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A Novel Hybrid Technique of Frequency Control for Distributed Energy Resources

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ABSTRACT

The rapid increase in the population and fastest development in the industrial sector has increased the energy demand throughout the world. Frequent outages and load shedding has seriously deteriorated the efficiency of the electrical power distribution system. Under such circumstances, the implementation of Distributed Generation (DG) is increasing. Small hydel generators are considered as the most-clean and economical for generating electrical energy. These are very complex nonlinear generators which usually exhibits low frequency electromechanical oscillations due to insufficient damping caused by severe operating conditions. These DGs are not connected to the utility in many cases because, under varying load, they cannot maintain the frequency to the permissible value. This work presents detailed analysis of operating characteristics and proposes a hybrid frequency control strategy of the small hydel systems. The simulation and testing is performed in MATLAB, the results verified the improved performance with the recommended method. The proposed method conserves half of the power consumption. The control scheme regulates the dump load by connecting and disconnecting it affectively. The application of presented methodology is convenient in the deregulated environment, especially under the severe shortage of energy. The proposed model keeps the frequency of system at desired level. It reduces the noise, thereby improving the response time of the designed controller as compared to conventional controllers. The innovative scheme also provides power for small scale industrial, agricultural and other domestic application of far-off areas where the supply of utility main grid is difficult to provide. The recommended scheme is environmental friendly and easy to implement wherever small hydel resources are available.

Keywords: Distributed Generation, Electric Power Distribution System, Environmental Friendly, Frequency Control, Hybrid Control Strategy, MATLAB, Renewable Energy Systems, Small Hydel.

1. INTRODUCTION

Renewable Energy (RE) sources are enchanting on a larger part of the electricity production in numerous power systems; the role of traditional power plants is altered from providers of base power to providers of balancing and flexible production [1]. Electric power generation from fossil fuel is the major cause of environmental pollution. Increased air contamination, global warming, greenhouse effect and climatic variations are primarily related to the use of fossil fuels [2-4]. The power systems are passing through innovative change because of growing demand of electrical energy throughout the world, developing the political pressure and community consciousness of environmental contamination [5]. Moreover, the ever increasing demand has forced for the expansion of existing networks, and reducing congestion on existing lines and threats from malicious entities. These factors combined with an inclination to stimulate the use of RE have led the expansion of RE [6]. The electricity generation from RE resources has increased significantly in the distant and rural areas [7]. To cope with the increasing demand of electrical

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energy, distribution companies are concentrating on renewable resources [8]. Water resources are frequent and hence, hydro power plants are getting increased attention for energy production worldwide as 19% of world's electricity demand is fulfilled by hydro power plants [9]. Hydro power is the prominent source of RE, providing more than 97% of all electricity generated by the renewable resources [10]. According to the report of the international journal of hydro power and dams, world's technically feasible hydro potential is estimated to be 14370 TWH/year out of which the economical most feasible proportion is 8080TWH/year [11]. This is mostly in the countries where increased power supplies from clean and renewable sources are most urgently desired to progress social and economic development.

Electrical energy is one of the core ingredients for socio-economic and industrial development of a country. Countries with rich hydro power potential, small hydro turbines have been established at distribution level, in order to sustain the distribution system in distant areas [12]. In majority of the underdeveloped countries the rural areas are the most affected in terms of access to electric power. The scenario can be changed if attention is given to a possibility of electrifying the rural areas by utilizing locally available energy sources for electricity generation, of which Small Hydropower Plant (SHP) is most attractive option. SHP is a well-proven technology, relying on non-polluting, renewable and indigenous resources, which can integrate easily both with irrigation as well as water supply projects. Over the last few decades, SHP is playing a key role in the economic growth of underdeveloped countries for remote rural areas, especially mountainous, where the access to main grid is difficult. SHP can also provide power for small scale industrial, agricultural and other domestic application.

In SHPs, the hydro turbine is a non-linear, non-stationary multivariable system with significantly varying characteristics due to the variable and unpredictable load, resulting in a great deal of complication in designing frequency control system. In context of micro-hydro power arrangements, the original price of traditional turbine unit is often high. Consequently, there is increasing interest in alternative technologies offering a more cost effective, yet highly proficient power generating alternative, finding application in the far-off area power supply and energy retrieval system [13]. A sudden load perturbation in distribution system will cause frequency of the system and the transferred power of the tie-lines to change [14]. The frequency control in power system is closely associated to keeps the balance between power generation and power consumption. The excess generated power leads to acceleration in the synchronous generators rotational speed and therefore positive power frequency deviation. Also frequency constancy imitates the sense of balance associated between the active power output of the generator and the load demand. Load Frequency Control (LFC) is kind of vital control that restores the system frequency and power flow to the adjacent areas back to their standards before a change in load.

The LFC is envisioned to keep the power stability in the system to safeguard the frequency variations within an identified bound [15]. As the security and the reliability of electrical energy network depend intimately on well-regulated power frequency signal in the system, it is indispensable to consider and allocate sufficient amount of reserve to be able to cope with power contingencies. It is essential for effective and benign operation of electrical devices; voltage level and frequency are needed to be kept within acceptable limits [16]. Frequency regulation is necessary not only for system security and reliability but also for the effective operation of electrical power system.

Power variation of RE resources and varying load demand causes frequency aberration in the system [15]. This alteration process takes place in three distinct stages. Primary Frequency Control (PEC) is the first regulation measure to respond to frequency disturbances. However, PFC method is unable to control the steady state faults in the power frequency signals and restore the system to its pre-contingency status. Hence, secondary frequency regulation is needed to eliminate the steady state errors in power frequency signals and reinstate the system to its pre-contingency state. Practically it has been observed that various design processes for this level of frequency control are required which may cause errors during their implementation [17]. In order to overcome such difficulties, third level of frequency control is applied. Third level of frequency control is intended at cost-effective and long term redistribution of load among the generation units. Smaller systems are more vulnerable to eventualities. Therefore, higher magnitudes of frequency deviations are predictable in forthcoming Electric Power System (EPS) with large penetration of RE resources [17].

The main purpose of control is to establish a balance between generation and loads, which can stabilize the frequency and voltage of power generation system at rated value. SHP generation technology is mature enough to achieve the balance between frequency and active power through regulating water and rotating speed of synchronous generator. The technology is effective to achieve the balance between voltage and reactive power through excitation system.

As the SHPs are mostly developed in remote areas, far away from the main grid, they are mostly isolated from grid network. The small hydel have some problems like their small storage potential, inaccessible from utility main grid and quick effect of a small change in the regime of river. However, the main difficulty faced during the operation of these plants is to keep the governor speed value constant in order to maintain the constant frequency of the generated power. If the active power balance is provided on the change of instantaneous power, frequency control can be provided. The load frequency control of small hydel is necessary to maintain the good quality electrical power. Many control techniques have been used for this operation. A combination of proportional, integral and derivative actions is more frequently referred to as Proportional-Integral-Derivative (PID) action. Hence, the name PID controller is used for precise application in order to get optimal response. Most common application of PID controller includes the regulation of speed, flow, pressure, temperature and other process variables. However, a conventional PID controller is usually not suitable for uncertain complex, nonlinear and small hydel power system. Its performance is mainly dependent on the tuning of their coefficients which is a difficult job [18]. Fuzzy logic has been implemented effectively for the modelling of the complex systems and designing their controllers.

The Distributed Energy Resources (DERs) are small-scale power generation sources located close to where electricity provides an alternative to the traditional electric power grid. Connecting such DRESs to the utility network introduces different dynamics to the system. If DERs are not properly controlled, the grid may become unstable and even fail [19]. In flow control techniques, frequency is controlled through the flow of water diverted to the hydro turbine by changing the quantity of water. In load control technique, generator output load remains constant despite any change in the consumer load. It has been observed that flow control approach has a slower response than the load control method, does not waste water, dissipate power and has a smooth power output [20]. The load control method has a superior response than flow control, but it wastes the power through ballast load.

The input mechanical power to the generator of SHP is used to control the frequency of the output electrical power and to maintain the power exchange between different areas as scheduled. The LFC in a multi area electric power system for small hydel generation using a novel hybrid control scheme has been implemented. This technique is compared with the conventional PI type controller for LFC. Simulation results show that the proposed method guarantees robust performance under a wide range of operating conditions and system uncertainties. However, the wrong selection of various parameters may adversely affect the performance of the system.

