CHAPTER 2
LITERATURE SURVEY

Various techniques have been developed in the past few years to get a more accurate approximation employing reduction in the order of a system. Initially developed MOR techniques promised good approximation of large-scale systems but didn't bother about the stability of reduced systems. It raised the concern of researchers to obtain the MOR technique providing reduced-order as well as stability. So, over time, the evolution of mixed approaches took place at the end of the first decade of the 21st century, which reduced the value of error amongst the system of higher and reduced order. The research work carried out in the field of reduction of the order of a system is briefed as follows:

A mixed MOR approach based on the dominant pole method and big bang big crunch optimisation method was presented by Philip (Philip & Pal, 2010). The denominator polynomial was reduced by finding its dominant poles, and these dominant poles were utilised to obtain the equation of denominator of reduced order. Then the equation for the numerator of the reduced-order was procured using the optimisation algorithm based on the big bang big crunch principle. The two polynomials were combined to form the complete reduced-order equation. An integral square error of the proposed method and some previous methods were compared. It was then concluded that the proposed method gives the most accurate result compared to the previous work.

A MOR technique based on the projection-based approach focused on stability (Castañé Selga et al., 2012). The reduced-order system obtained after the proposed method delivered less value of error, ensuring the stability of the obtained system. The concept of contractivity and matrix measure was used to obtain stability using the iterative matrix balancing method or Lyapunov's equations approximation.

A novel computer-aided method was presented later to procure the approximated system of reduced-order for an LTI system. The combined benefit of two techniques was used for the reduction process. An evolutionary mechanism, i.e. BBBC optimisation, was used to reduce the equation of reduced-order numerator. At the same time, the routh approximation principle procured the coefficients in the equation of denominator of reduced order. The proposed combination method was applied to SISO and MIMO LTI systems by obtaining the ISE between the higher-order and reduced-order systems. It was also verified that the proposed method possessed zero steady-state error and presented a stable reduced-order system (S. R. Desai & Prasad, 2013).

A modification in the existing balanced truncation method was proposed to reduce the model's order (Chongxin Huang et al., 2013). The previously shown balanced truncation method provided good controllability, observability, and transient response behaviour but had an inadequate steady-state response with a significant amount of steady-state error. The limitation of the balanced truncation technique was eliminated by employing a gain parameter with the transfer function of the system of reduced order. This gain factor reduced the deviated steady-state response and gave a better-approximated system from the system of large order. The proposed method was applied to the examples related to power systems, and it checked the feasibility of the reduced model.

A novel mixed approach was presented for reducing the order of a system (Narain et al., 2014). The fuzzy c-means clustering technique obtained the denominator of the reduced system. The fuzzy-based clustering provided a better approximation of the dominant poles by making clusters of the poles of the higher-order system. Then this denominator was used to fetch the numerator equation of the system of reduced-order by using the Padé approximation algorithm to match the parameters of Markov and time moments. The system was tested for the continuous type SISO system of order up to the 10^{th}. The technique presented here reduced the time-delay and distributed delay occurring in the systems.

A modified approach of model reduction employing particle swarm optimisation (PSO) was developed (Juneja & Nagar, 2015). The technique of pole clustering and a dominant pole was combined with PSO to form a hybrid approach. Hence, the techniques developed were a combination of PSO-pole clustering, PSO-dominant pole and PSO-PSO. The technique of PSO provided easiness in implementation, enhanced accuracy and decrease computation time. An inverted pendulum with a triple link was reduced to the reduced approximation of 3^{rd} order by the method proposed in the paper. Out of the three techniques developed, the technique of PSO with pole clustering was proven to be better than all the other techniques. So, the author proved that clustering was better than any other method of obtaining the reduced-order denominator.

