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Enhancement Of Power Transfer Capability For IEEE Bus Systems By Using Power Flow Methods

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ABSTRACT:- In order to facilitate the electricity market operation and trade in the restructured environment, ample transmission capability should be provided to satisfy the demand of increasing power transactions. The conflict of this requirement and the restrictions on the transmission expansion in the restructured electrical market has motivated the development of methodologies to enhance the Available Power Transfer Capability of the existing transmission grids. One of the conventional strategies is by inserting FACTS devices in electrical systems seems to be a promising strategy to enhance power transfer capability. In this paper, the work has been carried out on IEEE 14 bus system with different power flow methods like continuation power flow method, repeated power flow methods are employed to obtain the optimal settings for FACTS controllers and reducing losses, power balancing and control, reduce locational marginal price.

KEYWORDS:- Available Transfer Capability(ATC), Flexible AC Transmission Systems, continuation method, repeated power flow(RPF) methods, transient and steady state operations.

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I. INTRODUCTION

The restructuring of the electric industry throughout the world aims to create competitive markets to trade electricity and generates a host of new technical challenges to market participants and power system researchers. For transmission networks, one of the major consequences of the non-discriminatory open-access requirement is a substantial increase of power transfers, which demand adequate available transfer capability (ATC) to ensure all transactions are economical. FACTS technology enables line loading to increase flexibly, in some cases, even up to the thermal limits.Therefore, it can theoretically offer an effective and promising alternative to conventional methods for ATC enhancement. Undoubtedly, it is very important and imperative to carry out studies on exploitation of FACTS technology to enhance ATC [7]-[9]. The modeling of FACTS devices for power flow studies, the role of such modeling for power flow control and the integration of these devices into power flow studies were reported in the literature [1],[2]. Modeling and the role of important FACTS devices like static VAR compensator (SVC), Thyristor controlled series compensator(TCSC) and unified power flow controller (UPFC) in solving power system restructuring issues have been previously reported [3]-[5]. Some well established search algorithms such as GA [1] and evolutionary programming (EP) [7], [8] were successfully implemented to solve simple and complex problems efficiently and effectively. Most of the population based search approaches are motivated by evolution as seen in nature. Particle Swarm Optimization (PSO), on the other hand, is motivated from the simulation of social behavior and was introduced by Eberhart and Kennedy [9].

II. ATC

An easy way to comply with the paper formatting requirements is to use this document as a template and simply type your text into it.

ATC is a measure of the transfer capability remaining in the physical transmission network for further commercial activity over and above the already committed uses. It can be expressed as follows:

$$ATC = TTC - Existing\ Transmission\ Commitments \ldots(1)$$

Where, Total Transfer Capability (TTC) is defined as the amount of electric power that can be transferred over the interconnected transmission network or particular path or interface in a reliable manner while meeting all of a specific set of defined pre and post contingency conditions. ATC at the base case, between bus *m* and bus *n* using line flow limit (thermal limit) criterion is mathematically formulated using ACPTDF as given in the below equation:

$ATC_{mn} = min,\{ \ T_{ij}, mn \}i,j \in N_L$ ....(2)

III. POWER FLOW METHODS

The application of Optimal Power Flow (OPF) in power system congestion management has been studied by some researchers [6][7][1][2]. In the mean time, TTC calculation by OPF approach has been proposed since 1999 [3][4][5]. The basic concept of OPF approach is formulating the TTC calculation as an optimization problem, with equity constraints of power flow, inequality constraints from basic operation and equipment limits to more detailed approximation of transient stability security requirements. The objective function, obviously, is the maximum power flow on the specified transmission route. To determine the total transfer capability the objective is to maximize the power transfer between the two areas subjected to the conditions that there is no voltage or thermal or stability limit violations. Total transfer capability problem formulation can be explained as follows.