Increased demand of electrical power and incidences of electricity shortage, power quality problems including frequency control have made the electrical power system more complicated [21]. However, for traditional techniques, adequate time is required for convergence [22]. In this research study, the operating characteristics of small hydel are analyzed in detail and a hybrid control strategy is proposed for frequency control. An efficient algorithm is developed for the controller, which performs two functions, during the occurrence of system disturbance it connect the dump load with system and simply called “ON” and for other disturbance disconnect the dump load from system and simply known as “OFF”. This “ON” and “OFF” of the dump loads is carried out through solid state relay and adjust the intake water, applying hybrid control approach. Using this hybrid technique, the outcomes have been observed in the form of noise reduction and response time. The simulation is carried out in MATLAB software and the results verify the performance of the proposed method. Applying different techniques, the cost of various components for small Hydel power plants can be enumerated effectively [23].

In this research work, section 2 delineates the study of related literature regarding the different techniques of frequency control used for Small-hydroelectric power System. The merits and demerits and limitation of different frequency control techniques have been described in details. Section 3 belongs to the design of Small Hydro system. Currently, SHP utilizes the conventional equipments and appliances. In view of that, different parameters for design consideration have been discussed in this section. In section 4 describe the methodology used to control the frequency of mini hydro system. The innovative hybrid frequency control scheme is presented in this section. Section 5 provides the results and analyses. The conclusion, recommendation, acknowledgement and references are cited at the end respectively.

2. RELATED LITERATURE

Electric power system is a very complicated system developed by human being. Frequency control narrates to create equilibrium between generation and utilization. The maximum or minimum generation causes the positive and negative frequency deviation. When load is disconnected from the system, frequency increase, known as positive frequency change. When load is connected to the system frequency decreases, referred as negative frequency change. The reliability and security of electric power system depends upon effective control of frequency signal. Mostly, three frequency control levels (Primary, secondary and tertiary frequency control) are used to regulate the frequency of conventional electric power system. Large power system with more number of rotating masses has a chance to cause failure of electric power system. Various frequency control techniques have been discussed in this section. Few of them are briefly discussed as below.

2.1 Demand Side Management of Frequency Control

Demand side management for frequency control is new and undeveloped technique. Application of latest and cheap electronic and communication resources in electrical power networks enables a higher standard of controllability. It has been divided into five groups. These includes, Price response, Regulation response, Peak shaving, spinning reserve and Energy efficiency services [17].

Limitations: The controllable load should made sensitive to electric power frequency signal. It may be switch on or off throughout a power contingency and is able to account to frequency variation in electric power network. The residential loads' participation in frequency control must have the minimum disturbing effects on consumer's day-to-day activities, which is very difficult task. This technique is only applicable for thermal generating plants.

2.2 Demand Side Control Algorithms for Frequency Control

Demand side control algorithms used for frequency regulation are divided in to two groups i.e. centralized and decentralized control methods [17].

2.2.1 Centralized Control Algorithms for Frequency Control

In centralized control algorithms higher level controller in the control hierarchy makes commanding control signals for lower level entities. Therefore, consistent two-way communication network is essential to transmit data and control signals. Centralized control systems provide maximum reliability and controllability.

Limitations: Development of a safe communication network is complicated and costly, particularly when the numbers of contributors in the control process are unlimited. Enormous data processing is required by the centralized controller which increases the system complications.

2.2.2 Decentralized Control Algorithms for Frequency Control

In decentralized control techniques, assessments are carried out by the consumer's controllers locally. The application of this technique does not necessitate a consistent and secure communication system. During the operation, decision are taken by the local controllers, hence the quantity of data processing reduces for the controller.

Limitations: During the operation, accurate measurement power frequency signal by local controller is but certain complexities might arise regarding local measurement units. In demand management systems, local measurement of power frequency signal with proper precision is a tough job. For precise measurement of power frequency signal, expensive equipment and complicated network is required.

2.3 Centralized Direct Load Control Algorithm for Frequency Control

A centralized direct load control employs a priority listing technique established on current room temperatures. Using two-way communication circuits, the upcoming conditions of members are predicted by sending control signals to different loads. The system is designed in such a way that the main controller must have access to ambient temperatures of the apartments in order to estimate a space heater's competency to contribute to the system frequency control. Hence, the measurements of local household are referred back to the system central controller through the same communication circuit for taking appropriate action.

Limitations: Artificial changes in the room temperature may leads to wrong data collection, causing system collapse. The technique is applied only for thermal generating units.

2.4 Decentralized Load Controller Algorithm for Frequency Control

Decentralized load controller has been designed on pre- calculated fixed frequency threshold. During the operation of the system if network frequency variation surpasses a definite limit, control action is employed. The designed algorithm utilizes two dissimilar thresholds values for starting and stopping in order to eliminate oscillations in frequency signal of the system.

Limitations: Wrong selection of the threshold value may have drastic effects upon the decisions taken by the system controller, leading to total system failure. The designed system is only applicable to wind generating plants.

2.5 Fuzzy Logic Load Controller for Frequency Control

Fuzzy logic is mostly used where high level of uncertainty is expected. Based on fuzzy logic, controllers are designed while applying the frequency signals and Rate of Change of Frequency (ROCOF) as input [17]. Practically, it is notice that such artificial intelligence techniques are fruitful when applied as demand side management system. Literature review delineates that this method can be applied to DG (small hydel and wind generation).

Limitations: This method is applied for those cases where it is used as demand side management system. The system designed is expensive and complicated. This load control scheme is capable of dealing only ±2HZ frequency variation.

2.6 Time-Dependent Frequency Threshold Control System

Time-dependent frequency threshold control technique utilizes semi- inverse frequency-time curve. Various semi-inverse curves are allotted to different groups of loads. Different demand response accomplished from various groups of loads to frequency excursion. Necessary delay is recorded earlier or afterward exerting the control signal to the switch. Frequency reserve is procured according to a droop curve. In this way, semi-inverse curve is used to confirm the efficiency of domestic demand side participation in frequency control.

Limitations: Although, energy system having a high penetration of wind power generation, demand response improve only the negligible quality of frequency control. The technique is effective only for wind generation. Classification of domestic load is essential well before the implementation of this method.

2.7 Tuning Approach for Multi-Area Load, Frequency Control: Self Adaptive Modified Bat Algorithm

Khooban and Niknam [14] present artificial intelligent approach of multi-area load frequency control systems. It is used to tune the parameters of FLC which covers the frequency control of four-area interconnected large power system. FLC designing is robust and provides a desirable efficiency while encountered uncertain system parameters.

Limitations: The application of Self Adaptive Modified Bat algorithm is difficult for the linguistic and numerical uncertainties in system variables. The frequency bias setting, load disturbance, turbine reference power of each area in a power system is difficult to set.

2.8 Regulation Quality for Frequency Response of Turbine Regulating System of Isolated Hydro Electric Power Plant with Surge Tank

Guo *et al.* [24] proposes an isolated HPP (Hydroelectric Power Plant) with surge tank. The regulation quality for frequency response of turbine regulating system under load disturbance has been analyzed in this research work. Fifth order isolated hydroelectric power system is resolved and the regulation quality for frequency response is calculated. The research work effectively overcomes to resolve numerical simulation. The order of overall transfer function has been minimize by simplifying the mathematical model of turbine regulating system.

Limitations: Solution of higher order equations is complicated as much computational work is involved. Wrong selection of parameters adversely affects the end results. Poles of complete fifth order system cannot be solved analytically. Utilization of three different forms of hydroelectric power plants with different surge tanks further make the system complicated.

2.9 Modeling and Analysis of a Variable Speed Heat Pump for Frequency Regulation through Direct Load Control

A dynamic model of Variable Speed Heat Pump (VSHP) for Direct Load Control (DLC) signals is proposed by Kim *et. al.* [25]. The model is successfully used for the improvement of GFR (Grid Frequency Regulation). In a proposed model small signal investigation is executed to assess both the transient response of the DLC-enabled VSHP and its impact on GFR.

Limitations: Compressor fan power is neglected which adversely affect the simulation results. In order to avoid the complexity of the network and simulation time, the Variable Speed Drive (VSD) is modelled with ideal voltage sources which are very difficult for real time analyses. It has been observed that application of arbitrary ramp rate limits of 5, 10, 20, and 40 rad/s/s to the VSD-controlled VSHP model also causes the current or voltage problems. Apart from this many other values of variables and coefficients are arbitrary selected; wrong selection may affect the end results.

