Interconnector Participation in Capacity Mechanisms: A New De-rating Approach

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***Abstract*—In countries with Capacity Mechanisms in place, where Explicit Interconnector Participation model is to be used, one of the key market design questions to be answered is how the amount of interconnector capacity that is allowed to participate in the auctions should be determined. This paper argues for an interconnector capacity de-rating approach. In order for the de-rating factor to be representative of stochasticity inherent in the system, the concept of Interconnector Effective Load Carrying Capability is postulated in this paper. A method with probabilistic basis that allows for converting the name-plate capacity of a transmission line connecting two areas into a de-rated capacity is proposed. The proposed probabilistic methodology takes into account the technical availability of the line and captures the impact of simultaneous or co-incident scarcity. A simple case-study is presented to exemplify the proposed principle and methodology.**

***Index Terms*--Capacity Mechanism, De-rating, Effective Load Carrying Capability (ELCC), Loss of Load Expectation (LOLE)**

I. INTRODUCTION

Increasingly, European countries are introducing or planning to introduce capacity mechanisms. Capacity Mechanism is defined [1] as mechanism to value generation or demand response capacity, generally but not always leading to a revenue stream to owners of such capacity in addition to revenues from the energy market. For countries that have such a mechanism, where Explicit Interconnector Participation Model [2] is in place or is planned to be deployed, one of the design questions to be answered is how to handle interconnectors in the auction process.

It is a common practice that the amount of capacity that the suppliers of generator capacity resources are qualified to offer in capacity market auctions, such as in the UK [3] and PJM markets [4], is determined by the generator de-rated capacities. De-rated capacity of a generating unit is a specific percentage of its theoretical rated capacity, which is deemed to be the dependable net capacity that is accessible at all times. There are several deterministic, semi-deterministic and probabilistic approaches for determining the generation capacity reserve requirements in vogue [3-5], from where the concept and application of de-rated generation capacities stems.

An interconnector is a resource of capacity from the assisting system, and as such the amount of interconnection capacity that is allowed to be bid in the capacity market auction can also be based on its de-rated capacity. Hence, the name-plate rated capacity of the interconnector should be converted into an *appropriate* de-rated capacity. We believe that if done under the framework of a suitable probabilistic modeling, the de-rating can be representative of the realistic stochastic nature of reliability. After all, the availability of any capacity resource is a stochastic process; the stochastic nature is recognised only by a probabilistic approach, and has been advocated for incorporation in a consistent evaluation of reserve requirements [6].

In interconnected systems, simultaneous scarcity is said to occur when the assisted system is in need of assistance through the interconnector from the assisting system, but the assisting system cannot deliver due to contingencies in its own system. Existing methods or studies [7-9] under development in the de-rating of interconnectors are however not comprehensive in that they do not model both the availability of the line and the probability of simultaneous scarcity situations. Observations from the limited literature available in this regard, all for the North Sea Link, are: (i) De-rating done purely on historical data, e.g., historical price differentials [7]; (ii) Usage of *limited* Loss of Load Expectation (LOLE) computations to obtain *Area Diversity Benefit Factors* [8]; (iii) Qualitative methodology by Ofgem as recently as July 2016 [9]. Clearly, it can be inferred that de-rating an interconnector solely based on its technical availability is trivial since simultaneous scarcity is not accounted for.

In this paper, the concept of Interconnector Effective Load Carrying Capability (IELCC) is postulated, and justified as a suitable probabilistic basis for computing the interconnector de-rated capacity. IELCC is adapted from the well-established robust concept of generator Effective Load Carrying Capability (ELCC) [10]. Application of the ELCC methodology to non-dispatchable wind generators [11] has been recommended for obtaining capacity value, also known as capacity credit, of wind power, which is equivalent to the de-rated value of the wind generator. The concept of capacity credit has also been extended to assess the contribution of electrical energy storage and demand response to adequacy of supply [12].

De-rating of a non-dispatchable generator based on ELCC captures both the mechanical availability of the generator and the wind scarcity conditions that limit the output of the generator. In fact, this existing application of the concept of ELCC provides motivation for the approach leading to the postulated IELCC in this paper.

