Effect of Contingency on Available Transfer Capability (Atc) of Nigerian 330kv Network

[*1]A. A. Sadiq, [2]M. N. Nwohu, [3]J. G. Ambafi, [4]L. J Olatomiwa

[1, 2 3, 4]Department of Electrical and Electronics Engineering, Federal University of Technology, Minna, Nigeria

[*1]ahmad.abubakar@futminna.edu.ng

***Abstract*-Transfer capability Evaluation requires the consideration of various pre- and post- systems contingency to ascertain network security and the reliability of power system. In this paper, the effects of single line (N – 1) outage contingency and simultaneous transfer were considered in the Nigerian 330KV network. The result shows that a single line outage not only lower the ATC but can result in an infeasible operating condition (system collapse) of the Nigerian 330KV power grid. Moreover, an additional source area results in higher transfer capability.**

Keywords- Available Transfer Capability; Contingency; Line Outage; Simultaneous Transfer

I INTRODUCTION

Typically, the transmission system (or the grid) refers to the high-voltage, networked system of transmission lines and transformers. Transfer of bulk electrical power between areas over long distances is preferred in order to have a reliable and economical electrical power supply. For example, hydroelectric power generated can be transferred to load centres by using the high voltage transmission system [1]. A transmission element is however limited in capacity to transfer power because of the distinction between capacity and capability.

In power systems planning and operation, unpredictable events such as line outage, loss of load or generator and control action due to transients' condition is termed as contingency, and may often be caused by line outage in the system which could lead to entire system instability [2]. The investigation of the effects of contingency on line power flows, bus voltages and stability of the remaining system (post contingency) represents an important tool to study the effect of elements outages in power system security during planning and operation. Contingencies referring to disturbances such as transmission element outages or generator outages may cause sudden and large changes in both the configuration and the state of the system. Contingencies may result in severe violations of the system operating constraints. Consequently, planning for contingencies forms an important aspect of secure operation in the presence of emerging Nigerian power market deregulation.

North American Electric Reliability Council [3] in 1995 reviewed its reference document on transfer capability in order to provide clarification and framework on the requirement for transfer capability computations. First Contingency Total Transfer capability (FCTTC) is defined as First Contingency Incremental Transfer capability (FCITC) plus normal base case power transfers while, FCITC is the amount of electric power incremental above base case within acceptable constrained limitation ranges such that:

- Pre- contingency operating procedures allows all facilities loading within normal rating;
- The system returns to stability after any disturbances like single line (N -1) outage;
- Post contingency system has all facilities within acceptable emergency loading limits.

Total Transfer capability (TTC) is the same as the FCTTC while first contingency incremental transfer capability is now termed Available transfer capability [4].

An understanding of the effects of contingency on transfer capability of transmission interface can be critical to both the system operator and the market participants. Certainly, disturbances and discrete events such as line outage and simultaneous transactions can affect transfer capability [5]. Moreover transfer between neighbouring areas can cause power flows through the entire transmission network, and while another area is also engaged in loading its own transaction at the same time with the power flows. In reality this simultaneous transfer can counteract each other often with an unknown effect on transfer capability. Consequently, transfer capability is quantified by considering the effects of contingencies. In general, it is much easier to monitor the normal state power flows across an interface than to monitor the transfer capability of individual lines under normal and contingency states. Therefore, transfer capability are dependents on line outage contingencies considered, hence contingencies have to be taken into consideration in practice [6-8].

In Single line (N – 1) outage Contingency procedures, model of a single equipment failure event, that is one line or one generator outage; or multiple equipments failure events, that is two transmission lines, a transmission line and a generator, are simulated one after another in sequence until all credible outages have been studied. For each outage tested, the contingency analysis procedure checks all power flows and voltage levels in the network against their respective limit [9, 10].

In this paper, single line (N – 1) outage contingency and simultaneous power transfer were considered in the case study network (Nigeria 330KV).

