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Assessment of the influence of wind energy incorporated capacity benefit margin in ATC computation

Olatunji Obalowu Mohammed[1,2], Mohd Wazir Mustafa[1], Sani Salisu[3], Ahsanullah Memon[1], Saddam Hussain[1], Abdulrahaman Okino Otuoze[2], Oladimeji Ibrahim[2]
[1]School of Electrical Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, Johor Bahru, Malaysia
[2]Department of Electrical and Electronics Engineering, Faculty of Engineering and Technology, University of Ilorin, Kwara, Nigeria
[3]Department of Electrical Engineering, Faculty of Engineering, Ahmadu Belo University (ABU), Kaduna, Nigeria

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ABSTRACT

Available transfer capability (ATC) is an important metric used to measure the techno-economic viability of the transmission networks. Several methods have been presented in literature for ATC assessment, however, only some few articles incorporate CBM in ATC calculation and those few papers only considered conventional power generation sources in CBM evaluation. CBM is a function of the reliability of generating units. This paper presents the inter-area CBM calculation in the presence of wind energy source using graph theory technique and the results are incorporated in ATC computation using repeated power flow. CBM is incorporated in ATC computation as non-recallable and recallable power transfers. The results with and without CBM incorporation, in the presence of wind power system, are compared. The contribution of the paper is to study the influence of wind power (WP) integrated CBM on ATC evaluation. The results showed that the incorporation of CBM, in the presence of renewable energy, has a significant influence on ATC, without which ATC would be inaccurately estimated. Simulations using IEEE 24-Bus RTS is used to implement the proposed approach. This approach can be employed by transmission operators to assess the technoeconomic viability of the power network for possible power transactions.

Corresponding Author:

Olatunji Obalowu Mohammed
Industrial Power Lab, School of Electrical Engineering, Faculty of Engineering
Universiti Teknologi Malaysia (UTM)
Johor, Johor Bahru, Skudai, 81300, Malaysia
Email: o.obalowu.utm.my

1. INTRODUCTION

The vertical integrated utility, where generation, transmission and distribution are managed by a single entity, has been in existence for decades [1]. The operation of these utilities is controlled by the regulations and guidelines set by the government [2], [3]. They are also responsible for the expansion, maintenance, and standardisation of the electrical power industry [4]. This monopoly form of operation has created ineffective techno-economic turnout resulting in unsatisfactory service delivery. However, literature survey has revealed that an efficient restructuring approach in electric power sector is necessary for a sustainable techno-economic improvement and delivery [5], [6]. Therefore, the exiting utilities structure are going through reformation to improve the system for effective service delivery [7]. Following the restructuring of the sector, the role of the vertically integrated unit is shared by various market participants: generation, transmission, and distribution companies as well as the independent system operators (ISOs) [2], [8], [9].

To foster a competitive power market structure and to provide effective customer service delivery with the opportunity to have choice of utility selection by the customers, the U.S. Federal Energy Regulatory Commission (FERC) issued order 888 and 889, which instituted Open Access Same-Time Information System (OASIS). The OASIS provides non-discriminatory access to the use of transmission system, thereby enabling an effective competitive system known as deregulated system [10]. Despite the associated benefits of deregulated system, there are inherent disadvantages if there is no adequate control management to oversee the operation. The most probable bottleneck is network congestion [2], [11] congestion can occur in some part of the network which can result in system security challenges. To circumvent this condition and to deliver efficient information to the power market operators, available transfer capability is used as a measure of techno-economic feasibility of the network. The flexibility, robustness and security of the transmission system can be evaluated by the amount of ATC which the system can contain for possible power transfer [2]. Accurate evaluation of ATC can provide the necessary information required for the upgrading of transmission network [2]. ATC is the amount of transfer capability, in excess of the already committed uses, that can be used for the next power transaction [12].

In addition, to accurately calculate, other transmission reserve margins need to be incorporated in ATC computation. There exist two transmission reserve margins and total transfer capability (TTC) [2], [12]; capacity benefit margin (CBM) and transmission reliability margin (TRM). TRM represents the portion of transmission transfer capability that is reserved for the security of the interconnected systems under acceptable bounds of uncertainties in the system conditions. TTC is defined as the total amount of electric power that can be transferred over the interconnected network reliably while meeting a specific set of pre- and post-contingency system conditions. CBM is the amount of transmission capability earmarked for the load service entities to have access to external generation in order to meet generation reliability requirements [2]. The (1) shows the mathematical relationship between these metrics. Mathematically, ATC can be expressed as (1).

$$ATC = TTC - TRM - CBM - ETC \tag{1}$$

Where ETC represents existing transmission commitment.

Several mathematical techniques have been proposed in literature for ITC and TRM computations. However, despite the enormous body of research on ATC, only few researchers [13]–[18] incorporate CBM in ATC computation without considering renewable energy generation in CBM evaluation. Moreover, in recent years, power system generation sources have metamorphosed from being conventional sources to alloyed forms consisting of both conventional and renewable sources [19]–[22]. The integration of renewable energy sources has instigated power systems operators to perpetually improve the system security and stability. Karuppasamypandiyan *et al.* [18] incorporate wind power (WP) in ATC evaluation by adding WP into the test system to study the influence of WP on ATC but not on CBM. The addition of WP into the existing system generation will reduce power flow in some sections of the network and increase it in other sections of the system network depending on which area or bus the WP units are integrated. However, the stochastic effect of WP cannot be effectively assessed due to the usage of the predicted power output of the wind system, which mimics the addition of a conventional generating system. Existing literature has shown that CBM has a great impact on the calculated value of ATC as compared with TRM [13]. Accurate evaluation of CBM is very crucial to avoid over-/under-estimation of ATC. CBM is a function of the amount of generation capacity and the reliability of the generating units installed in the system. Therefore, it is imperative to investigate the influence of renewable energy on the evaluation of CBM while incorporating it in ATC computation.