2.10 Load Frequency Control Strategies

Shayeghi *et al.*]26] have outlined the history of control strategies. Different control approaches has been elaborated. For reliable and excellent power quality supply, LFC is a vital issue. Variable frequencies and tie line power transfers are combined together by linear combination to form a single variable. This single variable is used as control signal in LFC. Main purpose of LFC in electric power system is to:

- Ensure zero steady-state error for frequency variations.
- Reduce spontaneous tie line power exchange between neighbouring control networks.
- Obtain fair tracking for load demands and disturbances.
- Maintain allowable overshoot and settling time on the frequency as well as tie line power variations.

Generally, from the last few decades, LFC issues have been discussed comprehensively. The nonlinear dynamics of the electric power system have made it more complicated. In majority of the research studies, it has been considered as linearized models with multi-areas [27]. The generation rates constraints approach, flywheel governor of synchronous machine model, tie line bias control strategy, generalized dynamical model for a LFC and augmented generation participation matrix model for LFC have been discussed [26].

Limitations: The practical application of these LFC models is too difficult to apply them as they are assumed to be the linear systems. This does not necessarily guarantee the stability of the systems.

2.11 Advanced Control Technique for Micro Hydro Power Plants

Hanmandlu and Goyal [28] have proposed an advanced control technique for micro hydro power plants. A progressive controller is designed for which the control action is divided in to two parts (linear and non-linear). Adaptive fast transversal filter and normalized algorithms are used for linear control action. Fuzzy proportional integral is developed for non-linear control action.

Limitations: Simulation results indicates the improved performance of the scheme, however it is observed that during the Formulation of plant models for SHP plant, the approximation regarding the calculation of transfer function for the servo motor based governor is considered. Such assumption adversely affects performance of the controller. Parameters of the proposed controller are calculated while utilizing state space equation. Doing so much computational work is required. This may increase the convergence time. Although new idea is implemented for developing controller but the division of input signal into linear and non-linear portion makes the structure design of controller more complex. Weight adjustments for new algorithm in neural network are not a simple one.

2.12 Load Frequency Control of a Realistic Power System with Multi-Source Power Generation

Parmar *et al.* [29] multi-source generation for realistic power system load frequency control has been disused. The designed controller gives reasonable balance between frequency overshoot and transient oscillations having zero steady state error in the multi-source power system environment. The significance of the controller is quantified in terms of a performance index. The proposed controller provides significant frequency deviation response.

Limitations: Initial states are assumed to be uniformly distributed on the unit sphere which practically does not exist. Usually, all information's about the states are not available. Processing of such all information's is difficult and expensive. Variation of controller parameters may deteriorates controller output and hence its performance.

2.13 Inertia Response and Frequency Control Techniques for Renewable Energy Sources

Dreidy *et al.* [30], inertia response and frequency control techniques for RE sources have been presented. It is too difficult to obtain the frequency stability for electric power systems having less number of generating units. The system becomes more complicated when the inertia constant is insignificant. This research work presents numerous inertia and frequency control methods proposed for variable speed RE resources.

In frequency response of conventional power, the occurrence of event causes system unbalance, the system frequency starts decreasing with the frequency rates, depending on the total system inertia and the amount of unbalanced power. This relation is enumerated by swing equation. An extra power must be available to overcome the escalation in power requirements for this particular duration. The frequency regulation of RESs can be obtained through wind turbine and solar PV plants.

Limitations: Wind turbines have no reserve power to support the frequency control and can release the kinetic energy kept in revolving blades.

2.14 Inertia Emulation and Fast Power Reserve Techniques

Inertia emulation and fast power reserve techniques are used to overcome restoration problem of wind generation. The extra power is used to eliminate the frequency variation when system comes under unbalance actions.

Limitations: The application of this technique is costly.

2.15 Fast Power Reserve Technique

Fast power reserve scheme is applied to RESs. It is used to eliminate the frequency deviation of an electric power system.

Limitations: The technique replies to frequency changes by releasing constant power for pre-determined interval of time. The design of the proposed scheme is complicated.

2.16 Inertia Emulation Technique Used for Frequency Control

Two kinds of inertia response exist, single loop and double loop respectively. The former utilizes Rates of Change of Frequency (ROCOF) to extract the kinetic energy embedded in the revolving blades wind turbine. This energy is applied as inertia response in the range of 2-6 seconds. Double loop inertia response technique is based on ROCOF and frequency variation. One loop inertia response is added to the speed control system to enable the wind turbine to respond to the ROCOF, known as inertia emulation.

Limitations: The design of Inertia Emulation Technique used for frequency control is complicated and expensive. The involvement of the rotating part of the machine causes losses in the system.

2.17 Fast Power Reserve

This power is received from the kinetic energy kept in the revolving body of the wind turbine.

It may be received by monitoring the rotor speed set point. It is a short term power for various wind speeds. Operation of fast power reserve controller starts when frequency variation surpasses a definite threshold; a control signal is sent from the detecting system to bypass the extreme power point tracking, used by centralized controller. It is utilized for frequency regulation.

Limitations: Fast power reserve technique is much complicated and usually limited to wind generation.

2.18 Droop Control

The droop control technique controls the active power output of wind turbine and is proportional to frequency variation. Controller significantly increases the frequency lowest point as well as the frequency retrieval procedure after the occurrence of frequency disturbances.

Limitations: During the operation of the system, active power is adjusted according to nonlinear characteristics which are difficult to utilize for control action. The technique is restricted to wind generation.

2.19 De-Loading Control

De-loading method is used to obtain maximum reserve power by shifting the operating point from its optimal power extraction position, thereby reducing power level. The achieved power is used to address the frequency regulation.

Limitations: Complicated speed control methodology is required. The technique is expensive and limited to wind generation.

2.20 Control Techniques for LFC in Deregulated Power System

Abhijith and Fathima [31] have discussed different control techniques and strategies. Various control techniques used for deregulated power system comprises; the Classical control approaches, Optimal and sub optimal control approaches and Adaptive and self-tuning control approaches. Soft computing techniques used for LFC in deregulated power are; Artificial Neural Network (ANN), Fuzzy logic, (Genetic Algorithm (GA), Bacterial foraging optimization algorithm, Particle Swam Optimization (PSO) and the combination of ANN and Fuzzy logic known as the adaptive network fuzzy interface system.

As for as different strategies are involves, these includes; Centralized and decentralized control methods and Variable structure control methods.

Limitations: Majority of these techniques and strategies are complicated, in a developing stage and are expensive to apply.

2.21 Inter-Area Modes of Fast HVDC Primary Frequency Control

Two machines model, using inter-area modes of fast High-Voltage Direct Current (HVDC) primary frequency control was investigated in [32]. After a details analysis, it was concluded that by adding fast HVDC primary frequency control never decreases the inter-area modal damping for two-machine model.

Limitations: Although HVDC transmission is commonly used for interconnecting two non-synchronous ac grids and is effectively utilized for balancing against small hydroelectric resources but the application of many assumptions restricts the practical implementation of the model.

2.22 An Optimal Frequency Control Method through a Dynamic Load Frequency Control Model Incorporating Wind Farm

Gholamrezaie *et al.* [21] has proposed an optimal frequency control method through a dynamic LFC for wind generation. The designed model enhances the efficiency of the system by the implementation of pre-defined PID controller coefficients based on particle swarm optimization algorithm. The model is applied to a two-area electric power system successfully.

Limitations: It is noticed that the adjustment of PID controller coefficients is very difficult. As the behaviour of the frequency response is nonlinear, the accurate selection of these coefficients is essential. Wrong selection of these coefficients adversely effects on the supplementary control of the wind farm, the amount of inertia, and damping. Speed regulation of wind turbine itself is problematic and tough job. The model presented needs the finest value of the frequency control gains which is not possible for all cases. The optimization of de-loading factor is necessary for optimum frequency control which further complicates the implementation of proposed model. The selection of weighting factor for velocity vector of PSO algorithm is a challenging task.