A. The Nigeria 330kv Network

Nigerian 330kV voltage level heretofore is referred to as the Nigerian grid. In PSAT environment, the Nigerian grid is a power network of thirty two (32) buses, twenty seven (27) transmission lines and seven (7) generating stations. Capacity of the installed generating stations of the Nigerian grid is 7, 461MW which includes hydro resources and gas fired (thermal) plant. Nigerian grid consist of 5, 523.8km of 330 kV transmission lines and thirty two (32) 330/132kV substations with installed transformation capacity totalling 7, 688 MVA (which amount to 6, 534.8 MW). The Average Available Capacity on 330/132kV is 7, 364MVA that is about 95.8% of Installed capacity [11, 12]. The case study in this paper (Nigerian grid system), is zoned into four islanded areas which conforms with the control structure of the electric utility, Power Holding Company of Nigeria (PHCN). Table 1 gives the location of the seven power generating station and their respective installed capacity. A detail of the Nigerian 330KV is given in Ref. [13].

TABLE 1 ELECTRICITY POWER STATIONS OF THE NIGERIAN POWER GRID

Power Station	Egbin	Sapele	Afam	Delta	Kainji	Shiroro	Jebba
Type/Fuel Used	Gas	Thermal	Thermal	Thermal	Hydro	Hydro	Hydro
Installed Capacity(MW)	1320	1020	969.6	912	760	600	578.4

Source: PHCN (2004)

II ATC EVALUATION METHOD

The ATC problem formulation has been described in detail in [13]. ATC evaluation method adopted in this paper is the Hybridized continuous-repeated power flow structure. Hybridized Continuation-Repeated Power Flow implements power transfers by increasing complex load with uniform power factor at every load bus in sink area with increase in real power injection at generator buses in the source area at incremental steps up to a binding security limit, above which system security is compromised. The proposed algorithm is implemented in Power System Analysis Toolbox (PSAT) to:

1. Establish a feasible base case, by specifying generation and loading level, bus voltage magnitude and limits as well as line/transformer thermal limits;
2. Run the resulting feasible base case power flow by using Newton Raphson (NR) power flow;
3. Specify transfer direction by connecting power supply bid block at all generator buses in source area and connecting power demand bid block at all load buses in sink area;
4. Set up and run CPF in PSAT with specify number of points and step size control;
5. Check for limit violation in III;
6. If yes go to III and reduced step size else increase step size in III until the binding security limit is just removed or about to be encountered;
7. Calculate ATC by using Eq. (19) and report ATC value and the binding limitation.

Fig. 1 shows the flow chart of the proposed Hybridized Continuation-Repeated Power Flow structure.

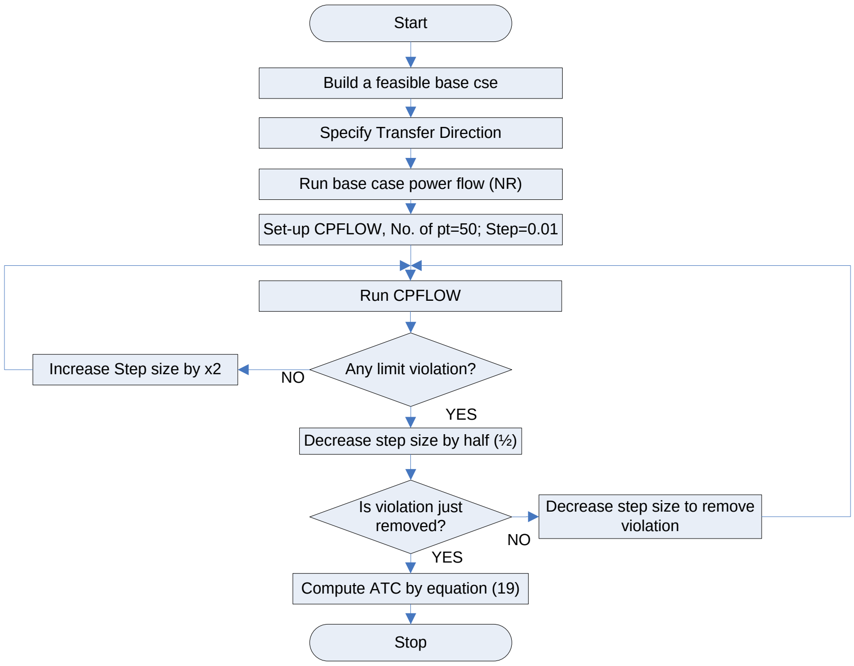

Fig. 1 Flowchart of the proposed Hybridized Continuation-Repeated Power Flow Structure

