Current Philosophies of Intelligent Techniques based AGC for Interconnected Power Systems

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Abstract - **This article presents the operation and control of complex interconnected power systems with automatic generation control (AGC). Keeping in view the current status of power systems in India, operation of interconnected power systems, the control functions employed at different control levels are discussed and reviewed. Recent advances in control strategies like the application of intelligent techniques is considered in the power systems.**

Keywords - AGC, Intelligent Techniques, Interconnected, Power Systems

I. INTRODUCTION

Power systems have been evolving over several decades from being autonomous entities to highly interconnected systems to cope up with the exponentially increasing demand for electrical power. Such a rapid growth in demand poses a challenging problem to the power systems community to generate electrical power in sufficient quantity at the most suitable generating locality, transmit it to the load centers and then distribute it to the individual customers in proper form, with due regard to the quality and security, at the lowest possible ecological and economical costs. This has led to numerous developments aimed at reliable operation and control of power systems.

Operating an electrical power systems network involves on-line control to maintain economic operation while avoiding disruption of service and ensuring a good quality of power supply to the customers. One of the major concerns is to increase the market value of the services. They provide with adequate quality and reliability and to lower its costs for operations, maintenance and construction in order to provide lower rates for electrical customers.

Utilities have the mission to maintain the highest level of service reliability to the customers, and have the obligation to improve service reliability consistently by planning, operations, construction and maintenance with their limited resources. The more capital the utilities invest, the higher service reliability. The developments in all concerned areas of power systems are therefore required to meet the requirement of the customers at their most satisfaction. Furthermore, there are environmental and social issues/constraints to be considered in the operation of the system also.

In India, lot of developments had been witnessed since independence in the area of electrical power generation. Through continuous developments, the power industry is able to provide about 101 GW in the twentieth century from a mere capacity of 1.362 GW in 1947 [1, 2]. The Indian government has identified that continued economic growth is at risk unless radical steps are taken to improve its power system infrastructure, equipment and necessary policies. This has created many opportunities across the value chain.

Moreover, India’s power needs are forecasted to increase by 300 GW in the next ten years [3, 4]. To meet future demand, the government is encouraging use of renewable energy sources (RESs) as well as the traditional generation technologies. Energy through RESs also has a significant favorable impact on the quality of the country’s air, water and forest resources. For future growth, both rapid and sustainable, it needs to be as resource efficient and environmentally benign as possible. RESs make India become one of the largest power efficient countries in the whole world.

II. POWER SECTOR IN INDIA

Electrical power growth is a significant part of the growing India. Growth term involves electrical power generation, transmission and distribution sectors development in the country. These sectors are the key decision makers to decide industrial enhancement and also the backbone of industry and all around development of the country.

Power generation capacities in India during 1996-2011 are depicted in the Fig. 1. The electrical power sector in India distributes the world's 6th largest electrical power consumer, accounting for 3.40% of global power consumption by more than 17% of the global population [5]. The electrical power policy of India is predominantly controlled by the Government of India's Ministry of Power and administered locally by Public Sector Undertakings (PSUs).

Total installed capacity of electrical power generation is 186.69 GW as on 31 December, 2011 in India. This capacity in India constitutes state sector, central sector and private sector power generations, which are 83.65 GW (44.79%), 57.73 GW (30.93%) and 45.31 GW (24.28%) with respect to the overall electrical power generations respectively [6]. Share of various types of generations in overall installed capacity are described in Fig. 2. This total installed capacity has several types of different generating units for electrical power generation. Main categories are descript with their electrical power generation units in the below paragraph.