2.23 A Distributed Model Predictive Control Based Load Frequency Control Scheme for Multi-Area Interconnected Power System Using Discrete-Time Laguerre Functions

Zheng *et al*. [33] recommends a distributed (Model Predictive Control Based Load Frequency Control (MPC-LFC) system to develop control presentations in the frequency regulation of electric power system. For improved performance, the Laguerre functions are employed to estimate the predicted control trajectory. Analyses have been performed for two-area thermal-hydro system and a typical three-area thermal scheme under the abrupt load trouble situations applying the suggested control system. The discrete-time Laguerre function is used to increase the efficiency of the frequency regulation in multi-area electric power network.

Limitations: Implementation of discrete-time Laguerre functions increases much computational burden which enhances the convergence time. Increasing the number of decision variables may cause the error in the end result. The system optimization significantly reduces by incorporating the terminal equality constraint.

The flow chart diagram of different frequency control techniques used for small hydel is depicted in Fig. 1. In Table 1 the name of frequency control techniques used for small hydroelectric power generation, the aim and scope, the methodology implemented contribution of each FC technique applied and the limitations of each scheme have been narrated. The hybrid technique presented in this research work is simple, cheap, easy to implement, no burden of heavy computational work is required for its execution. The controller design is modest, no load classification is needed, high efficiency, no assumptions required during the simulation. The analysis has been carried out in MATLAB conveniently. The methodology proposed has better response time to that of conventional frequency control system. The design scheme has high noise reduction, environment friendly and power consumption is significantly less than that of traditional schemes.

The elaborative works of many researchers have been presented in Table 1. Different methodologies have been adopted to resolve the problem of frequency control for small hydropower system. The detailed study delineates that every scheme designed by the area expert has its own merits and limitations as highlighted in Table 1. The technique presented in this research work is simple, easy to implement and has minimum power consumption.

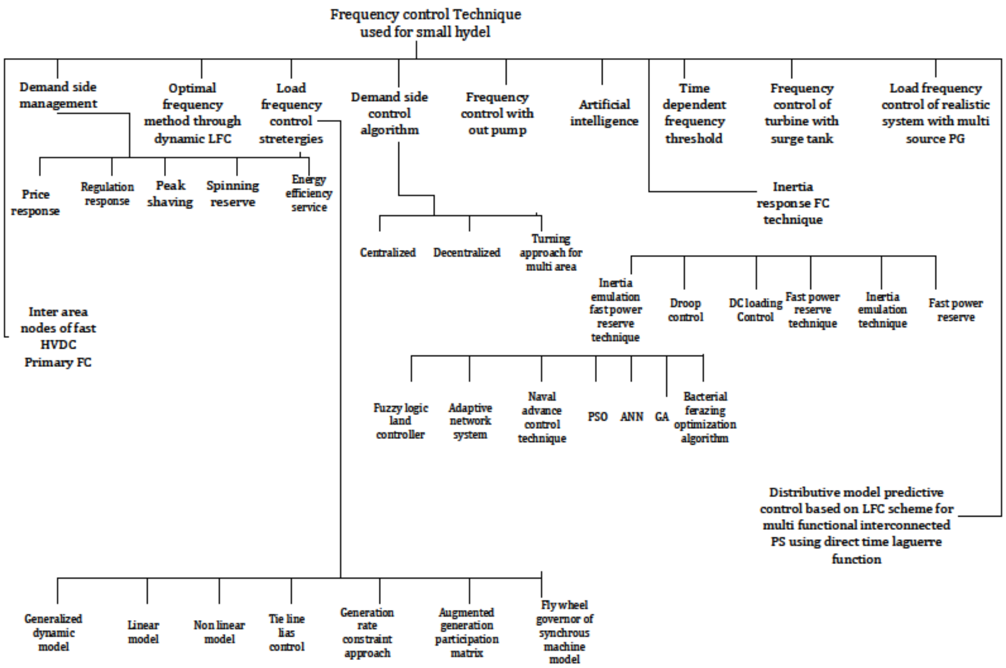

Fig. 1: The flow chart diagram of different frequency control techniques used for small hydel

Table 1: Name, aim and scope, methodology, contribution and limitations of each scheme.

No.	Name of Technique	Aim/Scope	Methodology	Contribution	Limitation
1.	Demand side management.	New Technology, Cheap equipment's is used.	Third level of Frequency control.	High level of controllability.	The residential loads greatly affect the frequency control technique.
2.	Demand side control algorithms.	Minimize the quantity of data required for controller.	A fixed frequency threshold control system.	Provides easy data processing for controller.	The methodology utilized is expensive and complicated.
3.	Artificial Intelligence AI.	Applied for high levels uncertainty areas.	ROCOF signal is used as input for controller.	Successfully applied for DSM & DG.	Design of controller is complicated & expensive.
4.	Time dependent F threshold CS	Mostly used for domestic DSP in Frequency.	Semi-Inverse frequency time curve is used.	Effective application to RERs.	Load classification is essential before the application of this scheme.
5.	Frequency control of turbine with surge tank.	May be applied for isolated hydroelectric power plant with surge tank.	Fifth order isolated hydropower system is resolve & regulation quality for frequency response is calculated.	Efficiently overcomes to resolve numerical simulation & minimize the computational work.	Solution of higher order equations is difficult. Poles of 5th order system cannot be solved analytically. Cannot find frequency for 3 different SHPs with different surge tanks interconnected power system.

6.	Variable speed heat pump for frequency regulation through direct load control.	Improve the grid frequency regulation.	Dynamic model of variable speed heat pump is used to direct load control signals. MATLAB/SIMULINK.	Successfully used for improvement of grid frequency regulation.	Compressor fan power is neglected which adversely affect the simulation results. Arbitrary values of variables & coefficients may affect the end result.
7.	Load Frequency Control strategies	Zero steady state error for frequency variation, reduce impulsive tie line power exchange b/w nearby control networks, fair tracking for LD, over short, setting time.	Constitute a linear model for frequency control of electric power system.	Provide reliable & excellent power quality.	The development of linear model with single variable for frequency control is a difficult task.
8.	Load frequency control realistic Power station with multi source power generation.	Develop a controller which is used for load frequency control of multi-source power generation system.	Optimal output feedback controller used only output state variable.	To provide satisfactory balance between frequency over shoot & transient oscillation with zero steady state error in multi-source power system.	In proposed model, initial states are assumed to be uniformly distributed on unit sphere which practically does not exist. All information's about states are not available. Processing of information is difficult & expensive. Variation of controller parameters affects the performances.
9.	Inertia response & frequency control technique.	To obtain frequency regulation of RESs & to preserve the environment.	Reviews several inertia & frequency control techniques used for variable speed RESs.	To achieve frequency stability of the electric power system with different RESs.	Wind turbines have no reserve power to support frequency control & can release the K.E kept in revolving blades.
10.	Inter area models of fast HVDC primary frequency control.	To control system of HVDC transmission that inter connects two non-synchronous AC grids.	Lossless HVDC trans; interconnects the two non-synchronous M/Cs networks "X" & "Y"& solved numerically for modal damping.	HVDC PFC can be made fast enough to permit inertia sharing among various AC grids. The max frequency fall can be minimized after loss of generation contingency.	The application of many assumptions restricts the practical implementation of this model.

11.	Optimal frequency Control method through a dynamic load frequency control.	To enhance the efficiency of the system by the implementation of pre-defined PID controller coefficients based on PSOA. To obtained the frequency control of two area system.	PSOA is used.	Used to control the freq; of multi-area PS. Integral controller, washout filter & PID controller can determine the active power variation value in different situation for FC.	Adjustment of PID controller coefficients is difficult. The wrong selection of these coefficients adversely effects on the supplementary control of RESs, the inertia & damping. The selection of weighting factor for velocity vector of PSOA is challenging task.
12.	Distributed model predictive control based LFC scheme of multi-area interconnected power station using discrete-time laguerre functions.	To enhance the control performance in the frequency regulation of power station, to minimize the computational burden.	Application of orthonormal laguerre functions to approximate the predicted control trajectory.	Control the performance of the power station for different interconnected power system of RESs. The application of model increases the FR in multi-area PS.	Computational burden of controller increases. Enhance convergence time. Increasing no of decision variables may cause the error in the end result.

