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A REVIEW OF NON-CLASSICAL LOAD FREQUENCY CONTROL (LFC) SCHEMES FOR MULTI-AREA INTERCONNECTED POWER SYSTEMS (MAIPS)

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Abstract-Load frequency control (LFC) is a critical factor in the design of an electrical power system. To obtain and sustain a steady state operation of a power system for the delivery of quality power, generated power must at all times equal the load demand plus the losses. To achieve this state a Load frequency control system also known as Automatic Generation Control system is employed in an interconnected power system. The load-frequency control (LFC) is used to maintain the balance between load and generation in each control area as well as maintain the tie-line power flow in a multi area interconnected power system (MAIPS). The main goal of LFC is to minimize the transient deviations and steady state error to zero in advance. In this paper, a literature review of some non-classical LFC schemes employed by researchers for multi area interconnected power system (MAIPS), using different techniques is presented, some advantage and drawbacks of the reviewed schemes highlighted, comparison of schemes stated.

Keywords- Load Frequency Control, Multi Area Interconnected Power Systems, Automatic Generation Control, Fuzzy controller, Interconnected Power Systems, Artificial Neural Network.

I. INTRODUCTION

An electrical power system can be in either of two prevalent operating conditions, the steady-state condition or transient condition. A power system should normally operate under the steady-state condition. In this state, it is important to maintain a power balance in the system, that is the balance between power generation and loads, which is critical and must be guaranteed at all times for the optimum and proper functioning of the system. Electric power cannot be stockpiled in large quantity hence its production must be equal to the consumption at each time,[8],[23]. The prime objective of an electrical power system is to ensure the balance between the total power generation with the total

load demand and the associated system losses, then regulating the system frequency and tie-line power exchange [6]. Power balance means that the total generated power (active and reactive) at power generating stations must match the sum of active and reactive powers demanded by the system loads and the active and reactive power transmission line losses. Under steady-state operation condition, both the system frequency and bus voltages are maintained at specified fixed values, this is essential to maintain a power balance in the system, for optimum performance of machines, industrial processes, etc. In actuality however, the system is never in steady state[13] as the active and reactive power load demands of the system are never stable but continually changing with increase or fall in load demand. Thus the power output of generators must be adjusted regularly to ensure a power balance. The active or real power delivered by a generator is changed by controlling the mechanical power output of a prime mover such as a steam turbine, hydro-turbine, gas turbine, or diesel engine depending on the type of generation [17]. In any generation system if the active power load increases, the active power generation must increase while if the active power load decreases, active power generation must decrease and vice versa. In both cases, the active power instability is observed through the change in generator speeds and/or frequency. When the active power generation is in excess, the generator will tend to speed up and the frequency will rise, conversely when there is a deficiency in active power generation, the generator speed and frequency will fall. These variations in speed and/or frequency are used as control signals in the system. The balance between generation and load is met by controlling the frequency of the system. Frequency constitutes a sensitive indicator of the energy balance in the power system that is normally used as the sensor portion of the load frequency control (LFC), whose job is to provide such power balance automatically [17],[11]. Frequency stability is one of three essential criteria to be achieved all the time to keep the system stable. The other two are voltage stability and angle stability[8]. Frequency stability is the ability of a power system to



maintain acceptable frequency in the event of an unforeseen system disturbance. This disturbance typically causes an unbalance between generation and load in the power system. It depends on the ability of the power system to maintain or restore equilibrium between generation and load and recover the power system frequency to acceptable levels. The stability of the load frequency is a sign of the smooth operation [3]. Instability results in an uncontrolled sustained increase or decrease over time (a “run-away” condition) or sustained un-damped oscillatory behavior [5], overall operation of a power system is better controlled if the frequency deviations are kept within strict limits, that is maintaining the deviation of frequency as close as possible to the nominal value. The real (active) and reactive powers of a power system are controlled separately.