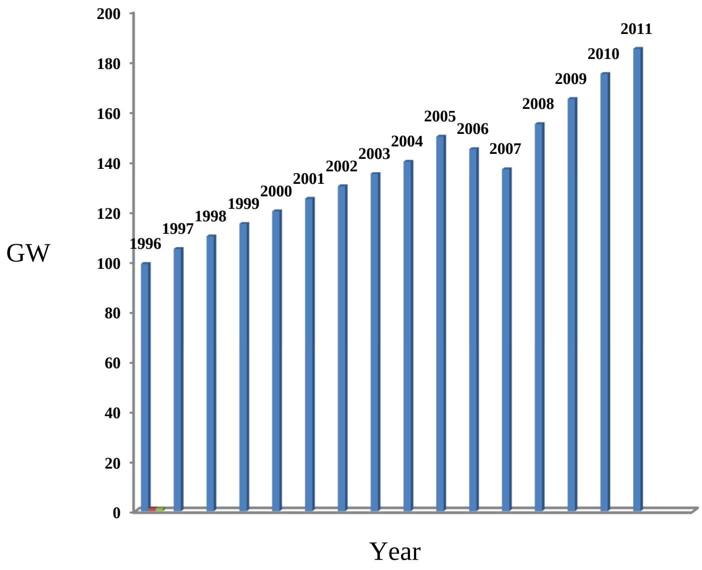


Fig. 1 Power generation capacities (Giga Watt) 1996-2011, India

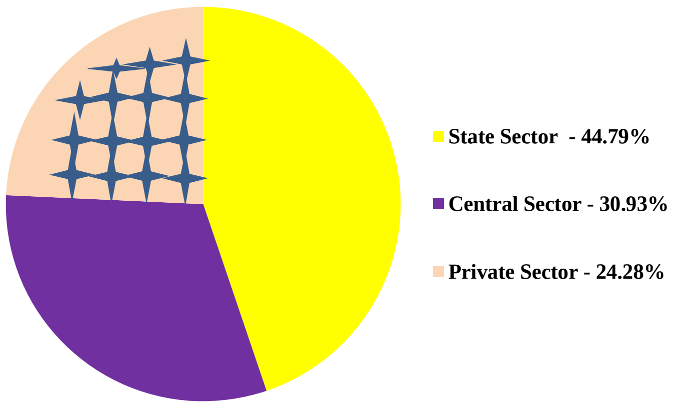


Fig. 2 Sector wise share of generation in India

The power generations through thermal (122.96 GW), hydro (38.78 GW), nuclear (4.78 GW) and RES (20.16 GW) are the main stream of the total electrical power generation in India [6, 7]. About 65.66% of the power consumed in India is generated by thermal power plants which consist of coal based thermal (55.75%), gas based thermal (9.50%) and oil based thermal (0.64%). Moreover, 20.75% is generated by hydroelectric power plants, 2.56% by nuclear power plants, and 10.80% by RES based plants. The complete percentage distribution of different power generations as per available fuel in India is represented in Fig. 3.

Nearly 60% of India's power demands are met through the country's vast coal reserves, which are available in abundance but is of a poor quality. About thirty percent of commercial power requirements are met by hydro power sources and RES resources. The remaining power is taken from other sources.

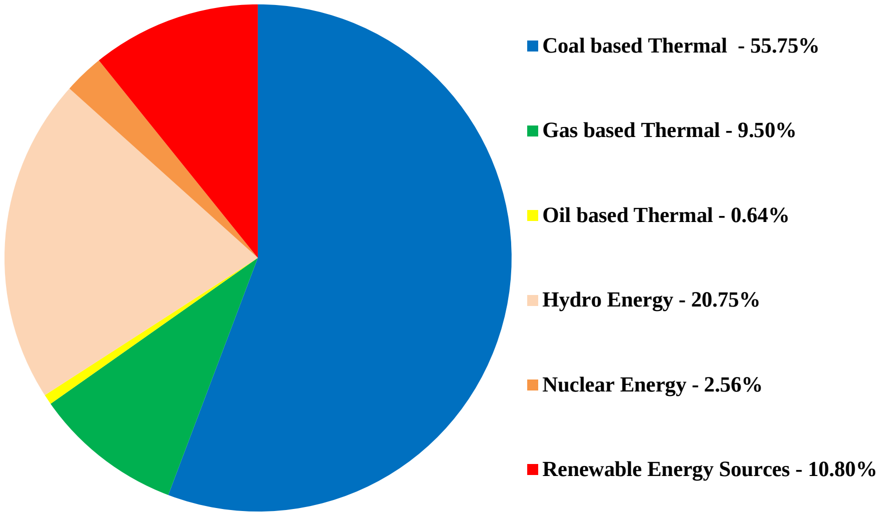


Fig. 3 Share of power generations through various generation resources (Ref. data of 2011)

The RESs constitute different sort of power resources available for power generation in nature. These are small hydro project, biomass gasifier, biomass power, urban and industrial waste power, etc. Generally, majority of RESs power plants are of less than 25 MW. So, small hydro project is also counted as RES. The country has also invested largely in recent years in hydro and wind power generation areas.