The organisation of the paper is as follows: Section II recapitulates the significance of ELCC, and relates ELCC to the treatment of import as a capacity resource. Section III presents the proposed methodology. In Section IV, a simple case-study system is chosen to serve as an exemplification of the proposed IELCC methodology. Concluding remarks are provided in Section V.

II. On Effective Load Carrying Capability

A. Measuring the Reliability Contribution of a Generator

Reliability contribution of a stand-alone dispatchable generator can be captured by its Availability.

Availability = 1- Forced Outage Rate (FOR) (1)

FOR is also known as Unavailability. It is not a rate, but rather an estimator for a probability. It is the percentage of time a unit is not available due to random failures. It is defined [13] as "*the percent of scheduled operating time that a unit is out of service due to unexpected failures*".

Two consequent aspects are of particular interest upon adding a new generator unit to an existing generation system:

1. How does the new generator unit when added to an existing generation system with a given peak load demand affect the overall resulting reliability of the system?

- This information is readily obtained by computing the altered (improved) Loss of Load Expectation (LOLE) of the system.

LOLE is the expected number of time units (e.g., amount of days or amount of hours) in a given period (e.g., a year) when a loss-of-load event arises due to random failures in the generation. LOLE is obtained by convolving a generation model with a suitable load model [6]. For the same load demand in a system, when an additional generating unit is added, it will decrease the numerical value of LOLE, thus creating a desired improvement in LOLE. The accepted industry standard is one day in 10 years.

2. In what proportion does the new generator unit contribute to meeting a future projected peak load demand, while still maintaining a desired LOLE standard?

- The well-established methodology of Effective Load Carrying Capability (ELCC) [10] provides this required information. This has long been considered a standard practice in the reliability-based generation expansion planning studies.

ELCC is the amount of additional load that can be served at the target reliability level (say, a given threshold of LOLE) with the addition of a given amount of generation. It can be interpreted as the amount of additional load demand that a generating unit can support without altering the pre-existing LOLE level, or while maintaining a certain required LOLE.

In order to compute the value of ELCC of an added capacity resource (e.g., generator), a method must be in place for computing LOLE. The most popular method of ELCC computation is a graphical one [10]. For large systems, instead of drawing curves, a computational approach is used that essentially achieves the same result.

For a quick recapitulation, a summary of the graphical method for obtaining ELCC of an added generator is given below:

i. LOLE values for various values of peak load are obtained for the base-case generation system, and plotted on a semi-logarithmic scale.

ii. LOLE values for various values of peak load are obtained for the new generation system configuration, and plotted on a semi-logarithmic scale. This new Peak Load vs. LOLE curve is an improvement in that the curve shifts away from the original curve, closer to the load-axis.

iii. The distance between the two Peak Load vs. LOLE curves at a chosen reliability standard, say LOLE of 0.1 days/year, is the ELCC of the added generator.

The ELCC approach has proven to be robust across both conventional and variable generation technologies [11]. The ELCC marking of a generator is a comprehensive way of quantifying the probabilistic reliability contribution of the generator to the system adequacy as a whole. If X MW of generator is added to an existing generation system, unless it has a perfect reliability, the corresponding extra load demand that can be met while still maintaining the pre-existing LOLE limit of the system will always be $X-\Delta X$, with ΔX strictly > 0. Thus, $X-\Delta X$, which is the ELCC of the added generator, can be considered as the de-rated capacity of the added generation of original capacity X. Though it might seem that ΔX is just the FOR multiplied with X, this is not the case. The important aspect of ELCC is that it takes into account both the availability of the generator and the effect of this particular generator on the system where it is commissioned. This effect will not be the same for different systems, depending, among others, on the size distribution of the (larger) generators and the correlation of the resource availability (e.g., wind, hydro) with the existing resources in the system.

B. On Import as a Capacity Resource

The interconnectors facilitating the capacity import, akin to generators have a non-zero outage probability, and are less than 100% available. However, reliable assistance through interconnection is not merely a function of technical availability of the tie-line. The characteristics of the power system at the exporting side have to be considered, both physically and with respect to market design and agreements.

