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CENTRE OF PROFESSIONAL RESEARCH PUBLICATIONS
ISSN 2049-3444

International Journal of Engineering and Technology Volume 3 No. 2, February, 2013

Evaluation of Inter – Area Available Transfer Capability of Nigeria 330KV Network

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ABSTRACT

The radial topology of Nigeria Grid makes various part of the network prone to blackout and even system collapse on occurrences of line outage, hence the need for transmission network performance evaluation. Available Transfer Capability (ATC) is an index for transmission network performance. This paper presents a hybridized Continuation-Repeated power flow structure for ATC computation that provides a good approximate alternative to determine the maximum loadability. Single line outage (N – 1) criterion is used to simulate the effect of line outages on ATC values thereby identifying overloaded transmission facility.

Keywords: *Available Transfer Capability, Grid, Transmission, Network, Inter-area, Violation, Limits*

1. INTRODUCTION

Generally, power system is divided into three sections, viz, generation, transmission and distribution. It is well-known that electric power is produced by generators, transported to loads by the transmission system and consumed by loads at distribution level. The power stations (generators) are often situated far away from the load centers. This calls for an extensive power supply network between generating stations and the consumer loads. The Nigerian Grid System constitutes the principal core study system in this research work. Herein, the grid system is conveniently zoned into four geographical areas in conformity with operational structure of the electric utility (PHCN). The three hydro power stations are situated in Area 1 while Area 2 has thermal power station located in it and areas 3 and 4 have gas power stations located in them. Transfer of bulk electrical power between areas over long distances is preferred in order to have a reliable and economical electrical supply [**1**]; however, a transmission facility has limited capacity to transfer power. Capacity is normally a specific device rating (i.e. thermal) or MVA rating in the name-plate of a transformer. This could be defined as on the context of ATC as the ability of a system to serve native load and engage in transfer of power. Whereas capability is a limitation which is highly dependent on power system conditions (Load demand, generation dispatch, network topology, etc.) and has the ability to only engage in power transfers [**2**].

Transfer capability is the measure of the ability of interconnected electric systems to reliably move or transfer power from one area to another over all transmission lines (or tie lines) between those areas under specified system conditions. Power system transfer capability indicates how much power transfers can be increased without compromising system security. To operate the power system safely and to gain the benefits of bulk power transfers, the transfer capabilities must be evaluated and the power system planned and operated so that the power transfers do not exceed the transfer capability. Moreover, as various electric power utilities embrace deregulation as well as the need for open access to transmission facilities, power transfers are increasing both in magnitude and direction. Total transfer capability (TTC) and Available transfer capability (ATC) are often the two indices used for transfer capability evaluation.

Total transfer capability (TTC) is defined as the amount of electric power that can be transferred over the interconnected transmission network in a reliable manner while meeting all of a specific set of defined pre- and post-contingency system conditions whereas Available transfer capability (ATC) is a measure of the transfer capability remaining in the physical transmission network for further commercial activity over and above already committed uses [**3**]. Mathematically, ATC is defined as the Total Transfer Capability (TTC) less the Transmission Reliability Margin (TRM), less the sum of existing transmission commitments and the Capacity Benefit Margin (CBM).

$$ATC = TTC - TRM - (ETC + CBM) \qquad (1)$$

Transmission Reliability Margin (TRM) is defined as that amount of transmission transfer capability necessary to ensure that the interconnected transmission network is secured under a reasonable range of uncertainties in system conditions. Capacity Benefit Margin (CBM) is defined as that amount of transmission transfer capability reserved by load serving entities to ensure access to generation from interconnected systems to meet generation reliability requirements. To account for Transmission Reliability Margin (TRM) on this paper, a fixed amount (say, 2%) was subtracted from the rated thermal ratings of the lines in this research work. The existing transmission commitment (ETC) is the normal transmission flows included in the given or solve based case. (NERC, 1996). The methods for determining TRM, CBM, and ETC may vary among individual systems operators and load serving entities; however, CBM can be incorporated as firm or non firm transfers. Area-to-area ATC is the additional amount of power that can be transferred from a given area (e.g. seller area) to another area (e.g. buyer area) in the case of a deregulated power network. ATC is also analyzed and quantified by considering effect of contingencies such as line outages [**4**,**5**].