In this work, repeated power flow is employed to calculate ATC, and graph theory is used to evaluate CBM in the presence of a wind power system considering the multistate wind power output. The modified IEEE 24 bus RTS [13] is used to implement the proposed approach. To effectively study the influence of wind power on the CBM and subsequently on ATC, the wind capacity is installed in proportion to the conventional generation capacity of the concerned area, and it is taken as 20% of the existing capacity of the area [23], [24]. The rest of the paper is organized as follows. Problem formulations for ATC computation is discussed in section 2. section 3 describes the proposed technique for calculating CBM, and section 4 presents the details of the test system. The results and discussion of the findings are presented in section 5. Section 6 concludes this paper.

2. ATC COMPUTATION

Repeated power flow (RPF) is a steady-state solution of a power system network that repeatedly solve power flow equations at a sequence of points via a specific transfer direction [2]. Compared to any OPF techniques, RPF provides P-V and V-Q curves for voltage stability verification. Its implementation is simple, and the convergence time is less than CPF [2]. The main reason for TTC computation is to ascertain the maximum active power transfer between two areas by increasing the power transfer via the tie-lines until a system constraint (voltage, thermal or stability) is reached at any part of the transmission system. Therefore, the TTC calculated for the most restrictive limitation is chosen as the network TTC value [25]. In this research, voltage and thermal constraints are considered. TTC is determined by increasing the power output of the generating units in the supply area and decreasing the power output of the generating units in the demand area [13]. RPF is used in this research to compute TTC because it is easier to implement, and it has a reduced convergence time [25]. From (1), ETC is the pre-power transfer power flow in the system. Existing literature have shown that CBM has greater impact on the calculated value of ATC compared with TRM [13], [18]. Therefore, the (1) becomes (2) as follows. The RPF algorithm for TTC computation is described in Algorithm 1.

$$ATC = TTC - CBM - ETC \tag{2}$$

After obtaining TTC and CBM, ATC can be easily evaluated subject to the equality and inequality constraints, as follows. Equality constraints

$$P_{Gi} - P_{Dj} = \sum_{j=1}^{N_B}(|V_i|\,|V_j||Y_{ij}|\cos\,(\delta_i - \delta_j - \theta_{ij})) \tag{3}$$

$$P_{Gi} - P_{Dj} = \sum_{j=1}^{N_B}(|V_i|\,|V_j||Y_{ij}|\cos\,(\delta_i - \delta_j - \theta_{ij})) \tag{4}$$

$$Q_{Gi} - Q_{Dj} = \sum_{j=1}^{N_B}(|V_i|\,|V_j||Y_{ij}|\sin\,(\delta_i - \delta_j - \theta_{ij})) \tag{5}$$

Inequality

$$P_{Gi}^{min} \leq P_{Gi} \leq P_{Gi}^{max} \qquad (5)$$

$$Q_{Gi}^{min} \leq Q_{Gi} \leq Q_{Gi}^{max} \tag{6}$$

$$V_i^{min} \leq V_i \leq V_i^{max} \tag{7}$$

$$S_{ij} \leq S_{ij}^{max} \tag{8}$$

Algorithm 1. Repeated power flow algorithm

Step 1. Run base case power flow
Step 2. Assign varying factor as a percentage of area generation capacity
Step 3. Perform power transfer by increment generation with the varying factor at seller area/bus and decrement generation with the varying factor at seller area/bus
Step 4. Re-run power flow after power transfer execution
Step 5. Any constraint violation? If yes, go to Step 6, If no, go to Step 3
Step 6. Decrease the varying factor
Step 7. Re-run power flow again
Step 8: Any constraint violation? If yes, go to Step 6, If no, go to Step 9
Step 9: Calculate the ATC by taking the difference between the case and the new case

3. CAPACITY BENEFIT MARGIN

The measure of transmission capability reserved for load serving entities (LSEs) to access external generation from interconnected areas in lieu of internal reserve during unplanned generation insufficiency is called CBM. Loss of load expectation (LOLE) is a reliability metric commonly employed for CBM evaluation. LOLE is the average number of days or hours in a specified period (typically one year) in which the daily/hourly peak load is envisaged to exceed the available generation capacity [26]–[28]. The condition is to maintain the LOLE of the concerned areas to be less than the standard value (usually 2.4 hours/year) [16], [29]. An area with LOLE higher than the standard value is deficient, and it needs external generation through CBM to improve its supply capability. On the other hand, if the LOLE value is below the standard value, then the area is efficient, and it can serve as an external generation source to the deficient areas. Therefore, this external generation is routed through the reserved CBM depending on the LOLE of an area.

Most of the existing techniques to determine CBM rely on optimization methods such as PSO [15], EP [30], DE [17], and trial and error [13] using the LOLE metric. These techniques are not efficient as they are time-consuming for multiarea CBM evaluation. In this work, the graph theory approach is employed to calculate inter-area CBM. This article aims to study the effects of CBM on ATC values with and without WP incorporated in CBM. The algorithm for generation reliability assessment is as follows:

Algorithm 2. Algorithm to calculate LOLE, identify deficient and efficient areas

Input: Gen_{matrix}, $Load_{area}$, Load duration curve, $LOLE_{target\_value}$
Output: P_D
Calculate LOLE using Gen_{matrix} and Load duration curve
If $LOLE < LOLE_{target\_value}$ (Efficient Area)
    Initialize L = $Load_{area}$
    While (1) {
    Compute LOLE using L
If $LOLE > LOLE_{target\_value}$ (Deficient Area)
    P_D = L – $Load_{area}$
    Break
    L = L + Step}
Else
    $Initialize\ G = Gen_{matrix}$
While (1) {
    Compute LOLE using G
If $LOLE < LOLE_{target\_value}$
    $P_D = Gen_{matrix} - G$
    Break
    $G = G + Step$ }