III STEP-SIZE CONTROL

Like Continuation Power Flow (CPFLOW), Hybridized Continuation-Repeated Power Flow (HCR-PF) is a procedure which employs predictor-corrector scheme in finding the solution path of reformulated sets of power flow equations that includes the loading parameter. Within the radius of convergence of the corrector, step - size control is a critical choice that affects the computational efficiency of HCR-PF. Theoretically, the step length is adapted to the shape of the path being traced; large length for flat part while small for part with high degree of curvature. The task of designing the step length is often difficult as the shape of the path to be trace is unknown beforehand. As illustrated in Fig. 2, the step size implementation adopted in the HCR-PF structure start with a step - size of 0.01 corresponding to a loading point A. If there is no violation (Line thermal limits, voltage magnitude and generator reactive power), HCR-PF structure increase the step size to a loading point B (0.02) and then to loading point C (0.04) where a limit violation is encountered. HCR-PF structure then reduces the step size by half of the increment between point B (0.02) and C (0.04) to a new loading point D (0.03); should there be violation at this new point, the structure move to point E (0.025) and continues repeatedly [13].

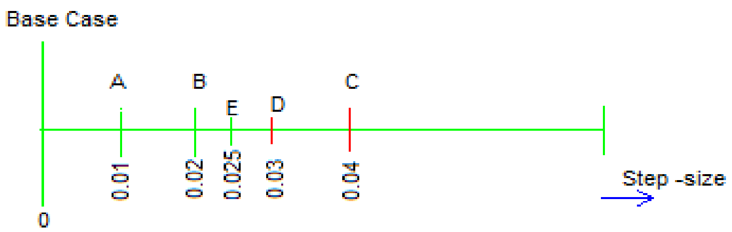

Fig. 2 Step – size control implementation of HCR-PF Structure

The ATC is calculated by using Eq. (1)

$$ATC = \sum_{i \in sink} P_L^i(\lambda_{max}) - \sum_{i \in sink} P_L^{i0} \tag{1}$$

IV SINGLE LINE (N – 1) OUTAGE CONTINGENCY

Power system analysis in terms of transfer capability evaluation takes into account single line outage (N – 1) criterion hence, is an important part of system security evaluation. In this paper, due to the radial nature of the Nigerian 330kV network, contingencies involving tie line were not considered, because outages of these lines which connect the areas will result in no physical path between areas. Specifically, tie line connecting Bus3_Jebba (TS) to Bus7_Oshogbo is critical for transaction from/to area 1. Besides, lines terminating only at a load bus and generator transformer outages are not considered as these contingencies lead to loss of load or generator outage respectively.

V SIMULTANEOUS INTER - AREA POWER TRANSFER

In terms of transfer capability evaluation, power system analysis takes the single line outage (N - 1) criterion into account, which therefore makes it an important part of system security evaluation. Various simultaneous transactions are feasible as presented [14, 15]. The simultaneous inter - area power transfer considered here is an additional source area power transfer implemented on the existing source area, a contingency which may results in a deregulated power market to complement an existing contractual bilateral/multilateral transaction. The aim of which is to supply the short-fall in transfer capability resulting from say a generator outage in the existing source area.

VI RESULTS AND DISCUSSION

Table 2 gives the contingency ATC values of IEEE-30 bus system, which shows the comparison between the Hybridized Continuous Repeated-Power Flow structure and that presented by Wu's method in reference [14]. The proposed method is seen to provide a good alternative to ATC computation. In addition the last corrector step solution result of CPF in PSAT environment which is obtainable in Excels identifies the limitation type and element rather than the searching techniques. Hence, as shown in table 2, the limiting line corresponding to each contingency transfer case is identified.

Fig. 3 compares clearly the HCR-PF method and the approach adopted by Wu's method in reference [14]. The transaction involves bus 14 to bus 21 with various (N-1) line outages considered as contingency.

TABLE 2 CONTINGENCY ATC VALUES FROM BUS 14 TO BUS 21 OF IEEE-30 BUS

Bilateral Transaction	Transaction Number	Outage Line		Limiting Line		ATC By Hybridized C-RPF	ATC By WU's Method
		From	To	From	To	ATC (MW)	ATC(MW)
From Bus 14 To Bus 21	1	12	14	14	15	22.2	22.2
	2	12	15	14	15	13.4131	13.5376
	3	12	16	14	15	28.77	28.0768
	4	14	15	10	21	28.49	28.4403
	5	15	18	10	21	33.7824	33.7682
	6	15	23	10	21	21.227	21.7515
	7	16	17	14	15	28.3627	28.8257
	8	10	17	10	21	29.3251	29.4786
	9	18	19	10	21	33.4643	32.5241
	10	19	20	10	21	28.7402	28.7572
	11	10	20	10	21	27.5504	27.9273
	12	10	21	21	22	11.669	14.289
	13	10	22	10	21	12.0471	13.1917
	14	22	24	10	21	27.8676	27.8809
	15	23	24	10	21	24.0214	24.1305