III. OPERATION OF INTERCONNECTED POWER SYSTEMS

Many economic and operating benefits can be derived by operating the power systems in an interconnected fashion. These include the achievement of greater stability, the ability to sell or exchange power over the interconnections, the ability to operate larger generating units, and perhaps of greatest importance, the increased reliability that results from being able to depend upon one's neighbors for help in times of need. An interconnection membership of power system also transports with its limited liabilities. One of these is the matching responsibility, one's generation to one's prevailing load so as not to apply hardships upon one's neighbors. Another is the shared responsibility of helping to maintain frequency and time error within acceptable limits [8].

When a member of the interconnection fails to meet its contract to match its generation to its predominant load, it is responsible to other members of the interconnection to over-generate with a resultant exchange of unspecified power. In addition, failure to meet this obligation may be the result of improper control, and not a choice for economic benefit. Interconnection has the economic benefit of minimizing the reserve generation capacity in each area. Under condition of sudden deviation in load or loss of generation in one area, it is without delay possible to borrow power from adjoining interconnected areas. It allows the development of larger and more beneficial generating units and the transmission of large amount of power from the generating plants to major load centers. It supplies capacity preserves by seasonal transfer of power between areas having contrary requirements. It permits capacity preserves from time zones and random diversity. It eases transmission of off-peak power. It also provides the manageable to meet undesired urgent loads.

IV. HIGH VOLTAGE DIRECT CURRENT TRANSMISSION SYSTEM

Due to economic and technical reasons, they operate in an interconnected fashion. The various areas or power pools are interconnected by tie-lines. These tie-lines are utilized for contractual power transaction between areas and provide inter-area support in case of abnormal conditions. Due to various merits of high voltage direct current (HVDC) transmission system over extra high voltage alternating current (EHVAC), many DC transmission lines have been laid down in the world and many projects established for future. In India, patterns towards laying down longer length DC transmission systems for power transactions between the control areas are evident. These advancements will have an impact on power scenario all over the world. The power engineers will witness a complex structure of interconnected power systems consisting of power pools of wide variety in nature of generations, namely hydropower, thermal and nuclear with different kinds of area interconnections like AC, DC and a parallel combination of AC/DC transmission systems. Moreover, HVDC transmission system can be utilized for frequency stability control of synchronously/asynchronously interconnected systems due to its fair power transfer capability and excellent controllability [9].

A HVDC transmission system uses DC for the large magnitude transmission of electrical power, in contrast with the more general AC system. For long distance transmission, HVDC systems are economical and have less electrical losses. HVDC systems permits power transmission between asynchronous AC distribution systems, and can increase stability of the system by covering cascading faults from propagating from one part of a larger power transmission grid to another. Hence each line conductor can be operated as an independent circuit [9-11].

In India, trends towards laying down overly long distances HVDC transmission system for power transmission between the control areas are evident. These advancements will have an impact on power scenario all over the world. The power industry has been moving towards more complex structure of interconnected power system consisting of power pools of wide variety of generations, namely thermal, hydro, nuclear and RESs, etc., incorporating various kinds of area interconnections like, AC/EHV AC, HVDC and a parallel combination of AC/ DC transmission systems [10].

Perhaps Vindhyachal (B2B) and Sileru to Barsoor HVDC links are the first HVDC links in India commissioned in 1989. These links are not economic as compared to EHV AC lines. Following these, Rihand-Delhi HVDC transmission system, 1500 MW, ± 500 KV and 814 km in length, was commissioned in 1990. The basic aim of the Rihand-Delhi HVDC link was to transmit the power efficiently to the Northern Region from Rihand, meeting necessary needs in the area. At present there are many types of HVDC systems installed for power transmission in India as detailed in Table-1 [11].

TABLE-1 HVDC SYSTEMS INSTALLED FOR POWER TRANSMISSION IN INDIA

Station	Overhead/Cable (in km)	Volt (KV)	Power (MW)	Year
Vindhyachal (B2B)	0	176	500	1989
Sileru - Barsoor	196	200	400	1989
Rihand - Delhi	814	500	1500	1990
Chandrapur - Padghe	900	500	1500	1997
Chandrapur (B2B)	0	205	1000	1998
Visakhapatnam - Gazuwaka	-	176	500	1999
Talcher - Kolar	1450	500	2000	2002
Sasaram (B2B)	0	205	500	2003
Visakhapatnam (B2B) Vizag II	-	176	500	2005
Ballia - Bhiwadi	780	500	2500	2009
Biswanath - Agra	1825	800	6000	2012*

