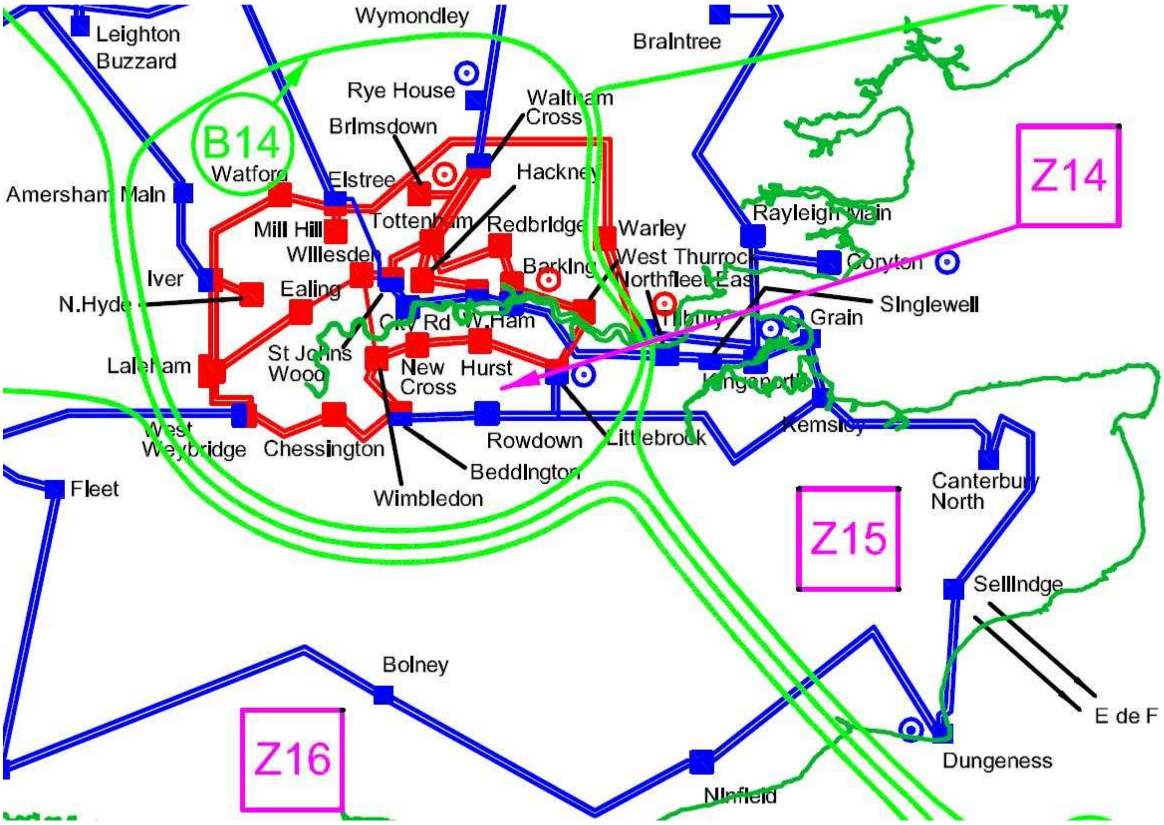

Fig. 2. Detailed view of the study zones [3]

amount of tradable access rights between any of the 54 generators (or a combination of them) and the entrant renewable generator of "London Array" while satisfying normal and contingent system conditions.

The initial operating point of the system, based on an expected 'ranking order' dispatch at time of peak demand with two units operating at the oil-fired station at Grain [5], satisfies all operating limits in the intact system state. 175 cases of credible single or double circuit contingencies were studied and some violations were found as listed in Table I. The loss of the double circuit between Kingsnorth, Singlewell and Northfleet East causes overloading on the two circuits between Warley and Elsetree, as well as a slight overload in one circuit between Kemsley and Littlebrook. Post-contingency MW flows can be determined from (7) and (3).

TABLE I
CRITICAL BRANCH CONTINGENCIES FOR BASE CASE

Contingency		Violation		% Load
from	to	from	to	
Kingsnorth	Singlewell	Warley	Elsetree (1)	115
Singlewell	Northfleet East	Warley	Elsetree (2)	103
		Kemseley	Littlebrook	101

In the normal operating condition, Circuit #1 between Warley and Elsetree is 75% loaded, whereas Circuit #2 is 72% loaded. The pre-contingency MW flow between Kemsley and Littlebrook is 70% loaded. If the pre-contingency MW flows on violated branches are reduced or balanced by a counterflow, the pre-contingency system state would be secure.

