CHAPTER 8

CONCLUSION AND FUTURE SCOPE

In this research work, an attempt has been made to develop a suitable control strategy for LFC in two area deregulated power system. To develop the control strategy, mathematical model of two area hydro thermal system is considered. Under deregulated environment, each generating unit meet a part of the total power demand in an area or DISCO. Thus, the operation of LFC depends on the market participation factor of each GENCO during contract and violation participation factor of each willing GENCO during violation. These participation factors depend on the market model that includes single buyer, bilateral and poolco. The formulas to calculate participation factors under different market conditions are developed. To improve the performance of LFC, an appropriate controller has been chosen among centralized and decentralized PI controller. In this research work, the parameters of centralized controller are tuned using ZN method, while, PI parameters in decentralized controller are tuned using ZN method and GA. To make use of reserve of willing GENCOs in neighbouring areas during contract violation, this research work develops a new strategy, GENCO reserve based control strategy. This strategy effectively makes use of willing GENCO reserve, however, allows any amount of power flow through TRANSCO. In order to have an effective and efficient LFC operation, GENCO and TRANSCO reserve based control strategy is finally developed in this research work. This strategy makes use of willing GENCOs in neighbouring areas and TRANSCO reserve till the maximum limit.

8.1 MAJOR CONCLUSIONS

8.1.1 Modelling of load frequency control in deregulated power system

Each generating unit is found to schedule its contracted power based on market model. The contracted power of each GENCO meets part of the contracted demands of areas or DISCO. The contribution of GENCO to meet scheduled demand of an area or DISCO is represented by market participation factor. While, the contribution of willing GENCOs to meet the un-contracted demand of an area or DISCO is represented by violation participation factor. The market participation factor, represented as, $gpf$ (under single buyer model), $cpf$
(under bilateral model) and \textit{apf} (under poolco model) and violation participation factor represented as \textit{epf} during violation is introduced.

The contracted power generation of each GENCO based on \textit{gpf} under single buyer model is formulated. Using this formulation, the mathematical model of market contracted power of GENCO under single buyer model is developed. The complete mathematical model of two area hydro thermal system under single buyer model is obtained by combining the mathematical model of market contracted power of GENCO under single buyer model with the mathematical model of hydro thermal turbine governor system.

Similarly, the contracted power generation of each GENCO based on \textit{cpf} under bilateral model is formulated. Using this formulation, the mathematical model of market contracted power of GENCO under bilateral model is then developed. The mathematical model of market contracted power of GENCO under bilateral model is combined with the mathematical model of hydro thermal turbine governor system to obtain the complete mathematical model of two area hydro thermal system under bilateral model.

The same is developed under poolco model using \textit{apf}. Finally, the complete mathematical model of two area hydro thermal system under poolco model is obtained by combining the mathematical model of market contracted power of GENCO under poolco model and mathematical model of hydro thermal turbine governor system. During contract violation, willing GENCOs participate in LFC to meet the un-contracted power demand based on \textit{epf}. Thus, the power output of these GENCOs is rescheduled. The power generation of willing GENCOs during contract violation is finally formulated. The \textit{epfs} are also incorporated in the mathematical model of considered two area system.

\textbf{8.1.2 Formulation of market and economic participation factors under different models}

An effective LFC performance is guaranteed by suitable formulation of market and violation participation factors. In this research work, the formulation of market participation factors are done based on the allotted power of each GENCO that are determined either trailing the auction procedure (under single buyer or poolco model) or through contract made between GENCO and DISCO (under bilateral model).

From the allotted power, obtained during market clearing, \textit{gpf} of each GENCO under single buyer market model is formulated. The final agreement for the contracted power is made between GENCO and DISCO following negotiations under bilateral model. \textit{cpf} is then
formulated from the contracted power of each GENCO. \( apf \) of GENCOs under poolco market model is formulated from the allotted power, determined during the market clearing procedure. Two conditions under poolco model, when both areas have equilibrium point and when no equilibrium point exist in both areas are considered to develop the formula for \( apf \). The contribution of each willing GENCO during violation under single buyer or poolco model, represented by \( epf \), is then formulated based on the offer price submitted during the second phase auction to clear the un-contracted power.

