

# Optimizing Congestion Management using Available Transfer Capability in the IEEE 14 Bus System

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## ABSTRACT

The objective of deregulating power systems is to encourage competition within power markets, thereby broadening the choices available to participants engaged in electricity trading. The determination of prices in the electricity market hinges on the intricate interplay of supply and demand. A notable challenge encountered by power systems is congestion, arising when power producers and consumers engage in the exchange of electricity to optimize profits, resulting in an overload of the transmission system. This congestion presents a substantial threat to both market power and efficiency, exerting a negative impact on the overall performance of the power system. The current study seeks to explain the concept of congestion management in IEEE 14 Bus systems using Available Transfer Capability (ATC).

Keywords: Congestion Management, Available Transfer Capability, Price Area Method, Generation Shift Factor, Participation Factor

## 1. INTRODUCTION

In the process of restructuring power systems, the primary goal is the establishment of a competitive market. Within the framework of a deregulated power system, there has been a notable shift away from the traditional vertically integrated structure. This transformation is characterized by a departure from the conventional model, where a single entity handles generation, transmission, and distribution, towards a more dynamic and competitive environment. The aim is to foster efficiency, encourage innovation, and provide participants with increased opportunities for engagement within the redefined power sector [1]. Under different policies, power sellers (generating companies) may supply power to buyers (loads)

through optimal, bilateral, or fixed participation transactions. These conditions may lead to congestion, exceeding the limits of specific network components and jeopardizing transmission network security. A thorough assessment of transmission network components is essential before permitting power transactions. Available Transfer Capability (ATC) precisely evaluates unused network capacity, crucial for facilitating efficient commercial processes. The limitations of transmission network transfer capability are influenced by factors such as thermal, voltage, and stability constraints [2]. Understanding the ATC value allows us to establish a congestion-free network for market operations [3]. The predetermined participation of generators must meet the real-time load demand. Therefore, ATC outcomes must consider the variations in load resulting from multiple generators rather than a single bilateral transaction [4]. When power producers and consumers seek to optimize profits through electricity exchange, the transmission system can surpass its transfer limit, leading to congestion on the transmission lines. The systematic control and handling of this overload on the transmission lines are commonly known as "congestion management [5]. Several approaches exist for congestion management, such as FACTS devices and distribution generation. However, each method comes with its distinct set of advantages and disadvantages [6]. In various congestion management approaches, the price area method is frequently employed in open access, bilateral, decentralized, and day-ahead electricity markets. Utilizing price area congestion management enables the mitigation of transmission congestion while preserving the advantages for stakeholders.

The document begins by introducing the concepts of congestion and its management in

section II. Section III explores ATC and the calculations involved. Building on this, section IV details the simulation and results for IEEE 14 Bus System, based on the experimental results conclusion provided in section V.

## II. CONGESTION MANAGEMENT

In a power system, the transfer capability of power relies on the physical and electrical attributes of transmission lines. The power transfer capability is influenced by operational reliability limits, which include thermal limits, voltage limits,

and stability limits. These limits can lead to the failure of transmission lines to meet power transfer requirements based on load demand, resulting in congestion. The occurrence of this issue is referred to as "Congestion." Congestion occurs when the capacity of transmission lines is insufficient to accommodate the desired power transfer dictated by market demands [3]. The resulting overload of transmission lines due to congestion can lead to damage to certain devices. To ensure the security and reliability of the system, it is essential to address and manage congestion, a process known as "congestion management."

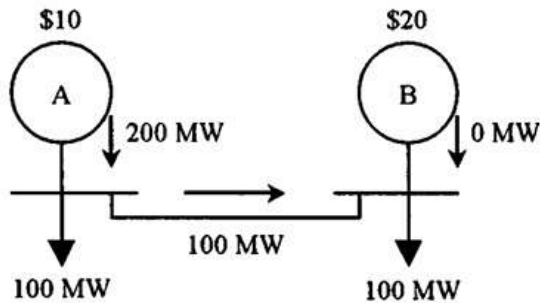


Fig 1: Normal Case

In normal case shown in figure 1 power flows freely between the two areas. Area B purchases 100 MW of power from Area A, total cost  $\square$  2,000 for 200 MW of load.

In congestion case shown in figure 2, the transmission line capacity is limited to 50 MW, introducing congestion. Area B can only buy 50 MW from Area A, while the remaining 50 MW is procured at a higher cost of  $\square$  20 MW/h. This results in a total cost of  $\square$  2,500 for 200 MW of load. Due to congestion, customers incur an additional 25% cost to access 200 MW of power, highlighting inefficiencies in the electricity market. As congestion levels increase, there is a risk of physical damage to power system devices.