3. DESIGN OF SMALL HYDRO POWER SYSTEM

SHP consists of natural source of water in which minimum flow of water is available throughout the year. The other components include reservoir, generator, turbine, governor, control mechanism and power transformer. The schematic block diagram of SHP is illustrated Fig. 2. A water channel is constructed through which water is allowed to pass to the turbine. This channel is called as penstock. When water fall upon the blades of turbine, it converts the kinetic energy of water into mechanical energy. The waterfall is controlled with the help of governor. Governor control generator speed such that its frequency remains constant throughout the operation. Presently, SHP employs the traditional equipment and appliances which are expensive and uneconomical. SHP can be made cost effective with the application new, sophisticated equipments. Keeping in view of that, different parameters for design consideration have been discussed in this section.

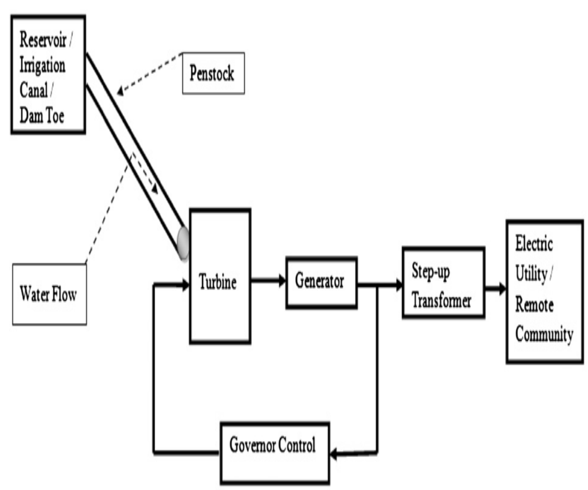

Fig. 2. Block Diagram showing different sections of a small Hydropower Station

To determine the flowing water potential, it is compulsory to calculate the head and flow rate (Q_s).

The flow rate is measured in cubic meters per second and head in meters.

In order to find the power, following calculation should be made:

$$P_{th} = H_s \times Q_s \times g_s \text{ kW} \quad (1)$$

where P_{th}=Theoretical power, H_s = Total head (meters), Q_s = Water flow rate (cubic meters per second), g_s = Gravitational acceleration (9.81 m/s^2)

When one form of the energy is converted into the other form of the energy, a little amount is lost. So the actual amount of power becomes as;

$$P = P_{th} \times \eta_{turbine} \times \eta_{genertor} \times \eta_{el\text{-}system} \quad (2)$$

where P= Actual power, P_{th}= Theoretical power, $\eta_{genertor}$ =Efficiency of generator which is approximately equal to 0.9, $\eta_{turbine}$= Efficiency of turbine from 0.6 to 0.8, $\eta_{el\text{-}system}$= Efficiency of the rest of system which is more than 0.9.

In this research work, the power of the SHP is taken to be 40 kW, when H = 6 m, Q = 1.3m^3/sec, g_s = 9.81 m/sec^2, η = 60% is considered. Using these components a complete simulation model is develop for SHP System.

Table 2: Parameters of newly modeled small Hydropower System

No.	Systems	Rating
1.	Capacity output:	40 kW
2.	Discharge Requirement	1 m^3 /sec– 2 m^3/sec
3.	Total Head:	6 m
4.	Turbine speed	800 rpm
5.	Runner diameter:	560 mm
6.	Kaplan Type:	Horizontal
7.	Generator power:	50 kW
8.	Voltage:	420 V
9.	Frequency:	50 Hz
10.	Generator speed:	1500 rpm
11.	Current:	85.9A

The specifications of newly modelled mini-hydro power plant system are listed in Table 2. Mostly; mini-hydro power plants are constructed in the areas where the facilities of utility main grid are not available. In this particular research study, the parameters are designed for those areas where minimum water discharge of 1-2 m^3 /sec with maximum head of 6m is available throughout the year. Installation of small water reaction type turbine (Kaplan) coupled with low speed generator of 50kW, 420V; 50 Hz having a speed of 1500rpm provides maximum output of 40kW. Practically it has been observed that such type turbine-generator set is very successful for providing electricity to consumers of far-off areas in isolation mode. However, such SHP plants can also be connected to utility main grid with a specified controlled mechanism. For a known value of water flow rate and head, theoretical power can be calculated using Equation (1). Knowing the theoretical power, it is convenient to find the actual power as illustrated in Equation (2). The intake velocity can be calculated in section 3.1as mentioned below.

3.1 Design of Intake Velocity

Intake is the primary means of conveyance of water from source to towards the waterways of mini-hydro power plant. It may be of side intake type or bottom intake type depending upon the geographical condition of site. Once flow rate is identified, it is easy to calculate the intake velocity of water, while utilizing the Equation (3). Suppose that entrance losses and trash rack losses, the intake should be designed to carry a flow of Q = 0.78m^3 /s.If C_d= Coefficient of discharge = 0.6, g_s = Gravitational acceleration = 9.81 m/s^2, h_e = Effective head from the centre line of intake = 0.5m, V = Velocity of water flow through intake, substituting these values in equation 3, the intake velocity be calculated, which is 1.88m/s.

$$V = C_d \sqrt{2 g_s h_e} \quad (3)$$
$$= 0.6 \sqrt{2 \times 9.81 \times 0.5}$$
$$= 1.88 \text{ m/s}$$

Knowing the value of intake velocity (V), the cross section area of intake can be designed by the substituting the values in Equation (4).

$$\text{Area of cross section of the intake} = Q / V \quad (4)$$
$$= 0.78 / 1.88 = 0.414 \text{ m}^2$$

The quantity of water flowing through the intake can be regulated by gate opening.

3.2 Design of penstock

Penstock helps to convey water from forebay tank to the turbine. The material used for the construction of penstock in this particular case is mild steel. In order to control the seasonal temperature variation, sliding type expansion joints are constructed between two consecutive pipe lengths. Anchor block is used to confine the penstock from any sort of movement during the operation. Penstock is an important component of mini-hydro power plant. After a detail site survey, the measured length of the penstock was 18m. The rate of water flow through penstock (Q_p) was $0.39m^3$ /s with a gross head of 9m. The thickness of penstock pipe and its inner diameter (D) were 0.008m and 0.4m respectively. The numbers of bends in penstock were 2 and the angle of bends was 45^0. Sand grain roughness (K_s) value was 0.02mm. Young's modulus of elasticity (E) and Bulk modulus of elasticity of water (K) were taken as 2121 and 231.12 Kg/m^2 respectively.

3.3 Hydraulic Design

In hydraulic design different parameters are essential to be calculated for mini-hydro power plant. As per field visit of the site, cross section area of the pipe used for flow of water intake was calculate while using formula $A_p = \pi D^2/ 4$ and it was taken as $0.126m^2$. The velocity of the intake water flow through the pipe was calculated by substituting the values in Equation (5).

Velocity of the flow through the pipe $V_p= Q_p / A_p = 3.09$ m/s (5)

Similarly, the Reynolds number (R_e), Relative roughness (Kr) and the Head loss due to friction (H_f) were calculated while applying Equations (6-8) respectively.

Reynolds number R_e = Vp x D x 10 6 = 1.24 ×106 (6)

Relative roughness $K_r = K_s/D = 0.00005$ (7)

Friction factor from Moody's chart f = 0.011

Head loss due to friction $H_f = f \times L_p \times 0.083\ Q^2/D^5 = 0.24$ m (8)

The outer diameter of the intake pipe, the wall thickness and the internal diameter were chosen as 400, 8 and 416mm respectively. During the field visit of the site, the gross head was measured as 9m. The total head loss and the net head loss were calculated while using Equations (9-11) respectively.

$$H_{turbulence} = \sum K {V_p}^2/2g \quad (9)$$

$H_{turbulenc\ e}$= (0.23 + 0.15 + 0.8 + 0.14) 3.09 ×3.09 /2 × 9.81= 0.64 m

Total head loss = $H_{loss} = H_f + H_{turbulence}$ = 0.24+ 0.64 = 0.88m (10)

Net head = $H_{net}= H_g$ – H loss = 9 – 0.88 = 8.12 m(11)

3.4 Three Phase Practical Power Output Calculations

There are two basic types of generators used for generating hydro-electricity. In mini-hydro power generation, power output levels are low. For low output power level, induction generators are extensively utilized. The induction generators are preferred to utilize for SHP generation as they can be operated at variable speed s with constant frequency. The construction of induction generator is simple, less repair and maintenance is required and most economical as compared to synchronous generators. However, it is not true for all cases. It varies from case to case. In this particular case study, synchronous generator with a specification of three phase, 4wire, 383V, 50Hz, 71.2A has been proposed. The power output has been calculated while using the formula given in Equation (12).

