Determination of Available Transfer Capability (ATC) Of The 330kv Nigeria Grid in A Deregulated Electricity Market

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Abstract- Deregulation of electricity industry throughout the world is aimed at creating a competitive market to trade electricity and Nigeria had just taken a queue. This generates a host of new technical challenges to market participants and power system researchers especially in the generation and distribution value chain. The transmission corridor remains the same for evacuation of electrical energy. Every player in the industry wants to maximize profit, as such the number of transaction increases. This may lead to congestion in transmission network when generation companies compete to sell electricity to the distributors or wholesale purchasers. To avoid congestion every operator should know the value of available transfer capability (ATC) remaining in the physical transmission network before every transaction. Determination of available transfer capability (ATC) is a complex task which has to be done at periodic intervals for each source and sink pairs. This requires real – time pre-determination of an index termed available transfer capability, between every possible pair of source (selling or injection point) and sinks (purchase or extraction point) buses. This becomes very important especially now that there is paucity of fund due to the present economic recession the country is facing as well as environmental concern which may not favor expansion of the grid. ATC between a given pair of source and sink buses is quantified by the allowable highest magnitude of active power (mw) that than be transferred from the source to the sink over and above already committed uses (base case) without violating the network limits. Though many methods abound to determine ATC, the most accurate method is repeated power flow using Newton Raphson (RPFN-R). Therefore the RPFN-R approach was used in this research work on a 3-bus system. The same system was simulated using power world simulator and the difference between ATC obtained from both procedures was negligible justifying its accuracy. A 52-bus system was further modeled determining the available transfer capability between nodes and areas. The solutions obtained are quite encouraging and useful in the present restructuring environment.

Indexed Terms- ATC, RPFN-R, 52-bus,

I. INTRODUCTION

The once bundled and vertically integrated structures in electric power system are changing to competitive, privatized and deregulated frameworks, around the globe. In the current electricity markets, transmission grids are going to function very close to their thermal and voltage limits. This is because the structure of electricity market has changed following deregulation. However, the transmission asset is still a regulated and monopolistic franchise business. An entity called independent system operator (ISO) is established with the sole responsibility of organizing the operation of the grid in order to get a secure and reliable operation of the system while also considering the economic factor. The ISO should discharge its duty independently and indiscriminately without participating in the market operation. In order to have open access and competition in the market, the first thing is to provide a detailed and transparent knowledge of the generation capacity as well as the transmission capability of the system to the players in the electricity industry. It is, therefore, imperative to know the amount of extra power that can be transferred from one point to another or from generators to loads in the power system at this moment and in future from the view point of system operation and planning.

Additionally, independent power producers and customers should have access to the transmission network; hence it becomes very crucial for the ISO to check the capability of the transmission path (ATC) as simply and efficiently as possible before the transaction of power through it is allowed [2].

II. BACKGROUND OF STUDY

Available Transfer Capability (ATC) is the measure of transfer capability available in a physical transmission network for further commercial activity over and above already committed uses. NERC (2012). It is the maximum amount of power above the present transactions that can be transferred reliably from one point to another over the transmission element without violating the security constraint.

In other words it is the un-utilized capability of transmission network.

Mathematically,
ATC = TTC – TRM – (ETC+CBM)
[15].

Where
ATC – Available Transfer Capability
TTC – Total Transfer Capability
TRM - Transmission Reliability Margin
ETC – Existing Transmission Commitments
CBM –Capability Benefit Margin

III. ATC TERMINOLOGIES

1. Total transfer capability (TTC) is defined as the summation of the electric power that can be transferred over the interconnected transmission network or particular or interface in a reliable manner while meeting all of a specific set of defined pre and post contingency system conditions.
2. Transmission Reliability Margin (TRM) is defined as that amount of transmission transfer capability necessary to ensure that the interconnected transmission network (the grid) is secure under a reasonable range of uncertainties in system conditions.
3. Capacity Benefit Margin (CBM) is defined as that amount of transmission transfer capability reserved for load serving entities on the host transmission system to ensure access to generation from interconnected system to meet generation reliability requirements. CBM is a part of TTC reserved by the serving entities in order to meet generation reliability in case of generation deficiency condition.
4. Existing Transmission Commitments (ETC) is the power flow over the transmission paths at the initial time before the ATC is calculated. This is the already committed used power on the transmission path.

   Competitive Electricity Market is a restructured/unbundled system in which power producers (Suppliers) compete with each other to provide the best possible service at lowest cost in order to attract and retain customers.