The maximum flow algorithm problem was formulated to calculate the CBMs for the three-area system in Figure 1. The possibility of the CBM allocation is assessed based on the calculated LOLE of the areas. If the flow on edge between area m and area n is represented with $f_{m,n}$ then the formulation of the maximum flow problem can be written as follows [31]:
Maximize:

$$\sum_{m:(S,m)\in A} f_{S,m} \tag{9}$$

Subject To:

$$f_{m,n} \leq u_{m,n},\ \forall(m,n) \in A \tag{10}$$

$$\sum_{k:(m,k)\in A} f_{m,k} - \sum_{k:(k,m)\in A} f_{k,m} = 0, \quad \forall m \in V \tag{11}$$

The pictorial representation of the interconnected areas using the graph technique is shown in Figure 1. The graph shows the CBM supports from efficient areas 2 and 3 to deficient area 1. Moreover, $u_{n,m}$ represents the amount of CBM supports from area n to area m and vice versa. Algorithm 3 is employed for CBM computation.

Algorithm 3. Algorithm for CBM Evaluation

Step 1: Employ Algorithm 1 to evaluate the graph solution of the interconnected areas
Step 2: Identify and connect (using edges) source and sink nodes
Step 3: Assign capacity to the edges in step 2 equal to $-\Delta_i$
Step 4: Assign capacity Δ_i to the edges from deficient nodes to sink node
Step 5: Execute the maximum flow procedure on the interconnected system
Step 6: If the flow from the supply node to demand node $= D_{total}$
Step 7: Allocate CBM from area n to area m = $f_{n,m}$
Step 8: Else
Step 9: No viable CBM allocation

In Algorithm 2, Gen_{matrix} represents the generation matrix of areas given by (12).

$$Gen_{matrix} = \begin{bmatrix} G_1 & n_1 & \mathrm{FOR}_1 \\ \vdots & \ddots & \vdots \\ G_n & n_n & \mathrm{FOR}_n \end{bmatrix} \tag{12}$$

Where, G_n, n_n and FOR_n represent generation unit capacity, number of units and forced outage rate of the corresponding generation unit respectively. The (12) is modified, as shown in (13), to incorporate wind power generation mix in Gen_{matrix} calculation. All the matrix inputs remain the same as in (12) except $\mathrm{G_{wn}}$, which represent the generation capacity of wind power in an area, $\mathrm{Cap\_prob(Avail_1\&FOR_1)}$ is the available capacity probability, $\mathrm{n_{n.......1}}$ is the number of wind power capacity multistate units. All these are used in the computation of LOLE in Algorithm 2.

$$\mathrm{Gen} = \begin{bmatrix} G_1 & n_1 & \mathrm{Cap\_prob(Avail_1\&FOR_1)} \\ \vdots & \ddots & \vdots \\ G_n & \mathrm{n_n} & \mathrm{Cap\_prob(Avail_n\&FOR_n)} \\ + & + & \cap \\ \mathrm{G_{wn}} & \mathrm{n_{n.......1}} & \mathrm{PDF(w\_speed)} \end{bmatrix} \tag{13}$$

CBM is incorporated in ATC as recallable and non-recallable transfers. In a recallable transfer, CBM is subtracted directly from the calculated TTC. In a non-recallable transfer, the generation output in all generators in the concerned areas is modified according to CBM allocated to the areas. Therefore, the TTC calculated in the second case is the same as ATC. Hence, the generators' outputs are modified using (14).

$$Gen_i^a = Gen_i^a \pm \frac{CBM_a}{N_g^a} \qquad a \in A, i \in N_g^a \tag{14}$$

Where, Gen_i^a is the output of generator *i* in area a, *A* is the number of areas in the interconnected system, CBM_a is the CBM of area a, and N_g^a is the number of generators in area a. The sign in (14) depends on whether it is receiving area or supply area, if it is the receiving area the sign will be negative and vice versa. Then the power transfer due to ATC is reduced with the influence CBM.

