# Enhancement of Available Transfer Capability Using FACTS Devices In Deregulated Power System

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***Abstract-*** *This paper proposes the requirement of Available Transfer Capability (ATC) is extremely significant in deregulated Power System. The computation of ATC at different buses plays a significant role on day to day operation and maintenance of any deregulated power system.ATC evolution is significant because it is the point at which power system reliability meets electricity market efficiency. In this project, more accurate PTDFs can be calculated using AC power flow model.The results have been determined for intact and line contingency cases taking bilateral transaction. In this project some transactions are elected and Available Transfer Capability for both intact and contingency cases are calculated in the transmission network. The above said methodology is applied on IEEE 6-bus and IEEE 30-bus test system. Load flow solution is observed by using Power world simulator software. Available Transfer Capability of the system is estimated by Sensitivity approach of PTDF method.ATC is enhanced by the optimum location of FACTS device in the power system. Hence the power capability of the system is improved.*

***Keywords***- Available Transfer Capability, Flexible AC Transmission System, Power Transfer Distribution Factor.

## I. INTRODUCTION

All over world the economical growth and enhancement of the technological achievements initiates the electrical power system continuously expanding its size and enhancing its complexity in many aspects. Therefore the governments have been changing their rules and regulations by allowing the private sectors into the power generation, transmission and distribution called as Deregulated Power System. The continuous monitoring and maintenance of security under different circumstances in the deregulated power system is becoming a complex task for the power system engineer in day to day operation, maintenance and planning of deregulated power system.

Since many utilities provide transaction services for wholesale customers, they must know about the post information on ATC of their transmission networks. Such information will help power marketers, sellers and buyers in reserving transmission services. ATC must be rapidly updated for new capacity reservations, schedules or transactions, various mathematical models have been developed by the researchers to determine the ATC of the transmission system [2-4]. The computation of ATC has been carried out by the various researchers. Yan-ou and Chanan Singh demonstrated on IEEE 24 bus reliability test system [6]. The linear ATC has been demonstrated using DC Power Transfer Distribution Factors (DCPTDF) and used to allocate real power flows on the transmission lines [7]. However, this method has a poor accuracy due to the assumption involved in the DC power flow model.Researchers have proposed the computation of ATC using AC Power Transfer Distribution Factors (ACPTDF) [10].

In this paper ATC is calculated in IEEE- 6 bus system and IEEE-30 bus system using AC Power Transfer Distribution Factors (ACPTDF) method and ATC is further enhanced by optimum location of TCSC.

## II. AVAILABLE TRANSFER CAPABILITY(ATC)

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. Mathematically, ATC is defined as the Total Transfer Capability (TTC) less the Transmission Reliability Margin (TRM), less the sum of existing transmission commitments (which includes retail customer service) and the Capacity Benefit Margin (CBM).

ATC can be expressed as:

**ATC= TTC – TRM – Existing Transmission Commitments** (including CBM)

The ATC between two areas provides an indication of the amount of additional electric power that can be transferred from one area to another for a specific time frame for a specific set of conditions.ATC can be a very dynamic quantity because it is a function of variable and interdependent parameters. These parameters are highly dependent upon the conditions of the network. Consequently, ATC calculations may need to be periodically updated. Because of the influence of conditions throughout the network, the accuracy of the ATC calculation is highly dependent on the completeness and accuracy of available network data.

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.

Transmission Reliability Margin (TRM) is defined as that amount of transmission transfer capability necessary to ensure that the interconnected transmission network is secure 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.

ATC can be mathematically formulated as follows,
$ATC_{ij}= \min \{T_{ij,\, mn}\}$

Where, $T_{ij,mn}$denotes the transfer limit value of the transmission between lines m,n by considering transaction between lines i,j.

## III. FLEXIBLE AC TRANSMISSION

Flexible transmission system is akin to high voltage dc and related thyristors developed designed to overcome the limitations of the present mechanically controlled ac power transmission system.Use of high speed power electronics controllers, gives 5 opportunities for increased efficiency

- Greater control of power so that it flows in the prescribed transmission routes.
- Secure loading(but not overloading) of transmission lines to levels nearer their required limits.
- Greater ability to transfer power between controlled areas, so that the generator reserve margin-typically 18% may be reduced to 15% or less.
- Prevention of cascading outages by limiting the effects of faults and equipment failure.
- Damping of power system oscillations, which could damage equipment and or limit usable transmission capacity.