A load frequency control (LFC) system sometimes referred to as automatic generation control (AGC) system [12], the most important control problems in the design and operation of power systems [19], [6], performs the function of controlling small and slow changes in real power load and frequency when a system is operating in the steady state. AGC is a feedback control system adjusting a generator output power to maintain a defined frequency. An LFC system also has the capability of maintaining the net interchange of power between pool members. It is designed to effectively function during small and slow changes in real power load and frequency, but with large imbalances in real power occasioned by rapid frequency changes that occur during a fault condition, an LFC system is unable to control frequency and is, therefore, ineffective. The load frequency control (LFC) loop is designed to regulate and control the real power output and frequency of the generator. The main objectives of the LFC are to maintain a steady and stable frequency, control the tie-line flows, distribute the load among participating generating units, maintain each unit's generation within the most economic viability and to ensure non-violation of operating limits, maintaining acceptable overshoot and settling time on the frequency and tie line power deviations. [23], [6], [11], [22].

Powers systems in modern days are becoming complex and intriguing owing to continuous expansion and integration of new power generating systems, creating an Interconnecting Power System (IPS). The different grids which make up the IPS called areas are connected via transmission lines called tie-lines, through which power sharing occurs between different areas. The LFC regulates the power flow between different areas while holding the frequency fixed or to as close to the nominal value as possible. To ensure the quality of power supply, it is mandatory to control the generator loads depending on the optimal frequency value through a secondary controller [6]. Different control strategies have been proposed in different literature for this secondary controller design. Researchers are mainly focused on the development of secondary controllers in LFC study; no matter the investigative power system model that is being

considered [13]. Researchers have investigated various power system models in the study of load frequency control (LFC). Classical controllers such as PI [19], PID and PIDN are the most widely accepted controllers by researchers in the study of LFC owing to their simplicity in design and implementation, as 90% of industries are still deploying [6] [13]. The performance of classical controllers depends on optimal parametric gains. However, classical controllers are not adequate to handle non-linear realistic power system models in course of perturbing conditions [13], their performances deteriorate when the complexity in the system increases due to disturbances like load variation boiler dynamics [19], [4]. The classical models allow only for the maximum of two inputs, which are frequency error and load disturbance, to be monitored [10], employs control gains to adjust the parameters associated with the power system LFC after measuring the frequency error and load disturbance. There is therefore the need of a controller which can overcome this challenge. The Artificial Intelligent controllers like Fuzzy and Neural control approaches are more suitable in this respect.

II. INTERCONNECTED POWER SYSTEMS (IPS)

Powers systems in modern days are becoming complex and intriguing owing to continuous expansion and integration of new power generating systems, creating an Interconnecting Power System (IPS). The different grids which make up the IPS called areas are connected via transmission lines called tie-lines, through which power sharing occurs between different control areas, thus forming a multi area interconnected power system (MAIPS) networks. Modern day power systems are divided into various areas [21]. Large Power Systems such as multi-area power system (MAPS), which includes many generating sets in each area, are characterized with long frequency transient time delay, area control error (ACE), parameter uncertainties, subsystem parameter deviation, random load disturbance, nonlinearity problem, tie-line power flow control problem, etc. [10] raising power quality issues. These characteristics have an impact on the LFC of the MAPS.

In recent times interconnected power system (IPS) is becoming complex owing to continuous expansion and integration of renewable energy systems [11]. One of the foremost challenging tasks facing a modern complex power system is providing quality power at the consumer end [13]. As already known, load on the system will never be steady and such arbitrary changes raises power quality issues. In IPS, frequency and tie-line power may never attain a steady state owing to arbitrary loading of the power network. Stability of a power system network is often assessed in terms of frequency and tie-line power deviations. [15], defined power system stability as the ability of an electric power system to regain a state of operating equilibrium after being subjected to a physical disturbance, for a given initial



operating condition. It is unachievable to maintain frequency within pre-specified range during normal and perturbed operating conditions without employing controls. This deviation in frequency is managed by controlling the mismatch between real power and demand (load) including the line losses. Hence, an intelligent regulatory mechanism is essential to reduce the real power mismatch is IPS. This will be achieved by the load frequency control (LFC) strategy.