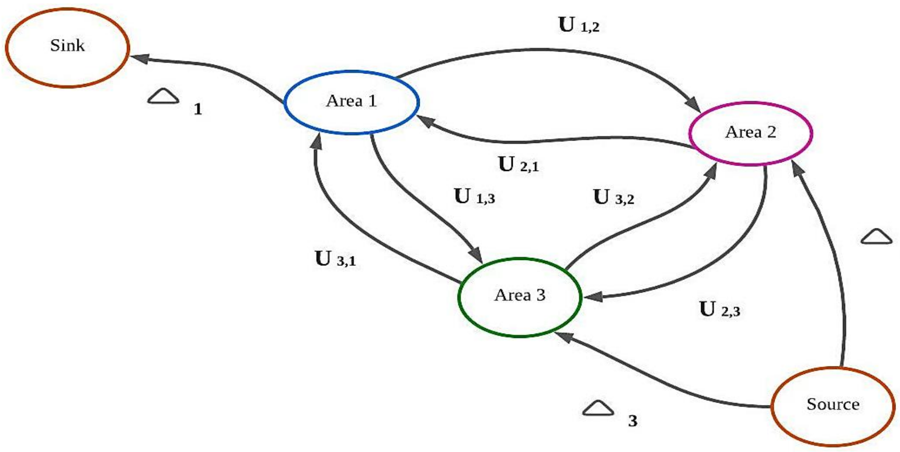


Figure 1. Interconnected systems graph with efficient and deficient areas

4. TEST SYSTEM

In this work, MATLAB 2016b is employed to implement the proposed approaches. Modified three-area IEEE 24-bus RTS data [13] is used to implement the proposed strategies for CBM and ATC computation evaluations. The system can be found in [32]. Initially, all three areas are deficient, i.e. the LOLE from all regions are higher than the standard value (2.4 hours/year), therefore the system was modified in [13], to employ the system for reliability assessment. Table 1 shows the details of the 24-bus reliability test system (RTS). To effectively study the effect of wind power (WP) in CBM computation, 20% of the installed capacity was replaced with WP in each area. As shown in Table 1, the percentage of WP has a notable influence on CBM [33]. The generation units with bold font show the WP replacement of the conventional generation units. Multistate WP output was considered in the reliability evaluation. The main contribution of this paper is to accurately incorporate CBM in ATC computation using RPF with and without WP in CBM and assess the influence on the ATC values.

Table 1. Modified test system

Area	Bus No	Primary Gen (MW)	Modified Gen (MW)	Generating Units (MW)	Units Replacement with Wind Power (MW)	Load (MW)
1	14, 15, 16, 17, 18, 19, 21, 24	1170	2035	12×5 155×5 400×3	12×5 155×5 400×2 400×1	1125
2	5, 6, 8, 9, 10,11, 12, 13, 20, 22, 23	1551	1748	50×6 155×2 197×4 350×1	50×6 155×2 197×4 350×1	1141
3	1, 2, 3, 4, 7, 24	684	784	20×4 76×4 100×4	20×1 76×4 100×3 100×1 20×3	584

5. RESULTS AND DISCUSSIONS

In this section, the results of ATC incorporating CBM are presented. The CBM values were evaluated using graph theory, while the ATC values between the concern areas are calculate using the repeated power flow (RPF) algorithm, as presented in section 2, considering voltage and thermal limits. After evaluating the ATC values, the CBM results for the three-area system with and without wind power (WP) integration are incorporated in ATC computation in two ways. The first method includes CBM as recallable transfer, while in the second case, the CBM values are integrated into ATC computation as a non-recallable transfer. In the first case, the value of CBM between two areas is directly deducted from the ATC value calculated between those areas. The outputs of the generators between the concerned areas are adjusted according to the value of the CBM allocation following (14) in the second case. Figure 2 shows the CBM results for the three-area system without WP; in this figure, only area 2 supports area 1 with a CBM of 79 MW. Figure 3 presents the CBM with WP integration in Areas 1, 2 and 3. The replacement of a conventional generation system with a WP system results in generation reliability degradation. Therefore, the ATCs between related areas are significantly affected, due to changes in the system's power flow, as explained in Figures 4, 5, 6 and 7. The paper's contribution is to study the influence of WP integrated CBM on ATC evaluation. Most of the existing research on ATC evaluation does not incorporate CBM in ATC calculation. The few articles [13]-[18] that integrate CBM do not include the stochastic effect of WP generation in the CBM before incorporating it in ATC despite its significant impact on CBM.

From Figure 4, there is 79 MW CBM allocation from Area2 to Arae1. Therefore, the ATC in the direction of Area1 to Area2 decreases from 593 MW to 514 MW and 549 MW for recallable and non-recallable evaluations, respectively. In the reverse direction, i.e. Area2 to Area1, ATC decreases from 1169 MW to 1090 MW and 1126 MW for recallable and non-recallable evaluations. There is no allocation of CBM from Area3 to Area1, however, the ATC in the direction of Area1 to Area3 increases from 273 MW to 281 MW for non-recallable transfer, this indicate that the power flow through Area3 has reduced due to the external supply to Area1 from Area2, thereby creating more ATC in the lines between Area1 and Area3. The ATC in the direction of Area 3 to Area1 remains the same, as shown in the Figure 4.

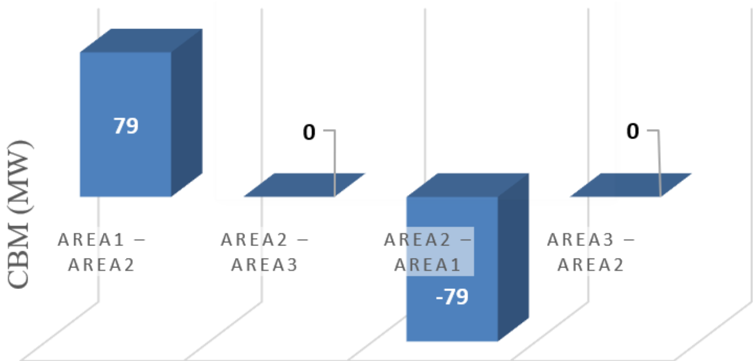


Figure 2. CMB between interconnected areas without WP

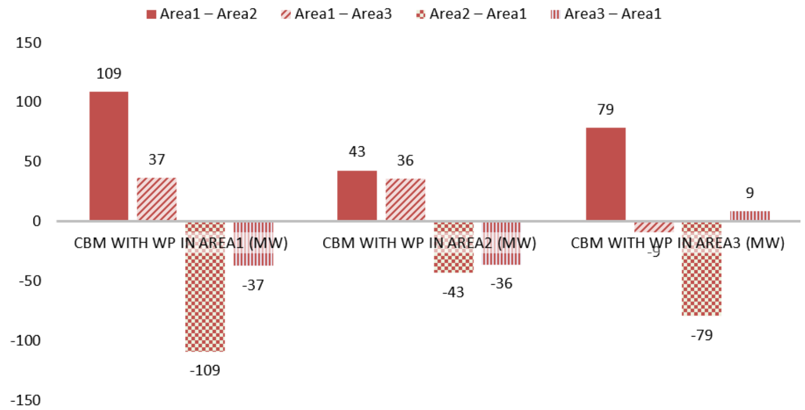


Figure 3. CMB between interconnected areas with WP integrated in all areas in sequence