2. TRANSFER CAPABILITY METHODS

Four major approaches are suggested in the literature for the calculation of ATC:

I. Sensitivity analysis
II. Optimal power flow (OPF)
III. Continuation power flow (CPF)
IV. Repeated power flow (RPF)

Sensitivity analysis is presented in [**6**] which is based on factors including: Line outage distribution factor (LODF), power transfer distribution factor (PTDF), and generation shift factor (GSF). These can be based on DC or AC power flow. It does not take into account the non-linear effects of reactive power and voltages. An OPF method as seen in [**7**] maximizes transfer capability between source and sink respecting contractual terms and economic dispatch of generation. However, open access allows transaction in practice from/to any point/area. CPF and RPF methods provide more accuracy compared to the sensitivity and OPF methods [**8**,**9**]. Each of these methods can lend themselves to deterministic or probabilistic method. The ATC evaluation method in this paper is based on hybridized Continuous-Repeated power flow. Transfer capability evaluation requires the interpretation of results and two methods are often being considered viable for this purpose, namely, Rated System Path (RSP) method and Network Response (NR) method. The network response method; transfer capability from a bus (A) to another bus (B) is the maximum real power transferrable from A to B by all physical paths. While in the rated system path method, transfer capability from bus A to bus B is the real power (maximum) flow over the physical paths directly connecting buses A and B under a limiting condition which is system-wide [**2**]. The proposed methodology is the hybridized Continuous-Repeated (HCR) power flow.

3. ATC PROBLEM FORMULATION

To apply continuation method to power flow problem, a loading parameter must be inserted into the power flow equations to parameterize the load-flow equation. [**10**]. A uniform power factor model is documented as follows:

Let the loading parameter (λ) be represented by equation (2)

$$0 \le \lambda \le \lambda_{limited} \qquad (2)$$

where $\lambda = 0$ corresponds to the base case loading and $\lambda = \lambda_{limited}$ corresponds to the maximum loading parameter above which a binding security limit is encountered. For an n bus system, the normal power flow equation of each bus i can be expressed in equations (3), (4), (5) and (6).

$$P^i{}_G - P^i{}_L - P^i{}_{injected} = 0 \qquad (3)$$

$$P^i{}_{injected} = \sum_{j=1}^{n} V_i V_j Y_{ij} \cos\left(\delta_i - \delta_j + \theta_{ij}\right) \qquad (4)$$

$$Q^i{}_G - Q^i{}_L - Q^i{}_{injected} = 0 \qquad (5)$$

$$Q^i{}_{injected} = \sum_{j=1}^{n} V_i V_j Y_{ij} \cos\left(\delta_i - \delta_j + \theta_{ij}\right) \qquad (6)$$

where G and L denotes generation and load; bus voltages at buses i and j are given by $V_i \angle \delta_i$ and $V_j \angle \delta_j$ while $Y_{ij} \angle \theta_{ij}$ is the (i, j) th element of the bus admittance matrix.

For Available Transfer Capability calculation, the increases in power (Real and Reactive) both at source and sink buses are functions of lambda (λ). In other to simulate a transfer change, $P^i{}_L, Q^i{}_L$ and $P^i{}_G$ terms must be modified such that each term be made of two component, viz, the base case component and the component due to change in loading parameter [**10**,**11**]. Thus,

$$P^i{}_L = P^{io}{}_L (1 + \lambda K_{pi}) \qquad (7)$$

$$Q^i{}_L = Q^{i0}{}_L (1 + \lambda K_{Qi}) \qquad (8)$$

$$P^{i}_{G} = P^{i0}_{G}(1+\lambda K_{Gi}) \tag{9}$$

where $P^{i}_{G}, P^{i}_{L}, Q^{i}_{L}$ are the real power generation, load and reactive load at ith bus while $P^{i0}_{G}, P^{i0}_{L}, Q^{i0}_{L}$ are their corresponding base case schedules. K_{Pi}, K_{Qi} and K_{Gi} are participation factor to designate the variation of real and reactive power at PQ buses and real power variation at PV buses (sensitivity of load and generation changes at the ith bus) as lambda (λ) changes.

When these new equations (7), (8) and (9) are inserted into (3) and (5) the resulting power flow equations becomes parameterized and given in (10) and (11).

$$P^{i0}_{G}(1+\lambda K_{Gi}) - P^{io}_{L}(1+\lambda K_{pi}) - P^{i}_{injected} = 0 \tag{10}$$

$$Q^{i0}_{G} - Q^{io}_{L}(1+\lambda K_{Qi}) - Q^{i}_{injected} = 0 \tag{11}$$

At generator (PV) buses, the term K_{Qi} is zero while at load (PQ) buses a constant power factor is maintained by making the ratio $\frac{K_{pi}}{K_{Qi}}$ constant.