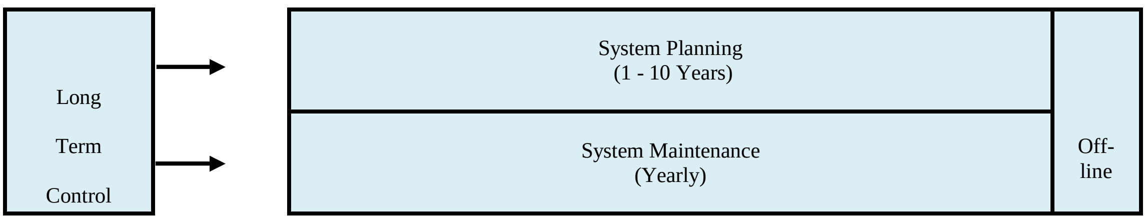
*currently established

V. CONTROL FUNCTIONS IN POWER SYSTEM OPERATION

The power system control refers to the collection of devices that monitor, control and protects the power system. The power system consists of generation, transmission and distribution with inherent variable characteristics. The equipment characteristics (physical) and constraints also change to a great limit. For that reason, there is not a defined technique for finding such power system operation with diversified characteristics, but there are convinced policies laid down by each power utility, which must be followed by its control centre for their prosperous operation. The main system operation and control can be categorised in two major divisions, showing the control time horizon [12]. These groups consist of long term and short term in control time horizon.

Meanwhile, power system management and control from the control centre of a power system is a complicated function needing interaction between several limits of command status and highly changing time scales. The control operation and the approximate time scale functions on which it operates are described by Fig. 4. From the time scale inspection of the control scheme, which is also liable for the functional stage of the control system, it is obvious that the complete control stages are being supported manually as well as automatically by analog or digital computers. The control at longer degrees to a great extent is considering slower time scales.

In the long term control function, unit commitment (UC) is the first level of control. Proving from the observations, it is not beneficial to continue run all the available units every time. To identify the plant units that should operate for a special load is the UC problem. Nevertheless, this problem is necessary for thermal plants as for other kind of generation, i.e. hydro; their costs of operation and start-up times are negligible so that their on/off condition is not necessary. The general well known strategy is generation scheduling, which may give a generation pattern for the units of generation for reliable system operation, and which may separate from that stated through economic generation scale. Thus cost coordination and security presents as an operational problem for this kind of system. These control levels share higher time spans, over a few hours to a decade, and are considered mainly as off-line functions.



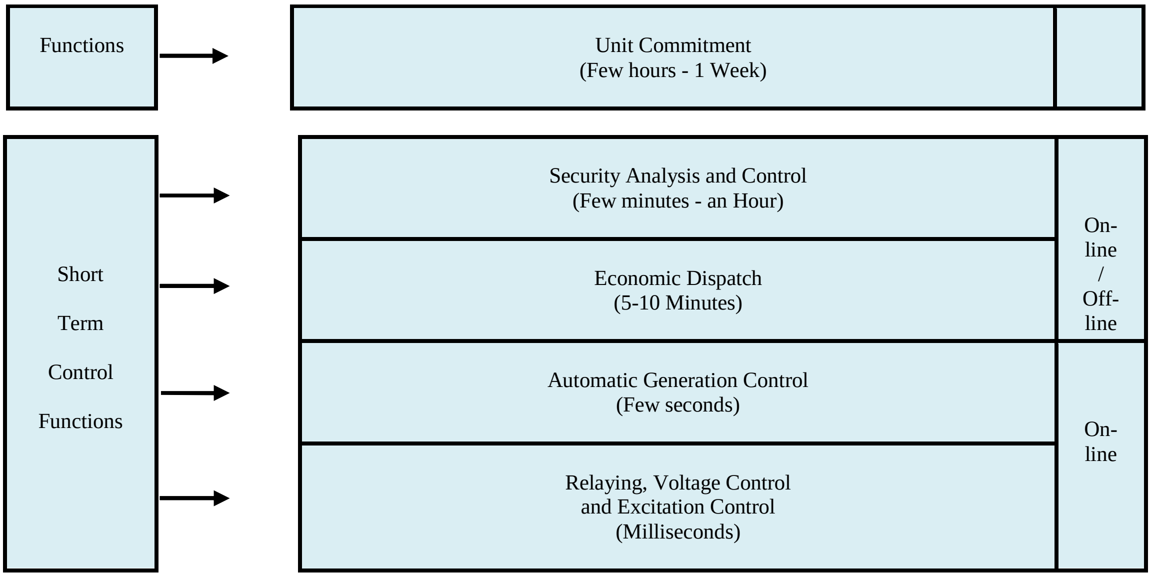


Fig. 4 Time horizon functions of power system control problems

The system planning and maintenance scheduling does not precisely come into the class of control problems. Although these operations are imposed manually, they need time to time extensive off-line evaluations to estimate the results of whole network presence or enhancement. The scheduling of plant or unit commitments is to analyse the less cost of each unit's hourly generation schedule, availability for generation, for one week period, and desirably is performed as an off-line function.