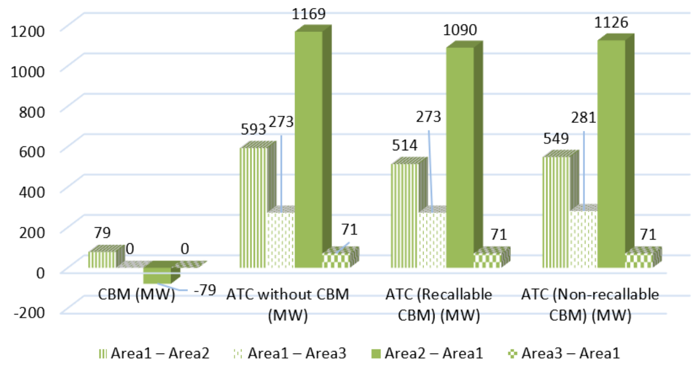


Figure 4. ATC incorporating CBM without WP

In the case where WP is integrated into Area1 as a replacement for conventional generation sources, the CBM required by Area1 increases from 79 MW to 109 MW due to the replacement of traditional generators with wind turbine generator, consequently the ATC in the direction of Area1 to Area2 decreases from 593 MW to 484 MW and 519 MW for recallable and non-recallable respectively, as indicated in Figure 5. However, the ATC in the reverse direction decreases from 1169 MW to 1060 MW and 1091 MW for both recallable and non-recallable techniques, respectively. Also, the CBM allocation from Area3 to Area1 increases from 0 MW to 37 MW compared with no WP integration in Area1. Therefore, the ATC in the direction of Area1 to Area3 drops from 273 MW to 236 MW and 257 MW for recallable and non-recallable estimations, respectively. However, the ATC in the reverse direction i.e., Area3 to Area1 decreases from 71 MW to 34 MW and 42 MW for both recallable and non-recallable evaluations, respectively. The increase in the CBM for Area1 was due to the generation reliability degradation due to replacing conventional generating units with WP systems. Therefore, CBM allocation to the area is increased from 79 MW to 146 MW. As expected, the support from Area2 could not be enough to sustain the Area1 generation reliability; therefore, the support was shared between the two supporting areas. This assessment is crucial because it helps the utility deploy the necessary measures o avoid system congestion and loss of load in the system.

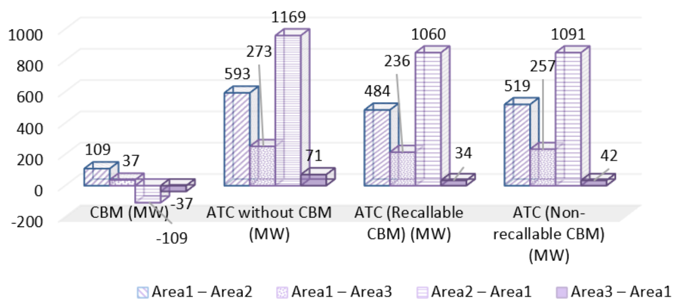


Figure 5. ATCincorporating CBM in the presence of WP in Area 1

In the case where WP is integrated to replace conventional source in Area2, the CBM support from Area2 to Area1 decreases from 79 MW to 43 MW due to the reduction in generation reliability of Area2, as shown in Figure 6. The ATC in the direction of Area1 to Area2 decreases from 593 MW to 550 MW and 571 MW for recallable and non-recallable evaluations, respectively. The ATC in the reverse direction falls from 1169 MW to 1126 MW and 1148 MW for recallable and non-recallable, respectively. It can be observed that the decrease in ATC is less compared with the case where the CBM support from Area2 was 109 MW; this is due to the reduction in the amount of flow between the areas.

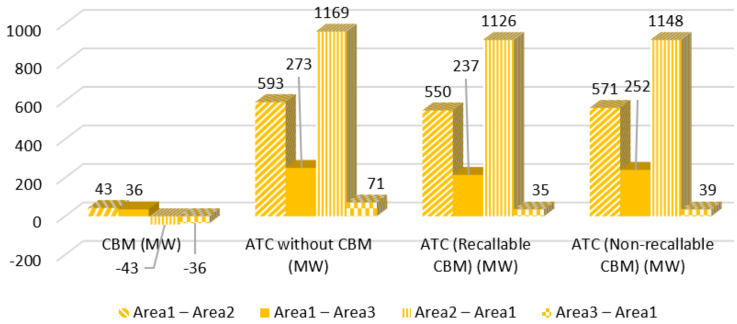


Figure 6. ATC incorporating CBM in te presence of WP Area 2

In the last case where WP is integrated in Area3, a critical scenario occurred due to degradation in the interconnected generation reliability, as shown in Figure 7. The three-area system was previously consisting of two supporting areas and one deficient area. However, due to the replacement of the convention source with WP in Area3, the system changed from two supporting areas and one deficient area to two deficient areas and one supporting area. In this case, only Area2 supports Area1 and Area3 with CBM of 79 MW and 9 MW, respectively, as shown in Figure 3. Therefore, the ATC in Area1 to Area2 decreases from 593 MW to 514 MW and 533 MW for recallable and non-recallable, respectively. However, the ATC in the reverse direction i.e., Area2 to Area1, decreases from 1169 MW to 1090 MW and 1123 MW for recallable and non-recallable approaches, respectively. This affirms that the recallable approach is unrealistic and can lead to inaccuracy in ATC computation. It has been affirmed in [13], [30], [34] that the recallable (non-firm transfer) approach can underestimate ATC. Also, the ATC in Area2 to Area3 decreases from 306 MW to 297 MW and 301 MW for recallable and non-recallable, respectively. Moreover, despite the allocation of 9 MW CBM from Area2 to Area3, the ATC from Area3 to Area2 decreases from 68 MW to 59 MW and 63 MW for the recallable and non-recallable, respectively as shown in the Figure 7.