Out Power $P = \sqrt{3}(VI\cos\theta)$ (12)

P = 1.73×383×71.2× 0.85 = 40100 W = 40.1kW
Horse Power = 1.43×40.1 = 53.734 HP

SHP can be made cost effective with the application of latest and advanced electronic controlled devices. General parameters of SHP are given in Table 2. However, there may be some sort of deviation in these parameters depending upon the geographical condition of the area as well as the availability of the amount of constant water flow throughout the year. The design of civil work including reservoir, forebay and penstock can be finalized only after the actual visit of the site.

4. METHODOLOGY

An electric power possesses specific voltage and frequency in order to maintain the balance between the demand and generation. During any disturbance of customer load, the permissible values of voltage and frequency deviate from actual value. The acceptable rating of voltage can be maintained by controlling the generator excitation. The standard rating of frequency can be managed by eliminating the difference between demand and generation. Therefore, a control system is needed to maintain these parameters at the required allowable levels. An equivalent block diagram of SHP system used for frequency control is illustrated in Fig. 3. It consists of turbine, generator, controller, frequency measurement device and load. Normal operating frequency of the system is 50Hz. When an event or any disturbance occurs on the system then a balance between energy generation and consumption is disturbed. The system frequency starts decreasing, depending upon the total system inertia and the amount of unbalanced power, as given by the swing equation. In a power system, various synchronous machines are functioning. During their usual operation, the relative position of the rotor axis and the resultant magnetic field axis are fixed. In case of any system disturbance, the rotor either decelerates or accelerates with respect to the synchronously rotating air gap mmf, creating relative motion. The equation explaining the relative motion is known as the swing equation [34].

In mathematical form, it can be written as:

$$\frac{df}{dt} = \frac{f_o}{2H_{SYS}S_B}(P_m - P_e) \tag{13}$$

Where $\frac{df}{dt} =$ Rate of change of frequency, $H_{SYS} =$ Total System inertia, $S_B =$ Rotating power of the generator, $P_m =$ Mechanical power, $P_e =$ Electrical power, $f_o =$ System frequency

Prior to any controller initiation and due to inertia response, the synchronous generator releases the kinetic energy kept in its revolving mass, which persists for ~10 s. If the frequency aberration exceeds a precise value, the primary frequency controller will be instantly actuated. The controller guides the generator governor to bring back the frequency to permissible value within 30s. After 30s, another control activates to yield the system frequency to its nominal value.

In this particular research study, emphases have been made to design an advance control strategy for the frequency control of SHP that may overcome the prevailing problems related to frequency control. The application of latest electronic equipment (frequency measuring devices, Solid state relays and dump load) as shown in Fig. 3 has significantly made the system cost effective as well as efficient.

4.1 Proposed Hybrid Scheme for Small Hydel

In the proposed technique an efficient control algorithm is developed, that exploits the arrangement of both modified load control technique as well as flow control technique. The hybrid technique utilizes the advantages of load control & flow control techniques. The implementation of only load control technique will dissipate the significant amount of power. On the other hand, if we use only modified flow control technique, the response time of system will be slow. However, the simulation results delineates that the application of proposed hybrid scheme is simple, has improved response time and also enhances the system

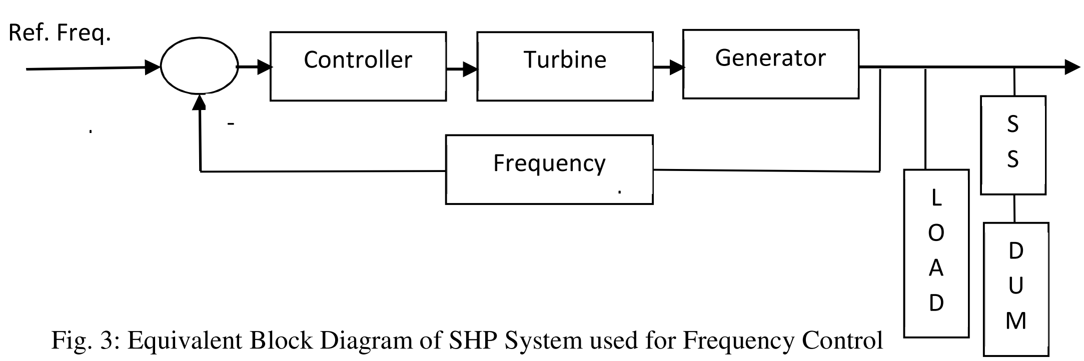

Fig. 3: Equivalent Block Diagram of SHP System used for Frequency Control

performance by saving 50% power. An electric power system is assumed to be a linear system for which normally, there is a balance between power generation and power consumption. During the occurrence of any disturbance, this balance is disturbed and generation frequency starts deviation. Usually it has been observed that electric power disturbance happens when there is sudden increase or decrease in the load demand causing frequency variation of the system. The proposed technique efficiently handles the situation in such a fashion that large change in load is covered through load control technique whereas small change is handled through modified flow control technique. The resultant frequency variation is brought into a permissible value very smoothly. Hence, the designed algorithm incorporates the controller which performs two functions during this operation. It automatically either switch "ON" or "OFF" the ballast loads through solid state relay and handled the situation by controlling the flow of water. The simulation results also expressed that the system response time has been improved and the noise has been decreased significantly as compared to the conventional control approaches. In the existing system scenario, Mini hydro has achieved great importance because no pollution agents like smoke, carbon monoxide; carbon dioxide or similarly other poisonous gases are discharged during the electric power generation. Hence, the Small hydropower system is clean and economic way of RE power generation. The aim of control technique is to keep balance between power generation and demand, which can stabilize the frequency and voltage parameters of power generation system at the standard value. The Schematic Hybrid control diagram of Mini hydro power is depicted in Fig. 4. It consists of turbine, generator, control algorithm, solid state switch, variable ballast and consumer load. During the normal operation of the system, the generation and demand are balanced. The system generation voltage and frequency are equal to load voltage and frequency. Whenever disturbance occur on the system, the voltage and frequency parameters of the system start changing depending upon the nature of load deviation. The controller of the control algorithm sense the fault, signal is generated that control the speed of turbine as well as the inertia of the rotating machine. In this way, the variations in the system parameters are controlled and the original state of the system is restored back. The deviation in the system frequency is controlled by varying the ballast load through solid state relay. In this research work, a hybrid scheme for SHP is designed while using MATLAB software. The results indicate best performance of the scheme as evident from the analyses.

The utilization of control algorithm as depicted in Fig. 4 can easily sense the fault and immediately sent the signal to speed regulating system (governor) of the turbine. The governor acts according to the situation and keep the balance between generation frequency and load frequency.

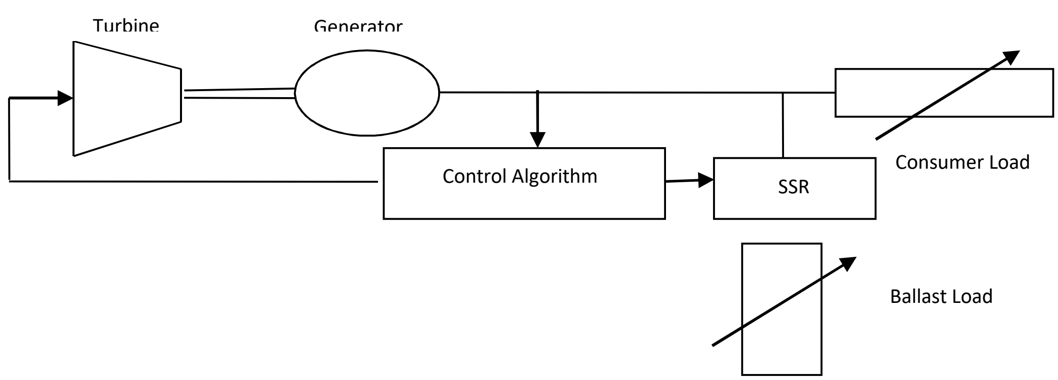

Fig. 4: Schematic Hybrid Control Diagram of Mini Hydro Power

4.2 Frequency Control

In this section, a mathematical form of system frequency parameters and coefficients are expressed. Power system frequency is one of the quality indexes. Frequency variation is unavoidable because of an inequity between generation and load [35]. The mathematical expression used for frequency control can be depicted as Equations (14-15).