Digital computers support a number of control centres that carry out the UC.

The power system operational control problem in real-time conditions, dealing from a shorter time perspective, is accomplished through major on-line functions. It can be exhibited in a multi-level control scheme. Long-term control functions like system planning, system maintenance and UC in these control functions are desirably implemented as off-line functions and they are not examined frequently. It is observable that manual control is much slower than automatic control. These control functions come into the category of the long term control function. Long term control function provides enough time to control the power system operations in abnormal situations.

A large number of control functions which were controlled manually or through analog technique in last decades have been substituted by highly efficient fast digital computers. The control scheme of short time horizon is the means operates the system within seconds to hours with random pattern of the disturbances.

In this time horizon, the first level control is the local control. It is at the lowest level of time horizon and has a higher value of power engineers. Local control works with fast control of relaying, voltage and the excitation control. It is observable to maintain the system frequency within prescribed limit. Turbine governors reschedule to achieve power to the system in frequency deviation response. This type of control is possible for isolated system; more than one generator is needed for frequency stabilization. As the involving units have a variety of dynamic characteristics, it antecedent oscillations in the power network mooting to the system instability. So, each unit is participated with a regulator in which change in frequency is turned back only by a proportional regulator. It is to be mentioned that base load units are not involved in frequency control of the system, and in these units only developed power is turned back.

The next level control is the AGC. Its main function is to match the generated active power to the changing load demand and also, maintain the frequency of the system and total power transactions near to the scheduled values. Whenever perturbation occur due to load addition, the frequency of system move down, which begins the local frequency control operation. Hence, a recent study states reached after a short time and change frequency and power transfer are set. At this instant, operation of AGC begins to readjust the actual set of values. Effective implementation of AGC is totally based on the power system's operating mode which is functionally related to the type, magnitude and disturbance location presented in the system. Normally, three types of disturbance are checked in power system: small (less than 2% of relate area capacity), moderately large (2% to 5%) and large (more than 5%) [12]. In operation mode, the load perturbations are such that each area is able to taking care of load variations by itself. In these types of perturbations, spinning reserve allocation has to be implemented on-line in advance, thereby taking the generation to changing load demand and assisted contingencies.

The third level control is economic dispatch (ED), taken for economic operation of power system. The optimal output assigned for each unit is evaluated in ED, so that the gross fuel price is minimized within varying constraints of the operation. Other main objectives of optimal AGC is to participate in economic generation of power, hence to reach this criteria, ED has to be taken out in conjunction with AGC within system operating constraints.

The end level is the security analysis in the short time control function. Some preventive actions like shifting of generation or security dispatch or increased reserves are needed throughout an abnormal operating condition in the power system [13]. Ordinary scheme is generation scheduling, which may give a generation fashion for generating unit for secure system operation that may be distinct in shape and directed by economic generation criterion. ED and security analysis functions are also operated as on-line/off-line that depends upon the requirements of the system operators. Hence economic and secured co-ordination becomes as an operational problem for such system.

As indicated, normally, control strategies are designed to minimize power generation cost while managing its standard and fulfilling the objectives of system security considering the system constraints.

VI. AUTOMATIC GENERATION CONTROL

The AGC is defined by Institution of Electrical and Electronics Engineers (IEEE) [14] as "The regulation of the power output of electric generators within a prescribed area in response to a changes in system frequency and/ or tie-line loading, or the regulation of these to each other, so as to maintain the scheduled system frequency and/or the established interchange with other areas within predetermined limits".

AGC in electrical power system represents the initial realization of a higher level control system. A characteristic of AGC lies in the fact that each partner in the interconnection has equal rights and possibilities being limited only by the installed power in the area and the capacity of the tie-lines. Thus, it is not a centralized control system when total interconnection is considered.