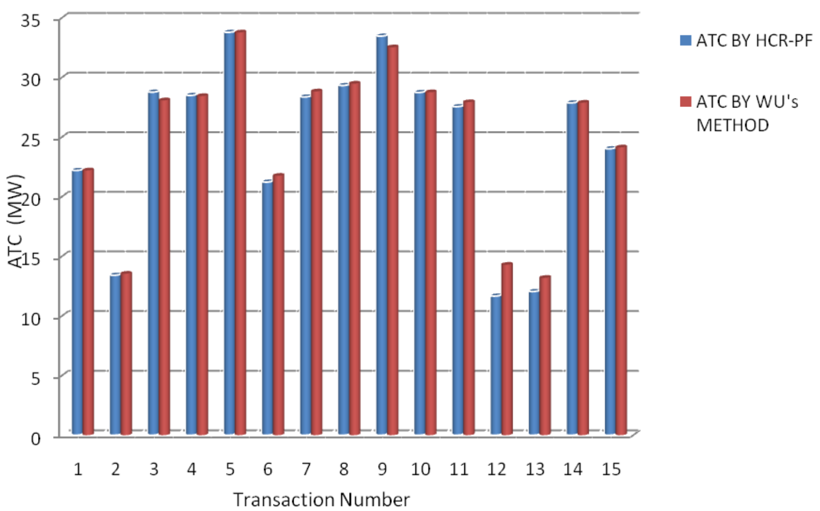

Fig. 3 Comparison between HCR-PF and WU's Method in IEEE 30 bus network for Bus 14 to bus 21 transactions

A. *Effect of Single Line (N - 1) Outage on ATC*

Table 3 gives the inter - area ATC computed values of Nigerian 330KV network before contingency consideration while Table 3 consists of the contingency ATC values, tie line outage considered and the transfer limitations to each direction. The void in Table 3 implies an infeasible operating condition. It is observed that single line outage generally results in lower Available Transfer capability values. As seen from Table 2, ATC computed value from area 1 to area 2 without (N - 1) line outage contingency is 121MW, with line outage from Bus7 to Bus9, the ATC value decreased to 1.7MW. Consequently, blackout and total system collapse could result from single line outage, particularly, line outage involving Bus7_Oshogbo to Bus9_Ayede, Bus7_Oshogbo to Bus29_Ikeja west, Bus25_Sapele (HT) to Bus2_Benin (TS) and Bus29_Ikeja west to Bus2_Benin (TS); for various inter -area transfers result in an infeasible ATC.

TABLE 3 INTER – AREA ATC COMPUTATIONS OF NIGERIAN GRID

INTER - AREA TRANSFERS (MW)					
Source/Sink Area		SOURCE AREAS			
		AREA 1	AREA 2	AREA 3	AREA 4
SINK AREAS	AREA 1	Void	2.61	167.26	6.58
	AREA 2	121.43	Void	213.30	7.01
	AREA 3	120.00	3.28	Void	6.59
	AREA 4	114.69	4.00	309.56	Void

B. *Effect of Simultaneous Inter - area Transfer on ATC*

Table 4 shows the simultaneous inter - Area transfers. Each transfer involves two source areas supplying the increase in load in a sink area.

TABLE 4 SIMULTANEOUS INTER - AREA ATC COMPUTATIONS OF NIGERIAN GRID

SIMULTANEOUS INTER - AREA TRANSFERS (MW)							
Sources/Sink Area		SOURCE AREAS					
		AREA 1&2	AREA 1&3	AREA 1&4	AREA 2&3	AREA 2&4	AREA 3&4
SINK AREAS	AREA 1	Void	Void	Void	8.31	5.92	167.28
	AREA 2	Void	213.04	129.84	Void	Void	215.78
	AREA 3	95.83	Void	168.17	Void	57.11	Void
	AREA 4	141.76	142.96	Void	97.84	Void	Void

Fig. 1 shows the effect of simultaneous Inter - Area power transfer on Inter -Area ATC computed values of Nigerian grid. It is observed that different areas have different effect on inter - area ATC values. It can be deduced and depicted clearly in Figs. 4(a), (b) and (d) that an additional source area could result in higher Transfer Capability with exception of Fig.4 (c). This abnormality in Fig. 4(c) could be attributed to the choice of slack generator. It is observed in Figure 1(c) that only the transaction from area2 to area3 results in that abnormal condition. With a change of slack generator from area two to area three, the deduction becomes true as in Figs. 4(a), 4(b) and 4(d).