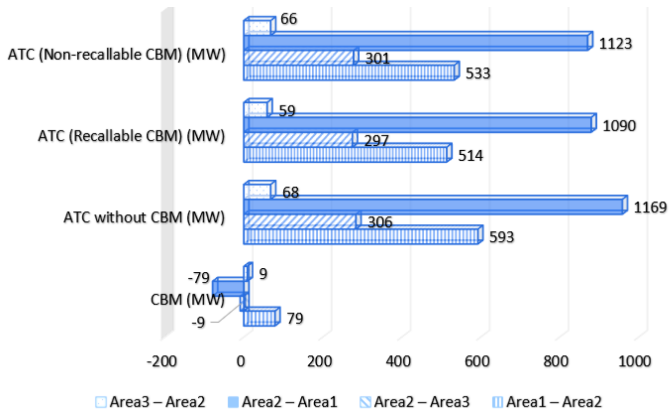


Figure 7. ATC incorporating CBM in the presence of WP Area3

It can be observed from the ATC results in Figures 4, 5, 6 and 7, that the influence of CBM allocation on ATC between interconnected areas does not solely depend on the amount of CBM allocated between the concern areas but also depends on the power flow in the interconnected system. The glaring example is the ATC in the direction of Area3 to Area2. Despite the allocation of 9 MW between the areas, the reduction in ATC is minimal (2 MW) compared to the 9 MW allocation; this is due to the change in power flow within the network.

6. CONCLUSION

ATC is an important metric used to measure the techno-economic viability of transmission networks. However, other transmission transfer capability margins need to be incorporated in the ATC evaluation for accurate assessment of this metric. Therefore, this paper presented a simple and precise strategy to assess the influence of wind power (WP) integrated CBM in ATC evaluation. Most of the existing approaches for ATC computation do not incorporate the stochastic effect of renewable energy in the CBM evaluation before integrating it in ATC computation despite its influence on ATC evaluation. In this study, the impact of CBM with and without WP on ATC is assessed. To effectively study the effect on ATC, WP was integrated into the system as a replacement for the conventional power generation, unlike the existing techniques where WP is usually incorporated as an additional generation source. The results of ATC without CBM, with CBM without wind power, and with CBM in the presence of wind power are compared. The proposed approach employed graph theory for CBM computation, and the CBM is incorporated in ATC using RPF. The obtained results have revealed that assessment of ATC without CBM incorporation would lead to overestimation or underestimation of ATC, which could threaten the security or result in underutilization of the transmission network resources. The modified IEEE RTS is employed for the implementation of the proposed approaches. Most of the existing methods of incorporating CBM in ATC do not consider stochastic wind power behaviour in CBM evaluation. They are basically relied on heuristic and optimization approaches which are inaccurate and time-consuming, respectively. The contribution of this paper, unlike the existing techniques where capacity benefit margin (CBM) is incorporated in Available Transfer Capability (ATC) without considering the stochastic nature of renewable energy sources in CBM. This paper considers the multistate output of wind power in the CBM evaluation before it was incorporated in ATC computation. Moreover, the wind power system replaced some percentage of conventional generation sources instead of adding it to the existing generation sources to effectively study the influence on the system generation reliability. Transmission operators can employ this approach to assess the viability of the system for possible power transactions.

REFERENCES

[1] W. W. Hogan, "Electricity market structure and infrastructure," in *Acting in Time on Energy Policy Conference, Harvard University*, 2008.

[2] O. O. Mohammed, M. W. Mustafa, D. S. S. Mohammed, and A. O. Otuoze, "Available transfer capability calculation methods: A comprehensive review," *International Transactions on Electrical Energy Systems*, vol. 29, no. 6, pp. 1–24, 2009, doi: 10.1002/2050-7038.2846.

[3] A. A. O. Mohammed, M. Mustafa, A. Otuoze, and S. Salisu, "A review of probabilistic approaches for available transfer capability calculation," *Arid Zone Journal of Engineering, Technology and Environment*, vol. 15, no. 1, pp. 97–108, 2019.

[4] R. Rajathy, "Investigations on power system operation and management in restructured market," Ph.D. dissertation, *Dept. of Electrical & Electronics Engg.*, Pondicherry University, 2011.

[5] M. T. T. Jamasb, R, Nepal, and G. Timilsina, "Energy Sector Reform, Economic Efficiency and Poverty Reduction," University of Queensland, Australia, 2014.

[6] M. S. S. and S. G. Ankaliki, "Computation of Available Transfer Capability in Electrical Transmission System-A Review," *i-Manager's Journal on Power Systems Engineering*, vol. 5, no. 1, pp. 35–39, 2017.

[7] W. Kröger, "Critical infrastructures at risk: a need for a new conceptual approach and extended analytical tools," *Reliability Engineering & System Safety*, vol. 93, no. 12, pp. 1781–1787, 2008, doi: 10.1016/j.ress.2008.03.005.

[8] B. M. P. K. Hota, "Automatic generation control of multi source power generation under deregulated environment," *International Journal of Electrical Power & Energy Systems*, vol. 75, pp. 205–214, 2016, doi: 10.1016/j.ijepes.2015.09.003.

[9] A. P. and A. P. Fathima, "Critical research areas on load frequency control issues in a deregulated power system: a state-of-the-art-of-review," *Renewable and Sustainable Energy Reviews*, vol. 72, pp. 163–177, 2017, doi: 10.1016/j.rser.2017.01.053.