At the initial operating point, "London Array" was not dispatched. Generator shift factors (GSFs) were calculated for the 54 generators, with the "London Array" generator considered to be the source balancing generator with respect to the double line contingency between Kingsnorth, Singlewell and Northfleet East. The most negative post-contingency cumulative GSFs (for the three violating branches) were –19% at Tilbury and -1.5% at Grain. This result indicates that generation reductions at Tilbury and Grain coupled with an increase from the "London Array" would be most effective in reducing the MW flow between Kingsnorth and Northfleet East.

The reduction of 500 MW at Tilbury and 500 MW at Grain, augmented by the increase of 1000 MW at "London Array" were found to remove any post-contingency branch violation. However, since in the initial dispatch Tilbury had three units each producing 350 MW and Grain had two units contributing 650 MW each, the owners of Tilbury and Grain will practically want to decommit the unit output fully but not to scale it down (owing to the minimum output constraints of generating units). Therefore, the "London Array" can eventually buy short-term access rights of 700 MW from Tilbury and 650 MW from Grain. Even though the "London Array" is capable of producing 1000 MW, it would seem to have to acquire 1350 MW of access rights due to the practical constraints of generating units.

Still, the trade of access rights in this case promises to be a win-win situation for all the involved parties. The owners of both Tilbury (relatively low merit coal) and Grain (very low merit oil) acquired their access rights in the past. While Tilbury runs more often than Grain for contribution to the meeting of bilateral energy contracts and units at both stations run for relatively few hours each year, retention of access rights in both cases provides the opportunity to sell balancing services, i.e. the provision of system reserve, response or network constraint management. When not required by their owners for meeting of bilateral contracts or by the system operator for balancing services, they could sell part of their rights to "London Array" on a short-term basis thus allowing the "London Array" to exploit favourable wind conditions when they arise, to operate for much of the time and to contribute towards the meeting of renewables targets.

V. Conclusions

The trading of short-term transmission access rights between incumbent conventional generators and new renewable generators to integrate the latter into the system, temporarily until transmission upgrades are in place, has been described in this paper. Based on contingency analysis and linear sensitivity calculation, an approach has been outlined to find the promising locations for the trading of short-term access rights with the entrant renewable generation. Application of the approach to a portion of the real GB system has demonstrated its potential viability for the part resolution of transmission access issues in a simple and efficient manner.

The resulting trade of access rights is not only beneficial for the rapid integration of renewables into the system but also for individual power suppliers to fulfil their renewables obligation and include renewable generation into their energy portfolio.

Results also indicate that renewable generators may need to buy more access rights than what they can physically deliver themselves due to practical constraints.

The results presented herein are intended only to illustrate the idea and not to provide a comprehensive appraisal of the total benefits for the GB system. Further analysis to incorporate more renewables into larger parts of the GB system may well require the extension of intrazonal transmission access sharing to a multi-zone designation (comprising two zones or more) to accommodate multiple users concurrently.

References

[1] Office of Gas and Electricity Markets (Ofgem), *Renewable Obligation: What is the Renewable Obligation (RO)?*, [online] Available: http://www.ofgem.gov.uk/Sustainability/Environment/RenewablObl/Pages/RenewablObl.aspx. *Accessed* May 15, 2009.

[2] K. W. R. Bell, "System development issues concerning integration of wind generation in Great Britain," *Proc. of Cigre/IEEE Symposium on the Integration of Wide-Scale of Renewable Resources into the Power Delivery System,* Calgary, Alberta, Canada, July 2009.

[3] National Grid Electricity Transmission, *2008 Seven Year Statement*, [online] Available: http://www.natinalgrid.com/uk/Electricity/SYS.

[4] H. P. Chao, S. Peck, S. Oren, and R. Wilson, "Flow-based transmission rights and congestion management," *Electricity Journal*, vol. 13, no. 8, pp. 38-58, October 2000.

[5] National Grid Electricity Transmission, *GB Security and Quality of Supply Standard (GB SQSS)*, ver. 1, September 2004, [online] Available:http://www.natinalgrid.com/uk/Electricity/Codes/gbsqsscode.

[6] A. J. Wood, and B. F. Wollenberg, *Power Generation Operation and Control*. 2nd ed., New York: Wiley, 1996.

[7] X. Wang, and J. R. McDonald, *Modern Power System Planning*. London: McGraw Hill, 1994.

[8] R. C. Dugan, T. E. McDermott, and G. J. Ball, "Planning for distributed generation," *IEEE Industry Application Magazine*, vol. 7, no. 2, pp. 80-88, March/April 2001.