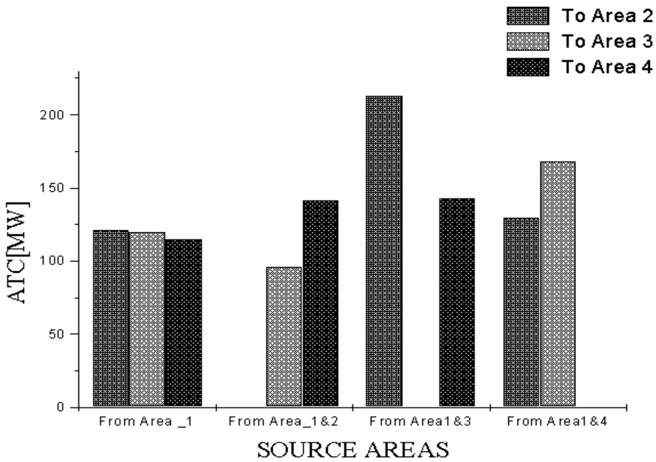

Fig. 4(a) Effect of Simultaneous Transaction on Area_1 ATC Computed Values

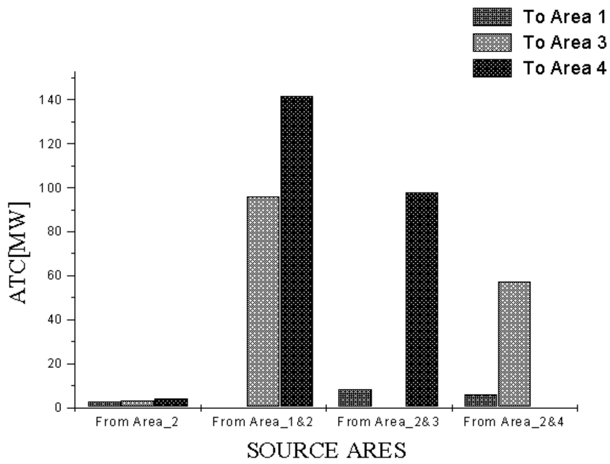

Fig. 4(b) Effect of Simultaneous Transaction on Area_2 ATC Computed Values

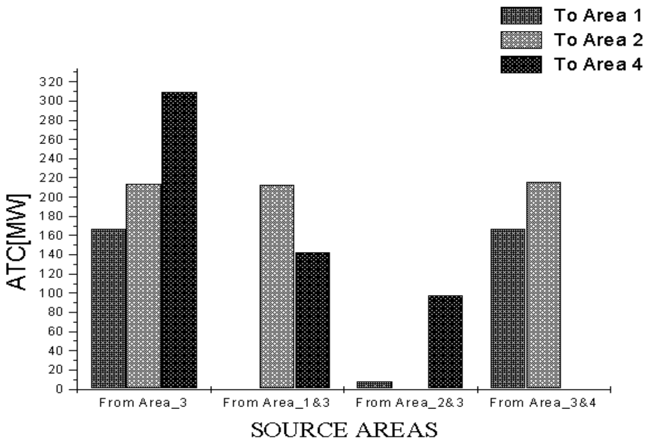

Fig. 4 (c) Effect of Simultaneous Transaction on Area_3 ATC Computed Values

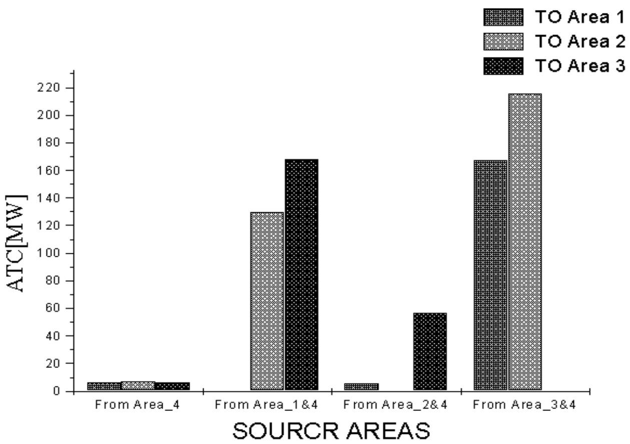

Fig. 4 (d) Effect of Simultaneous Transaction on Area_4 ATC Computed Values

TABLE 5 CONTINGENCY ATC COMPUTATIONS OF NIGERIAN GRID

INTER - AREA (N - 1) CONTINGENCY					
TRANSACTIONS		LINE OUTAGE		ATC [MW]	LIMITATIONS
From	To				
AREA 1	AREA 2	Bus7	Bus9	**1.7**	Bus16 [Qg_max = 450]
		Bus7	Bus29	19.5	Bus16 [Qg_max = 450]
		Bus9	Bus29	86.2	Bus16 [Qg_max = 450]
AREA 1	AREA 3	Bus7	Bus29	66.5	Bus16 [Qg_max = 450]
		Bus7	Bus2	114	Bus3 TO Bus7
		Bus29	Bus2	13.6	Bus16 [Qg_max = 450]
AREA 1	AREA 4	Bus7	Bus29	63.4	Bus16 [Qg_max = 450]
		Bus7	Bus2	109	Bus3 TO Bus7
		Bus29	Bus2	11.9	Bus16 [Qg_max = 450]
AREA 3	AREA 1	Bus24	Bus2	148	Bus25 TO Bus2
		Bus25	Bus2	142	Bus24 TO Bus2
		Bus7	Bus29	165	Bus4 [V_min < 297]
		Bus7	Bus2	164	Bus4 [V_min < 297]
		Bus29	Bus2	6.68	Bus16 [Qg_max = 450]
AREA 3	AREA 2	Bus24	Bus2	160	Bus25 TO Bus2
		Bus25	Bus2	149	Bus24 TO Bus2
		Bus29	Bus2	**1.01**	Bus16 [Qg_max = 450]
		Bus7	Bus2	170	Bus16 [Qg_max = 450]
AREA 3	AREA 4	Bus24	Bus2	159	Bus25 TO Bus2
