ABSTRACT

Restructuring of the power industry brings several benefits to the energy sellers and buyers. The reform process of power industry creates competition in the electricity business. It improves power sector efficiency and provides consumers with the option of getting quality and economical electricity from different sellers. As a result, the competitive electricity market brings about energy security, and efficient operation of the system in which the congestion in the system is one of the major issues [1].

The purpose of the power industry restructuring is to eliminate monopoly in the production and trading sectors, thereby, introducing competition at various levels wherever possible. Generating companies may have contracts for the supply of generated power to the electricity dealers/distributors or wholesale consumers. They can also sell electricity in a pool in which electricity producers and customers also participate. Thus, electricity trading will be freed from traditional rules and become competitive. The restructuring of the existing rules and regulations to provide a competitive electricity market is known as deregulation. According to Phillipson and Willis [2], "*Deregulation is a restructuring of the rules and economic incentives that governing authority sets up to control and drive the electric power industry*".

It is desirable to transmit power from one node to another node of the power system without violating the operating constraints while meeting the load demand. The voltage, thermal, and stability limits of the transmission lines are important operating constraints. The transmission system is said to be congested when the transfer of power is not possible due to violation of any constraints. This is undesirable in the system and needs to be eliminated as soon as possible to maintain system security. Congestion causes the increase in electricity prices, insecure operation of the electric power system, etc [3]–[6].

The techniques used to alleviate congestion in the transmission line are called congestion management (CM). There are several methods discussed in the literature, such as sensitive factor-based method [7], [8], auction-based [9], price-based [10]–[12], generator redispatch [13], optimum power flow (OPF) [14], available transfer capability (ATC) based methods [15], [16], ready to pay, load curtailment, flexible AC transmissions systems (FACTS) devices based

methods [17]–[19], demand response (DR) based methods [20], [21], etc. In the present work, ATC determination for CM is presented.

ATC helps to find the most suitable line in the system to transact extra power from that line. The ATC value is continuously displayed on the open access same time information system (OASIS) that gives the information about possible transactions for the market participants. Thus, it requires fast and accurate ATC calculation to help independent system operators (ISO). There are several methods for ATC calculation discussed in the literature i.e., optimal power flow based, continuation power flow based, network sensitive based method, etc.

To reduce the consumption of fossil fuels, renewable energy integration is the best choice due to less carbon emission and availability in abundant. The loads are varying continuously throughout the time so to match this demand, conventional and renewable power generations are to be used. Due to intermittent nature of wind speed, the power output from the wind power generation is not constant. One of the major challenges is to calculate the wind farm (WF) power considering the wind direction and wind speed variation [22]–[24]. The reactive power role is very important in the power system as it supports active power transfer. It also maintains line power flow and bus voltage within the limits. Total transfer capability can be enhanced by load compensation and additional reactive power support. The generator may not supply reactive power in normal condition however, it has to reserve it for contingency conditions. During the contingency condition, optimal reactive power supports from generators and capacitors help in CM. One challenge is the use of wind power generation (WPG) as reactive power compensation devices for ATC enhancement and CM [25], [26]. The literature survey shows that there are very less works in the calculation of WF power considering the reactive power capability curve with wind direction for ATC enhancement and CM [27], [28].

The stochastic nature of wind speed causes intermittency in the WF power injection. The system requires some additional backup to inject power without interruption. The comprehensive survey shows that these shortcomings can be overcome by energy storage systems (ESS). Among the ESS, the battery energy storage system (BESS) is the best match with WF due to its capacity, size, and charging/discharging characteristics [29], [30]. BESS is used in the system to balance the power from WPG. When the system has high load demand, the battery will discharge to support the grid and if there is a low load condition, the battery will charge. Proper charging and discharging of the battery make the system stable and secure [31], [32].

ATC-based CM has been used in this thesis to relieve the congestion of the system. To enhance the ATC value, the integration of a wind battery system has also been used. Technical challenges i.e., selection of critical zones, optimum location for WPG and BESS, ATC enhancement using proper charging/discharging of battery in a wind battery system, and CM have been considered. Hence, the main objectives of the present work are

- To propose average transmission congestion distribution factor (ATCDF) values for different congested lines for single line outage.
- To create the congested zones for integration of WPG using ATCDF values.
- To analyze the effect of WPG's active and reactive power injections on ATC in the system considering the reactive power capability curve of doubly fed induction generator (DFIG).
- To propose the new mathematical equation for WF power calculation considering wind speed, wind direction, and wake effect.
- To level the ATC by using WF with BESS during contingency cases and make the criteria for charging/discharging of BESS for ATC enhancement. In addition, to use the BESS to make WPG more reliable by reducing the fluctuation and providing backup.

In the present work, CM using different techniques have been studied i.e., ATCDF technique, WT's reactive power control technique, WF with BESS using power levelling technique.

This thesis has seven chapters in which **Chapter 1** introduces the restructured electricity market, renewable energy sources (RES) scope in the future power industry, brief idea about ESS, challenges, and opportunities in a wind battery integration system and different CM methods in hybrid electricity markets. It also sets the motivation behind the work carried out in this thesis.

Chapter 2 presents a comprehensive literature survey on different optimization techniques and methodologies used to manage congestion of the networks. In addition, the CM methods have been divided according to the generation side, transmission side, and distribution side i.e., one can analyze the contingency condition from the generation side and can use technology to alleviate it. Generation rescheduling, optimal location, and size of distributed generation (DG) are used to manage congestion. The OPF, optimal location of FACTS devices, and ATC based CM are used in the transmission side. Similarly, DR, load curtailment, zonal pricing, nodal pricing, market splitting, counter trading, and auctioning methods are used in the demand side. The key issues and challenges of CM methods have also been discussed.

In **Chapter 3**, a new sensitive based transmission congestion distribution factor (TCDF) has been proposed to define the congestion zones. The ATCDF values are used to find the optimal location of generating source to enhance the ATC value of the system. ATC is calculated using the DC power transfer distribution factor (DCPTDF) and AC power transfer distribution factor (ACPTDF) methods. The line outage contingency condition has been taken to form the clusters/zones. The ATCDF values are calculated by taking the average value of TCDF values (obtain for different congested lines) for single-line outage conditions. Once the ATCDF values are calculated, the highest ATCDF value bus is selected to integrate the WPG. ATC variation using WPG at different bus locations has also been studied.

In **Chapter 4**, ATC variation with the integration of WPG has been discussed. The active and reactive power variations of DFIG-based WT are considered during ATC calculations. WT's reactive power support is also used to enhance the ATC in case of line outage conditions. Comparative analysis of ATC for different cases has been discussed i.e., base case when there is no WPG; when there is WPG; and when there is line outage in presence of WPG.

In **Chapter 5**, WT's power curve using the real time wind speed data has been developed. A 3-parameter deterministic (3P-DP) model is used to obtain the power curve. A new equation is suggested to calculate the total power of the WF considering the wake effect, varying wind speed, and changing wind direction. The power output using the wake effect has been calculated using the proposed equation and validated from the actual data.

In **Chapter 6**, the WF power has been calculated using the mathematical equation as discussed in Chapter 5. WF and BESS have been integrated using the ATCDF method in the critical congested zones as discussed in Chapter 3. The average ATC is considered as a base line and according to variation of load, the charging/discharging criteria of BESS has been proposed. The BESS will charge when there is a low load in the system i.e. when ATC is high in the system and it will discharge when the demand is more or ATC is low. The BESS is used to enhance the ATC value and levels it near the base line.

Chapter 7 concludes the main findings of the thesis and suggests the future scope for further research in this area.