III. LITERATURE REVIEW

Several approaches for load frequency control of interconnected power systems have been carried out and various control algorithms proposed by different researchers over the decades. This elaborate and extensive research is attributed to the fact that LFC constitutes a critical part of the modern power system operation, with the main objective to keep the output power of individual power generators at defined operating value while maintaining the frequency within acceptable limits.

[13] Suggested a seagull optimization algorithm (SOA) based 3-Degree-of-freedom (DOF) proportional-integral-derivative (3DOFPID) controller for load frequency control of multi-area interconnected power system (MAIPS). The considered MAIPS comprises of two areas with Thermal-Hydro-Nuclear generation units in each area. Analysis was carried out by subjugating area-1 of MAIPS with a step load disturbance (SLD) of 10%. The sovereignty of presented SOA tuned 3DOFPID in regulating the stability of MAIPS is revealed upon comparing with the performances of 2DOFPID and conventional PID controllers. MAIPS dynamical behavior is slightly more deviated up on considering CTDs and is justified. The authors recommended the adoption of CTDs with IPS models in LFC study to avoid power system instability due to unintended delays.

[11] Discussed the effect of renewable sources and electric vehicles on the load frequency deviation. They presented new techniques for tuning the PI controllers based on different types of Artificial Intelligent (AI) optimization techniques such as Fuzzy logic, FOPID tuned by fuzzy and Model Predictive Control (MPC) for a four area interconnected power system. The performance of the controller under study was tested and validated using MATLAB/SIMULINK tools. The simulation results showed that the new technique succeeded in improving the controller performance by reducing the percentage overshoot. Fractional Order Proportional Integral Derivative (FOPID) controller tuned by fuzzy, gave the best performance for the proposed model that was tested.

[6] Investigated a robust Fractional Order $PI^{\lambda}D^{\mu}$ controller that contains an integral fraction action and a simple filtered derivative action on Automatic Generation Control (AGC) of a three areas reheat-thermal system considering several

nonlinear constraints such as Governor Dead Band (GDB), Generation Rate Constraints (GRC) and boiler dynamics. The optimal controller parameters were tuned through an evolutionary algorithm called Differential Evolution Algorithm by minimizing the Integral of Squared Error (ISE) index which was chosen as a performance index. Results revealed the superiority of the investigated controller compared to the other controllers such as PID, PID^{μ} and $PI^{\lambda}D^{\mu}$ in terms of the performance index, peak overshoots, peak undershoots and settling time. The robustness analysis of the proposed controller against higher degree of load disturbance and severe parametric variations revealed that this controller performed well compared to the other controllers in terms of the performance index, peak overshoots, peak undershoots and settling time.[9],[26],[2]. [20] Proposed the designing of a multi-objective (MO) proportional, integral and derivative (PID) for load frequency control (LFC) based on adaptive weighted particle swarm optimization (AWPSO). In this study multi-objective particle swarm optimization (MOPSO) was used for tuning PID controller parameters for LFC in interconnected power system. The proposed method is used for designing of PID parameters for two area interconnected power system, with simulation results showing efficiency of proposed controller design.

[27] Designed a sliding model control strategy for hybrid energy storage system by combining interval observer and disturbance reconstruction technology, to handle the problems of frequency of fluctuations occasioned by load disturbances in multi-area interconnected power systems. Simulation results showed the proposed control strategy can effectively suppress the frequency and tie-line power fluctuations caused by load disturbances, and ensure the reliability and stability of the power system.

[19] Presented an analysis on dynamic performance of Load Frequency Control (LFC) of three area interconnected hydrothermal reheat power system by the use of Artificial Intelligent and PI Controller. In the proposed scheme, the control methodology was developed using conventional PI controller, Artificial Neural Network (ANN) and Fuzzy Logic controller (FLC) for a three area interconnected hydro-thermal reheat power system. The performances of the controllers were simulated using MATLAB/SIMULINK package and tabulated as a comparative performance in view of settling time and peak over shoot. Obtained result showed that the conventional(PI) and Intelligent control approach (Fuzzy Controller and ANN controller) with inclusion of slider gain provides better dynamic performance and reduces the oscillation of the frequency deviation and the tie line power flow in each area in hydro-thermal combination of three area interconnected power system.