An approach for reducing the order of integer type system of large order was described by Sikander. The approach proposed in the paper was formed of two existing methods of reduction of order: one was fetching the equation of reduced numerator by factor division algorithm, and another was the procurement of equation of reduced denominator by stability equation method. The reduced numerator and denominator polynomial formed the combined transfer function, compared with the original system based on integral square error (ISE). The obtained system of reduced-order had the same characteristics as that of the system of a large order (Sikander & Prasad, 2015b).

The integer type LTI system of high order was reduced using an optimisation-based cuckoo search algorithm and another technique named routh approximation algorithms (Narwal & Prasad, 2015). Initially, the given transfer function matrix was reversed in this method, and then the routh approximation was applied. After that, using the cuckoo search algorithm, other parameters were calculated and by using these parameters, the reduced-order equation was formed. The step response of this reduced-order transfer function was found out and compared with the original LTI system. The error (ISE) was calculated and compared with the pre-existing techniques, and it was concluded that the proposed method gave better results after reduction.

A MOR technique was presented later on based on Legendre wavelet and harmony search algorithm (Nasiri Soloklo et al., 2015). Initially, a higher-order system was expanded based on the Legendre wavelet; then, a reduced-order model was approximated with unknown parameters. The parameters of the reduced-order system were obtained from comparing higher-order and lower-order systems by harmony search algorithm and minimizing the error amongst them. The proposed method was applied to various continuous and discrete-time systems. It was proven that it provided better results than other techniques based on various time-domain performance characteristics.

Imran presented the frequency band-limited approach for reducing the order of the model of the descriptor system. For this purpose, frequency limited balanced truncation was used as a new generalized form of balanced truncation technique. The results of the higher-order descriptor system were generalized by frequency interval grammians. The large-scale system was reduced to keep the reduced-order model stable. Some practical systems like the flow mechanism of liquid and supersonic inlet flow system were reduced by the presented technique showing similar response for higher and reduced-order systems with the slightest error and good stability (Imran & Ghafoor, 2015).

The LTI system's optimisation was performed through a modified clustering algorithm and cuckoo search algorithm (Narwal & Prasad, 2015). The cuckoo search algorithm mitigated the numerator polynomial of the large scale LTI system, and a modified form of clustering mitigated the equation of denominator. Both polynomials were then combined, and the error between the reduced and original system was a minimum of the existing methods.

The two techniques of reducing order of an LTI system were combined to reduce the order of the equation of numerator and denominator by two earlier developed methods of MOR (Tiwari & Kaur, 2016). The well-known factor division algorithm reduced the equation of numerator, whereas the equation of denominator was procured through the clustering method. Then the reduced-order numerators and denominators were combined, and a reduced-order system was formed. The method of reduced-order procured by the method developed in the paper and other previously defined methods was compared. It was concluded that the proposed method preserves the parametric values of the original system better.

Alsmadi used the techniques based on soft computing methods for reducing the order of a continuous-time LTI system. Various optimisation techniques were applied on the same system for MOR with substructure preservation. The optimisation techniques provided stability and convergence. It was analysed from the comparison of various techniques that all techniques provided better results than the traditional methods of model order reduction. The performance of optimisation algorithms deteriorates very quickly with the increase in system dimensions (O. Alsmadi et al., 2016).

A mixed approach for reducing the order of a model was presented by forming a combination of improved clustering of poles and improved Padé approximation (J. Singh et al., 2016). In the method of clustering of poles, the poles of the left half and right half-plane were kept separate during the clustering process while retaining the poles lying on the origin and imaginary axis. The coefficients of the equation of the numerator of the reduced system were procured by Padé approximation by finding time moments and Markov's parameter. The feasibility of the proposed methodology was judged by obtaining ISE and IAE error values and comparing them with the already available values from the present techniques. The method was equally applicable to both SISO and MIMO systems.

A new technique of MOR was presented, which is based on the concept of artificial neural network prediction. The principle of neural networks estimated the unknown coefficients of the system of reduced order. The difference amongst the system of high order and the system of low order become the cost reduction function which was minimized by the neural training and preserving the dominant critical frequency (Adel & Salah, 2017). The SISO system of 10^{th} order was reduced by the technique, which promises minor error and stability.