For an inter-area transfer schedule, the nonlinear power flow equation parameterized with lambda (λ) can be expressed in compact form as in (12) and (13)

$$f(x,\lambda) = 0 \tag{12}$$

$$f(x,\lambda) \equiv f(x) - \lambda b \tag{13}$$

Where the state variable $x = (\delta, V)$ is a vector of bus voltage magnitude and angles.

The formulation by [**6**] and [**12**] shows there is a close connection between optimization, CPFLOW and repeated power flow (RPF) or successive iterative load flow computation for Transfer Capability computations or determination. CPFLOW can therefore solve the power flow equation as an optimization problem stated thus: [**13**]

$$\max(\lambda)$$

Subject to:

$$f(x,\lambda) = 0 \tag{14}$$

$$\left|P^{i}_{G}\right|_{\min} \le \left|P^{i}_{G}\right| \le \left|P^{i}_{G}\right|_{\max} \tag{15}$$

$$\left|Q^{i}_{G}\right|_{\min} \le \left|Q^{i}_{G}\right| \le \left|Q^{i}_{G}\right|_{\max} \tag{16}$$

$$\left|V_{i}\right|_{\min} \le \left|V_{i}\right| \le \left|V_{i}\right|_{\max} \tag{17}$$

$$\left|P_{ij}\right|_{\min} \le \left|P_{ij}\right| \le \left|P_{ij}\right|_{\max} \tag{18}$$

Equations (14) is the compact power flow equation, (15) and (16) are the PV real and reactive power limitations, (17) is the bus voltage limits while (18) is the thermal limits of lines connecting buses. At the maximum loading parameter ($\lambda_{\max}$), the ATC is calculated using equation (19) [**14**].

$$ATC = \sum_{i \in \sin k} P_{L}^{\,i}(\lambda_{\max}) - \sum_{i \in \sin k} P_{L}^{\,i0} \tag{19}$$

4. PROPOSED ATC EVALUATION METHOD

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:-

I. Establish a feasible base case, by specifying generation and loading level, bus voltage magnitude and limits as well as line/transformer thermal limits.
II. Run the resulting feasible base case power flow using Newton Raphson (NR) power flow.
III. 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
IV. Set up and run CPF in PSAT with specify number of points and step size control.
V. Check for limit violation in III
VI. 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.
VII. Calculate ATC using equations (19) and report ATC value and the binding limitation.

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

5. STEP-SIZE CONTROL

Within the radius of convergence of the corrector, step – size control is a critical choice that affects the computational efficiency of CPF. A constant, small step length is safe in any continuation algorithm; it, however, may lead to inefficient computation especially along the flat part of the solution path. Similarly, large step length results in convergence issues as the predictor will lie far away from the true solution. In principle, 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 figure 2, the step size implementation proposed 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.

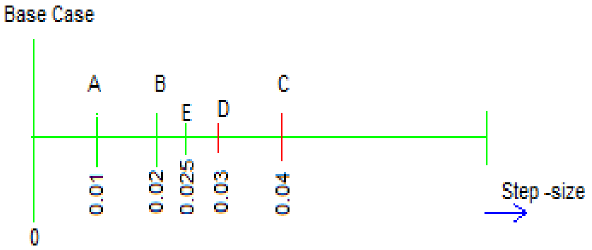

Fig. 2 Step – size control implementation of HCR-PF Structure

6. TEST NETWORK CASE STUDIES

In this paper the proposed method is tested in both IEEE 30-bus system and the Nigeria 330kv network modeled in PSAT environment. Results obtained in the IEEE 30-bus system where compared with that of reference [**2**]. A 32-bus model of the Nigerian 330kV network implemented in PSAT and used in this paper, (henceforth referred to here as the Nigerian grid), consist of seven (7) generating stations, seven (7) transformers, twenty seven (27) transmission lines and twenty two (22) loads. The installed generating capacity of the Nigerian grid is 7461MW including hydro resources and resources gas fired (thermal). The Nigerian grid is made up of 5,523.8km of 330 kV of Transmission lines, thirty two (32) 330/132kV Substations with total installed transformation capacity of 7,688 MVA (equivalent to 6,534.8 MW). The Average Available Capacity on 330/132kV is 7,364MVA which is about 95.8% of Installed capacity [**15,16**]. The Nigerian grid system in this paper is zoned into four geographical areas and conforms to the control structure of the electric utility (PHCN). The lines Amperage ratings converted to its MVA equivalent is given in Table 7.