Maximize

$$P_i = \sum_{j \in i} P_{ij}$$

Subjected to

$$P_i - \sum_{j \in i} V_i V_j Y_{ij} Cos(\theta_{ij} + \delta_i - \delta_j) = 0$$

$$Q_i - \sum_{j \in i} V_i V_j Y_{ij} Sin(\theta_{ij} + \delta_i - \delta_j) = 0$$

$$P_{g\,min} \le P_g \le P_{g\,max}$$

$$Q_{g\,min} \le Q_g \le Q_{g\,max}$$

$$S_{ij} \le S_{ij\,max}$$

$$V_{i\,min} \le V_i \le V_{i\,max}$$

CONTINUATION POWER FLOW:

The general principle behind the continuation power flow is simple. It employs a predictor-corrector scheme to find a solution path. It adopts locally parameterized continuation technique. It includes load parameter, step length for load parameter and state variable.

Locally Parameterized Continuation

A parameterization is a mathematical means of identifying each solution on the branch, a kind of measure along the branch. When we say "branch," we refer to a curve consisting of points joined together in *n + 1* dimensional space that are solutions of the nonlinear equations F(x , λ) = 0 (1). This equation is obtained by introducing a load parameter λ into the original system of nonlinear equations, *F(x)* = 0. For a range of values of λ. The solution of mathematical equations can be solved along a given path can be found for each value of λ, although problems arise when a solution does not exist for maximum possible λ value. At this point, one of the state variables, X can be used effectively as the parameter to be varied, choice of which is determined locally at each continuation step. Thus, the method is designated as the locally parameterized continuation. In summary, local parameterization allows not only the added load parameter, but also the state variables to be used as continuation parameters. Continuation power flow finds successive load flow solutions according to a load scenario.

From a known base solution, a tangent predictor is used so as to estimate next solution for a specified pattern of load increase. The corrector step then determines the exact solution using Newton-Raphson technique employed by a conventional power flow. After that a new prediction is made for a specified increase in load based upon the new tangent vector. Then corrector step is applied. This process goes until critical point is reached. The critical point is the point where the tangent vector is zero. The illustration of predictor-corrector scheme is depicted in Fig 1.

Here continuation power flow method is applied to following sample system using MATLAB based power system analysis tools. IEEE bus systems consists of generators, transmission lines and loads. Here buses are renumbered .So, in this bus system slack bus, PV buses, and PQ buses. IEEE-14 bus test system shown in Fig.2. The continuation power flow is run with two different conditions. 1) Without considering any Generator reactive power limits. 2) With considering Generator reactive power limits. Load flow analysis considers with and without reactive power limit constrains. Continuation power flow is run up to bifurcation point, that means when maximum loading point reaches power flow will stop. Here distributed slack bus is used so all transmission losses distributed among all buses. At base case loading point lambda is taken 1 and load increasing at each bus proportional to base load.

In practice, it is possible to find the Thevenin's equivalent of any system with respect to the bus under consideration. It is to be noted that the generations are rescheduled at each step of change of the load. Some of the generators may hit the reactive power limit. The network topology may keep changing with respect to the critical bus, with change in the loading, thereby reducing the accuracy of the method. This method works well in the case of an infinite bus and isolated load scenario.

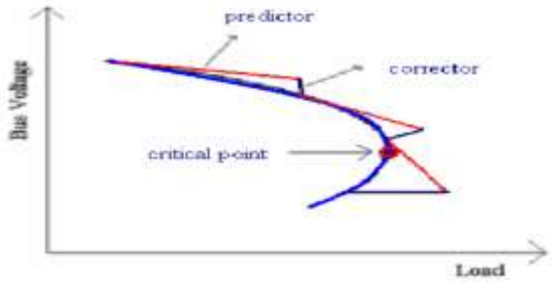


Fig 1: Bus voltage versus Load

Repeated Power Flow method:

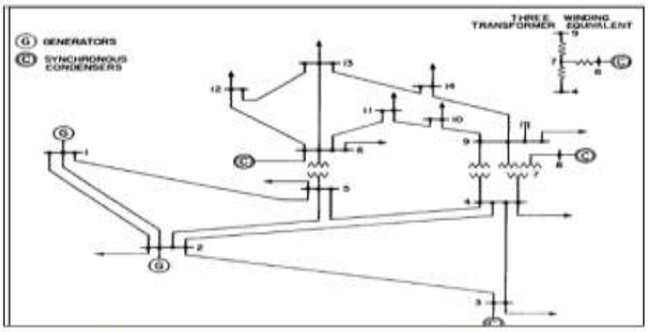
At a specified hour with congestion free market schedule, the maximum value of ATC can be obtained using RPF method, as the name implies, finds TTC by successively solving a set of power flow problems. The demand at buyer bus, and the generation at the seller bus are increased in an increment step until any of the operating constraints' violation. In this paper, the voltage limit, thermal limit and generation capacity limits are considered. Finally the ATC will be equal to TTC minus base load at sink bus which can be further useful to bilateral transaction.

The computational procedure of this approach is as follows:

i. Establish and solve for a base case
ii. Select a transfer case
iii. Solve for the transfer case
iv. Increase step size if transfer is successful
v. Decrease step size if transfer is unsuccessful
vi. Repeat the procedure until minimum step size reached

IV. RESULTS AND ANALYSIS

Selection of IEEE 14-bus system



Single line diagrams of the IEEE 14 Bus systems

Fig 2: Single Line diagram of IEEE 14 Bus system

Analysis: Our test system is the IEEE 14 BUS system is a case study , which has 22 lines and 14 buses. Bus 1 is Slack Bus and Buses 2,3,6,8 are the generator buses. All the buses except bus 1 contains loads also. So it is important to decide that which bus is the most critical bus. A single line diagram of the IEEE 14-bus standard system taken from [9]. It consists of five synchronous machines with IEEE type-1 exciters, three of which are Synchronous compensators used only for reactive power support. There are 11 loads in the system. The dynamic data for the generators exciters was selected from [9]. The system consists of 16 transmission lines and 10 loads.

Identification of the line data, bus data

```
function busdata = busdata14()
%          |Bus | Type | Vsp | theta | PGi | QGi | PLi | QLi |  Qmin | Qmax |
busdata = [ 1    1    1.0600    0     30    20     0     0      0      0;
            2    2    1.0430    0     40   50.0  21.7  12.7   -40     50;
            3    3    1.0335    0      0     0    2.4   1.2     0      0;
            4    3    1.0767    0      0     0    7.6   1.6     0      0;
            5    2    1.0100    0      0   37.0  94.2  19.0   -40     40;
            6    3    1.0238    0      0     0    0.0   0.0     0      0;
            7    3    1.0105    0      0     0   22.8  10.9     0      0;
            8    2    1.0200    0      0   37.3  30.0  30.0   -10     40;
            9    3    1.0619    0      0     0    0.0   0.0     0      0;
            10   3    1.0593    0      0     0    5.8   2.0     0      0;
            11   2    1.0820    0      0   16.2   0.0   0.0    -6     24;
            12   3    1.0803    0      0     0   11.2   7.5     0      0;
            13   2    1.0810    0      0   10.6   0.0   0.0    -6     24;
            14   3    1.0693    0      0     0    6.2   1.6     0      0;
             ];

%             |  From |  To   |    R     |    X     |     B/2   |  X'mer  |
%             |  Bus  | Bus   |    pu    |    pu    |     pu    | TAP (a) |
linedata = [ 1       2       0.0192     0.0575     0.0264        1
             1       5       0.0452     0.1652     0.0204        1
             2       3       0.0570     0.1737     0.0184        1
             3       4       0.0132     0.0379     0.0042        1
             2       4       0.0472     0.1983     0.0209        1
             2       5       0.0581     0.1763     0.0187        1
             4       7       0.0119     0.0414     0.0045        1
             5       6       0.0460     0.1160     0.0102        1
             6       11       0.0267     0.0820     0.0085        1
             6       12       0.0120     0.0420     0.0045        1
             6       13       0.0        0.2080     0.0         0.978
             4       9       0.0        0.5560     0.0         0.969
             9       11       0.0        0.2080     0.0          1
             10      11       0.0        0.1100     0.0          1
             7       8       0.0        0.2560     0.0         0.932
            12       13       0.0        0.1400     0.0          1
            12       14       0.1231     0.2559     0.0          1
             ];
```