Sikander reduced the LTI systems based on a modified form of pole clustering and factor division algorithm. This technique could be applied to SISO and MIMO, both types of systems. Then the equation of the denominator of the system of reduced-order was fetched by the modified form of clustering. The factor division algorithm determined the equation of numerator multinomial. Based on the value of ITAE, ISE, IAE errors, the characteristics of original and reduced systems were compared. It was concluded that the reduced system was the best approximation to the original SISO or MIMO system (Sikander & Prasad, 2017).

The order of a power network that consisted of loads and generators was reduced using the reduction in the order of the system (Cheng & Scherpen, 2018). Using the clustering approach, the dissimilitude in the junctions of load and generator was established by utilizing controllability grammian. Then these generator and load buses were grouped using hierarchical clustering of the dissimilarities to fetch the system of reduced-order of an original power network. By a case study, the system of reduced-order and the high order power system were compared. It was concluded that the power systems could be reduced with the help of the clustering approach preserving all the qualities of generators and loads.

A new approach of MOR was introduced based on the asymptotic waveform evaluation (AWE). The multilevel Krylov subspaces were formed, having embedded AWE over this subspace in parallel. This ortho-normalization process of AWE and Krylov subspaces required a well-conditioned approach achieved by a moment matching algorithm. Hence the novel technique was termed as well-conditioned multilevel Krylov MOR. The technique was used to illustrate a perfect electric conductor having a patch buried in its dielectric cavity (N. Kumar et al., 2018).

A novel mixed technique for reducing a model was presented by combining two existing MOR techniques, i.e. algorithm of factor division and fuzzy c-means approach of clustering (Gautam et al., 2019). The stability of the reduced system was also checked by pole-zero analysis. The fuzzy c-means approach of clustering formed the pole clusters of the poles having similar characteristics and differentiating clusters by their dissimilarities. The method developed in the paper was compared with the techniques presented in the literature based on the different time-domain error parameters. It was obtained that the proposed technique gave better accuracy and provided stability.

Al-dabooni presented a new form of clustering for reducing large-scale dynamic systems based on the hierarchy of the poles. The base layer was an ‘n’ order model, and the previous layer obtained each successive layer in reduced form until the desired reduced-order was achieved. The reduction was done to reduce the mean square error in each layer. The coefficients of the reduced-order system were obtained here by the Padé approximation or generic algorithm (GA) (Al-Dabooni & Wunsch, 2019). Moreover, the reduction of several SISO and MIMO systems was procured by the method developed in the paper. The obtained system of reduced-order was compared to the techniques developed in literature based on the value of mean square error. The stability was also preserved in the system of reduced order.

A new method was developed and applied for reducing the order of a linear dynamic system by forming a blended approach, which combined the existing balanced truncation method with the factor division based algorithm (Prajapati & Prasad, 2019). Then the denominator polynomial was reduced by balanced truncation by truncating the higher states of less energy, and then the numerator multinomial was mitigated by the factor division method. The method developed in the paper ensured stability and preserved the steady-state characteristics of the system of higher-order into its lower order approximation. This technique was applied to a dc-dc convertor, where it performed exceptionally well. The effectiveness of the system of reduced-order was checked based on several error indices like ISE, ITAE, IAE and the value of these errors were found to be minimal compared to other techniques.

Goyal presented a novel approach of reduction in the order of a model based on the behaviour of weed plants, i.e. invasive weed optimisation (IWO) for the simplification and control of the system. A SISO system is obtained and reduced by the proposed technique by taking ISE as the objective function of the optimisation process. The transient and frequency domain parameters were used to analyse the method's effectiveness developed in the paper, which gave the most negligible value of ISE compared to the already available techniques (Goyal et al., 2019).