[10] Developed a single-phase sliding mode control-based state observer (SPSMCBSO) for the load frequency control (LFC) of the multi-area multisource power system



(MAMSPS). The two-area gas-hydrothermal power system (TAGHTPS) model was chosen for testing the feasibility of the constructed SPSMCBSO. The uncertainty of the state and interconnected parameters was considered for the TAGHTPS model. The proof of the stability of TAGHTPS was established by a new linear matrix inequality via the Lyapunov theory. The superiority of the SPSMCBSO was concentrated in the comparison of the simulation results with the results of some recent methods which shows that the performance improvement of the TAGHTPS with the proposed SPSMCBSO is better than that of the classical control schemes such as proportional-integral (PI) and proportional-integral-differential (PID). The SPSMCBSO further demonstrated robustness and is not affected by subsystem parameter deviation, random load disturbance, and parameter uncertainty in state and interconnected matrix. Therefore, the proposed SPSMCBSO is very useful for the LFC of MAMSPS.

[14] Investigated LFC using proportional integral (PI) Controller and Adaptive Neuro Fuzzy Inference System (ANFIS) for two area system. The controllers were compared MATLAB/Simulink software package. Obtained results proved that the Adaptive Neuro Fuzzy Inference System based LFC gives better response as compared to conventional controller in terms of peak overshoot, settling time and steady state error. Hence, the Adaptive Neuro Fuzzy Inference System based Load Frequency Control is proposed for a two area power system in each control area. The proposed ANFIS Controller is simple to design and easy to implement and has the ability to adapt to disturbances, making it more effective.

[16] Proposed a LFC synchronized with AVR in three-area IPS. Model predictive controller (MPC) configured in a dense distributed pattern, due to its online set-point tracking was used as the supplementary controller. They also studied the dynamics of the IPS subjected to multi-area step and random load disturbances, and the efficacy of the developed scheme was ascertained by simulating the disturbed system in MATLAB/ Simulink. Results show a reduction in the maximum deviations and settling times in the system states, which indicates that introducing the Voltage Control via AVR loop improves the frequency control significantly. While the lower standard deviation and variance of the integral time absolute error signify improvement in the robustness of the developed algorithm.

[25] Proposed a model-predictive scheme for load frequency control of a multi-area power system. The method depends on a decoupling technique which allows for a control design with a distributed architecture. Treating the total power inflows of each area as input variables a decoupled linearized model for each area is derived, allowing for the formulation and solution of a model predictive control problem with a quadratic performance index and input saturating constraints on the individual tie-line power flows, along with an overall equality constraint to address the

energy balance of the network. The effectiveness of the method is illustrated via a simulation study of a three-area network.

[7] proposed the use of a sliding mode control (SMC) for load frequency problems in power system. For their work an adaptive super twisting SMC (ST-SMC) was designed for two area interconnected power network under load disturbance. The two control areas are nonlinearly coupled thus making the control objective more challenging. The advantage of the proposed design is observed in control input which is significantly less affected by chattering without any loss in the control accuracy. The design is also validated with typical nonlinearities in power systems like generation rate constraints (GRC) and governor dead band (GDB). Adaptive ST-SMC confirmed frequency and tie line power stabilization under load disturbance.

[18] proposed a neuro-fuzzy based controller load frequency controller on a two-area interconnected nonlinear power system. They adapted the data from a typical hydrothermal power grid for the study. It was recorded that the neuro-fuzzy controller enjoyed a settling time of 5 seconds while under the same operating condition the system stability is achieved at 12 seconds using the PI controller. This, demonstrates the robustness of the neuro-fuzzy controller in contrast to the fuzzy logic and proportional-integral (PI) controllers. The simulation results showed the superiority of the neuro-fuzzy controller in LFC to PI and fuzzy logic controllers in terms of settling time and overshoot percentage.