Fig 3: load flow line data and bus data (Without Reactive power Limits)

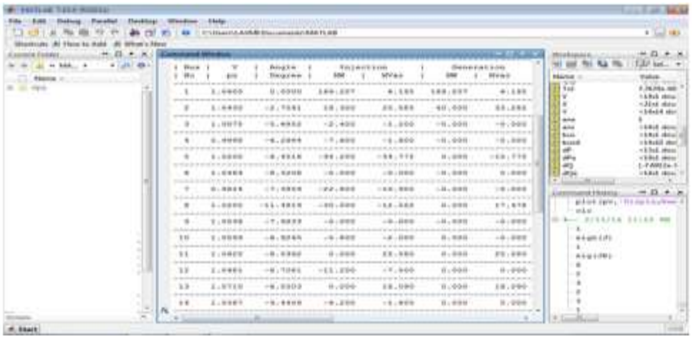


Fig 4: Load Flow using power flow Method (With Reactive power Limits)

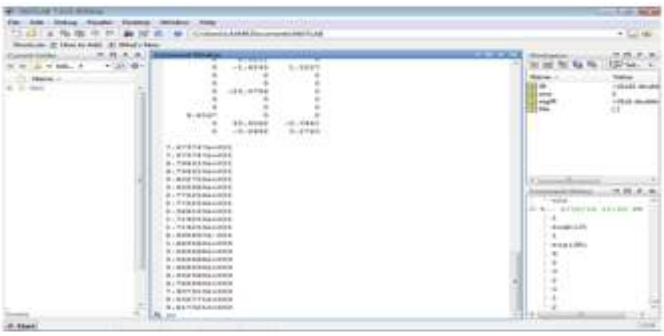


Fig 5: Framing reduced Jacobian matrix

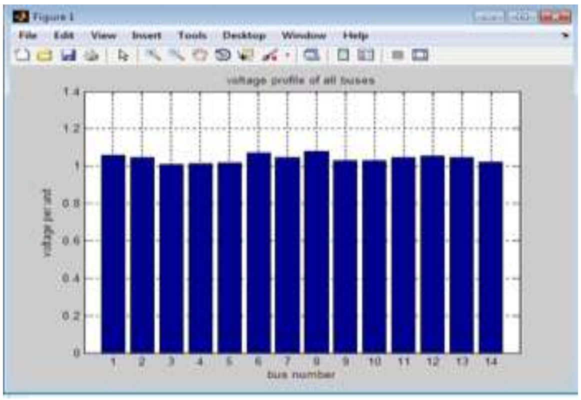


Fig 6: The voltage profile of all buses of the IEEE14 system as obtained from the load flow

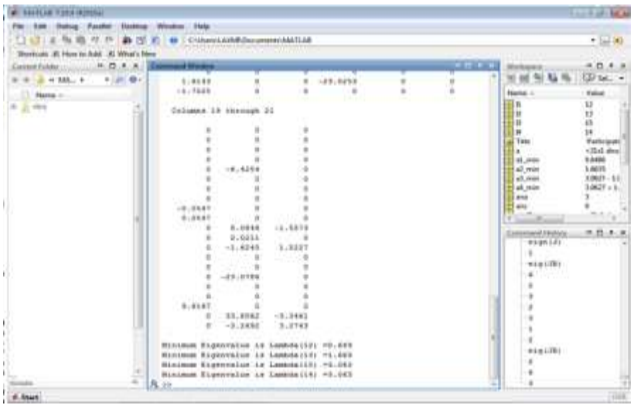


Fig 7: Obtaining the minimum Eigen value

.Table 1: The value Eigen value associated of the reduced Jacobian matrix.