Flexible system requires tighter transmission control and efficient management of inter-related parameters that constraints today’s system including-

- Series impedance-phase angle.
- Shunt impedance-Occurrence of oscillations at various below rated frequencies.
- This results in transmission line to operate near its thermal rating.

Example - A 1000KV line may have loading limit 3000-4000MW. but the thermal limit may be 5000MW.

### THYRISTOR CONTROLLED REACTOR

Static compensators of tcr type are characterized by the ability to perform continuous control, maximum delay of one half cycle and practically no transients. Principal disadvantage being generation of low frequency harmonic current component and higher losses when working in inductive region(eg absorbing reactive power). However the harmonics can be eliminated using filters.

### COMBINED TCR AND TCS

These are characterized by continuous control, practically no transients, low generation of harmonics and flexibility in control and operation. Thyristor Controlled series compensation: It’s effective in controlling sub-synchronous resonance which mainly occurs because of interactive between large thermal generating units and series compensated transmission system.

## IV. POWER WORLD SIMULATOR

Power World Simulator is a user-friendly and highly interactive power system analysis and visualizations platform. It integrates many commonly performed power sysem tasks like contingency Analysis, Time-step Simulation, OPF, ATC, PVQV, Fault analysis, SCOPF, Sensitivity Analysis, Loss Analysis, Transient Stability, GIC. It is designed to operate on Microsoft windows XP/2008/7/8 Platforms.

### POWER WORLD SIMUALTOR HISTORY

Power World Simulator version 1.0 created in May 1994 at the university of Illinois Urbana-Champaign by professor Thomas Overbye(Ph.D.). The impetus for early versions was to each power system operation to non-technical audiences.

Power World Corporation was formed in 1996 with the goal of further developing and commercializing the simulator tool. The Simulator version 18 is virtually unrecognizable from the early versions of the software. It has evolved into a powerful power system analysis and visualization environment capable of solving very large systems.

**TRAINING GOALS**

It provides a better understanding of how to use PowerWorld simulator for power system analysis and visualization. It provide techniques for building good power system models and show how these techniques can be used to analyze system issues.

**MODES OF OPERATION**

The graphical power system case editor and the power flow package are implemented in simulator's two distinct modes:

- Edit Mode
- Run Mode

**EDIT MODE**

The tasks performed are

- Create new power flow cases
- Modify existing cases
- Abilities
- Cases can be modified either graphically or via text displays

**RUN MODE**

- Stand alone power flow
- Power flow analysis tools and sensitivities
- Contigency Analysis
- Time-Step Simulation
- Optimal Power Flo(OPF)
- PV and QV Curve Tools(PVQV)
- Available Transfer Capability(ATC)
- Security Constrained OPF(SCOPF)
- Sensitivity Analysis
- Loss Analysis
- Fault Analysis
- Transient Stability
- Geomagnetically Induced Current(GIC)

**Thyristor Controlled Series Compensator**

It consists of a series capacitor bank shunted by a thyristor-controlled reactor in order to provide a smoothly variable series capacitive reactance as shown, the bi-directional thyristor valve that is fired with an angle α ranging between 90° and 180° with respect to the capacitor voltage.

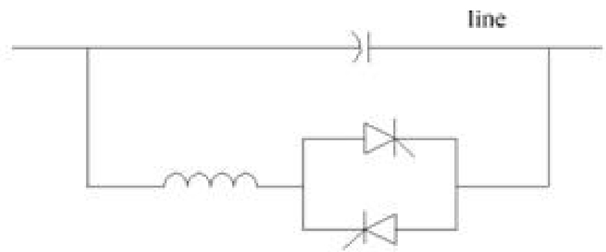


Fig 1. Shows the TCSC Circuit.

The TCSC can be operated in bypass–thyristor mode, blocked-thyristor mode and vernier mode.

In bypass-thyristor mode, the thyristors are made to fully conduct with a conduction angle of 1800.Gate pulses are applied as soon as the voltage across the thyristors reaches zero and becomes positive, resulting in a continuous flow of current through the thyristor valves. The TCSC module behaves like a parallel capacitor-inductor combination. In blocked-thyristor mode, the firing pulses to the thyristor valves are blocked. If the thyristors are conducting and a blocking command is given, the thyristors turn off as soon as the current through them reaches a zero crossing. Thenet TCSC reactance is capacitive.