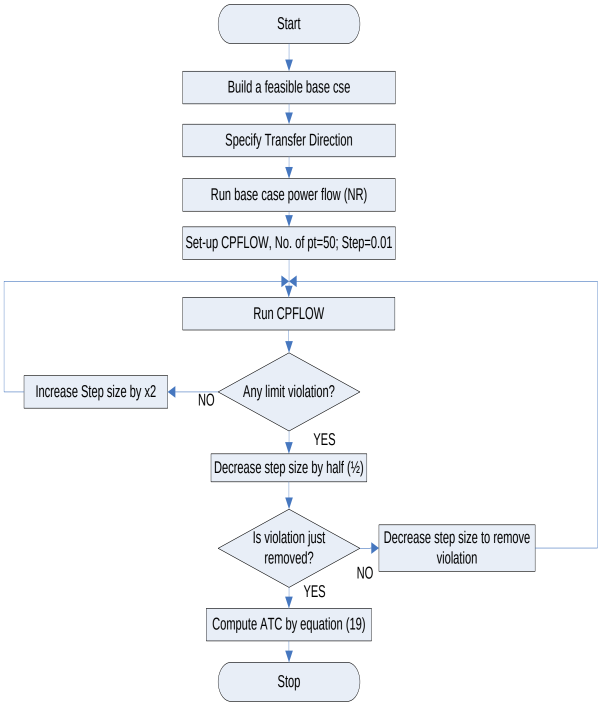

Fig. 1 Flowchart of the proposed Hybridized Continuation-Repeated Power Flow Structure

7. RESULTS

7.1 IEEE 30-Bus

Various transactions in reference were implemented for both contingency and normal study cases and the results were compared. Table 1 gives the contingency ATC (ATC by Wu's method) presented in reference [**4**] and our proposed Hybridized CR-PF structure. 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.

7.2 Nigerian Grid

Inter–Area Transfer transaction were implemented and the results are given in Tables 2 and 3 while Tables 4 and 5 gives results of simultaneous transactions involving two areas as source and a single sink area. Three (3) constraints were considered namely: Line thermal ratings, Voltage and generator reactive power limits. Generator reactive power is allow within Q_{min} and Q_{max} in the range -2.5p.u to 4.5p.u while voltage limits range (V_{min} and V_{max}) is 0.9p.u to 1.1p.u. Transmission line parameters, bus and description as well as the line thermal ratings are given in Table 7.

Table 1: Contingency ATC Comparison

Bilateral Transaction	**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	12	14	14	15	22.2000	22.2000
	12	15	14	15	13.4131	13.5376
	12	16	14	15	28.7700	28.0768
	14	15	10	21	28.4900	28.4403
	15	18	10	21	33.7824	33.7682
	15	23	10	21	21.2270	21.7515
	16	17	14	15	28.3627	28.8257
	10	17	10	21	29.3251	29.4786
	18	19	10	21	33.4643	32.5241
	19	20	10	21	28.7402	28.7572
	10	20	10	21	27.5504	27.9273
	10	21	21	22	11.6690	14.2890
	10	22	10	21	12.0471	13.1917
	22	24	10	21	27.8676	27.8809
	23	24	10	21	24.0214	24.1305

Table 2: Inter–Area ATC Computed values of Nigeria 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

Table 3: Limitations to Inter – Area ATC Computed values of Nigeria Grid

LIMITIONS TO TRANSFER					
Source/Sink Area		SOURCE AREAS			
		AREA 1	AREA 2	AREA 3	AREA 4
SINK AREAS	AREA 1	Void	Bus15_Egbin(HT) TO Bus29_Ikeja West	Bus4_Kano[V < 297]	Bus21_Afam(PS) TO Bus22_Afam(HT) (Generator Transformers)
	AREA 2	Bus3_Jebba (TS) TO Bus7_Oshogbo	Void	Bus16_Egbin(PS) [Qg_max = 450]	Bus21_Afam(PS) TO Bus22_Afam(HT) (Generator Transformers)
	AREA 3	Bus3_Jebba (TS) TO Bus7_Oshogbo	Bus15_Egbin(HT) TO Bus29_Ikeja West	Void	Bus21_Afam(PS) TO Bus22_Afam(HT) (Generator Transformers)
	AREA 4	Bus3_Jebba (TS) TO Bus7_Oshogbo	Bus15_Egbin(HT) TO Bus29_Ikeja West	Bus 17_New haven [V_min < 297]	Void