Before moving into the interconnected power system, the single area power system is initially considered. To identify the model, researchers should realize the turbine speed governing system as frequency changes depend on speed. AGC functions of a power system are exhibited in Fig. 5.

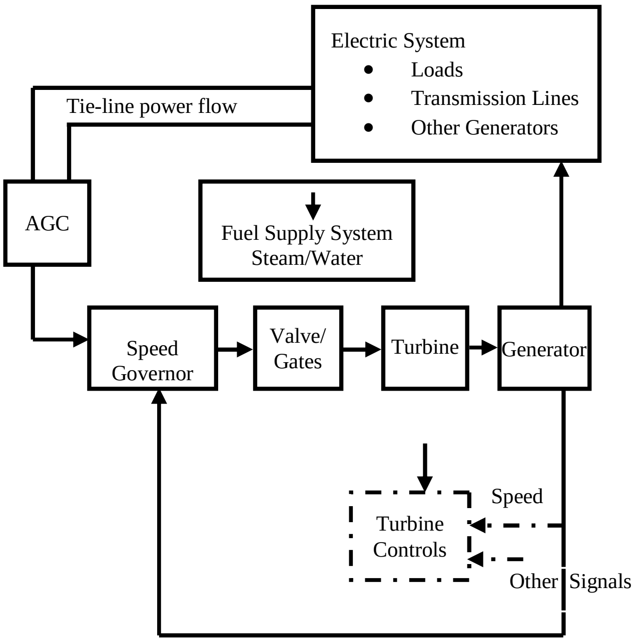


Fig. 5 Functional block diagram of AGC of a power system

AGC is also referred to as real power control or megawatt frequency control. The objective of this control is to maintain real power balance in the system by the control of system frequency. Whenever the real power demand changes, a frequency change occurs. This frequency error is amplified, mixed and changed to a command signal which is sent to the speed governor of turbine. The governor operates to restore the balance between the input and output by changing the turbine input. AGC has gained in importance with the growth of interconnected system and has made the operation of interconnected system possible. In recent traditions, it is still the basis of many modern concepts for the control of large complex power system.

AGC tries to achieve this balance by maintaining the system frequency and the tie-line power flows at their scheduled values. The AGC function is directed by the area control error (ACE), which is a function of change in system frequency (ΔF) and change in tie-line flows (ΔP_{tie}). The ACE represents a mismatch between load of the area and generation taking into account any interchange deal with the neighboring areas. The ACE for the i^{th} area is defined as $ACE_i = \Delta P_{tieij} + B_i \Delta F_i$, where B_i is referred to as the frequency bias coefficient. This philosophy of control is widely used and is normally referred to as the tie-line bias control.

VII. POWER SYSTEM AUTOMATION

Automation is a very essential part of every type of control system (equipments) in the real world. The control equipments are useless without automation because any equipment cannot be properly operated in the fast random pattern operational scenarios without automation, and manual control fails to handle these operating conditions. If these equipments relate to power system, it is very necessary to be automated to cope with the operation and control problems. In power system operation and control problems, power engineers deal with the huge amount of electrical power. The large amount of electrical power cannot be handled manually in fast abnormal conditions. These operating conditions need very fast control actions. Therefore, power system assets and equipments have to be automated.

Automation of electrical power system is the function of automatically controlling the power system through control devices. Substation automation indicates to use data from intelligent electronic devices (IEDs), automation control capabilities within the substation, and control signals from remote consumers to control power system devices.

Since substation integration is the basis for fully automated substation, the means are often utilized interchangeably. Automation of power system incorporates processes joined with generation and delivery of power. Monitoring and control of power delivery systems in the substation, and minimize the presence of outages and shorten the duration of outages that do present.

The IEDs, interactions protocols and approaches, work jointly as a system to perform automation. The power system inferred the gathering of devices that make up the physical system that generate, transmit and distribute power [15]. The AGC is one of the applications of power system automation.

VIII. TRADITIONAL OPTIMAL AGC

The presence of the traditional optimization methods can be used for many power system planning, operation, and control problems. The development of the mathematical formulations of power engineering problems are evaluated under certain approximations and even with these approximations, the large-scale power system solution is not very easy.

Apart from this, many abnormal conditions/uncertainties are present in the power system modeling because of large and complex size of power system regions. The solution to power system problems should be globally optimum, which is expectable, but traditional optimization technique is generally used to search local optimum solution in certain region. It is difficult to adjust effectively with several power systems by estimated formulation of the single mathematics.