[10] X. W. and W. F. T. G. C. Ejebe, J. Tong, J. G. Waight, J. G. Frame, "Available transfer capability calculations," *IEEE Transactions on Power Systems*, vol. 13, no. 4, pp. 1521–1527, 1998, doi: 10.1109/59.736300.

[11] Q. W. Ali and A. ul Asar, "Smart Power Transmission System Using FACTS Device," *International Journal of Applied Power Engineering (IJAPE)*, vol. 2, no. 2, pp. 61–70, 2013.

[12] N. Rep, "Available Transfer Capability Definitions and Determination," *North American Electric Reliability Council*, 1996.

[13] Y. Ou and C. Singh, "Assessment of available transfer capability and margins," *IEEE Transactions on Power Systems*, vol. 17, no. 2, pp. 463–468, 2002, doi: 10.1109/TPWRS.2002.1007919.

[14] "Transmission Capability Margins and Their Use in ATC Determination, White Paper, Available Transfer Capability Working Group," *The Nourth American Electric Reliability Council*, 1999.

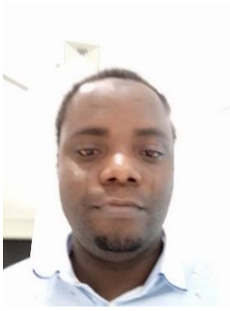
[15] M. P. M. M. Ramezani, M. Haghifam, C. Singh, H. Seifi, "Determination of Capacity Benefit Margin in Multiarea Power Systems Using Particle Swarm Optimization," *IEEE Transactions on Power Systems*, vol. 24, no. 2, pp. 631–641, 2009, doi: 10.1109/TPWRS.2008.2005712.

[16] A. P. Ford and W. L. Harm, "Market based adequacy: reliability and CBM/ATC calculations. An independent system operator's perspective," *IEEE Power Engineering Society Winter Meeting. Conference Proceedings (Cat. No.02CH37309)*, vol. 1, pp. 18–23, 2002, doi: 10.1109/PESW.2002.984932.

[17] H. K. R. Rajathy, R. Gnanadass, K. Manivannan, "Computation of capacity benefit margin using differential evolution," *International Journal of Computing Science and Mathematics*, vol. 3, no. 3, pp. 275–287, 2010, doi: 10.1504/IJCSM.2010.037448.

[18] V. A. I. S. M. Karuppasamypandiyan, P. A. Jeyanthy, D. Devaraj, "Day ahead dynamic available transfer capability evaluation incorporating probabilistic transmission capacity margins in presence of wind generators," *International Transactions on Electrical Energy Systems*, vol. 31, no. 1, 2021, doi: 10.1002/2050-7038.12693.
[19] G. A. K. O. Ibrahim, S. A. Amuda, O. O. Mohammed, "Performance Evaluation of three PID Controller Tuning Algorithm on a process plant," *International Journal of Electrical and Computer Engineering*, vol. 5, no. 5, pp. 1075–1082, 2015, doi: 10.11591/ijece.v5i5.pp1075-1082.
[20] O. O. M. S. Salisu, M. W. Mustafa, L. Olatomiwa, "Assessment of technical and economic feasibility for a hybrid PV-wind-diesel-battery energy system in a remote community of north central Nigeria," *Alexandria Engineering Journal*, vol. 58, no. 4, pp. 1103–1118, 2019, doi: 10.1016/j.aej.2019.09.013.
[21] J. A. T. S. Salisu, M. Wazir, O. O. Mohammed, M. Mustapha, "Techno-Economic Feasibility Analysis of an Off-Grid Hybrid Energy System for Rural Electrification in Nigeria," *International Journal of Renewable Energy Research*, vol. 9, no. 1, 2019, doi: 10.20508/ijrer.v9i1.8873.g7581.
[22] H. K. M. Hammoud, J. Hallal, T. Moussa, "Techno-economic study of a hybrid power generation system at the Lebanese coastal highways," *International Journal of Applied Power Engineering*, vol. 10, no. 4, pp. 373–382, 2021, doi: 10.11591/ijape.v10.i4.pp373-382.
[23] EUR-Lex, "Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC," *Special edition in Croatian*, vol. 11, pp. 39–85, 2009.
[24] N. A. R. O. O. Mohammed, A. O. Otuoze, S. Salisu, O. Ibrahim, "Virtual synchronous generator: an overview," *Nigerian Journal of Technology*, vol. 38, no. 1, pp. 153–164, 2019, doi: 10.4314/njt.v38i1.20.
[25] G. Luo *et al.*, "Fast calculation of available transfer capability in bulk interconnected grid," *IEEE Power and Energy Society General Meeting*, pp. 1–8, 2012, doi: 10.1109/PESGM.2012.6343973.
[26] R. Billinton and W. Li, "Reliability assessment of electric power systems using Monte Carlo methods," Springer Science & Business Media, Berlin, Heidelberg, 2013.
[27] O. O. Mohammed, M. W. Mustafa, D. S. Sasi Mohammed, S. Salisu, and N. Ahmad Rufa'i, "A systematic approach to evaluating the influence of demand side management resources on the interarea capacity benefit margin," *Bulletin of Electrical Engineering and Informatics*, vol. 8, no. 4, Dec. 2019, doi: 10.11591/eei.v8i4.1587.
[28] O. O. Mohammed, M. W. Mustafa, and M. N. Aman, "A Graph-Theoretic Approach to Capacity Benefit Margin Calculation for Large Multiarea Power Systems," *IEEE Systems Journal*, vol. 14, no. 1, pp. 1230–1233, Mar. 2020, doi: 10.1109/JSYST.2019.2910554.
[29] O. O. Mohammed, M. W. Mustafa, M. N. Aman, S. Salisu, and A. O. Otuoze, "Capacity benefit margin assessment in the presence of renewable energy," *International Transactions on Electrical Energy Systems*, vol. 30, no. 9, Sep. 2020, doi: 10.1002/2050-7038.12502.
[30] M. M. Othman, A. Mohamed, and A. Hussain, "Available transfer capability assessment using evolutionary programming based capacity benefit margin," *International Journal of Electrical Power & Energy Systems*, vol. 28, no. 3, pp. 166–176, Mar. 2006, doi: 10.1016/j.ijepes.2005.11.017.
[31] Y. Boykov and V. Kolmogorov, "An experimental comparison of min-cut/max- flow algorithms for energy minimization in vision," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 26, no. 9, pp. 1124–1137, Sep. 2004, doi: 10.1109/TPAMI.2004.60.
[32] C. Grigg *et al.*, "The IEEE Reliability Test System-1996. A report prepared by the Reliability Test System Task Force of the Application of Probability Methods Subcommittee," *IEEE Transactions on Power Systems*, vol. 14, no. 3, pp. 1010–1020, 1999, doi: 10.1109/59.780914.
[33] R. Karki, P. Hu, and R. Billinton, "A Simplified Wind Power Generation Model for Reliability Evaluation," *IEEE Transactions on Energy Conversion*, vol. 21, no. 2, pp. 533–540, Jun. 2006, doi: 10.1109/TEC.2006.874233.

