Abstract

The thesis introduces a paradigm shift from traditional to renewable integrated power systems. The rapid increase in electricity demand and the technical modernization of supply have stressed the power system. The paradigm shift occurs as the power sector adopts renewable sources as excellent options for sources of power. Wind and solar power sources are eminent for their sustainability and cleanliness at a meager cost and are being integrated with the power system. The load keeps changing with time and can even be estimated, but it shows significant fluctuation in real-time. The system operator always desires to maintain the generation-load balance for the secure operation of the power system. The traditional conventional power systems were inherently flexible to cope with the change in load or system component outages. The net load change is served either by adjusting the generation of the generating unit or by adjusting the loads over various time intervals. The integration of variable and uncertain renewable sources has raised uncertainty. Integration of renewable sources has increased the need for flexibility on conventional generators' part, creating considerable challenges for generation-load balance maintenance. This has instigated research on developing/boosting the flexibility of the power system. Flexibility across the power system must be addressed and ensured by flexible generation, transmission, demand-side resources, and system operations. The rise in flexibility needs with the proliferation of renewable energy sources (RES) in the system is seen due to increased supply-side variability and uncertainty, displacing part of the conventional generation capacity. Hence, the power system must comprise quick and efficient ramp-up and down power plants that run at low output levels. It should have transmission networks that access a broad range of generation and load resources with sufficient capacity and limited bottlenecks to access for better-optimized transmission usage. Smart grids allow customers to respond directly to market signals and control load by enabling demand response, storage, and distribution, thus facilitating demand-side flexibility. Flexible system operations incorporate practices that help extract flexibility from the existing physical system, such as making more frequent decisions closer to real-time, improved use of wind and solar forecasting, and better collaboration with neighbors. Thus, the thesis will discuss the flexibility and the approaches to enhance its assessment.

The thesis introduces the unit commitment framework for temporal flexibility assessment (by conventional generating units) at different levels of renewable penetration. It could be a vital exercise to evaluate the flexibility needs of a power system and to know the cause for limiting the system flexibility in accommodating a large amount of RE and uncertainties increment due to it. Unit commitment (UC) plays an essential role in the secure and reliable operation of the power system as it schedules on/off patterns and the generation output of all generating units to meet the load at minimum operating cost for a given time interval. It would reflect the need for flexibility assessment by the conventional generating unit. The work encourages finding out the impact of RES integration on the flexibility requirement of the thermal generation system. The work comprises modeling the traditional deterministic and stochastic unit commitment model and performing comparative analysis underlining the participation of different generating units for providing generation and flexibility.

The thesis also addresses another critical analysis, i.e., the generation schedule varies dramatically, including uncertainty at different levels of wind energy penetration. In RES-integrated power systems, the power generated by the available RES may be less or greater than the day-ahead (DA) RES schedule due to the random nature of RE. Finding a DA schedule

closer to the schedule required in real-time (RT) becomes a challenging task for renewable integrated systems. Conventional thermal generators must be flexible enough to ramp up and down to fulfill the changing net demand. The Independent system operator (ISO) clears the market to maximize social welfare in the multi-settlement market system typically used in US centralized dispatch models. The locational marginal price (LMP) is obtained for both DA and RT markets. As market clearing incorporates load forecast, uncertainties dwell in its mechanism and confirm the need to appropriately adapt the DA market clearing strategies with uncertainties in wind power generation and load forecast. Hence, ensuring operational flexibility by developing the UC model to create a DA schedule close to the RT schedule could be of great importance. The thesis proposes the best day-ahead schedule essential for the secured operation of wind-integrated power systems. This thesis investigates the role of real-time adjustment cost in the unit commitment framework and analyses its impact on the scheduling of generating units. The work is accomplished by developing a unit commitment framework with real-time adjustment costs in a deterministic and stochastic manner for integrated wind systems; and by carrying out a comprehensive comparison between unit commitment models with and without real-time adjustment costs. The work ascertains the need and impact of real-time adjustment cost on the contribution of different generating units in providing generation and flexibility at various levels of wind energy penetration.

Majorly the location and the type of RES suitable to integrate into the power system are based on geographical details and load patterns. The penetration of RES in the system may affect the voltage stability or build congestion in particular lines of the system. As voltage stability and congestion are substantial concerns, analyzing the power system parameters would also play a significant role while planning for integrating RE into the system. Hence, integrating RES at suitable sites will help to get locational flexibility of the system. the thesis light on the fact that the proliferation of renewable energy sources into the traditional power system raises concern about the site selection for integrating RES at the transmission level. Besides the geographical information and load pattern, the system parameters must be considered to select the site. This thesis provides a proposal in three steps: in the first step, the problem is modeled for identifying the buses suitable for integrating RES in terms of voltage stability. The second step determines the best sites or buses based on network constraints. The final step is combining the above two approaches and finding the most suitable and unsuitable sites for RES integration into the power system by accounting for both methods. Thus, the work facilitates the determination of the best and worst locations for RES integration and the crucial lines or buses responsible for limiting the RE.

The thesis brings forward another issue, i.e., the network's power-transferring capability may limit any generating units' scheduling. Similarly, it can restrict renewable energy utilization due to the RES location in the system. Strengthening the transmission corridors is required to support the maximum dispatch of renewable power. The network must be expanded with minimum additional lines to extract maximum renewable energy from the possible installed RE. Thus, the thesis provides transmission expansion planning to help in identifying congested lines and corridors and gives an idea about system flexibility and the need for new corridors. The work is demonstrated on a real power system network. It identifies the critical lines and the number of circuits for expansion planning in normal and contingency states in a deterministic and stochastic manner. It would provide locational or transmission flexibility, which further helps in delivering operational flexibility.