   The transmission corridor is a vital mechanism in competitive electricity markets. In a restructured power system, the transmission network is where generators compete to supply large users and distribution companies [12].

However, with increase in demand due to rapid industrialization and urbanization recent years have witnessed, in some countries, participation of private companies termed Independent Power Producers IPPs) in the generation sector. The IPPs sell electricity to the utilities. Since mid-1990s, in view of the key role played by electricity, and customer benefits achievable from competition under a free market configuration, the electric utilities all over the world have been subjected by governments to the process of a gradual transition from a regulated and monopolistic configuration towards a full-scale deregulation. In the new environment, the generation, transmission and distribution sectors are unbundled as independent entities to promote competition in supplying affordable but reliable electricity to the consumers.

With the deregulation of power sector, several independent power producers have evolved in the country thereby creating opportunity for competition, this development has also led to the increase in the amount of electric power generated in the country to about 4,405.60MW as at May 2017(Transmission Company of Nigeria plc (TCN) OSOGBO)

With such competition in the market, and corresponding increase in power been generated, accurate determination of ATC in transmission network becomes paramount

In a competitive environment, proper transmission pricing could meet revenue expectations, promote an efficient operation of electricity markets and most importantly promote fairness and be practical. However, it is difficult to achieve an efficient transmission pricing scheme that could fit all market structures in different locations [19].

IV. METHODOLOGY AND RESULT

a) Review of related literature on ATC and competitive electricity marketing from 2007 – 2015.
b) The real power, reactive power, bus voltages and angles of the Nigeria 330kv network. From Jan. 2015 – May 2017 was obtained from the National Control Centre (NCC), *Oshogbo*.
c) The repeated power flow method was used to obtain the power flows through the transmission line in the network.
d) Obtain the values of real power to compute ATC of the network.
e) Simulation of the network using power world simulator (PWS).
f) The effect of line contingency and generator contingency was evaluated and observed in the simulated network.

A part of the northern section of Nigeria 330KV grid network is used as a case study in determining available transfer capability. The 3-bus system is considered;

V. PROCEDURE FOR USING RPFN-R

In applying Newton Raphson power flow equations, a base case (system initial conditions) is established and solved. The solution of the base case produces the transfer case which is done iteratively until convergence.

The values for the real power, reactive power; bus voltage and voltage angles are obtained as follows:

$$Pi = \sum_{k=1}^{n} /Y_{ik}/V_i/V_k\cos(\theta_{ik} - \delta_i + \delta_k) \quad \ldots\ldots\ldots\ldots\ldots 3.1$$

$$Qi = -\sum_{k=1}^{n} /Yik/Vi/Vk/Sin(\theta_{ik} - \delta_i + \delta_k) \quad \ldots\ldots\ldots\ldots\ldots 3.2$$

After several iterations using the two equations above values were obtained as shown on tables.

VI. ATC EVALUATION

$$ATC = \sum(P_{gi} - P_{LI}) - \sum(P_{gi} - P_{ij}) \quad \ldots\ldots\ldots\ldots\ldots 3.3$$

ATC (Kainji-Birnin Kebbi)

ATC = [(-17.6-0) - 0] – [(0-(356 - 69.9)]

ATC = -17.6 + 343= 269.5

ATC (Kainji- Jebba) = $\sum(P_{gi} - P_{LI}) - \sum(P_{gi} - P_{ji})$

[(-17.6-0) - 0]- [(115 -240)-0] = -17.6 + 125= 109.4

ATC (Jebba-Birnin Kebbi) = $\sum(P_{gi} - P_{LI}) - \sum(P_{gi} - P_{LJ})$

[(115 – 240)] – [(0 - (356 - 69.9)] = -93.4

VII. SIMULATION- 52-BUS NETWORK IN A NORMAL CONDITION

The entire 52 bus of Nigeria 330kv transmission network was also modeled using the power world simulator, the power flow was obtained and the ATC from one bus to another was determined including the ATC between areas.

These results obtained were analyzed and explained within the context of this research satisfying the claims that accurate determination of ATC facilitates congestion management, transmission pricing and transmission reservation.

Determination of available transfer capability does not only show us how much power can be sent through a particular network at a point in time, it also shows us the transactions that are not possible considering the constraints and limits of the system. When you reverse the order of transaction in table 4.8, in order words when the buyer becomes seller and seller becomes buyer, you will discover that the available transfer capability becomes positive. This shows you the transactions that are possible, if this order is violated, it will lead to congestion and overloading in the network.