The vernier mode allows the TCSC to behave either as a continuously controllable capacitive reactance or as a continuously controllable inductive reactance. It is achieved by varying the thyristor-pair firing angle in an appropriate range.

**Basic Principle of TCSC:**

A TCSC provides continuous control of power on the ac line over a wide range. The principle of variable-series compensation is simply to increase the fundamental-frequency voltage across the fixed capacitor. (FC) in a series compensated line through appropriate variation of the firing angle Alpha. This enhanced voltage changes the effective value of the series-capacitive reactance.

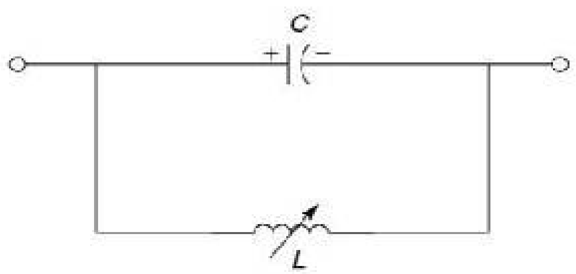


Fig 2 This shows that a variable Inductor connected in Shunt with an FC.

A simple understanding of TCSC functioning can be obtained by analyzing the behaviour of a variable inductor connected in parallel with an FC.

**SIMULATION DATA**

**CASE 1:(IEEE 6 Bus system)**

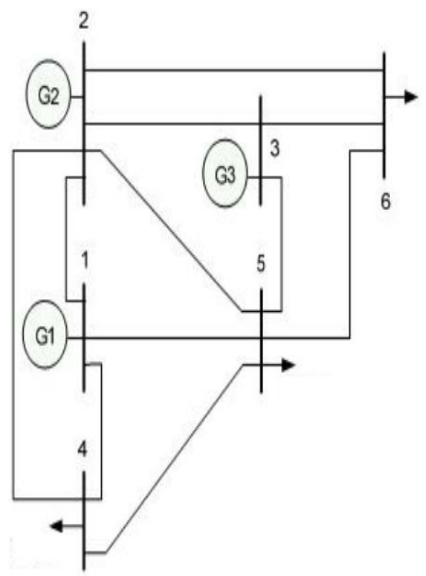


Fig.3 IEEE 6 Bus system

**DATA FOR 6 BUS SYSTEM**

Table.1 Data for 6 Bus System

| Bus No | Bus type | V(p.u) | $P_d$ (MW) | $Q_d$ (MVAR) | $P_g$ (MW) | $Q_g$ (MVAR) |
|---|---|---|---|---|---|---|
| 1 | slack | 1.05 | 0 | 0 | - | - |
| 2 | PV | 1.05 | 0 | 0 | 50 | - |
| 3 | PV | 1.07 | 0 | 0 | 60 | - |
| 4 | PQ | 1.0 | 70 | 70 | 0 | 0 |
| 5 | PQ | 1.0 | 70 | 70 | 0 | 0 |
| 6 | PQ | 1.0 | 70 | 70 | 0 | 0 |

Generator data-IEEE 6 Bus system

Table.2 Generator data-IEEE 6 Bus system

| BUS No | Pmin (MW) | Pmax (MW) | Qmin (MVAR) | Qmax (MVAR) |
|---|---|---|---|---|
| 1 | 50 | 200 | -20 | 100 |
| 2 | 37.5 | 150 | -20 | 100 |
| 3 | 45 | 180 | -15 | 100 |

line data-IEEE 6 Bus system

Table.3 line data-IEEE 6 Bus system

| Tx - Line | R (p.u) | X (p.u) | Line charging susceptance (p.u) | Thermal limit(MVA) |
|---|---|---|---|---|
| 1-2 | 2 | 0.2 | 0.02 | 40 |
| 1-4 | 4 | 0.2 | 0.02 | 60 |
| 1-5 | 5 | 0.3 | 0.03 | 50 |
| 2-3 | 3 | 0.25 | 0.03 | 40 |
| 2-4 | 4 | 0.1 | 0.01 | 70 |
| 2-5 | 5 | 0.3 | 0.02 | 30 |
| 2-6 | 6 | 0.2 | 0.025 | 90 |
| 3-5 | 5 | 0.26 | 0.025 | 70 |
| 3-6 | 6 | 0.1 | 0.01 | 80 |
| 4-5 | 5 | 0.4 | 0.04 | 20 |
| 5-6 | 6 | 0.3 | 0.03 | 40 |