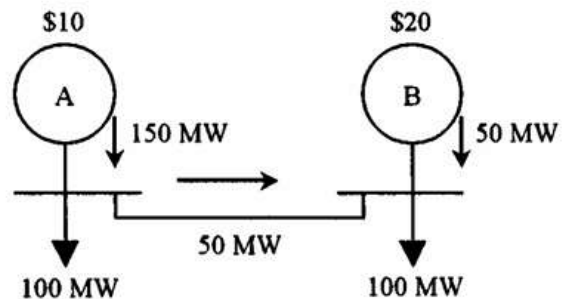


Fig 2: Congestion Case

## III. AVAILABLE TRANSFER CAPABILITY (ATC)

The deregulation of power systems has introduced new challenges and complexities in managing the transmission of electrical energy. Available Transfer Capability (ATC) emerges as a critical parameter in assessing the capability of a power system to accommodate additional transactions while maintaining system reliability. ATC represents the maximum amount of additional power transfer capability available in the transmission network without violating predefined reliability constraints. It accounts for the limitations imposed by equipment capacities, thermal and voltage stability, and other operational factors.

$$ATC = TTC - TRM - \{CBM + ETC\}$$



Fig. 3: ATC for Normal case

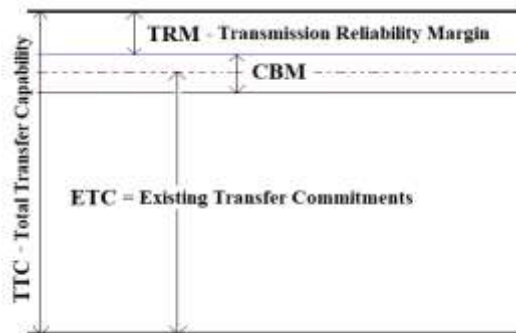


Fig. 4: ATC for Congestion case

ATC distinguishes itself from transfer capacity by considering more than just the specified line rating associated with thermal limits. While capacity solely reflects thermal constraints, ATC takes into account the line capability of various elements within the transmission network. Power Transfer Distribution Factor (PTDF) and Available Transfer Capability (ATC) are interconnected concepts within the realm of power system analysis, particularly in the context of evaluating and optimizing power transfer capacities in a network.

**Power Transfer Distribution Factor (PTDF):**

PTDF represents the sensitivity of power flows in the transmission network to changes in generation or load at specific locations [3]. In simpler terms, it quantifies how a unit change in generation or load at one location affects the power flows on various transmission lines throughout the network. PTDF is a crucial tool for understanding the impact of changes in the power system, facilitating efficient grid operation and market transactions.

**Relation to Available Transfer Capability (ATC):**

The relationship between PTDF and ATC is inherent in the determination of the latter. ATC is essentially a measure of the maximum amount of power that can be transferred between areas or entities within the power system, considering the constraints imposed by the transmission network's physical limitations.

**Calculation of ATC Using PTDF:**

PTDF plays a significant role in the calculation of ATC. By utilizing PTDF values, system operators and planners can assess the impact of changes in power injections or withdrawals at different locations on the available transfer capacity [3].

$$PTDF_{lm,ij} = \frac{X_{li} - X_{mi} - X_{lj} + X_{mj}}{X_{lm}} \dots\dots\dots (1)$$

$$\Delta P_{lm} = PTDF_{lm,ij} * P_{ij} \dots\dots\dots (2)$$

$$P_{lm}^{new} = P_{lm}^0 + PTDF_{lm,ij} * P_{ij} \dots\dots\dots (3)$$

$$P_{lm,ij}^{max} = \frac{P_{lm}^{max} - P_{lm}^0}{PTDF_{lm,ij}} \dots\dots\dots (4)$$

$$ATC_{ij} = \min(P_{lm,ij}^{max}) \dots\dots\dots (5)$$

Where, i and j are buses at the receiving end of line being specified,

m and n area from and to zone numbers for the suggested new transaction,

$P_{lm}^{new}$  is new transaction in MW,

$P_{lm,ij}^{max}$  is the maximum allowable transaction amount from zone l to zone m.

**Generation Shift Factor (G.S.F):**

The Generation Shift Factor plays a crucial role in assessing the variation in the actual power generated by the generator in reaction to demand, especially when the generator is accessible for AGC, and the region is under G.S.F control. The Generation Shift Factor for a generator is defined as the proportion of the generator's power change to the alteration in load. This is mathematically expressed as,

$$G.S.F(X) = \frac{\Delta T_{ik}}{\Delta P_k}$$

Where,  $\Delta T_{ik}$  is change in generator power at  $i^{th}$  bus due to change in load at  $k^{th}$  bus,

$\Delta P_k$  = Change in load at  $k^{th}$  bus.