In the traditional optimization technique, the aim is to minimize ideas like cost, power loss, control action time, disturbances, etc. [16]. Any traditional model can be optimized by different types of mathematical programming methods. These methods are seeking optimum points in the problem domain. There are a wide range of sensible mathematical programming methods, such as linear programming, interior point method, quadratic programming, non-linear programming, decomposition technique, integer, mixed-integer programming and dynamic programming [17].

Few problems are raised after traditional programming techniques in the field of the power system control because the solution to the problems is not varied according to the human knowledge, practical results, uncertainty characteristics of the system, demand variations, etc. Therefore, intelligent techniques have emerged to promise nearly global or globally optimum solution. Intelligent techniques can easily handle the control issues with fast random uncertain problems related to the real world. The recent optimization approaches are also called non-traditional optimization methods.

IX. MODERN OPTIMAL AGC REGULATOR DESIGN TECHNIQUES

In modern days, the leading principle of intelligent technique is also making use of the tolerance for these things to achieve tractability, robustness and optimum result. Human mind can find the solution to any type of power system operation and control problems. Therefore, the ideal model for intelligent technique is the human mind [18].

TABLE-2 OPTIMIZATION METHODS IN POWER SYSTEMS

Traditional Optimization Techniques	**Non-traditional Optimization Techniques**
Linear programming	Genetic algorithms
Interior point method	Simulated annealing
Quadratic programming	Ant colony optimization
Non-linear programming	Particle swarm optimization
Decomposition technique	Fuzzy based optimization
Integer programming	Artificial neural networks based optimization
Mixed-integer programming	
Dynamic programming	Hybrid intelligent technique

The main components of intelligent techniques, such as genetic algorithm (GA), simulated annealing (SA), particle swarm optimization (PSO), ant colony optimization (ACO), fuzzy logic based optimization (FL) and artificial neural networks (ANN) based optimization are powerful and successful methods for solving power systems optimization problems. Most of these techniques are bio-inspired optimization techniques. Majority of the traditional and non-traditional optimizations are presented in Table-2.

The intelligent techniques based AGC regulators have become the main subject of research for the power system engineers. The ensuring paragraphs are dedicated to provide a brief discussion on these techniques as applied to design AGC regulators of the power system.

A. Genetic Algorithm

Genetic algorithms are computerized searching and optimization algorithms based on the mechanics of natural genetics and natural selection. GA is a global search technique with a high probability. The GAs were originally proposed by J. Holland in 1975 [19]. The number of GA applications to electric power system problems has been identified in the literature during about the last three decades.

The basic things of analysis and design of modern AGC regulators are based on the concepts of biological evolution can be found. This operates on a population of potential results applying the principle of survival of the fittest to generate better and better probabilities to a result. In each generation, a new list of probabilities is yielded by selecting the parents according to their levels of fitness in the old generation domain and breeding them together using operators acquired from natural genetics. Thus, the population of new generation is successively improved with respect to the search objective by replacing least fit parents with new ones (children of parents from the previous generation), better suited to the environment, just as in natural evolution [16, 19].

B. Simulated Annealing

The optimization technique SA method is based on the simulation of thermal annealing of critically heated solids. The SA method simulates the process of slow cooling of molten metal to obtain the optimum function value in an optimization problem. This technique is suggested by S. Kirkpatrick et al. [16]. From the beginning, the SA algorithm creates at random new combinations from the neighborhood of the basic pattern. If the updated results are in a better pattern, then the transition to the new pattern is accepted as it is. If the new pattern is worse than the old one, then the transition is also accepted by using Boltzmann probability factor [20].

The probability factor is controlled by a parameter called temperature and provides a mechanism for accepting a bad move. In the initial iterations, this probability is high (almost one) and in the final stages of iterations it comes down to almost zero. This approach enables the SA algorithm to avoid being trapped in a local optimum in its search for the global optimum. The ability to keep away from local minima and reach an optimal result makes it better than Hopfield network [16]. The final solution quality is not affected by the initial assumptions, except that the computational effort may increase with worse starting designs. This is also used to solve mixed-integer, discrete, or continuous problems.

C. Particle Swarm Optimization

PSO is a population based optimization technique based on intelligent scheme developed by J. Kennedy and R. Eberhart in 1995 [16]. The PSO is a global (near) optimization algorithm for dealing with different problems in which a best solution can be presented as a point or surface in an N-dimensional space. Hypotheses are represented in this space and seeded with a starting velocity, as well as an information channel between the particles [16, 21]. These particles are then shifted through the solution space. These are calculated according to some fitness criterion after each timestamp. Over time, the particles are accelerated towards those particles that have better fitness values within their information grouping.