An interconnector participating in a capacity market is limited by its technical availability and the amount of reserve available from the assisting system. This amount depends on the applicable agreements. On the one hand, such agreements may guarantee the contracted quantity, leaving it to the exporting TSO to ultimately shed local demand, if need be, in order to satisfy the agreement. On the other hand, the contracted quantity may only be guaranteed to the extent that local reserve capacity is available in the exporting system. This imposes a so-called simultaneous "scarcity constraint", since provision of assistance by the exporting system in times of need for the assisted system is predicated upon there arising no conditions in the assisting system's area that would limit its usage of its reserve capacity as dictated by its own reliability standards.

We believe that if the impact of reliability contribution of an interconnector on the assisted system's overall probabilistic reliability is to be quantified appropriately, ELCC of the interconnector will be a fitting metric. As already explained in the previous sub-section, ELCC takes into account the characteristics of the system where the additional capacity is added. Extending it by also incorporating the probability of coincident scarcity is therefore a logical extension. A so-called Interconnector Effective Load Carrying Capability (IELCC), adapted from the concept of generator ELCC, is defined in this paper. It is conceived as a measure of probabilistically modeling the reliability contribution of a tie-line in an interconnected two-area system by also taking coincident scarcity into account. IELCC is chosen as the de-rated capacity of the interconnector that is allowed to be bid.

LOLE, and hence ELCC by association, is representative of the expected contribution of the capacity resources to Security of Supply. We believe that if models involving the de-rating of capacity resources include such probabilistic approaches, the resulting de-rating factors will also be representative of the expected contribution of the capacity resources to Security of Supply.

III. PROPOSED METHODOLOGY

Capacity Outage Probability Table (COPT) [6] is an essential intermediate input for the LOLE studies of generation systems. Once the COPT is computed from the preliminary input data (generator capacities and FORs), LOLE can be found by convolving it with a load model. The load model can be a constant peak load curve or a daily peak load curve or an hourly peak load curve.

One of the standard ways of constructing a COPT for a generation system is by the use of a recursive algorithm [6, 14]. The structure of a sample COPT is as shown in Table 1. Consider a generation system consisting of two generators G1 and G2 of rated capacities C1 and C2, respectively, and FORs of U1 and U2, respectively, each of which can either be fully functional (UP state) or non-functional (DN state). The generator availabilities are A1 (i.e., 1-U1) and A2 (i.e., 1-U2). From the state space enumeration, distinct capacity states are obtained and arranged in the increasing order of their available capacities as shown in Table 1.

TABLE 1. SAMPLE COPT STRUCTURE

State No.	State	Capacity Available	Capacity Outage	Probability of Occurrence
1	G1 UP, G2 UP	C1 + C2	(C1 + C2) – (C1 + C2)	A1 × A2
2	G1 UP, G2 DN	C1	(C1 + C2) – (C1)	A1 × U2
3	G1 DN, G2 UP	C2	(C1 + C2) – (C2)	U1 × A2
4	G1 DN, G2 DN	0	(C1 + C2) – (0)	U1 × U2

Say C1 = 25 MW; C2 = 20 MW, and a constant load demand of 30 is considered for an interval. Each of the states 2, 3 and 4 in Table 1 results in a loss of load situation, since the capacity on outage for these states is greater than the difference between the installed generation capacity and the load demand. Summing up the probabilities corresponding to the occurrence of each of the states 2, 3 and 4 thus yields a loss of load probability (LOLP) value for the interval considered. LOLE, a probabilistic expectation, is the summation of LOLPs for the entire time period of study.

The way the COPT is computed for a generation addition to an existing system is different from the way COPT is computed when the source of additional capacity is an interconnector facilitating import from a neighbouring system. From literature [6], an established sequence of steps is executed to investigate the adequacy of two-area interconnected systems, based on the following premises: COPTs of generation systems can be 'merged'; COPT of an interconnector can be obtained (termed as 'tie-line constrained equivalent assisting unit model of the assisting system'); and, COPT of an interconnector can be merged with the COPT of a generation system. For explicit details pertaining to 'merging', the reader is referred to [6]. As pointed out in Section II, computing ELCC for a capacity resource is conditioned on the presence of a methodology for computing LOLE. The LOLE of a two-area interconnected system can be obtained by using the Equivalent Assisting Unit (EAU) methodology [6]. A methodology is proposed utilising the EAU approach, for obtaining the ELCC of an interconnector in 2 steps as follows:

Step 1: When the capacity source is an interconnecting tie-line instead of a new generator, the procedure to obtain LOLE can be summarised as follows :

- Obtain COPT of System A: $COPT_A$
- Obtain COPT of System B : $COPT_B$
- Obtain COPT of the interconnector: $COPT_L$
- Merge $COPT_B$ and $COPT_L$ to get the assistance COPT: $COPT_{Asst}$
- Merge $COPT_A$ and $COPT_{Asst}$ to get a Unified COPT for system A: $COPT_{Unified}$
- Convolve $COPT_{Unified}$ and the load curve of System A. Obtain $LOLE_{Unified-A}$.