BIOGRAPHIES OF AUTHORS



Olatunji Obalowu Mohammed received the B.Eng. degree in Electrical Engineering from Bayero University Kano, Nigeria. He obtained his MSc in Electrical and Electronics Engineering from Coventry University, Coventry, UK and Ph.D in Electrical Engineering at the School of Electrical Engineering, Universiti Teknologi Malaysia (UTM) in 2014 and 2019 respectively. He is currently a Postdoctoral Fellow in the School of Electrical Engineering, Universiti Teknologi Malaysia. He is also a Lecturer at the Department of Electrical and Electronics Engineering, University of Ilorin, Nigeria. He is a Registered Engineer with Council for the Regulation of Engineering in Nigeria (COREN), Member of the Nigerian Society of Engineers (MNSE) and IEEE member. His research area is on Energy efficiency, Demand side management, transfer capability assessment, sustainability and control of Renewable energy and distributed system. He has published more than 30 publications in variouis Journals and conference proceedings. He can be contacted at email

Mohd Wazir Mustafa received his B. Eng. Degree (1988), M. Sc. (1993) and PhD (1997) from University of Strathclyde, Scotland, UK. He is currently a Professor and the Chair of the School of Electrical Engineering, Universiti Teknologi Malaysia. He is a member of Institution of Engineers, Malaysia (IEM) and a member of IEEE. His research interest includes power system stability, FACTS, wireless power transmission and power system distribution automation. He has published books, and has more than 300 publications in variouis Journals and conference proceedings.

Ahsanullah Memon is currently pursuing his Ph.D. from Universiti Teknologi Malaysia. He did his B.E and ME in electrical engineering from Mehran University of Engineering and Technology, SZAB Campus Khairpur Mirs, Pakistan. His area of interest is Machine learning, optimization, Power system analysis, Power Quality, Grid Integration of Renewable Energy Sources.

Saddam Hussain currently doing PhD in Electrical Engineering from UTM, JB Malaysia. He has done M.E and B.E in Electrical Power engineering from MUET, Jamshoro Pakistan. His area of interest are Machine learning, Power system Distribution and Power system analysis.

Sani Salisu is a senior Lecturer in the Department of Electrical Engineering, Ahmadu Bello University Zaria, Nigeria. He obtained his B.Eng Electrical Engineering from Ahmadu University Zaria, Nigeria. MSc in Renewable Energy Engineering from Kingston University London and PhD Electrical Engineering from Universiti Teknologi Malaysia. He has more than 50 publications including journals and conferences presented nationally and internationally. His main research interest includes nano grid/micro grid design, load forecasting, renewable energy systems control, Energy efficiency.

Abdulrahaman Okino Otuoze is a Senior Lecturer at the Deptment Of Electrical and Electronics Engineering, University of Ilorin, Ilorin, Nigeria. He obtained B.Eng. in Electrical Engineering, M.Eng. in Power and Machines and PhD in Electrical Engineering from University of Ilorin, Ilorin, University of Benin, Benin, you and University Teknologi Malaysia, Johor in 2008, 2012 and 2020, respectively. He specializes in the areas of Smart Girds, Electricity Theft Detections and general Electrical Power Systems and Machines. He is a Registered Engineer with Council for the Regulation of Engineering in Nigeria (COREN), Member of the Nigerian Society of Engineers (MNSE) and IEEE member. He has published more than 30 publications in various Journals and conference proceedings.

Oladimeji Ibrahim graduated with B.Eng degree in Electrical Engineering from the University of Ilorin, Nigeria in 2005. He obtained Masters degree in Applied Instrumentation and Control from Glasgow Caledonian University, the UK in 2009 and PhD degree in Electrical and Electronics Engineering from the Universiti Teknologi PETRONAS (UTP), Malaysia in 2018. He is currently a senior lecturer in the Department of Electrical and Electronics Engineering, University of Ilorin, Ilorin Nigeria. His research interests include modelling and control of power converters, demand-side management and energy efficiency, renewable energy interface scheme and microgrid control. Oladimeji is a member of The Nigerian Society of Engineers (MNSE), The Institute of Electrical & Electronics Engineers (MIEEE) and The Institute of Measurement and Control (MInstMC) UK.