**IV. SIMULATION MODEL & RESULTS**

**Case Study:**

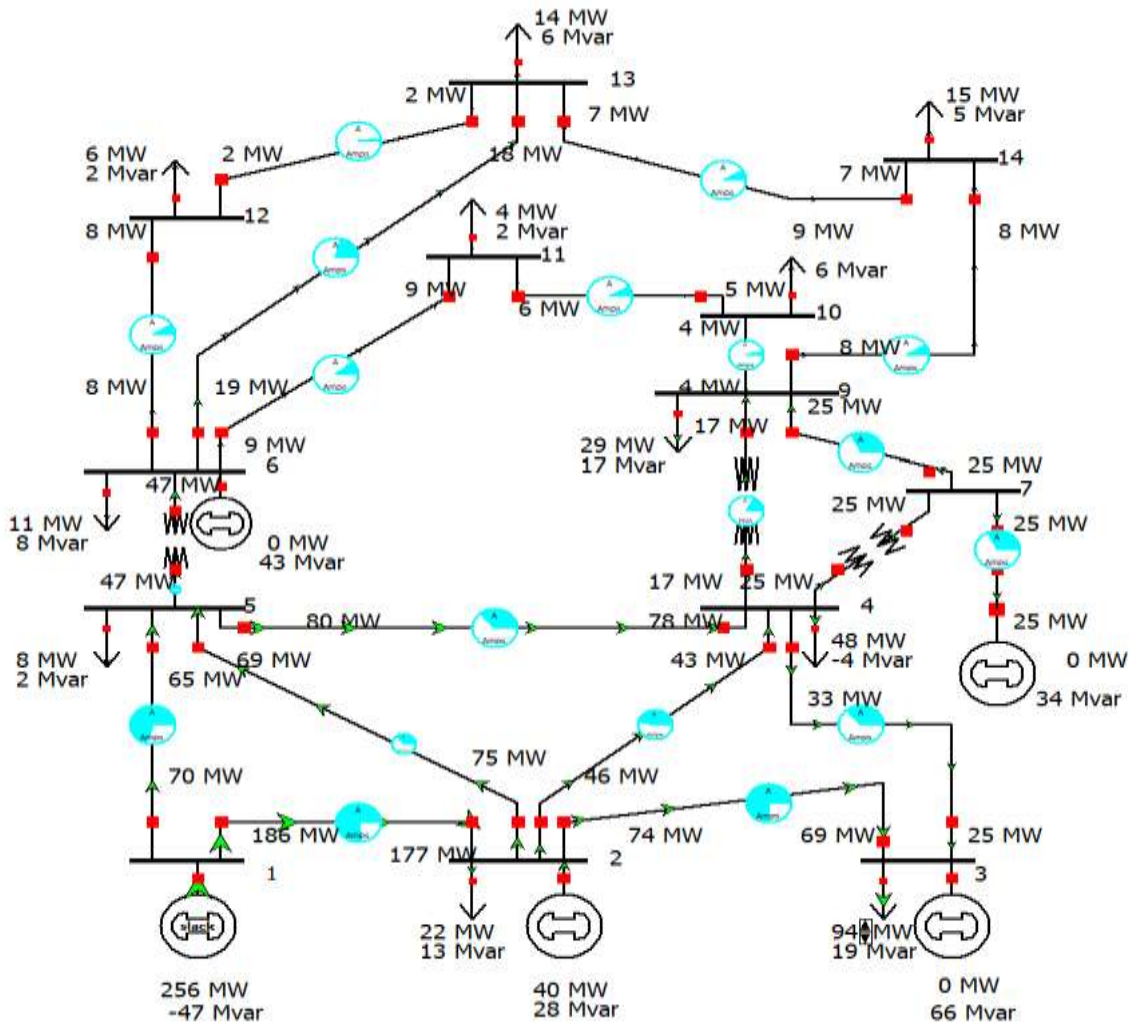
To gain insights into congestion and available transfer capability (ATC) within a deregulated power system, consider and explore the

IEEE 14 bus system through simulation using Power World Simulator, followed by the analysis of the obtained results.

The provided diagram (Figure 5) showcases a 14-bus system. Generator 1 and generator 2 placed at buses 1 and 2, synchronous condensers placed at 3, 6 and 8. There is a prescribed maximum limit of 250 MW for power exchange between bus 1 and bus 2, whereas all other buses have a limit of 100 MW.