$$b_p K_d \frac{dy^2}{d^2t} + \left(1 + b_p k_p\right)\frac{dy}{dt} + b_p k_i (y - y_c) = -\left[K_d \frac{dx_f^2}{d^2t} + K_p \frac{dx_f}{dt} + K_i x_f\right] \quad (14)$$

$$e_p K_d \frac{dp_g^2}{d^2t} + e_p K_p \frac{dp_g}{dt} + e_p k_i \left(p_g - p_c\right) + \frac{dy}{dt} = -\left[K_d \frac{dx_f^2}{d^2t} + K_p \frac{dx_f}{dt} + K_i x_f\right] \quad (15)$$

Governor controls the opening according to the specified value of y_c which is equivalent to the frequency control under opening feedback without frequency variation input x_f. Considering y_c and neglecting x_f, the equation of opening control can expressed as Equations (16);

$$b_p K_d \frac{d(y-y_c)^2}{d^2t} + \left(1 + b_p k_p\right)\frac{d(y-y_c)}{dt} + b_p k_i (y - y_c) = 0 \quad (16)$$

Modelling of opening control process can be simplified by setting the opening directly equal to the given value as shown in Equation (17):

$$Y = y_c \quad (17)$$

During the power regulation, governor operates the opening according to the power signals, leading the power output to accomplish the specified value. The equation of power control can be deducted by deleting the frequency (x_f) term while considering the adjustable known power (p_c) and feed-forward. In mathematical form it is expressed as Equation (18).

$$e_p K_d \frac{d(p_g-p_c)^2}{d^2t} + e_p K_d \frac{d(p_g-p_c)}{dt} + e_p k_i (\left(p_g - p_c\right) - \frac{dp_c}{dt} + \frac{dy}{dt} = 0 \quad (18)$$

where p_c is given power, p_g is generator power xf is relative value of speed (frequency) deviation, y is opening deviation after PID terms, y_c is given opening, y is guide vane opening, $b_p K_d k_i$ is coefficient of constants.

In an isolated SHP system, load an important parameter that often changed according to customers demand. It must be studied thoroughly for detail and accurate analyses. For a precise control system, load variation must be taken into account. In order to develop a precise and exact control system, measurement of sensor should be accurate. In the proposed methodology, a sub system is developed for accurate measurement of generator frequency. Different steps used for effective frequency measurement are illustrated in flow chart of Fig. 5. It is updated every 0.2 seconds. Timer and counter are used to measure the frequency of SHP system. During the operation, timer and counter are initialized. If the numbers of counts are ten then the timer is stopped and counter value is assigned to “P”. So by dividing “P” with timer value T, the frequency of system is calculated as F=P/T.

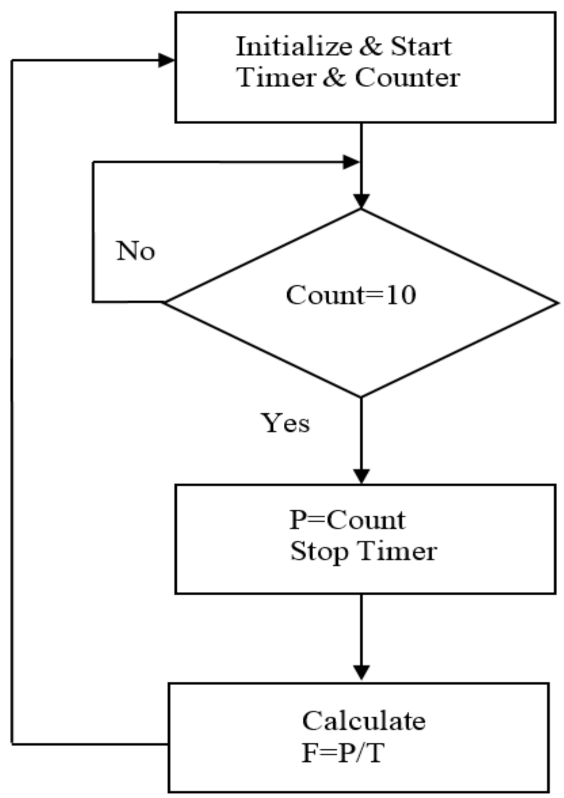

Fig. 5: Flow Chart Diagram used for Frequency Measurement of SHP

During the process of frequency measurement, sensor plays a key role. Inaccurate measurement of sensor may leads to system failure. Therefore, the successful functioning of the flow chart as illustrated Fig. 5 essentially depends upon the precise and exact measurement of the sensor.

4.3 Solid State Relays

The Solid State Relays (SSR) is static electronic device and has an improved performance as compared to other mechanical devices having moving parts. Mostly it used for precise and an accurate operation in an electric power system. It an integral part of SHP power control system. An opto-coupler is the main part of SSR. The function of opto-isolator is to provide high degree of the input/ output isolation. It is capable to transmit very low frequency signals for performing appropriate actions during occurrence of faults on electric power system. When input increases behind a pre-defined threshold value, signal is generated and sent to controller necessary action against the faulty network by SSR.

4.4 Main Controller

Frequency is inter-related with the load. Any type of change in Load directly changes the frequency which is not acceptable for the effective operation of the power system. PID controller is affectively used to control the frequency variation [36]. For any control system, input to the controller is always an error signal, which is difference of the reference signal and actual output of the system. In this particular case, the frequency is the output signal which is accurately measured and produces error signal by comparing measured signal with the reference signal, which is then given to controller.

$$\Delta \mathrm{f} = \mathrm{f}_{\mathrm{ref}} - \mathrm{f}_{\mathrm{m}} \tag{19}$$

where ΔF = Error signal, F_{ref}= Reference signal, F_m= Measured signal

The controller will perform an action on the basis of these error signal Δf.

During the smooth operation of power system, the mechanical power (P_m) and electrical load (P_i) are same. Change in load causes the variation in the speed (ω) of turbine as narrated in Equation (20).

$$\mathrm{P_m} - \mathrm{P_i} = \mathrm{M}\left[\frac{\mathrm{d}\omega}{\mathrm{dt}}\right] \tag{20}$$

where, M is rotating inertia of the rotor. The governing mechanism senses the change of speed ($\Delta\omega$) and regulate control valve such that P_m =P_i

The change in frequency can be defined in terms of change in load, using the following Equation (21).

$$\Delta\omega = -[\Delta P_i][R] \tag{21}$$

where, R is known as speed regulation.

The swing equation for small perturbation can be written as;

$$\frac{2\mathrm{H}}{\omega}\frac{\mathrm{d}^2\Delta\delta}{\mathrm{dt}^2} = \Delta\mathrm{P_m} - \Delta\mathrm{P_e} \tag{22}$$

In term of small variation in the speed,

$$\frac{\mathrm{d}\Delta\frac{\omega}{\omega\mathrm{s}}}{\mathrm{dt}} = \frac{1}{2\mathrm{H}}(\Delta\mathrm{P_m} - \Delta\mathrm{P_e}) \tag{23}$$

While taking Laplace Transform;

$$\Delta\Omega(\mathrm{s}) = \frac{1}{2\mathrm{H(s)}}[\Delta\mathrm{P_m}(\mathrm{s}) - \Delta\mathrm{P_e}\ (\mathrm{s})] \tag{24}$$

Electrical power system loads comprises of varying nature of loads. The distinguishing speed-load characteristic of complex load is given by Equation (25);

$$\Delta\mathrm{P_e} = \Delta\mathrm{P_L} + \mathrm{D}\Delta\omega \tag{25}$$

where, ΔP_L is the non- frequency sensitive load change and $D\Delta\omega$ is the frequency sensitive load change. D denoted the percent change in load by percent change in frequency.

It has been observed that the electronic load controller has better response time than the flow control, but it wastes the power through blast load which cannot be utilized. Flow control approach has slower response time than the electronic load controller; however, this technique saves water, does not waste power and has a smooth power output.

An efficient and effective algorithm is presented for the frequency control of the SHP system in the proposed hybrid scheme. When system is operating smoothly, the main parameters of the system on generation and load sides are same, the system is balanced. However, in case of any disturbance, the balance of the system is disturbed. If the generation is more than consumption, the frequency of the system starts increasing. In order to bring the frequency back to standard value, the extra generation is consumed by connecting dump load to the system, using SSR switch. This function of the controller is referred as switching on or simply "on". On the other hand, when demand exceeded the generation, the frequency of the system starts decreasing. To this effect, the dump load or non-critical load connected with the system is disconnected through SSR switch. This operation of the controller is known as switching off or simply "off". Such operation of the controller in the proposed algorithm helps to keep frequency of SHP within standard value.