Thus, for the interconnected system with a given generation-load profile in two systems, and tie-line with a specific capacity, and FORs of all capacity resource units, LOLE of the assisted system can be found.

Step 2: The Peak Load vs. LOLE curve is drawn for System A, the assisted system, for its original generation profile. For different peak loads in System A, obtain the corresponding $LOLE_{Unified\text{-}A}$ values based on the steps outlined in Step 1.

- Draw the Peak Load vs. $LOLE_{Unified\text{-}A}$ curve.
- Compare this with the Peak Load vs. LOLE curve of System A.
- Obtain ELCC for the chosen reliability standard (i.e., a given LOLE). The distance between the two LOLE vs. Peak Load curves at a chosen reliability standard, say LOLE of 0.1 days/year, is the ELCC of the interconnector. This distance is the Interconnector Effective Load Carrying Capability.

IV. Illustrative Case-Study

The two-area test configuration system used in [6] (for demonstrating the concepts of adequacy of interconnected systems), shown in Fig. 1, is used to serve as an exemplification of the proposed principle and methodology. The data pertaining to Fig. 1 is shown in Table 2. Systems A and B have installed capacities of 75 MW and 60 MW, respectively; they have peak loads of 50 MW and 40 MW, respectively. The two systems are interconnected by a tie-line of finite capacity 10 MW. The operating agreement is that System B will provide assistance up to 10 MW to System A in times of need, as long as System B has sufficient reserve capacity to meet the requirement. Thus, System A is the assisted system, and System B is the assisting system. The load model considered is the simplest version: a constant daily peak load model lasting the entire year of study. Detailed load models can be subsequently studied. For the base-case generation configuration as shown in Table 2, four different scenarios of capacity resource addition for improving the reliability of System A are considered further for analysis.

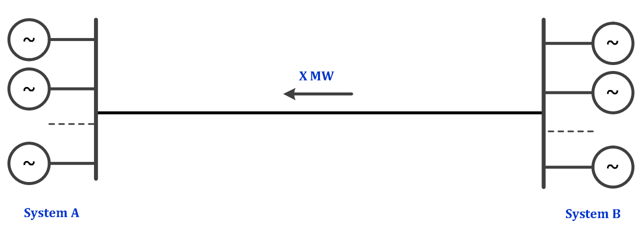

Fig. 1. Example case-study system

The example case study assumes that internal transmission lines in both the assisted system and the assisting system are perfectly reliable, i.e., only generation adequacy was considered in the configuration of the assisted system and the assisting system.

Scenario 1: A generator of 10 MW rated capacity and perfect availability, i.e., FOR = 0, is added to the base-case generation of System A. The modified COPT is obtained for the changed generation profile. Based on this, LOLE for the existing peak load profile of 50 MW is found to be 0.00007762 days/year. For a future projected load demand, ELCC at the desired LOLE standard of 0.1 days/year is the distance between Curve 1 and Curve 2 at y=0.1 of Fig. 2, which is 10 MW.

TABLE 2. Data for the Test System

System	No. of Units	Unit Capacity (MW)	FOR (Each Unit)	Peak Load (MW)
A	5	10	0.02	50
	1	25	0.02	
B	4	10	0.02	40
	1	20	0.02	

This ELCC of the generator is its de-rated capacity for the designated LOLE standard, and is the same as the name-plate rated capacity of the added generator. This is so because the added generator is assumed to have a perfect reliability, and is dispatchable.

Scenario 2: A generator of 10 MW rated capacity and FOR of 0.1 is added to the base-case generation of System A. For a future projected load demand, ELCC at the desired LOLE standard of 0.1 days/year is the distance between Curve 1 and Curve 2 at y=0.1 of Fig. 3, which is 8.48 MW. This ELCC of the generator is its de-rated capacity for the designated LOLE standard.