The firefly algorithm was implemented as an artificial intelligence technique to reduce multi-variable systems by preserving their structure (O. Alsmadi et al., 2019). The objective function of the evolutionary technique was the error existing amongst the system of high order and reduced order. A single-machine infinite bus power system of 10^{th} order was reduced to 6^{th} order using the proposed technique and minimized the root mean square error among both systems. The root means square error acted as a cost function which was minimized here. The simulation results were compared with other soft computing techniques like GA, PSO, and IWO.

The technique of model order reduction was utilised in biomedical engineering by creating a patient-specific model of human liver and computed medicine (Lauzeral et al., 2019). A renowned technique of proper orthogonal distribution was used for this purpose. The method generated a model of the human liver based on data of 385 three dimensional liver shapers. This model generated was very complex, and hence a technique for reducing order a model was necessary to study the mechanical model of the human liver. Hence, it was concluded that model order reduction also helped in biomedical engineering.

A technique to reduce the stable or unstable system was presented by blending clustering with a factor division algorithm (Tiwari & Kaur, 2020b). For a stable system, the dominant poles available in the original system were obtained. They then formed a cluster of all poles based on the contribution of essential poles in forming poles of the system of reduced order. The reduced denominator polynomial was obtained using the clustering approach, and the factor division methodology was then implemented to develop the reduced numerator polynomial. This approach was then extended to reducing unstable systems through system decomposition to preserve the reduced model's poles' instability. This technique helped in reducing the system order with reduced dynamic errors and zero steady-state error.

Vasu reduced the linear time-invariant system of high-order by a novel method developed in the paper. Advancements obtained the technique proposed herein existing optimisation-based reduction techniques. The enhanced form of particle swarm optimisation was combined with an algorithm based on differentially perturbed velocity forming a novel PSO-DV technique. This technique was used to fetch the denominator multinomial of the system of reduced order. Then the numerator multinomial was fetched by the improved multipoint Padé approximation (MPPA) method (Vasu et al., 2020). The developed method was suited better for stability, passivity and accuracy. This method provided better results for SISO as well as MIMO system based on integral square error.

Prajapati obtained the reduced-order approximation of linear, dynamic and continuous-time systems of SISO and MIMO type (Prajapati & Prasad, 2020a). It was achieved by proposing a combination of pole clustering techniques with a mathematical algorithm. The pole clustering technique made the clusters of poles depending on their position on the s-plane, and then these clusters gave the poles of reduced-order denominator polynomial. Then a mathematical algorithm was applied on the obtained denominator polynomial, and the reduced numerator polynomial was obtained. The MOR method was proven to be better based on its stability preservation, performance in the time domain for the step input and the value of different errors existing amongst the system of high order and reduced order. The methodology developed was then utilised for the design of a compensator. It revealed that the newly designed compensator from ROM worked equally well as the compensator designed for a higher-order system. Later on, Prajapati proposed another novel combination of pole clustering approach with the factor division algorithm. The proposed MOR technique was applied to reduce the large scale linear dynamic stable systems (Prajapati & Prasad, 2020b). This technique was developed, making the dominant pole retention the basis of reduction and then retaining time moments. The technique was applied to various higher-order systems to approximate reduced order with better accuracy and stability and having the most negligible error among the two systems. The proposed MOR technique was also applied to make a compensator. The performance of the obtained compensator was compared to the higher-order systems compensator, which revealed that both the compensators provided similar time response performance. It made the proposed technique more interesting to study.

The algorithm for reducing SISO and MIMO continuous-time systems by a single technique was presented, and its applications are discussed (Dewangan et al., 2020). The technique proposed in the paper was based on a multipoint Padé approximation. The equation of the denominator of the system of reduced-order was procured by reducing the higher p-order system’s denominator by forming its routh table. After that, the multipoint Padé approximation was utilised for obtaining the numerator multinomial. Hence a routh integrated multipoint Padé approximation method was proposed here.