It becomes clear how ATC can be used to determine the possibility of a transaction, direction of transaction and manage congestion in the network. The figures in table 4.5, shows the amount of extra power that can still be sent through the respective lines over and above their commitments. The result shows you which lines are congested and the quantity of electric power being passed through such lines. This helps you in discovering causes of congestion in the network and possible solution because the paradigm of power flow is revealed. Consequently, you realize that the amount of electric power which eventually get to stations that are far away from the Generating stations becomes little (such as *Yola, and Maiduguri*) thereby delivering poor services in those areas.

The excess power in these congested transmission lines can be re-dispatched through other lines that have available transfer capability to ensure stability in this Network. More so, transmission lines can be strategically introduced into the network to boost the ATC of the network.

VIII. CONTINGENCES

Two contingencies were considered namely:

a) Line contingency
b) Generator contingency

IX. SIMULATION - 52-BUS NETWORK CONSIDERING LINE CONTINGENCY

It was observed that the system reacted to sudden disturbances in the network, when the *Kaduna – Kano* line was opened, the bus and line parameters were seen to vary and consequently the ATC of the network. In the case of line contingency, the value of the ATC in most lines were observed to have increased, the figure below shows the modeled network when *Kaduna – Kano* was opened. The ATC for most lines when the Kaduna – Kano line was opened were positive in contrast to the ATC under normal condition which were largely negative. It can therefore be inferred that ATC increases with increase in the power generated by the system or reduction in the load connected to the system. It also shows us how the ATC of all the lines can be altered with a single disturbance in a particular part of the network, therefore affecting the general performance of the system. In fact this was proven with the generator contingency, when the Jebba G.S was removed, the ATC of most of the lines were observed to have reduced.

X. SIMULATION - 52-BUS NETWORK (GENERATOR CONTINGENCY)

In considering the effect of generator contingency on the power flow and ATC of the network, Jebba GS was removed from the network and the model was obtained.

The information of ATC displayed by the ISO on the OASIS helps both the buyers and sellers to plan about transaction to be made. It helps in ensuring that transactions are adequately economic and secure. It also gives sellers an idea of how much power to transfer or reserve.

XI. AREA POWER TRANSFER

The 52 bus system that was modeled was divided into four areas, area 1, area 2, area 3, and area 4respectively. In an attempt to transfer power form area 1 to area 2, area 2 to area 3, area 3 to area 4 the major tie-line connecting the four areas must be located first which happens to be the transmission line between *Jebba GS, shiroro* GS, *Oshogbo* and Benin Then the ATC is determined accordingly.

XII. SUMMARY OF FINDINGS

Transfer capability plays an important role in bi-lateral energy market. It indicates the amount of extra power that can be transferred on a transmission network between two interconnected buses or areas.

From this research work, it is safe to say that computation of transfer capability is essential and useful for the following reasons:

1. Available transfer capability is indicative of the relative system security
2. Available transfer capability is very useful in system planning

3. It helps in appreciating the effects of multi area commerce and transactions.
4. It helps in furnishing details of in expensive power likely to be available to insufficient generation or high cost regions.
5. It is a useful tool in evaluating transmission reservations in energy market applications.

XIII. RECOMMENDATIONS

I strongly recommend that the Transmission Company of Nigeria (TCN) adopts this model to make the current power sector privatization worthwhile.

Also, the bulk traders can use this model to make their work easy and bring efficiency to the grid.

Finally, I recommend that further research be carried out cover more buses so as to take care of future expansion in grid.

S/N	BUS NAME	GENERATOR		LOAD		VOLTAGE(pu)	ANGLE (Degree	BUS TYPE
		P	Q	P	Q			
1	Shiroro	-	-	41	21	1.041	-26.02	PQ
2	Afam vi	340	83	-	-	1.038	-34.59	PV
3	Ikot Ekpene	-	-	239	27	1.042	-21.41	PQ
4	Port Harcourt	-	-	63	30	1.023	-12.44	PQ
5	Aiyede	-	-	150	94	1.038	-14.47	PQ
6	Ikeja West	-	-	964	172	1.002	-27.61	PQ
7	Olorunsogo	145	52	-	-	1.043	-18.67	PV
8	Aja	-	-	100	62	1.023	-33.82	PQ
9	Egbin P.S	348	143	-	-	1.04	-13.68	PV
10	Ajaokuta	-	-	215	134	0.986	-8.95	PQ
11	Benin	-	-	289	130	1.032	-8.45	PQ
12	Geregu	322	77	-	-	1.043	-9.54	PV
13	Lokoja	-	-	239	166	1.022	-9.56	PQ
14	Akangba	-	-	193	120	1.021	12.45	PQ
15	Sapele	219	76	-	-	1.029	-11.31	PV
16	Aladja	-	-	131	106	1.001	-11.69	PQ
17	Delta P.S	300	98	-	-	1.045	-10.69	PV
18	Alaoji NIPP	197	38	-	-	1.034	-6.53	PV
19	Aliade	-	-	26	19	1.037	-28.91	PQ
20	New Haven	-	-	80	66	1.052	-23.38	PQ
21	New Haven South	-	-	47	26	0.964	-12.11	PQ
22	Makurdi	-	-	31	24	0.931	-14.76	PQ
23	B.Kebbi	-	-	-	-	0.985	7.32	PQ