The participation factors are then calculated using available bidding data through a developed MATLAB code. The allotted powers are incorporated in the formulation to determine \( gpf \) of each GENCO under single buyer model. The contracted power of each GENCO and TRANSCO are then determined using \( gpf \). Using the offer price of GENCOs participating in second round auction, \( epf \) is calculated. \( gpf \) and \( epf \) values are then incorporated in the complete mathematical model of two area hydro thermal system operating under single buyer model. This model is analysed with tie line bias control under contract and violation. The GENCOs and TRANSCO powers are found to match with the calculated values.

The contracted power of each GENCO under bilateral model is decided through agreement. The \( cpf \) of GENCOs are calculated from these contracted power. The percentage of participation of each willing GENCO during violation is also decided through agreement. The total contract power is then calculated using \( cpf \) values. The power output of each GENCO during contract violation, is calculated using \( epf \) value. The \( cpf \) and \( epf \) values are then incorporated in the complete mathematical model of two area hydro thermal system under bilateral model. The model is then analysed incorporating tie line bias control during contract and violation. The GENCOs and TRANSCO powers are found to be intact with the calculated values.

Under poolco model, the allotted powers are obtained through a MATLAB code to clear market. Using these allotted powers, \( apf \) is calculated using the developed formula. The total contracted power is then determined using \( apf \) values. From the offer price submitted by GENCOs taking part in second round auction, \( epf \) value of each willing GENCO is calculated. The \( apf \) and \( epf \) values are then incorporated in the mathematical model of two area hydro thermal system operating under poolco model. The mathematical model is analysed incorporating tie line bias control, to get the GENCOs and TRANSCO power.
responses during contract and violation. The GENCOs generated powers are found to be based on \( apf \) and these powers are identified to be same as calculated.

8.1.3 **Tuning of secondary controller based on system characteristics and market**

The performance of LFC is improved by proper selection of suitable secondary controller and tuning method to determine the gain parameters. This research work attempts to select an apt controller for two area hydro thermal system. The considered mathematical model is incorporated with centralized and decentralized PI secondary controllers. A well designed secondary controller allows LFC to settle system frequency at nominal value and TRANSCO power at contract value. For this, the proposed controller gains are to be tuned properly.

The gain parameters of centralized controllers are tuned using ZN method. The gain values of PI controller are found to be 1.04513 and 1.25415 respectively. The decentralized controller gains are tuned using ZN method and GA. The PI gain parameters of ZN tuned decentralized controller are found to be 0.714 and 0.612 respectively for hydro and thermal units. The PI controller is tuned using GA with ISE as the fitness function. The proportional gain parameter values of GA tuned decentralized controller of hydro units in area 1 and area 2 are found to be 0.4060 and 0.9516 respectively and 2.3878 and 0.3551 for thermal units in area 1 and area 2 respectively. The integral value for all the units obtained for GA tuned decentralized controller is 0.6048. It is now required to analyse the LFC performance incorporating these proposed controllers. The best suitable controller is selected using the performance index, ISE.

Analysing two area hydro thermal system incorporating different controllers, it is seen that GA tuned decentralized controller gives 43.4%, 25.12% and 64.7% less ISE under single buyer, bilateral and poolco model respectively, compared to the system incorporating ZN tuned centralized controller. At the same time, incorporating GA tuned decentralized controller contribute 40.32%, 1.29% and 23.42% less ISE under single buyer, bilateral and poolco model respectively than with ZN tuned decentralized controller.

8.1.4 **GENCO reserve based control strategy for two area deregulated power system**

Cohn’s strategy of tie line bias control maintains TRANSCO power at contracted value such that GENCOs in same area of violation participate in LFC to meet un-contracted power demand. However, there can be GENCOs in the neighbouring areas willing to compensate the violated power. The participation of these neighbouring area GENCOs cause increase or
decrease in TRANSCO power from the contracted value, thereby utilizing TRANSCO reserve. The existing tie line bias control strategy fail to achieve this.