Table 4: Simultaneous ATC Computed values of Nigerian Grid

SIMULTENEUOS 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

Table 5: Limitations to Simultaneous ATC Computed values of Nigerian Grid

SIMULTENEUOS INTER - AREA TRANSFERS LIMITATIONS							
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	Bus15_Egbin(HT) TO Bus29_Ikeja West	Bus15_Egbin(HT) TO Bus29_Ikeja West	Bus4_Kano [V_min < 297]
	AREA 2	Void	Bus16_Egbin(PS) [Qg_max = 450]	Bus3_Jebba (TS) TO Bus7_Oshogbo	Void	Void	Bus16_Egbin (PS) [Qg_max = 450]
	AREA 3	Bus3_Jebba (TS) TO Bus7_Oshogbo	Void	Bus3_Jebba (TS) TO Bus7_Oshogbo	Void	Bus15_Egbin(HT) TO Bus29_Ikeja West	Void
	AREA 4	Bus3_Jebba (TS) TO Bus7_Oshogbo	Bus3_Jebba (TS) TO Bus7_Oshogbo	Void	Bus15_Egbin(HT) TO Bus29_Ikeja West	Void	Void

8. CONTINGENCY CONSIDERATION

Single line outage (N – 1) criterion, is an important part of system security evaluation. In this paper, due to the topology of the Nigeria grid, tie line contingencies were not considered; as outage of lines connecting the areas will results in no physical path between areas. In particular, tie line between Bus3_Jebba (TS) to Bus7_Oshogbo is critical for transaction from/to area 1. In addition, 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. Table 6 gives the contingency ATC values, line outage considered and the limitations to each transfer direction.

9. DISCUSSION OF RESULTS

Figure 3 shows the ATC computed values between the four areas, it is observed that area 2 and area 4 has little or no transfer capability when compared to area 1 and area 3. As also expected, transfer capability is directional as the transfer from area 1 to area 2 is not the same as area 2 to area 1. Figure 4 shows the linearity between the step size control and the loading parameter (λ) as the step size increases for Area 1 to Area 2 Transfer.

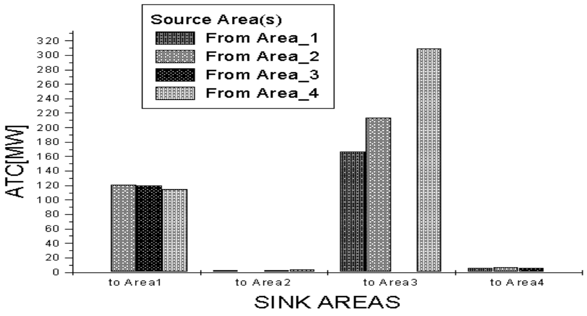

Fig. 3: Inter – Area ATC of Nigeria Grid

Figure 5 shows that from Area 1 to Area 2 transfer, all the source area generators (Jebba PS, Shiroro PS and Kainji PS) start at their respective base case (450MW, 490MWand 596MW) up to the transfer limitation point where the maximum loading parameter (λ_{max}) is 0.0889 corresponding to 490MW, 533MW and 640MW respectively. Figure 6 shows the increase in real power demand at the PQ buses of the sink area. All values are on 100MVA base. Figure 7 shows the tie line's additional real power flow increment up to the binding security limit for Area 1 to Area 2 transfer.

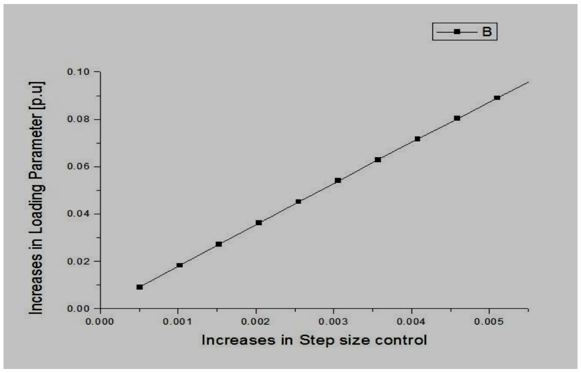

Fig. 4: Increase in loading parameter with increasing Step size for Area 1 to Area 2 Transfer