24	Kainji	333	133	-	-	1.012	-9.62	Slack
25	Oshogbo	-	-	77	50	1.044	-12.66	PQ
26	Onitsha	-	-	77	50	1.021	-9.72	PQ
27	Benin North	-	-	31	19	1.042	-11.09	PQ
28	Omotosho	283	83	-	-	1.051	-13.57	PV
29	Eyaen	-	-	29	17	1.023	-6.56	PQ
30	Calabar	-	-	213	142	1.035	0	PQ
31	Alagbon	-	-	19	12	0.993	-12.31	PQ
32	Damaturu	-	-	37	24	0.934	-19.69	PQ
33	Gombe	-	-	124	63	0.941	-25.65	PQ
34	Maiduguri	-	-	49	33	0.943	-8.03	PQ
35	Egbema	-	-	18	11	1.032	-18.11	PQ
36	Omoku	85	10	-	-	1.045	-33.38	PV
37	Owerri	-	-	181	102	1.023	-9.11	PQ
38	Erunkan	-	-	260	106	0.932	-34.76	PQ
39	Ganmo	-	-	214	115	0.983	-14.22	PQ
40	Jos	-	-	94	42	0.937	-11.44	PQ
41	Yola	-	-	46	13	0.921	-6.86	PQ
42	Gwagwalada	-	-	18	11	0.998	-24.32	PQ
43	Sakete	-	-	174	40	0.983	-8.29	PQ
44	Ikot Abasi	-	-	46	32	1.024	-13.47	PQ
45	Jalingo	-	-	88	11	0.929	-4.45	PQ
46	Kaduna			188	98	0.992	-8.61	PQ
47	Jebba G.S	177	67	298	103	0.994	-15.43	PV
48	Kano	-	-	298	103	0.994	-9.05	PQ
49	Katampe	-	-	264	73	1.001	-8.48	PQ
50	Okpai	319	86	-	-	1.034	-12.45	PV
51	Jebba TS	-	-	258	173	1.045	-7.97	PQ
52	Odukpani	310	149	-	-	1.023	-12.18	PV

XIV. CONTRIBUTION TO KNOWLEDGE

The research work introduced the concept of Area Power Transfer where the respective areas serve as independent grids with tie-line interconnecting each other for power transfer between the areas in case of contingencies thereby improving the stability and security of network greatly.

This research work has been able to introduce a direct bilateral transaction between the Gencos and Discos as well as the Bulk Electricity Trading Company of Nigeria (the off-takers). The job of the off-takers is thereby simplified with the help of this model thereby enhancing flexibility and economic efficiency where the Bulk Traders through the ISO only determines the possibility of the transaction in terms of ATC and system security

CONCLUSION

In this research work, the Newton *Raphson* power flow method was used to compute the available transfer capability of a 3-bus and 52-bus systems from bus to bus, and area to area. The results obtained using the Newton *Raphson* power flow on the 3-bus system was compared to the results of the modeled network and the difference/error was evaluated. The difference was observed to be negligible.

From this research work, the effect of contingencies (sudden disturbance) on the Available Transfer capability of a transmission network was considered. When line contingency occurs the ATC of the network improves or increases, while Generator contingency reduces the ATC of the network.

This research work also established how to accurately and easily pick the transmission lines that are congested and deal with those congestion either by re-dispatching the excess power being transferred, allocating the congestion changes on the source and sink Pair responsible for the congestion or even opening such a line completely. This is done by ISO.

In the current deregulated environment, players in the electricity market can consume energy in huge amounts, forcing transmission lines to be operated beyond their capacities resulting in congestion. Congestion can lead to increase in market price and may become an obstacle to the open electricity trade in the current deregulated market. This work did not just show methods of computing ATC but also showed how this computation can be useful in congestion management transmission pricing and transmission reservation.

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