Tie line bias control strategy is modified so as to allow willing GENCOs in neighbouring areas to compensate for the violated power, thereby availing reserves of both willing GENCOs and TRANSCO. The input to the secondary controller under GENCO reserve based strategy now includes only change in system frequency. This makes frequency deviation to vanish, while, permitting TRANSCO power variation. It is now required to analyse the performance of LFC with the proposed GENCO reserve based control strategy under different market models.

$epf$ values are calculated from the offer price of willing GENCOs that participate during contract violation. Using these $epf$ values, power generation of GENCOs and TRANSCO powers are calculated. The proposed GENCO reserve based control strategy is incorporated in the mathematical model of two area hydro thermal system under different market models. The system is analysed during contract violation. It is observed that the power generation of willing GENCOs increase based on $epf$ values. The power generation of GENCOs and TRANSCO power flow are observed to match with the calculated values.

Under single buyer model, each pool is treated as separate and hence the unscheduled power is met by same area GENCOs, thereby maintaining TRANSCO power at zero. Thus, the proposed GENCO reserve based control strategy operates similar to tie line bias control under single buyer model. Conversely, the proposed GENCO reserve based control strategy effectively makes use of reserves of GENCOs and TRANSCO under bilateral and poolco model.

8.1.5 GENCO and TRANSCO reserve based control strategy for two area deregulated power system

The proposed GENCO reserve based control strategy allows any amount of power flow through TRANSCO. This may cause TRANSCO power to exceed the maximum limit, resulting in line congestion. The proposed GENCO reserve based control strategy fails to limit the TRANSCO power till maximum limit, and hence do not work efficiently.

The GENCO reserve based control strategy is modified to allow neighbouring willing GENCOs to meet the unscheduled power till maximum TRANSCO limit. The input to the secondary controller under the proposed GENCO and TRANSCO reserve based control strategy is change in system frequency, till TRANSCO limit and combination of change in
system frequency and TRANSCO power error, when TRANSCO power reaches limit. At any instance, if the contract violation creates TRANSCO line congestion, the strategy allows neighbouring GENCOs to meet part of the unscheduled power demand equal to the available transfer capability of TRANSCO. The remaining violated power is met by same area willing GENCOs. The newly proposed GENCO and TRANSCO reserve based control strategy is to be analysed in two area hydro thermal system under different market models.

Based on the offer price of willing GENCOs that take part in second round auction, the \( epf \) values are calculated. The GENCOs and TRANSCO powers are then calculated from these \( epf \) values.

The proposed GENCO and TRANSCO reserve based control strategy is incorporated in the mathematical model of two area LFC system under different market models. The system is analysed while subjected to violations that cause TRANSCO power to exceed the maximum limit of 0.5 p.u..

Under single buyer model, the unscheduled demand is met by same area GENCOs, maintaining the pools separately. Thus, the proposed GENCO and TRANSCO reserve based control strategy operates similar to tie line bias control strategy, under single buyer model.

Under bilateral and poolco models, it is found that the willing GENCOs in neighbouring area meet part of the violated demand till the TRANSCO limit of 0.5 p.u. based on its \( epf \) values. The remaining violated power demand is met by same area GENCOs based on their \( epf \) values. The observed GENCOs and TRANSCO powers are found to match well with the calculated values.