The concept of a deep neural network was introduced to reduce the model of high order (Daniel et al., 2020). A technique based on projection was implemented with the assistance of a deep neural network. Initially, a dictionary of reduced-order models of a particular higher-order model was formed using clustering and then using a deep neural network; the best local reduced-order approximation was selected from the dictionary. With a deep neural network combination, selecting the best reduced-order model was performed 60 times faster than a simple clustering method.

The model order reduction was applied to simplify the delay systems (Alfke et al., 2021). The transfer function of the higher-order system was interpolated at multiple points using greedy iterations. These interpolation points were then collected to form a model of reduced-order by minimizing the error amongst the system of high and reduced order. The algorithm developed in the paper was faster and more accurate than other interpolation algorithms.

The model order reduction theory was utilised to study the behaviour of materials based on symmetries in the energy reflected from the material (Ganghoffer et al., 2021). The model order reduction theory worked in two ways: reducing the number of symmetric measurements and equivalence transformation of similar parameters. So, the measurements and parameters were reduced by the phenomenon of model order reduction. The development of the proposed methodology reduced the computational cost and computation time.

The knowledge-driven model order reduction method was implemented to analyse the porous material in a thin domain (Armiti-Juber & Ricken, 2021). The simplifying model for fluid control in porous material was obtained in the form of differential equations of fluid pressure and solid displacement. The complexity of these differential equations was reduced by model order reduction techniques like singular value decomposition and proper orthogonal distribution.

Vu developed another technique of reducing the order of a system based on the preservation of dominant poles. The technique presented in the paper was applied to stable and unstable systems having linearity in nature. The method developed in the paper firstly formed an upper triangular matrix from the state matrix. Then, the poles' dominancy was analysed based on the H errors on the diagonal of the upper triangular matrix (Vu, N.K., Nguyen, 2021). The development was proven to be providing a better approximation of the reduced order.

Vlachas implemented a technique for reducing the order of the physics system having nonlinearities in the material (Vlachas et al., 2021). The already available orthogonal decomposition method for reducing order was combined with a novel interpolation approach. This interpolation moved from the local base to the global base approach to fetch the best possible solution for the reduction process. Hence, the optimised system of reduced-order was obtained by the novel approach.

Even though reducing the order of a model is useful only for reducing large-scale systems, it is now general practice to design PID controllers for various real-life problems occurring in today's developing era. The use of PID controllers for the power systems resulted in the decreased fluctuations in these power systems. In other words, PID controllers are proven to be successful in the removal of the LFC problem occurring in the power systems. Some literature has been studied justifying the use of PID controllers for LFC as follows:

The technique of grey wolf optimisation was utilised for obtaining the LFC based PID controller for various two and three area power systems (Guha et al., 2016). The simulation of the power system employing the proposed controller resulted that the grey wolf optimisation provided better tuning abilities than other optimisation methods. The time to settle down the frequency for the proposed controller decreases but undershoot possessed higher.

A 2-dof PID controller based on the teaching-learning optimisation algorithm was designed to resolve the LFC problem in the power system (Sahu et al., 2016). The proposed controller was designed for hydro, thermal and gas power plants. The proposed controller provided oscillations in frequency response with little higher undershoot but had the advantage of lesser settling time. The proposed technique was proven to be better than other existing techniques.

Azeer designed an intelligent controller to eliminate the LFC problem in the power system consisting of two areas. Then a PID controller, a fuzzy logic controller and an artificial neural network-based controller were designed and compared. All these controllers possessed zero deviation in the frequency with the highest undershoot and oscillations in the PID controller (Azeer et al., 2017). The neural network-based controllers provided the best response out of the three controllers.

The gain parameters of the PI controller was obtained based on the fuzzy logic optimisation for LFC control in two areas reheated thermal-thermal power system (Pritam et al., 2017). The transient and steady-state behaviour of the system employing the proposed controller was studied in the paper. The fuzzy PI controller resulted in a better value of the time domain performance characteristics than the previous techniques. Also, the deviation in frequency resulted that the value of undershooting, oscillations and settling time was better.