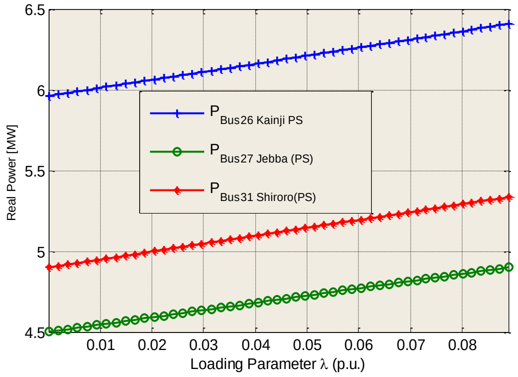

Fig. 5: Increase in real power Supply at the PV buses for Area 1 to Area 2 Transfer

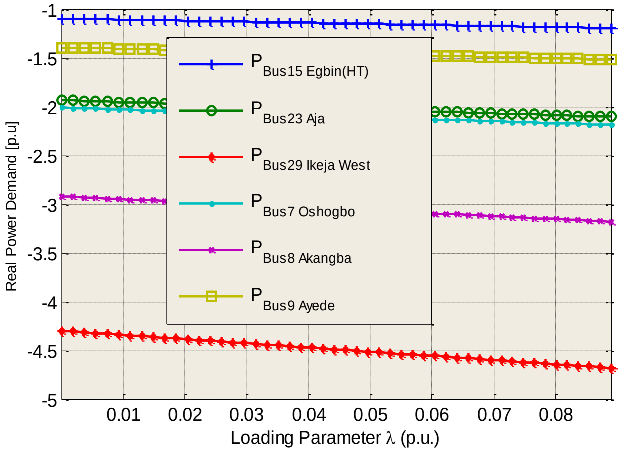

Fig. 6: Increase in real power demand at the PQ buses for Area 1 to Area 2 Transfer.

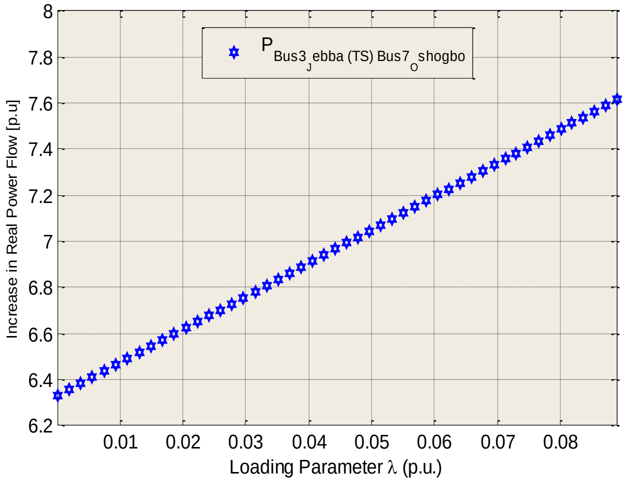

Fig. 7: Increase in Line (Jebba TS to Oshogbo) Real power flow with loading parameter for Area 1 to Area 2 Transfer

10. CONCLUSION

A method for calculating Inter–Area ATC was presented. A noble technique, hybridized Continuous-Repeated Power Flow was used which takes into account thermal, voltage and generator reactive power constraints as limitations to real power transfer. The stopping criteria for CPF is at the limit where violation has just occurred, hence, between 0.5MVA to 1MVA power flows is allowed in other to identify the limiting element to a specify transfer case. Results of IEEE 30-bus systems and Nigeria Grid were presented and compared, hence, hybridized Continuous-Repeated PF provide a good alternative means to ATC determination.