		Bus25	Bus2	150	Bus24 TO Bus2
AREA 2	AREA 1	Bus7	Bus9	**Void**	Bus15 TO Bus29
		Bus7	Bus29	**Void**	Bus15 TO Bus29
		Bus9	Bus29	**Void**	Bus15 TO Bus29
AREA 2	AREA 3	Bus24	Bus2	**2.28**	Bus15 TO Bus29
		Bus25	Bus2	**Void**	Bus15 TO Bus29
		Bus29	Bus2	**Void**	Bus16 [Qg_max = 450]
		Bus7	Bus29	**Void**	Bus15 TO Bus29
		Bus7	Bus2	**2.11**	Bus15 TO Bus29
AREA 2	AREA 4	Bus7	Bus2	**1.46**	Bus15 TO Bus29
		Bus29	Bus2	**Void**	Bus16 [Qg_max = 450]
		Bus7	Bus29	**Void**	Bus15 TO Bus29
AREA 4	AREA 1	Bus7	Bus29	5.37	Bus22 TO Bus21
		Bus7	Bus2	5.48	Bus22 TO Bus21
		Bus29	Bus2	**Void**	Bus22 TO Bus21
AREA 4	AREA 2	Bus7	Bus2	5.51	Bus22 TO Bus21
		Bus29	Bus2	**Void**	Bus22 TO Bus21
		Bus7	Bus29	5.61	Bus22 (PS) TO Bus21
AREA 4	AREA 3	Bus24	Bus2	5.73	Bus22 (PS) TO Bus21
		Bus25	Bus2	3.27	Bus22 (PS) TO Bus21

VII CONCLUSION

This paper uses Hybridized Continuous-Repeated Power flow structure for the assessment of Inter - Area Available Transfer Capability of Nigeria 330KV power grid. Normal and contingency ATC(s) were computed. Single line (N - 1) outage criterion was implemented and the effects of simultaneous Inter - area power transfers on ATC computed values were investigated. It is therefore concluded that HCR-PF provides a good approximate alternative to ATC calculation.

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