Notably, bus 3 bears the highest load demand, with power transmitted through bus 2, which, in turn, receives power from bus 1. Consequently, bus 3 is particularly sensitive to variations in load. Experimental results were obtained by incrementally increasing the load in 10 MW steps, and the resulting analysis incorporates the variation of Available Transfer Capability (ATC) in conjunction with load variations. The summarized findings are presented in Table 1.

Fig 5. : IEEE 14 Bus System Simulation Model



**Steps to run simulation:**

1. In the initial scenario, essential parameters like bus voltage, bus angle, generator details, load information, and power flow are determined.

2. Introducing a change in active power at bus 3, a power flow analysis is conducted using Power World Simulator.

3. PTDF and ATC values for each transaction are then computed.

4. Individual Transmission Capability (TC) is calculated for each transaction, followed by the overall ATC determination for the entire network.

5. Subsequent transactions are implemented, and the aforementioned steps (2, 3, and 4) are reiterated.

Table 1: Available Transfer Capability values for various load values at bus 3.

S.No	Applied step size at bus 3 load (MW)	Load at bus 3 (MW)	Bus to Bus	Power flow (MW)	ATC (MW)	Maximum Limit (MW)
1	10	104	1 to 2	185	68	250
			2 to 3	74	39.53	100
2	20	114	1 to 2	194	56.46	250
			2 to 3	80	28.06	100
3	30	124	1 to 2	202	44.7	250
			2 to 3	85	16.5	100
4	40	134	1 to 2	211	32.79	250
			2 to 3	91	4.88	100
5	50	144	1 to 2	220	20.72	250
			2 to 3	96	-6.82	100
6	60	154	1 to 2	229	8.5	250
			2 to 3	102	-18.61	100
7	70	164	1 to 2	237	-3.88	250
			2 to 3	107	-30.48	100
8	80	174	1 to 2	246	-16.43	250
			2 to 3	113	-42.43	100
9	90	184	1 to 2	256	-29.15	250
			2 to 3	118	-54.47	100

Figure 5 portrays the standard power flow dynamics within the IEEE 14 bus system, where the power flow is contained within predefined maximum limits, ensuring the continuous preservation of Available Transfer Capability (ATC). The congestion case is shown in figure 2, ATC variation during congestion shown in figure 4. In this context, an incremental increase in load at bus 3, with increments of 10 MW, was monitored for the power flow between bus 1 to 2 and bus 2 to 3. The observations revealed that, with the escalating load, the ATC between the specified buses diminished. Beyond point 5, ATC became unavailable, posing a potential risk of physical

harm to the system and compromising its stability and reliability.

All experimental data is documented in Table 1 below. Further analysis, incorporating in Figure 6 and Figure 7, explains the relationship between ATC and load. In Figure 6, the bar graph delineates the ATC variation with load for bus 1 to 2, pinpointing point 4 as the congestion threshold. Similarly, Figure 7 depicts the ATC variation with load for bus 2 to 3, with point 4 on the graph indicating the congestion threshold. From both graphs, it is discernible that ATC experiences a decline with the variation in load, and point 4 is identified as the congestion threshold, signalling the onset of ATC unavailability thereafter.