**CASE 2:(IEEE 30 Bus system)**

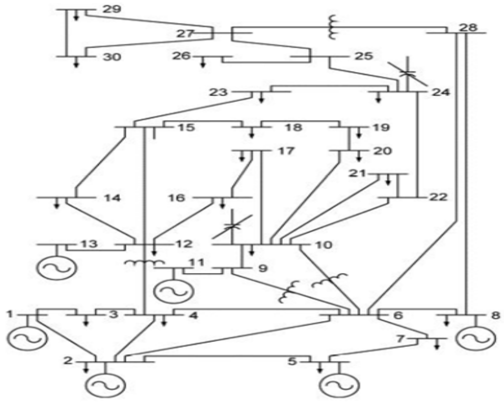

Fig.4 IEEE 30 Bus system

## GENERATOR DATA

Table.4 Generator Data

| BUS No | $P_{min}$ (MW) | $P_{max}$ (MW) | $Q_{min}$ (MVAR) | $Q_{max}$ (MVAR) |
|---|---|---|---|---|
| 1 | 50 | 200 | -20 | 100 |
| 2 | 20 | 80 | -20 | 80 |
| 5 | 15 | 50 | -15 | 80 |
| 8 | 10 | 35 | -15 | 60 |
| 11 | 10 | 30 | -10 | 50 |
| 13 | 10 | 40 | -15 | 60 |

## BUS DATA

Table.5 Bus Data

| Bus No | Bus type | V (p.u.) | $P_d$ (MW) | $Q_d$ (MVAR) | Pg(MW) | $Q_g$ (MVAR) |
|---|---|---|---|---|---|---|
| 1 | slack | 1.05 | 0 | 0 | 120 | 0 |
| 2 | PV | 1.03 | 21.7 | 12.7 | 62.24 | 0 |
| 3 | PV | 1.03 | 2.4 | 1.2 | 0 | 0 |
| 4 | PQ | 1.02 | 7.6 | 1.6 | 0 | 0 |
| 5 | PQ | 1.00 | 9.4 | 19 | 34.46 | 0 |
| 6 | PQ | 1.02 | 0 | 0 | 0 | 0 |
| 7 | PQ | 1.00 | 22.8 | 10.9 | 0 | 0 |
| 8 | PV | 1.02 | 30 | 30 | 24.28 | 0 |
| 9 | PQ | 1.03 | 0 | 0 | 0 | 0 |
| 10 | PQ | 1.01 | 5.8 | 2 | 0 | 0 |
| 11 | PV | 1.09 | 0 | 0 | 21.62 | 0 |
| 12 | PQ | 1.03 | 11.2 | 7.5 | 0 | 0 |
| 13 | PV | 1.08 | 0 | 0 | 28.07 | 0 |
| 14 | PQ | 1.02 | 6.2 | 1.6 | 0 | 0 |
| 15 | PQ | 1.01 | 8.2 | 2.5 | 0 | 0 |
| 16 | PQ | 1.02 | 3.5 | 1.8 | 0 | 0 |
| 17 | PQ | 1.01 | 9 | 5.8 | 0 | 0 |
| 18 | PQ | 1.00 | 3.2 | 0.9 | 0 | 0 |
| 19 | PQ | 1.00 | 9.5 | 3.4 | 0 | 0 |
| 20 | PQ | 1.00 | 2.2 | 0.7 | 0 | 0 |
| 21 | PQ | 1.00 | 17.5 | 11.2 | 0 | 0 |
| 22 | PQ | 1.00 | 0 | 0 | 0 | 0 |
| 23 | PQ | 1.00 | 3.2 | 1.6 | 0 | 0 |
| 24 | PQ | 0.99 | 8,7 | 6.7 | 0 | 0 |
| 25 | PQ | 1.00 | 0 | 0 | 0 | 0 |
| 26 | PQ | 0.99 | 3.5 | 2.3 | 0 | 0 |
| 27 | PQ | 1.02 | 0 | 0 | 0 | 0 |
| 28 | PQ | 1.01 | 0 | 0 | 0 | 0 |
| 29 | PQ | 1.00 | 2.4 | 0.9 | 0 | 0 |
| 30 | PQ | 0.99 | 10.6 | 1.9 | 0 | 0 |