Mode	Eigen value
1	74.7375 +23.0420i
2	74.7375 -23.0420i
3	67.9441 +18.4470i
4	67.9441 -18.4470i
5	36.0275
6	34.0436
7	27.7525 + 7.2245i
8	27.7525 - 7.2245i
9	23.6614
10	17.1925 + 0.4839i
11	17.1925 - 0.4839i
12	0.6486
13	1.6635
14	3.0627 + 1.0611i
15	3.0627 - 1.0611i
16	4.9664
17	6.0025
18	6.7607
19	7.4874
20	8.5508
21	9.6173

This factor indicates the areas that are most critical mode due to variation of reactive power. From the load flow analysis, weakest buses and participation factors are identified. The largest participation factor value (0.36) at bus 6 indicates the highest contribution of this bus to the voltage collapse. Through the technique modal analysis, is possible the identification of the best places to proceed to the installation of static compensator in order to improve the voltage margin of the system.

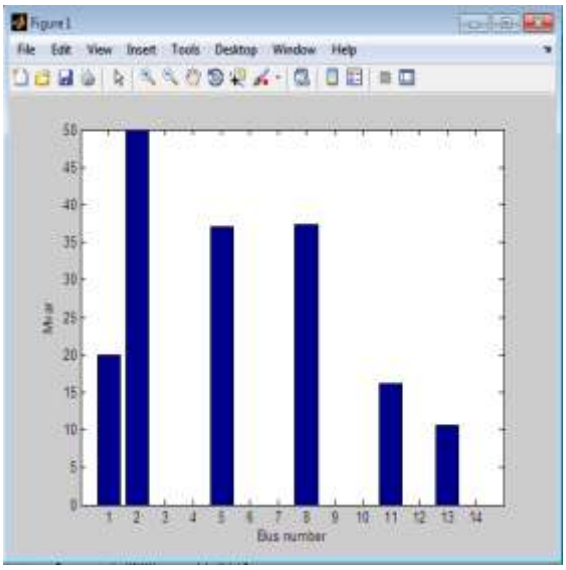


Fig 8: Margin of reactive power in IEEE 14 bus bar test system

Analysis:

Continuation power flow finds successive load flow solutions according to a load scenario. From a known base solution, a tangent predictor is used so as to estimate next solution for a specified pattern of load increase. The corrector step then determines the exact solution using Newton-Raphson technique employed by a conventional power flow. After that a new prediction is made for a specified increase in load based upon the new tangent vector. Then corrector step is applied. This process goes until critical point is reached. The critical point is the point where the tangent vector is zero.

Table 2: Transmission lines data (R, X and B in Pu on 100MVA base) for the 14-bus test system

End buses	R	X	B/2
1-2	0.0192	0.0575	0.0264
2-4	0.0472	0.1983	0.0209
12-13	0	0.1400	0

Table 3: Transformer data in transmission line for tap setting (R, X in pu on 100 MVA base) for the 14-bus test system

End buses	MVAR(pu)
4	0.191
5	0.016

Table 4: Shunt capacitor (R, X in pu on 100 MVA base) for the 14-bus test system for compensation

End buses	R	X
3-8	0.0671	0.17173
7-9	0	0.11001
6-7	0	0.2522

Table 5: Base case load data (Pu on 100 MVA base) for the 14-bus test system

Bus	V(pu)
1	1.06
2	1.045

Table 6: Base case generator data (Pu on 100 MVA base) for the 14-bus test system

bus	P(MW)	QMVAR(pu)
3	0.217	0.127
4	0.942	0.191
7	0.112	0.075
8	0.050	0
9	0.295	0.166
10	0.09	0.058
11	0.035	0.018
12	0.061	0.016
13	0.135	0.058
14	0.1499	0.050

Table 7: Eigen values of reduced Jacobian matrix (Pu on 100 MVA base) for the 14-bus test system

K	E1	E2	E3	E4
1.124	0.1861	0.3190	0.1361	0.5786

Table 8: Transformer data for different load levels (Pu on 100 MVA base) for the 14-bus test system

End buses	R	X	Tap setting
9-10	0.03181	0.08450	1
			0.978
			0.969
			0.932

Table 9: Load data for different load levels (Pu on 100 MVA base) for the 14-bus test system