The main advantage of such an approach over other near to global optimization strategies such as GA, SA is that the large numbers of variables that make up the PSO technique are impressively resilient to the problem domain of local minima. The model simulates a random search in the design space for the maximum value of the objective function, which is independent of the past experiences. All the variables in the solution space share their experiences to the other variables in the system.

D. Ant Colony Optimization

Ant colony optimization was developed by M. Dorigo in the early 1990s [17]. This is depending upon the cooperative behavior of physical ant colonies, which are able to search the shortest path from their nest to a substance taken in to maintain life and growth. Whenever optimization process (iterations) starts, all the reaching points are initialized with an equal amount of pheromone. All the ants move from initial point to destination point by randomly selecting a reaching point in each search. The specified maximum number of iterations is reached or no better solution is searched in a successive number of iterations, then optimization process is terminated.

The design variables information of the power system by the reaching point on the way with huge amount of pheromone is identified as the parts of the optimum solution in the vector scale. With the optimum solution, all ants travel along the similar converged (optimal) way normally. All the ants always select the similar optimal path in the travelling process.

E. Fuzzy Logic Optimization

Initially, L. A. Zadeh proposed fuzzy logic approach in 1964 [17]. The traditional optimization methods deal with selection of the design variables that optimize an objective function subject to the satisfaction of the stated constraints. In traditional designs, the optimization problem is reflected in precise mathematical terms. However, power system problems, the design data, objective function, and constraints are stated in vague and linguistic means. FL optimization techniques can be utilized to model and design systems involving vague and imprecise knowledge. Although it is developed in digital computers, which totally make only true/false results, FL deals with ranges of values, solving problems in a way that more resembles human logic. The FL is a multi-valued logic implemented to deal with imprecise or vague data.

When the probable reasoning of FL optimization is implemented with a learned system, logical inferences can be drawn from imprecise relationships [22]. The FL is operated for solving problems with real time power system (learned system) that must react to an ambiguous environment of highly variable, volatile or unpredictable conditions. It enhances the edges so as to explain, circumventing abrupt modifications in operation that could output from relying on traditional optimizations.

F. Artificial Neural Network based Optimization

The source point of ANN is the training algorithm proposed by D. Hebb in 1949 [16], which details how a network of neurons could show learning behaviour. The immense computational power of neural system to evaluate perceptional problems in the availability of massive amount of sensory information has been associated with its parallel processing ability. ANN are normally divided by their architecture, topology, and learning method. The architecture of ANN has number of layers, topology covers, connectivity pattern and feed forward or recurrent. The neural schemes have been selected to solve optimization problems in modern days.

Power system has utilized the ANN applications as the architecture of multi-layer feed forward network. The major benefits of ANN are its fast speed, robustness, capability for non-linear modelling and learning ability. These benefits propose the utilization of ANN in power system operation and control problems. Once the neural network is trained, it takes negligible time to power system control. In spite of these benefits, the ANN has large dimensions, optimum structure of selection, selection of training methodology and availability as a ‘black box’. Moreover, results are always developed even if the input data are unsuitable or excessive [17].

G. Hybrid Intelligent Techniques

The most recent idea in this area is the application of hybrid techniques such as GA, SA, PSO, ACO, FL and ANN to tackle the difficulties associated with the design of AGC regulators for power system with non-linear models and/or insufficient knowledge about the system required for its accurate modeling.

Apart from advances in control concepts, there have been many changes during the last decade or more, such as the deregulation of the power industry and the use of superconducting magnetic energy storage (SMES), wind turbines (WT) and photovoltaic (PV) cells as other sources of electrical power to the system. Therefore, the control philosophies associated with the AGC of the power system problem have changed to accommodating of their dynamics and their effects on the overall system dynamic performance. The hybrid approaches are utilized to overcome the limitations of the single intelligent techniques and these hybrid approaches consist of heuristic quality of global optimization of the AGC problems [18, 23, 24].

X. CONCLUSION

Indian power system’s operational and control philosophies are summarized considering the AGC. Research findings in the area of AGC are presented. Research reported in the literature on interconnected power systems with parallel EHVAC and HVDC links is discussed. An effort has also been made to review the findings of research work reported based on intelligent techniques.

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