## LINE DATA

Table.6 Line Data

| Tx – Line | R (p.u) | X (p.u) | Line charging susceptance (p.u) | Thermal limit(MVA) |
|---|---|---|---|---|
| 1-2 | 0.019 | 0.057 | 0.026 | 250 |
| 1-3 | 0.045 | 0.185 | 0.02 | 250 |
| 2-4 | 0.057 | 0.173 | 0.018 | 150 |
| 3-4 | 0.013 | 0.037 | 0.004 | 250 |
| 2-5 | 0.047 | 0.198 | 0.02 | 150 |
| 2-6 | 0.058 | 0.176 | 0.018 | 250 |
| 4-6 | 0.11 | 0.041 | 0.005 | 200 |
| 5-7 | 0.046 | 0.116 | 0.01 | 150 |
| 6-7 | 0.026 | 0.082 | 0.008 | 170 |
| 6-8 | 0.012 | 0.042 | 0.004 | 50 |
| 6-9 | 0.0 | 0.14 | 0 | 140 |
| 6-10 | 0.0 | 0.25 | 0 | 155 |
| 9-11 | 0.0 | 0.13 | 0 | 120 |
| 9-10 | 0.0 | 0.198 | 0 | 120 |
| 4-12 | 0.0 | 0.199 | 0 | 120 |

| Tx – Line | X (p.u) | R (p.u) | Line charging susceptance (p.u) | Thermal limit(MVA) |
|---|---|---|---|---|
| 12-13 | 0.14 | 0 | 0 | 150 |
| 12-14 | 0.225 | 0.123 | 0 | 150 |
| 12-15 | 0.13 | 0.066 | 0 | 120 |
| 12-16 | 0.198 | 0.094 | 0 | 120 |
| 14-15 | 0.199 | 0.221 | 0 | 120 |
| 16-17 | 0.193 | 0.082 | 0 | 120 |
| 15-18 | 0.218 | 0.107 | 0 | 150 |
| 18-19 | 0.129 | 0.063 | 0 | 120 |
| 19-20 | 0.068 | 0.034 | 0 | 120 |
| 10-20 | 0.209 | 0.936 | 0 | 120 |
| 10-17 | 0.084 | 0.032 | 0 | 100 |
| 10-21 | 0.074 | 0.034 | 0 | 100 |
| 10-22 | 0.149 | 0.072 | 0 | 100 |

| Tx – Line | X (p.u) | R (p.u) | Line charging susceptance (p.u) | Thermal limit(MVA) |
|---|---|---|---|---|
| 22-24 | 0.27 | 0.115 | 0 | 130 |
| 23-25 | 0.32 | 0.132 | 0 | 130 |
| 24-26 | 0.38 | 0.188 | 0 | 100 |
| 25-27 | 0.208 | 0.254 | 0 | 170 |
| 28-29 | 0.396 | 0.109 | 0 | 100 |
| 27-29 | 0.415 | 0.0 | 0 | 100 |
| 27-30 | 0.602 | 0.219 | 0 | 100 |
| 29-30 | 0.453 | 0.32 | 0 | 100 |
| 6-28 | 0.2 | 0.063 | 0.021 | 170 |
| 8-28 | 0.059 | 0.016 | 0.0065 | 100 |
| 15-24 | 0.202 | 0.1 | 0 | 100 |
| 21-23 | 0.023 | 0.011 | 0 | 100 |

**SIMULATION RESULTS:**

IEEE 6 Bus system With Contingency

Table.7 shows the IEEE 6 Bus System With Contingency

| Transaction | WithoutFact devices | WithFact devices |
|---|---|---|
| LINE 2-4 | 45 | 54 |
| LINE 2-5 | 32 | 52 |
| LINE 2-6 | 75 | 107 |
| LINE 3-5 | 59 | 93 |
| LINE 3-6 | 52 | 63 |

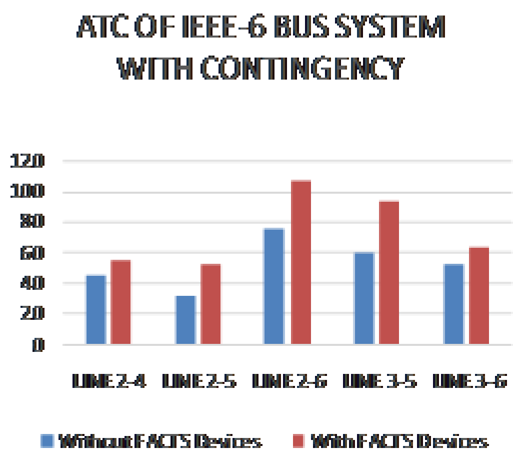


Fig.5 IEEE-6 Bus system With Contingency

ATC of the transmission before placing the facts devices and after placing the facts devices are compared. From the chart it is inferred that after placing of facts devices ATC is Enhanced.