The frequency of the wind farm that was connected to the existing power system was controlled by employing a PID controller (Gholamrezaie et al., 2018). The optimisation algorithm, i.e. particle swarm optimisation, was utilised to obtain the PID controller's gain parameters. Hence, the controller applied to a power system of two-area, which resulted that the oscillations in frequency deviation were removed. Still, the settling time taken to remove the frequency deviation was comparatively higher.

The firefly optimisation algorithm was utilised to control frequency variation in two area power systems consisting of PV grid interconnected with thermal power system (Abd-Elazim & Ali, 2018). The firefly algorithm obtained the maximum power tracking point by optimisation of power at different points. The firefly algorithm provided a higher number of oscillations in the frequency variation response, and hence the settling time was increased. The value of undershooting was also higher.

A PID controller based on a disturbance rejection approach known as gravitational search algorithm was developed to eliminate the LFC problem in the power system consisting of two-area interconnected altogether (Congzhi Huang et al., 2019). Hence, the controller provided oscillations for some input-output combination with the increased value of undershooting, but the settling time improved compared to other designed controllers.

Arya designed a fuzzy logic based controller by adding a filter along with the controller. The newly developed controller was named as FPIDF – (1+PI) controller. This controller was designed to control LFC in energy storage units that are capacitive, i.e. CES units. These units were installed in the photovoltaic based thermal energy system and photovoltaic based hydrothermal energy systems. The controller developed in the paper was proved as an intelligent controller having a multi-stage fuzzy assisted PID controller with a filter (Arya, 2019). It was observed that the proposed controller possessed a higher value of overshoot and settling time but reduced the number of oscillations was occurring in the frequency response curve.

A predictive approach, i.e. MPC approach, was presented to design the controller to remove the LFC problem in a hybrid power system (Liu et al., 2019). The hybrid power system was formed by combining a wind turbine generator and a thermal power generation system. The MPC controller developed here resulted in a better response than the other controllers based on the performance characteristics of frequency deviation occurring in the power system. The proposed controller took little time to reach the final value with less overshoot and reduced oscillations than the other controllers used in the comparative analysis.

A combination of the integral and proportional derivative controller was performed to design a 2-dof controller for LFC control (Prakash & Parida, 2019). The proposed 2-dof controller was implemented in a thermal power plant consisting of a solar photovoltaic generation system integrated with it. The study revealed that the 2-dof controller provided better performance characteristics than the conventional 1-dof controller, and the proposed controller provided better frequency characteristics.

Various techniques were presented for PID controller design to eliminate the fluctuation in frequency and the power at tie-line in a power system (Tungadio & Sun, 2019). Different optimisation techniques like genetic algorithm, fuzzy logic, particle swarm optimisation and model predictive approaches were presented to achieve the task. From the study, it was concluded that the internal model control based techniques performed better than other techniques.

Ahmad presented a novel PID controller design based on genetic and cuckoo search algorithms for maximized power tracking of the power system having a photovoltaic system according to perturbation and observation algorithm, i.e. P&O algorithm. The optimised value of gain parameters of the PID controller was obtained from the genetic algorithm and cuckoo search algorithm to provide maximum power (Ahmed et al., 2020). The proposed algorithm analysed the transient and steady state performance characteristics.

A sliding mode control PID controller was proposed for LFC problem removal in the power system with multiple interconnected areas (AH & Li, 2020). The optimised value of the PID controller’s gain parameters was procured by the ant lion optimisation (ALO) algorithm. Despite removing the LFC problem in the power system, the proposed system was revealed to remove the nonlinearities occurring in the power system. These nonlinearities may be generator dead band (GDB) or generator rate constant (GRC).