Bus	P(pu)	Q(pu)	Load level
4	0.942	0.191	1
	0.931	0.185	0.978
	0.928	0.189	0.969
	0.940	0.172	0.932
5	0.478	0.197	1
	0.435	0.192	0.978

Table 10: Load voltages and reactive power outputs of generator 2 and 3 at load level 2 (Pu on 100 MVA base) for the 14-bus test system

Contingency	V5	V6	QG3	QG2
Without outage, fixed tap	1.03	1.11	290	-83
Without outage, LTC active (Load Level 2)	0.99	1.08	227	164
Without outage, LTC active (Load Level 3)	0.98	1.07	700	249

Table 11: Voltage Sensitivity Factor of PQ Buses of IEEE 14 Buses at Base Case and Diff Contingencies

PQ Bus No	VSF without RP limit	VSF with RP limit	VSF Line outage (2-3)
6	0.0929	0.2469	0.3388
9	0.0681	0.1594	0.2841
10	0.0969	0.2527	0.2763
12	0.0257	0.2295	0.3025
14	0.0409	0.2408	0.3152

Analysis: At the time of contingency case line outage (2-3) rank of most four weakest buses is changed, while for other contingency it remains same .Bus no. 6 is weakest bus in all contingencies cases. Above all results shows that voltage stability margin can be found easily by CPF. And P-V curve and max. Loading point can access. Only collapse point is not enough for voltage stability assessment .So, using tangent vector sensitivity analysis can be done. From voltage sensitivity factor weakest bus can identify. The Weakest bus identification is done by without excessive calculation. Placement of reactive power sources such as FACTS devices, capacitor bank can be inserted. From the comparison results CPF method is more accurate and simple for Voltage stability analysis but compensators can be easily placed by using RPF Method.

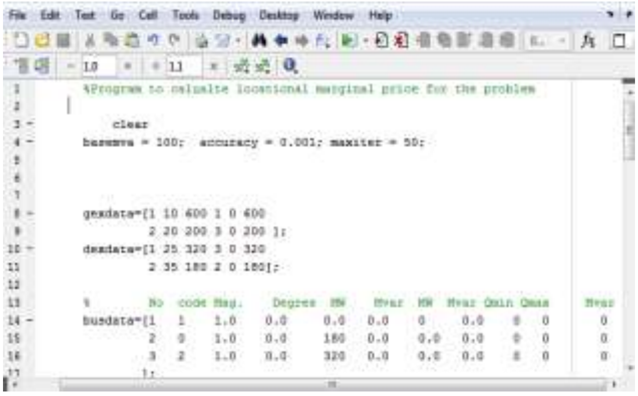


Fig 9: Locational Marginal Price for the IEEE 14 system by using RPF method

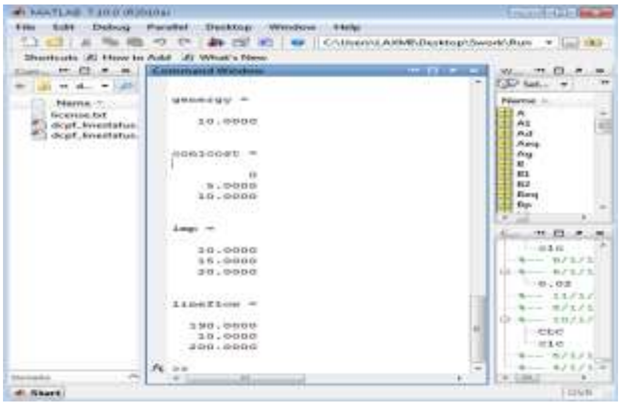


Fig 10: Line flow data for IEEE 14-bus using RPF method

IEEE 30- Bus system (Case study):

The IEEE 30 Bus system is considered in estimation of TTC using different power flow methods. The 11 kV and 1.0 kV base voltages are considered as initial conditions. The model actually has these buses at either 132 or 33 kV.