IEEE 6 Bus system Without Contingency

Table.8 shows the IEEE 6 Bus System Without Contingency

| Transaction | Without Fact devices | With Fact devices |
|---|---|---|
| LINE 2-4 | 52 | 62 |
| LINE 2-5 | 48.5 | 64 |
| LINE 2-6 | 108.5 | 114 |
| LINE 3-5 | 89.3 | 103 |
| LINE 3-6 | 51 | 62 |

ATC of the transmission before placing the facts devices and after placing the facts devices are compared. From the chart it is inferred that after placing of facts devices ATC is Enhanced.

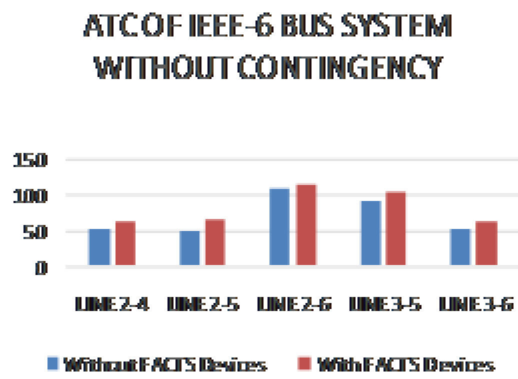


Fig.6 IEEE-6 Bus system Without Contingency

**IEEE 30 Bus system with contingency**

Table.9 shows the IEEE 30 Bus System With Contingency

| Transaction | Without Fact devices | With Fact devices |
|---|---|---|
| LINE 2-4 | 248 | 328 |
| LINE 5-7 | 207 | 225 |
| LINE 8-6 | 313 | 320 |
| LINE 2-5 | 82 | 91 |
| LINE 5-8 | 209 | 215 |

ATC of the transmission before placing the facts devices and after placing the facts devices are compared. From the chart it is inferred that after placing of facts devices ATC is Enhanced.

**IEEE 30 Bus system Without Contingency**

Table.10 shows the IEEE 30 Bus System Without Contingency

| Transaction | Without Fact devices | With Fact devices |
|---|---|---|
| LINE 2-4 | 325 | 446 |
| LINE 5-7 | 205 | 222 |
| LINE 8-6 | 314 | 333 |
| LINE 2-5 | 163 | 194 |
| LINE 5-8 | 276 | 287 |

ATC of the transmission before placing the facts devices and after placing the facts devices are compared. From the chart it is inferred that after placing of facts devices ATC is Enhanced.

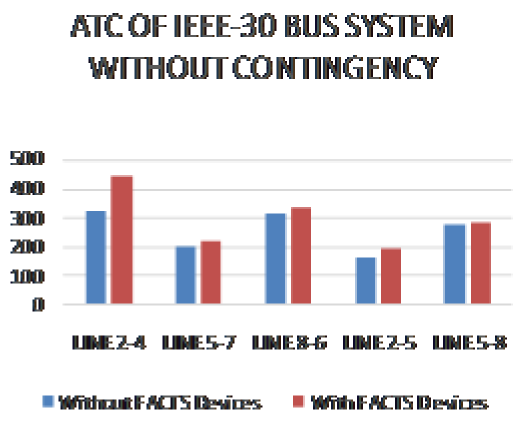


Fig.7 IEEE-30 Bus system Without Contingency

## V. CONCLUSION

Estimation of available transfer capability using Outage Transfer Distribution Factor was done under conditions like with and without contingency using FACTS Devices in IEEE 6 bus system and IEEE 30 bus system.

ATC of the proposed system is enhanced by placing the FACTS devices in appropriate transmission lines. The locations of FACTS Devices is determined based on the minimum value of OTDF of the proposed system.

It is observed that the Enhancement of Available Transfer Capability comparison between various buses of an IEEE-6 Bus System and IEEE-30 Bus System. Also Observed that the enhancement of ATC using FACTS Devices by placing optimally with Sensitivity Approach.

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