From the above analysis it is found that the newly proposed GENCO and TRANSCO reserve based control strategy prove to provide an effective and efficient performance under bilateral and poolco market models depending on the participation factors. To analyse the economic performance of the proposed GENCO and TRANSCO reserve based strategy, the total cost incurred in meeting the violated demand is also tabulated. For a violation in an area, the participation of willing, more economic, neighbouring area GENCOs, incorporating the proposed GENCO and TRANSCO reserve based control strategy cause the total cost of meeting the violated demand to reduce. With tie line bias control strategy, the cost of meeting the violated demand of 0.2 p.u. in area 2 is found to be high and equal to Rs. 360. Incorporating GENCO reserve based control strategy, allow economic GENCOs too to meet the violated demand and hence the cost is found to reduce by 7.05% with a value of Rs.
334.6. However this strategy fails to keep track of TRANSCO power within maximum limit. The solution to this problem is overcome by the incorporation of GENCO and TRANSCO reserve based control strategy. The strategy limits the TRANSCO power within limit, making the contribution of area 1 GENCOs to reduce. This result in the total cost to be Rs. 335.46, which is 6.8% less than the cost incurred with tie line bias control. The strategy hence proves to give an effective, efficient and economic LFC operation.

8.2 CONTRIBUTION OF THE RESEARCH WORK

Electric power industry is under the process of deregulation. The new structure creates independent companies that include generation company, transmission company, distribution company and retailer company. The new paradigm creates competition, performed in a platform, called as market. Market models include single buyer, bilateral and poolco. In single buyer model, the generating companies submit offers to the operator for a specific time period. The operator performs auction settlement procedure and finalise the in-merit players who are allowed to do power trading, the allotted power of each in-merit player, market power and market clearing price. In bilateral model, the power sellers and buyers enter to negotiations and finally make agreement for an amount of power and price for a time window. In poolco model, the sellers and buyers presents offers and bids to the operator for a time slot. The operator settles the auction and finds the market power, market price and in-merit players with their allotted power. Contracted power transactions are done between in-merit suppliers and buyers. In case of contract violation, willing suppliers contribute for the violated demand. Thus, during contract, each generating units schedules its power output, while, willing units reschedules the output to meet unscheduled demand. This action is possible with the help of load frequency control. Many research works are done related to modelling of load frequency control under deregulated environment. However, the literatures emphasized on bilateral model and employed assumed random participation factors for analysis. The researchers fail to compare the performance between centralized and decentralized controllers. Existing research works employs tie line bias control that allows only GENCOs in the same area of violation to contribute to the violated demand. This existing control strategy served as the prime motivation of the research work.

The important contributions of this research work are:

- The mathematical model of two area hydro thermal system is developed under single buyer, bilateral and poolco model by introducing and incorporating GENCO, contract
and area participation factors respectively. The model is also included with economic participation factor.

- The mathematical method to compute participation factors of each GENCOs from bidding data is formulated.
- The best secondary PI controller is chosen among ZN tuned centralized, ZN tuned decentralized and GA tuned decentralized controllers for the developed two area deregulated system. The best controller is chosen based on performance index, ISE.
- A control strategy, unlike tie line bias control’ that allows willing GENCOs in neighbouring area to contribute for the unscheduled power is proposed and developed. This strategy makes use of GENCOs and TRANSCO reserve. The strategy is effective compared to tie line bias control.
- The proposed control strategy is modified to ‘TRANSCO reserve based strategy’ to allow willing GENCOs in neighbouring area to contribute for the unscheduled power, considering TRANSCO limit is developed. In case of any violation, this strategy allows willing GENCOs in neighbouring area to contribute till the maximum TRANSCO limit, while, the remaining power is met by GENCOs in the same area of violation. The proposed strategy is proved to be effective, efficient and economic than tie line bias control and GENCO reserve based strategy.

8.3 SCOPE FOR FUTURE WORK

In future, the two area hydro thermal units can be replaced by a multi source multi area system with different loop configurations. Renewable energy sources can be considered in the model. Inclusion of renewable energy sources completely modifies the auction and operating scenario.

The proposed decentralized PI controller can be replaced by PID controller. The controller parameters can be tuned using various soft computing techniques like Firefly Algorithm, Bee mating Algorithm, with various objective functions. Adaptive controller can also be proposed which is suitable for any market with any violation. A control strategy based on availability tariff can be developed and incorporated in LFC under deregulated power system.

The various time windows for contract can be considered with must run units. Locational marginal pricing and price area congestion management can be included in the control strategy to limit the TRANSCO power. In case of TRANSCO congestion, re-auction can also be conducted to clear the market.