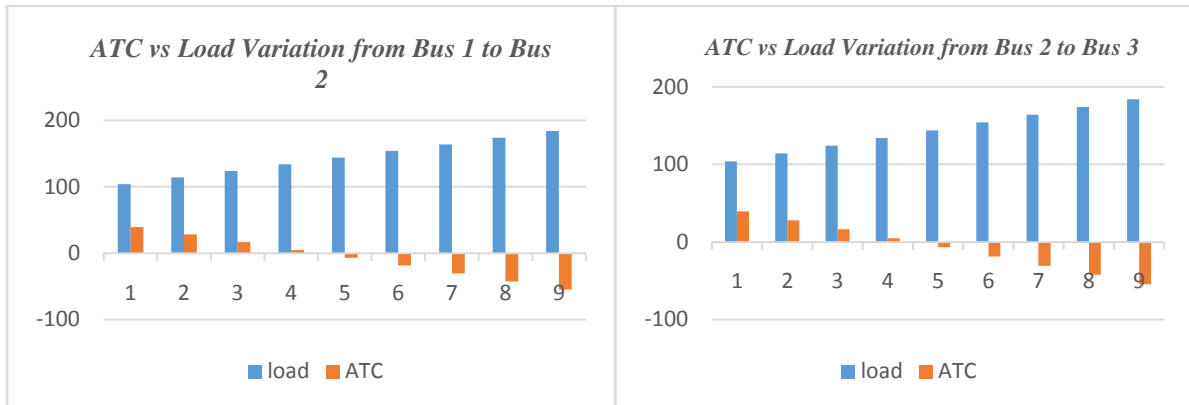


Fig 6: ATC vs Load variation Bus 1 to 2

Fig 7: ATC vs Load variation Bus 2 to 3

Load variation at Bus 3 (MW)	ATC for X1=0.2,X2=0.4	ATC for X1=0.3,X2=0.5	ATC for X1=0.4,X2=0.3	ATC for X1=0.6,X2=0.2
94	50.94	51.37	51.66	51.93
96	48.89	49.11	49.38	49.66
100	44.34	44.56	44.83	45.1
103	40.91	41.13	41.4	41.68
105	38.63	38.85	39.12	39.39
108	35.19	35.41	35.68	35.96
110	32.9	33.12	33.39	33.66

Table 2: Load variation at bus 3 for different generation shift factor

Based on the experimental findings, it is evident that an increase in load leads to a decrease in Available Transfer Capability (ATC) for both scenarios - specifically, from Bus 1 to 2 and from Bus 2 to 3. The graphical representation indicates that prior to point 4, ATC values are positive, signifying availability, while after point 4, they turn

negative, indicating a deficiency. Point 4 serves as a congestion point in the results, where ATC diminishes significantly or reaches zero. To uphold a congestion-free system, it is crucial to maintain the load at or above the level observed at point 4 in the network.

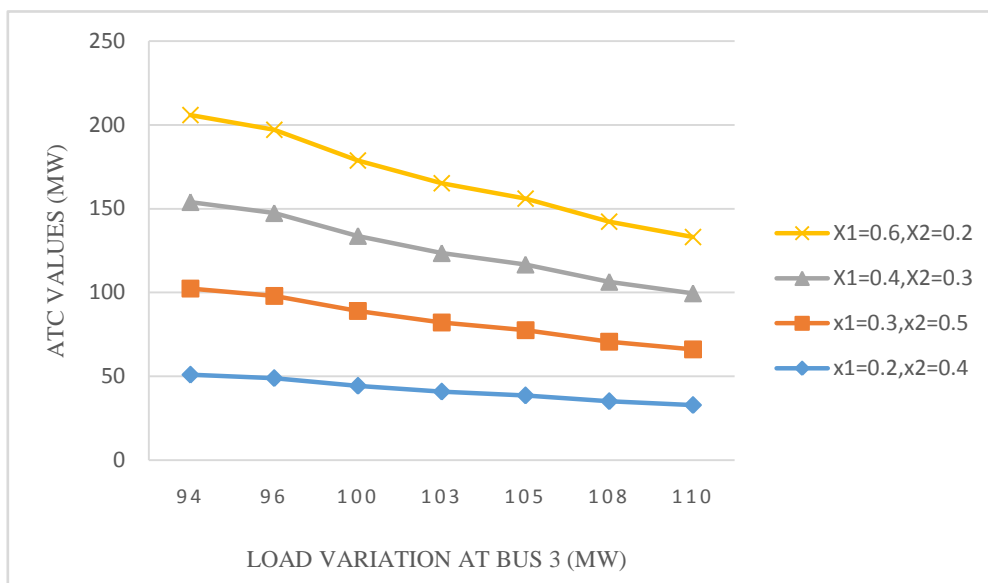


Fig 8: ATC variation for various sets of generation shift factor

In Figure 8, it is clear that changing the generation shift factor has a big effect on the Available Transfer Capability (ATC) of the network. By looking at the load changes at bus 3 for different generation shift factor in Table 2, it's clear that a generator with a higher G.S.F has a big influence on the network's ATC. A generator with a higher G.S.F can really help improve the system's overall power transfer capability. So, it's evident that adjusting the G.S.F can change the ATC of the network.

### V.CONCLUSION

Congestion poses a significant challenge in contemporary power systems due to the escalating day-to-day load demand. The Available Transfer Capability (ATC) serves as a crucial indicator of system performance. From Figure 8, it is clear that ATC of the network can be changed by changing the generation shift factor. Analysing load variations at bus 3 for different G.S.F in Table 2 reveals that a higher G.S.F significantly influences the network's ATC, enhancing the overall power transfer capability. The challenge of congestion in modern power systems arises from escalating daily load demand. ATC plays a pivotal role in secure power transfer and congestion control. Experimental results demonstrate a decrease in ATC values with increasing load demand, highlighting the need for effective congestion management strategies. To maintain a congestion-free system, load and ATC values should equal or surpass point 4. Beyond this threshold, implementing various ATC enhancement techniques and congestion management strategies, including FACTS devices and the Price Area Method, becomes imperative.

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