Table 6: Contingency ATC Computed values of Nigeria Grid

INTER - AREA (N - 1) CONTINGENCY					
TRANSACTIONS		LINE OUTAGE		ATC [MW]	LIMITATIONS
AREA 1	AREA 2	Bus7_Oshogbo	Bus9_Ayede	1.70	Bus16_Egbin(PS) [Qg_max = 450]
		Bus7_Oshogbo	Bus29_Ikeja West	19.51	Bus16_Egbin(PS) [Qg_max = 450]
		Bus9_Ayede	Bus29_Ikeja West	86.20	Bus16_Egbin(PS) [Qg_max = 450]
AREA 1	AREA 3	Bus7_Oshogbo	Bus29_Ikeja West	66.52	Bus16_Egbin(PS) [Qg_max = 450]
		Bus7_Oshogbo	Bus2_Benin(TS)	114.17	Bus3_Jebba (TS) TO Bus7_Oshogbo
		Bus29_Ikeja West	Bus2_Benin(TS)	13.62	Bus16_Egbin(PS) [Qg_max = 450]
AREA 1	AREA 4	Bus7_Oshogbo	Bus29_Ikeja West	63.42	Bus16_Egbin(PS) [Qg_max = 450]
		Bus7_Oshogbo	Bus2_Benin(TS)	108.64	Bus3_Jebba (TS) TO Bus7_Oshogbo
		Bus29_Ikeja West	Bus2_Benin(TS)	11.92	Bus16_Egbin(PS) [Qg_max = 450]
AREA 3	AREA 1	Bus24_Delta(HT)	Bus2_Benin(TS)	147.73	Bus25_Sapele(HT)TOBus2_Benin(TS)
		Bus25_Sapele(HT)	Bus2_Benin(TS)	142.07	Bus24_Delta(HT) TO Bus2_Benin(TS)
		Bus7_Oshogbo	Bus29_Ikeja West	164.59	Bus4_Kano [V_min < 297]
		Bus7_Oshogbo	Bus2_Benin(TS)	164.26	Bus4_Kano [V_min < 297]
		Bus29_Ikeja West	Bus2_Benin(TS)	6.68	Bus16_Egbin(PS) [Qg_max = 450]
AREA 3	AREA 2	Bus24_Delta(HT)	Bus2_Benin(TS)	160.12	Bus25_Sapele(HT)TOBus2_Benin(TS)
		Bus25_Sapele(HT)	Bus2_Benin(TS)	149.29	Bus16_Egbin(PS) [Qg_max = 450] and Bus24_Delta(HT) TO Bus2_Benin(TS)
		Bus29_Ikeja West	Bus2_Benin(TS)	1.01	Bus16_Egbin(PS) [Qg_max = 450]
		Bus7_Oshogbo	Bus2_Benin(TS)	169.70	Bus16_Egbin(PS) [Qg_max = 450]
AREA 3	AREA 4	Bus24_Delta(HT)	Bus2_Benin(TS)	159.44	Bus25_Sapele(HT)TO Bus2_Benin(TS)
		Bus25_Sapele(HT)	Bus2_Benin(TS)	149.60	Bus24_Delta(HT) TO Bus2_Benin(TS)
AREA 2	AREA 1	Bus7_Oshogbo	Bus9_Ayede	Void	Bus15_Egbin(HT) TO Bus29_Ikeja West
		Bus7_Oshogbo	Bus29_Ikeja West	Void	Bus15_Egbin(HT) TO Bus29_Ikeja West
		Bus9_Ayede	Bus29_Ikeja West	Void	Bus15_Egbin(HT) TO Bus29_Ikeja West
AREA 2	AREA 3	Bus24_Delta(HT)	Bus2_Benin(TS)	2.28	Bus15_Egbin(HT) TO Bus29_Ikeja West
		Bus25_Sapele(HT)	Bus2_Benin(TS)	Void	Bus15_Egbin(HT) TO Bus29_Ikeja West
		Bus29_Ikeja West	Bus2_Benin(TS)	Void	Bus16_Egbin(PS) [Qg_max = 450] AND Bus15_Egbin(HT) TO Bus29_Ikeja West
		Bus7_Oshogbo	Bus29_Ikeja West	Void	Bus15_Egbin(HT) TO Bus29_Ikeja West
		Bus7_Oshogbo	Bus2_Benin(TS)	2.11	Bus15_Egbin(HT) TO Bus29_Ikeja West
AREA 2	AREA 4	Bus7_Oshogbo	Bus2_Benin(TS)	1.46	Bus15_Egbin(HT) TO Bus29_Ikeja West