[24] Presented a fuzzy logic based load frequency controller for a two area power system. They compared they proposed simulation model with the classical regulating systems to verify and show the superiority of the model and controller developed. The result they obtained shows that intelligent controller (Fuzzy logic controller) have more improved dynamic response as compared with the conventional or normal control system. It has less distortion and also came to stability and normality.

IV. CONTROL SCHEMES

The many control approaches that have been suggested for LFC in interconnected power systems can be categorized (i) classical control approaches[22], [1] focus on designing proportional-integral-derivative (PID) controllers for controlling the frequency and tie-lines power flows; (ii) modern control approaches including optimal control method, sliding mode control schemes, and adaptive control systems; (iii) intelligent control schemes[22][1] such as fuzzy control systems; and (iv) soft computing-based approaches for controllers' parameter tuning which had a considerable attention from researchers in the last decade. In the reviewed literatures whereas [19],[7], [27] and [10] adopted modern control approaches to solving LFC problems, [14], [24] and [18] employed intelligent control



schemes in their attempt to controlling the frequency and ensuring quality power output in a power system network. On the other hand, [13], [16], [25], [11], [6] and [20] utilized the more advanced and robust soft computing-based approaches in mitigating the effect of frequency deviations in interconnected power networks. From the foregoing it can be said that researchers are leaning more towards the use of soft computing-based approaches to solving load frequency control problems in interconnected power systems. This is so because the approach gives a better response in terms of peak overshoot, settling time and steady state error and has shown robustness against higher degree of load disturbance and severe parametric constraints in the power system.

The modern control approach which includes optimal control method, sliding mode control schemes and adaptive control schemes have several advantages such as optimally controlling the systems and regulating all the dynamic states of the controlled systems. Optimal controllers have certain drawbacks like no real time observation of the dynamic states of the power system, cyber-attacks issues on the designed estimators, parametric uncertainties in the designed observers. Adaptive controllers are complicated and need a perfect model following condition, and on-line model or explicit parameters identification. Therefore, these methods are sometimes unrealistic and difficult for implementation[1]. These schemes can play an important role in the power system if the above drawbacks are addressed.

The intelligent control methods on the other hand are effective controllers that can handle parametric uncertainties. However, these methods have several drawbacks regarding their applications to frequency control in power systems. These are that there is no good knowledge of the system dynamic models in power systems. They are often designed for a band of uncertainties that is highly variable, and prevailing concerns of cyber-attacks and unknown inputs.

Soft computing-based control approaches have gained enormous attention from researchers around the world in the last decade owing to its advantages. Low costs, guaranteed solution, and practicability are some of the prominent advantages of the soft computing methods. They also have the ability to handle technical issues such as uncertainties, nonlinearities, and complexity. The practicability of control methods based on soft computing technique has been verified by several studies in contrast to other methods. Soft computing techniques have been used for optimizing the load frequency controllers' parameters in order to achieve good control and dynamic system performance.

V. CONCLUSION

To deliver quality power to consumers without distortions and disruptions, power generation must at all times equate load demand. This is however not an ideal condition as

system disturbance regularly occur as a result of continued expansion of the power network and increase in load. To mitigate these fluctuations a load frequency control (LFC) is employed. The LFC which is an important part of a power system network has the main objective of maintaining the balance between generation and load by keeping the frequency within stated limits. Several research approaches have developed and proposed by researchers with the classical/conventional methods being widely used. However, owing its weakness in the face nonlinear uncertainties research has designed advanced method of load frequency control. In this paper, we undertook a review of some non-classical load frequency control schemes developed for multi-area interconnected power systems. It is observed that in the last decade researchers have shown more interest in the use of soft computing-based approaches in solving the problems of frequency deviations in power systems. This is so because the approach gives a better response in terms of peak overshoot, settling time and steady state error and has shown robustness against higher degree of load disturbance and severe parametric constraints in the power system. This is in addition to its low cost, guaranteed solution, and practicability with the ability to handle technical issues such as uncertainties, nonlinearities, and complexity.

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