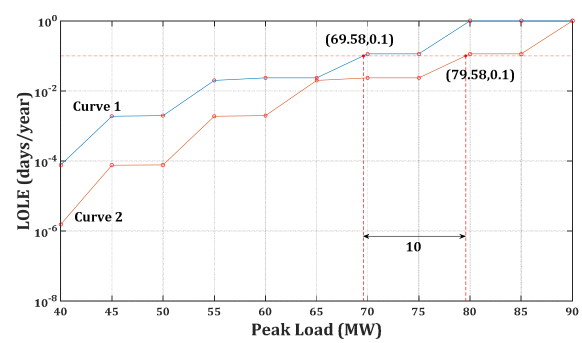

Fig. 2. Scenario 1: ELCC of added generator with perfect availability

This ELCC value of 8.48 MW is interpreted as follows: Out of the 10 MW of added generation, only an additional 8.48 MW of peak load demand can be met while still prescribing to the established LOLE standard of 0.1 days/year.

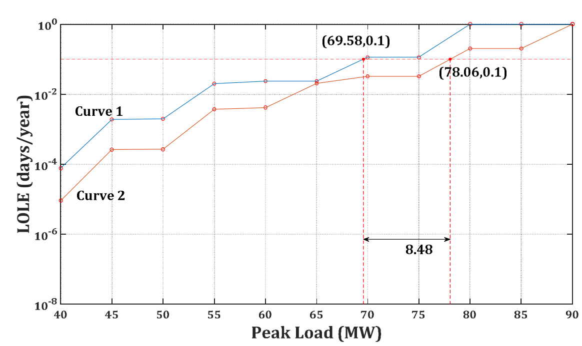

Fig. 3. Scenario 2: ELCC of added generator with a given FOR

Thus, the de-rated capacity of the added 10 MW generator is 8.48 MW. In the parlance of wind generator studies, this is also termed as the capacity value (or capacity credit) of wind power, which takes into account both the mechanical availability of the wind generator and the wind scarcity.

Scenario 3: An interconnector of 10 MW rated capacity and FOR of 0 (i.e., perfect availability) is considered to be the source of capacity addition to the base-case generation of System A. The procedure outlined in Step 1 of the proposed methodology for obtaining ELCC of an interconnector in Section III is applied here.

Curve 2 of Fig. 4 is a plot of $LOLE_{Unified-A}$ values for different values of peak load of System A. If the desired LOLE reliability standard of the system were to be 0.1 days/year, the maximum future peak load at which the system LOLE will be less than or equal to the desired LOLE standard = 79.12 MW. Curve 1 of Fig. 4 is the plot of Peak Load vs. LOLE for the base-case generation of System A. With assistance from the interconnector, there is an obvious improvement in the LOLE of System A from the base-case value of 0.00199765 to 0.00012042 days/year, for the peak load profile of 50 MW.

For a future projected load demand, ELCC at the desired LOLE standard of 0.1 days/year is the distance between Curve 1 and Curve 2 at y=0.1 of Fig. 4, which is 9.54 MW. This ELCC of the interconnector, termed as IELCC, is its de-rated capacity for the designated LOLE standard. Even though the interconnector has perfect availability, the IELCC is not 10 MW as one might expect, considering the results of Scenario 1, since scarcity in System B plays a role.

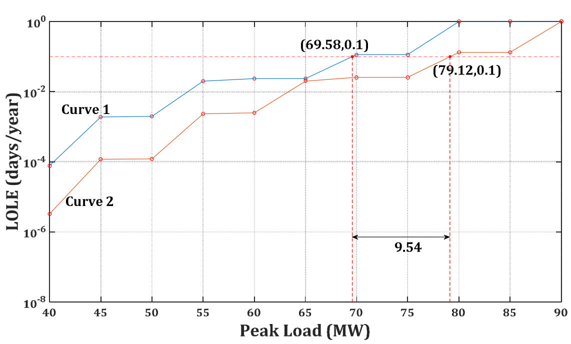

Fig. 4. Scenario 3: IELCC of added interconnector with perfect availability

Scenario 4: The steps performed for Scenario 3 are repeated, but this time considering the interconnector to be having FOR = 0.01. The effect of interconnector FOR on the LOLE of System A is obtained by employing the conditional probability rule as follows:

LOLE= LOLE(when interconnector is UP)*P(interconnector being in UP state) + LOLE(when interconnector is DOWN)*P(interconnector being in DOWN state) (2)

The $LOLE_{Unified-A}$ values for different values of peak load in System A are computed and plotted as Curve 2 of Fig. 5. Curve 1 of Fig. 5 is the plot of Peak Load vs. LOLE for the base-case generation of System A. With assistance from the interconnector, there is an obvious improvement in the LOLE of System A from the base-case value of 0.00199765 to 0.00013572 days/year, for the peak load profile of 50 MW. This is a lesser reduction than that compared to Scenario 3 when the interconnector was considered to be having perfect availability.

If the desired LOLE reliability standard of the system were to be 0.1 days/year, the maximum future peak load at which the system LOLE will be less than or equal to the desired LOLE standard = 78.97 MW. For a future projected load demand, ELCC at the desired LOLE standard of 0.1 days/year is the distance between Curve 1 and Curve 2 at y=0.1 of Fig. 8, which is 9.39 MW. This ELCC of the interconnector, termed as IELCC, is its de-rated capacity for the designated LOLE Standard.

Discussion of Results: The interconnector of rated capacity 10 MW, should be de-rated to its IELCC value of 9.39 MW (considering an FOR of 0.01, and the possibility of co-incident scarcity). This means that the interconnector will be able to supply 9.39 MW of extra load in System A while maintaining a prescribed LOLE of 0.1 days/year. The net capacity of 9.39 MW is what can be allowed to participate in the capacity market auction.

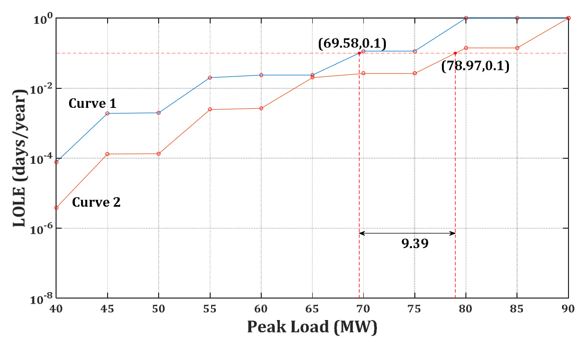

Fig. 5. Scenario 4: IELCC of added interconnector with a given FOR

- If the interconnector has perfect availability and there is no co-incident scarcity, its IELCC will be 10 MW.
- If the interconnector has perfect availability and only co-incident scarcity is a possible scenario, its IELCC will be 9.54 MW.
- If co-incident scarcity is non-existent, the interconnector de-rating could be done on the basis of its unavailability (FOR) alone.
- As the unavailability of the interconnector increases, the resulting de-rated capacity of the interconnector further goes down. For example, if the FOR increases to 0.05, the co-incident scarcity probability being the same as in the base case, the de-rated capacity will be 8.81 MW.
- As the co-incident scarcity probability increases, the FOR being the same as in the base case, the resulting de-rated capacity of the interconnector further goes down.
- If instead of the interconnector, an extra generator of 10 MW capacity and FOR 0.1 (generators have a higher unavailability than lines) is added to System A, the added generator will be able to supply an

additional load of 8.49 MW in System A while maintaining an LOLE of 0.1 days/year.

- The co-incident scarcity of the interconnected system, if appropriately offset/modelled by a corresponding increase in FOR of a new thermal generator addition will result in the same reliability advantage as would be possible with interconnection.

It should be noted that the proposed approach is conservative because it potentially underestimates the contribution from the interconnector. This is because it is assumed that whenever there is simultaneous scarcity, the interconnector will not deliver. In reality, however, the interconnector could partially deliver during a scarcity event that involves a shortage that is less than the capacity of the interconnector. For instance, an interconnector of 1000 MW, might have a (technical + market) de-rated capacity of 900 MW. During a scarcity situation of, say, 100 MW in the exporting country, the interconnector might still deliver up to 800 MW, provided that agreements are in place (as the market will not direct the power if both countries have the same price cap). A more advanced approach could take this into account.