		Bus29_Ikeja West	Bus2_Benin(TS)	Void	Bus16_Egbin(PS) [Qg_max = 450] AND Bus15_Egbin(HT) TO Bus29_Ikeja West
		Bus7_Oshogbo	Bus29_Ikeja West	Void	Bus15_Egbin(HT) TO Bus29_Ikeja West
AREA 4	AREA 1	Bus7_Oshogbo	Bus29_Ikeja West	5.37	Bus22_Afam(PS) TO Bus21_Afam(HT)
		Bus7_Oshogbo	Bus2_Benin(TS)	5.48	Bus22_Afam(PS) TO Bus21_Afam(HT)
		Bus29_Ikeja West	Bus2_Benin(TS)	Void	Bus22_Afam(PS) TO Bus21_Afam(HT)
AREA 4	AREA 2	Bus7_Oshogbo	Bus2_Benin(TS)	5.51	Bus22_Afam(PS) TO Bus21_Afam(HT)
		Bus29_Ikeja West	Bus2_Benin(TS)	Void	Bus22_Afam(PS) TO Bus21_Afam(HT)
		Bus7_Oshogbo	Bus29_Ikeja West	5.61	Bus22_Afam(PS) TO Bus21_Afam(HT)
AREA 4	AREA 3	Bus24_Delta(HT)	Bus2_Benin(TS)	5.73	Bus22_Afam(PS) TO Bus21_Afam(HT)
		Bus25_Sapele(HT)	Bus2_Benin(TS)	3.27	Bus22_Afam(PS) TO Bus21_Afam(HT)

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APPENDIX A

Table 7: Transmission line parameters of Nigeria Grid

LINE NO.	LOCATION DESCRIPTION i	LOCATION DESCRIPTION j	LINE PARAMETERS (P.U.)			Thermal Rating (AMPS)	Thermal Rating (MVA)
			R	X	B		
1	kainji (HT)	Birnin kebbi	0.01218	0.09163	1.0269	1360	777.4
2	kainji (HT)	Jebba (TS)	0.00159	0.01197	0.5366	1360	777.4
3	Kainji (PS)	Kainji (HT)	0	0.01351	0	1505	860
4	Jebba (HT)	Jebba (TS)	0.00016	0.00118	0.053	1360	777.4
5	Jebba (TS)	Oshogbo	0.00206	0.01547	1.56	1360	777.4
6	Shiroro (HT)	Jebba (TS)	0.0048	0.03606	1.6165	1360	777.4
7	Jebba (PS)	Jebba (HT)	0	0.01932	0		714
8	Oshogbo	Benin(TS)	0.00987	0.07419	0.8315	1360	777.4
9	Oshogbo	Ayede	0.00412	0.03098	0.3472	1360	777.4
10	Oshogbo	Ikeja West	0.01163	0.0875	0.9805	1360	777.4
11	Shiroro (PS)	Shiroro (HT)	0	0.01638	0		800
12	Shiroro (HT)	Kaduna(Mando)	0.00189	0.01419	0.636	1360	777.4
13	Kaduna(Mando)	Kano(Kumbotso)	0.00904	0.06799	0.7619	1360	777.4
14	Kaduna(Mando)	Jos	0.00774	0.05832	0.6526	1360	777.4
15	Benin(TS)	Ajaokuta	0.00766	0.05764	0.646	1360	777.4
16	Jos	Gombe	0.01042	0.07833	0.8778	1360	777.4
17	Ayede	Ikeja West	0.00538	0.0405	0.4538	1360	777.4
18	Ikeja West	Benin(TS)	0.0055	0.04139	1.885	1360	777.4
19	Delta (HT)	Benin(TS)	0.00287	0.02158	0.2418	1360	777.4
20	Sapele (HT)	Benin(TS)	0.00098	0.00739	0.3313	1360	777.4
21	Onitsha	New haven	0.00377	0.02838	0.318	1360	777.4
22	Alaoji	Onitsha	0.00605	0.04552	0.5101	1360	777.4
23	Benin(TS)	Onitsha	0.00538	0.0405	0.454	1360	777.4
24	Afam (HT)	Alaoji	0.00049	0.00369	0.1656	1360	777.4
25	Ikeja West	Akangba	0.00036	0.00266	0.119	1360	777.4
26	Egbin (HT)	Ikeja West	0.00122	0.00916	0.4108	1360	777.4
27	Egbin (PS)	Egbin (HT)	0	0.00648	0		1620
28	Egbin (HT)	Aja	0.00028	0.00207	0.0928	1360	777.4
29	Sapele (PS)	Sapele (HT)	0	0.01204	0		1177
30	Delta (HT)	Alaodja	0.00102	0.00769	0.08613	1360	777.4

31	Sapele (HT)	Alaodja	0.00248	0.01862	0.2087	1360	777.4
32	Delta (PS)	Delta (HT)	0	0.01333	0		720
33	Afam (PS)	Afam (HT)	0	0.01422	0		504
34	Shiroro (HT)	Katampe (Abuja)	0.0025	0.0195	0.413	1360	777.4

APPENDIX B

The Nigeria 330kv Grid in PSAT