Revathi proposed a fuzzy gain scheduling based controller of PI type for the LFC of the photovoltaic based power system having three different areas interconnected (Revathi & Mohan Kumar, 2020). The FGS controller and the conventional PI controller were then compared. Depending on the deviation in frequency and the power response at tie-line in all areas, it was concluded that the fuzzy gain scheduling controller performs better with reduction of overshoots, settling time and number of oscillations.

An adaptive type-2 fuzzy controller was designed to control the power system's frequency having two areas (Shakibjoo, Moradzadeh, Moussavi, et al., 2020). The controller developed in the paper was based on the descending gradient training and error back-propagation. Firstly, the neural network obtained the reduced-order model, and then the model estimated here was applied to the controller. The fuzzy type controller hence obtained provided stability and robustness against disturbances. The proposed methodology was applied to the New-England 39-bus power system, and it resulted that the proposed controller provided a better frequency deviation response.

The control of frequency variation in the photovoltaic integrated power system of multiple areas is obtained by designing a novel PID controller based on double equivalent-input-disturbance (EID) (Minghui Yang, Chunsheng Wang, Yukun Hu, Zijian Liu & He, 2020). By employing the proposed controller on the power system, the frequency deviation range got reduced. The EID based controllers were analysed better than the previously developed firefly based controller and simple PI controller.

An IMC based controller was presented to reduce the LFC problem occurring in the two areas reheated thermal-thermal power system using the concept of reducing the order of high order power systems (Vasu et al., 2021). An enhanced differential evolution (EDE) technique of reduction of order was employed to reduce the order of the power system. It reduced the complexity of the power system of a high order. The compensated power system was then compared with other existing methods to analyse the effectiveness of the controller developed in the paper.

Gupta designed a new PID controller by combining the features of three optimisation-based algorithms, gravitational search algorithm, PSO, firefly algorithm, in a single controller (D. K. Gupta et al., 2021). An interconnected three area power system containing thermal, hydro and gas generation was compensated by the proposed controller. The simulation outlined that the frequency deviation of the power system got reduced by employing the proposed controller. All the characteristics of the frequency deviation response got improved by the usage of the proposed controller.

A sliding mode controller design method was presented to regulate frequency in a single area or multi-area power system (A. Kumar et al., 2021). The parameters of the sliding surface were obtained by grey wolf optimisation and particle swarm optimisation. The frequency deviation and power changes in the power system were improved by employing the proposed controller. The proposed controller also worked for the removal of nonlinearities that existed in the power system.

The time delay and other uncertainties occurring in the LFC controller was removed by designing a sliding mode controller (Tran et al., 2021). For this purpose, Lyapunov’s stability conditions checked for the system's stability. Then the design of second-order newly developed sliding mode controller of adaptive integral type ensured the states of the system to reach the stable value in finite time.

Wang presented a methodology to remove the effect of uncertainties like time delays in the power system. In the proposed methodology, two inequalities, like inequality of reciprocal matrix and another inequality based on wirtinger integral, caused the $H\infty$ error in a PI controller for the power system having two areas removed (Wang et al., 2021).

The novel technique based on elephant herding type optimisation was applied to design the LFC controller for a thermal interconnected power system consisting of two areas (Dewangan S, Prakash T, 2021). The controller designed by the method developed in the paper provided better results than other controllers used for analysing the effectiveness of the controllers designed by various methods.

A fuzzy-based controller with a filter was proposed to eliminate the effect of variation in load on the operational frequency (Yakout A.H., Kotb H., Hasanien M., 2021). The algorithm of marine predator is utilised initially to optimise gains and factors of scaling, which helped develop the membership function of fuzzy. The controller hence developed was tested by applying the proposed methodology on the power system of two areas.

Changmai eliminated the LFC problem from an interconnected power system of two areas by designing a regulator based on the linear-quadratic method for the system. The performance of the controller developed in the paper was compared with the design of the PID controller and checked the effectiveness of the novel controller developed here (Changmai H., 2021).