V. CONCLUDING REMARKS

The name-plate rated capacity of an interconnector can be converted into an appropriate de-rated capacity through a suitable probabilistic modelling, taking into account both the interconnector availability and the probability of simultaneous scarcity. Such modelling, as proposed in this paper, is consistent with the well-established scientific approach of calculating LOLE, and subsequently ELCC. The proposed methodology with the illustrative example can be easily extended to real-life systems, and is applicable to both AC and HVDC interconnectors.

The IELCC as conceived is a reliability-based interconnector de-rating, and gives a prescriptive way of probabilistic design for ensuring Security of Supply. The de-rated capacity of an interconnector, obtained using the proposed methodology, can be used as a basis to determine the amount of interconnector capacity that is qualified to be offered in capacity market auctions. One MW of de-rated capacity represents the same contribution to the reliability of the system, regardless of its source – domestic generation or interconnectors, provided an appropriate factoring exists that also takes into account the probability that the exporting system will not deliver in times of need.

Though execution of the proposed algorithm has been shown only for four specific scenarios for a simple load model on a simple illustrative system to bring out the salient features of the narrative, the algorithm is generic and also applicable to complex load models. Further work, currently being carried out, includes extensive testing of the proposed methodology with relevant sensitivity analyses on large-scale systems with detailed load profiles, and investigation into de-rating of interconnectors for multi-area interconnected systems.

REFERENCES

[1] CIGRE Working Group C5.17, “Capacity mechanisms: needs, solutions and state of affairs,” CIGRE Technical Brochure TB 647, Mar. 2016.

[2] European Commission, “Framework for cross-border participation in capacity mechanisms,” Technical Report, Dec. 2016. [Online]. Available: https://ec.europa.eu/energy/sites/ener/files/documents/cross-border_crm_study_-_final_report_-_170106.pdf [Accessed: May 2017.]

[3] National Grid EMR (Electricity Market Reform) Electricity Capacity Report, May 2016. [Online]. Available: https://www.emrdeliverybody.com/Lists/Latest News/Attachments/47/Electricity Capacity Report 2016_Final_080716.pdf [Accessed: Sep. 2016.]

[4] State of the Market Report for PJM: Detailed Analysis, Mar. 2015. [Online]. Available: https://www.hks.harvard.edu/hepg/Papers/2015/2014-som-pjm-volume2.pdf

[5] ENTSO-E Scenario Outlook & Adequacy Forecast Report, Jun. 2015. [Online]. Available: https://www.entsoe.eu/Documents/SDC%20documents/SOAF/150630_SOAF_2015_publication_wcover.pdf

[6] R. Billinton and R. N. Allan, *Reliability Evaluation of Power Systems*, Plenum Press, New York, 1996.

[7] FTI-CL Energy Consulting presentation, Jun. 2016. [Online]. Available: http://www.eprg.group.cam.ac.uk/wp-content/uploads/2015/06/Mann_Presentation-to-EPRG-final.pdf [Accessed: Sep. 2016.]

[8] National Grid EMR Electricity Capacity Report, Jun. 2015. [Online]. Available: https://www.gov.uk/government/publications/emr-panel-of-technical-experts-2015-final-report-on-national-grids-electricity-capacity-report-2015 [Accessed: Sep. 2016.]

[9] Letter from Ofgem to DECC, Jul. 2016. [Online]. Available: https://www.gov.uk/government/publications/a-letter-from-ofgem-to-decc-regarding-interconnection-and-the-capacity-market [Accessed: Sep. 2016.]

[10] L. L. Garver, “Effective load carrying capability of generating units,” *IEEE Transactions on Power Apparatus and Systems*, vol. PAS-85, pp. 910-919, Aug. 1966.

[11] IEEE Task Force on Capacity Value of Wind Power, “Capacity value of wind power,” *IEEE Transactions on Power Systems*, vol. 26, no. 2, pp. 564-572, May 2011.

[12] Y. Zhou, P. Mancarella, and J. Mutale, “Framework for capacity credit assessment of electrical energy storage and demand response," IET Generation, Transmission & Distribution, vol. 10, pp. 2267-2276, Jun. 2016.

[13] *IEEE standard definitions for use in reporting electric generating unit reliability, availability, and productivity*, IEEE Standard 762-2006, Mar. 2007.

[14] H. G. Stoll, *Least-Cost Electric Utility Planning*, John Wiley & Sons, New York, 1989.