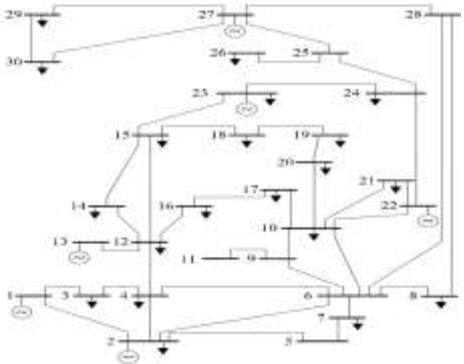


Fig 11: Single line diagram

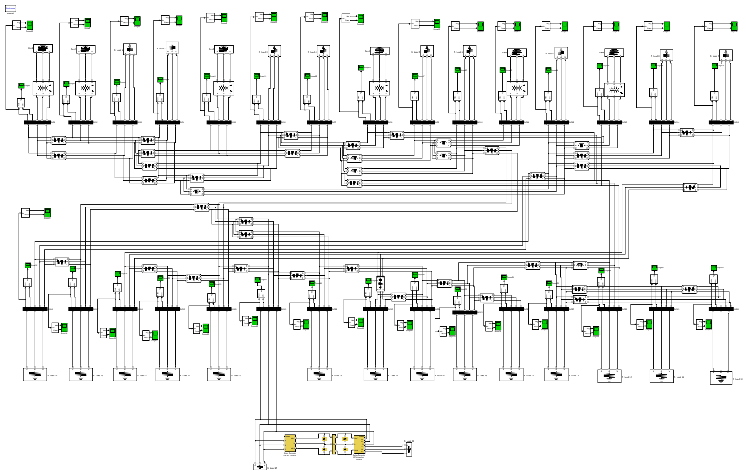


Fig 12: Simulation model of IEEE 30-bus system

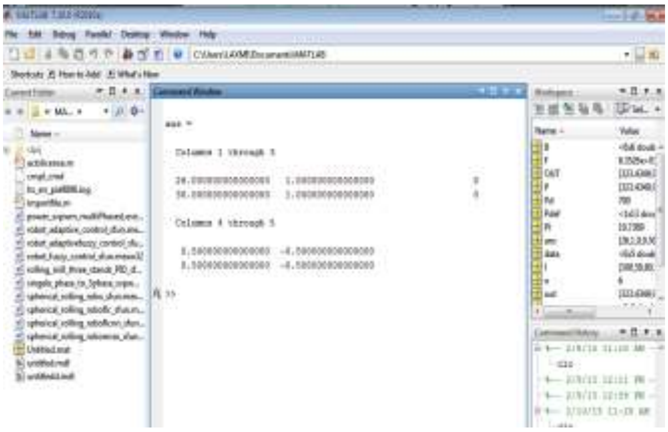


Fig 13: TTC for 30-bus system

Table 12: Enhancement of power transfer capability for IEEE 14-Bus system

From Area	To Area	TTC in MW			Constraint
		OPF	CPF	RPF	
1	2	36	36	**42**	Violating reactive power limit of generator at bus: 1;
3	2	44	48	**53**	Voltages at all buses are within permissible limits
1	5	43	45	**50.2**	Violating reactive power limit of generator at bus: 1;

Table 13: Enhancement of power transfer capability for IEEE 30-Bus system

From Area	To Area	TTC in MW			Constraint
		OPF	CPF	RPF	
25	26	115.9	115.1	**168.1**	Violating reactive power limit of generator at bus: 26;
29	30	116.18	115.3	**168.4**	Violating reactive power limit of generator at bus: 30;

V. CONCLUSIONS

This paper reviews the influence of different uncertainties on the ATC value. In addition to the general contingencies, the stress due to strategic bidding or trading schemes in the competitive market is also studied for modeling. The ATC value between a specified seller bus and buyer bus can vary significantly with the change in bid since it causes to alter the schedule as a result system operating state. The higher value of bidding parameter from the case study , causes to allocate lower schedule at that generator and ATC value to any bus from that source is increased. The results have been improved by using Repeated Power Flow (RPF) for the computation of transfer capabilities between system areas. A significant reduction in computational time, thus making it a potential candidate for online application. The work proposed in this paper can also be used to calculate available transfer capabilities (ATC) under the open access environment.

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