The application of proposed hybrid technique has been utilized effectively for mini hydro system. The technique has improved response time, almost power consumption has been minimized to 50%, improves noise reduction and easy to implement as compared to conventional frequency control schemes.

4.5 MATLAB Based Simulation

MATLAB based simulation model is developed for the small hydropower system. The flowchart is given in Fig. 6. It contains a three phase generator model, sensor measurement model, controller model, dump load and user load. The system parameters for modeling are illustrated as per the specification of small hydropower system and are listed in Table 2.

If the end user switch "ON" (connected with the system) or switch "OFF" (disconnected from the system) at any time, frequency changes, it may increase or may decrease depending upon the load connection and disconnection. This frequency deviation is then compared with reference frequency (50Hz). An error signal Δf is generated, which is input to the controller. On the basis of error signal Δf, controller will take the decisions. If input to the controller is zero (Δf =0), it will perform no action. It means that system is functioning smoothly and there is no change in system frequency. In case of non-zero input, the controller either sends command to dump load through SSR, or perform flow control through PI servo control. The system has the option of utilizing the hybrid technique i.e. combination of flow control mechanism and electronic load controller to keep the frequency of system at desired level as explain in section 4.4 and is shown in Fig. 7.

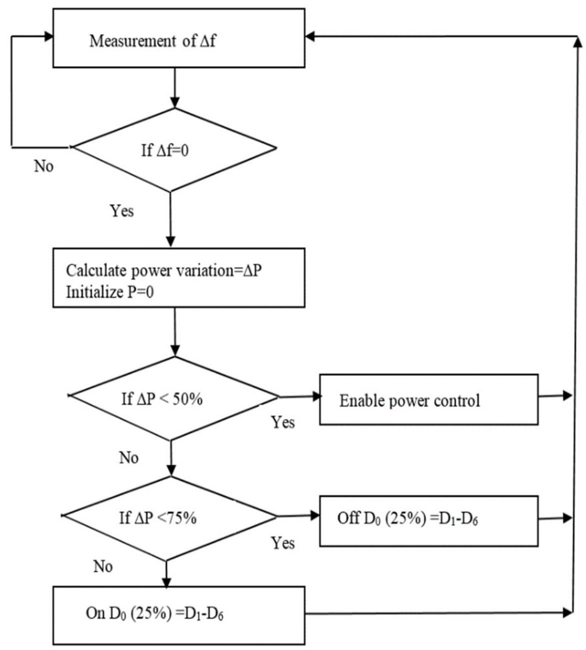

Fig. 6: Flow Chart Diagram of Designed Hybrid Scheme used for SHP

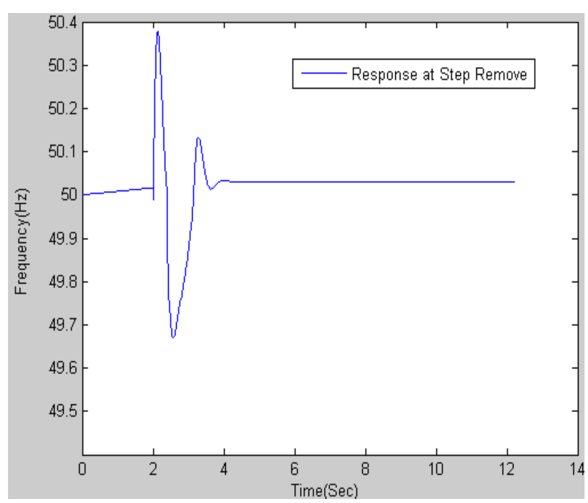

Fig. 7: Response of Proposed Hybrid Scheme for SHP at Step Removes

In the proposed technique, minimum and maximum threshold values are set for consumers load variation (ΔP). Measuring Δf, calculate the power variation (ΔP) at the total load. If ΔP is less than 50% of the total load connected to the system, the controller will implement flow control technique using the servo motor PI control. If the ΔP is greater than 50% of the total load, controller will check whether the ΔP is less or greater than75% of the total load connected. If ΔP is less than 75%, it will adjust through dump load D1-D6 and will "OFF" the first dump load. If ΔP is greater than 75%, it will adjust through dump load D1-D6 and will "ON" the first dump load. The SSR are fast switching devices, used to reduce the noise, thereby improving the response time of the proposed controller as compared to conventional controllers. Transient Voltage Suppressors (TVS) are used to suppress the noise at transient state, so immunes noise nicely. Hence the overall response time becomes better than conventional controllers.

The design of proposed hybrid scheme is very flexible in it application as expressed in Fig. 6. It has the dual option of utilizing flow control technique using the servo motor PI control or the adjustment of dump loads through fast switching devices. Therefore, the application of proposed hybrid scheme is very much effective for the frequency control of SHP. The response curve of Fig.7 also delineates that the practical application of proposed hybrid scheme has significantly improved the response time as compared to the traditional schemes.

5. RESULTS AND ANALYSES

The simulation is accomplished to verify the effectiveness of the recommended scheme for regulating the frequency of system, using MATLAB Tool box (Simulink). A three phase four wire synchronous generator models are used (Sim Power System), parameters for modelling are defined as per the specification of small hydropower system. Proposed model is simulated with initial condition as per specifications given in Table 2. Since the system is isolated from national grid, hence it is operated at full load. At any time end user can be switch off. Therefore, first disturbance in the system, is considered as the step removal of load at t = 2 seconds. While removing the load, system frequency increases significantly. The increased frequency is detected by the controller which attempts to stabilize it. Implementing the proposed scheme, the system frequency becomes stable at t = 4 seconds. During the application of scheme, the control algorithm will check the load variation. If the consumer load is changed in small quantity i.e. less than 50% of total load on the system, then controller will perform only flow control approach using servo motor PI control. If the user load is altered in large amount i.e. greater than 50% of total load on the system, controller will check whether the load is changed less than or greater than 75% of the total load. If the change in load is less than 75%, it will adjust through dump load D1-D6 and "off" the first dump load. If the load changed is greater than 75%, it will adjust through dump load D1-D6 and "on" the first dump load. The results show that the proposed technique not only stabilizes the system frequency but will also increase its performances. The response of system is illustrated in Figs.7-8 respectively. When first disturbance occur on the system by removing the end user or dump load, the system frequency changes between50.4(positive side) and 49.7(negative side) between the time interval of 2-4 second and then after that stabilized itself to standard value. This change of frequency is referred as system frequency response at step remove as illustrated in Fig. 7. During the occurrence of second disturbance on the system by connecting the end user or dump load with the system, the system frequency again changes between 49.6 (negative side) and 50.3 (positive side) for the same time interval of 2-4 second and then after that stabilized itself to standard value. This change of frequency is referred as system response at unit step as depicted in Fig. 8**.** System three phase voltages and currents are also shown in Fig. 9-10 respectively. The proposed hybrid scheme has the unique characteristic of not only maintaining the frequency parameter of the system during the occurrence of disturbance but it also manage to keeps the other system parameters like three phase voltage waveforms and current waveform within a standard allowable values. During the system variation, the monitored values of three phase voltages and currents are expressed in Figs. 9-10 respectively. The details study of these waveforms delineates that the newly designed hybrid scheme is capable to maintain these system parameter effectively.

The response of system for flow control technique is depicted in Fig. 11. The utility has the option to implement the flow control scheme for such sorts of

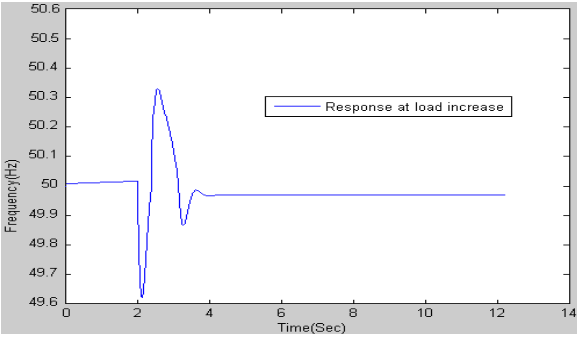

Fig. 8: Response of Proposed Hybrid Scheme for SHP at Unit Step

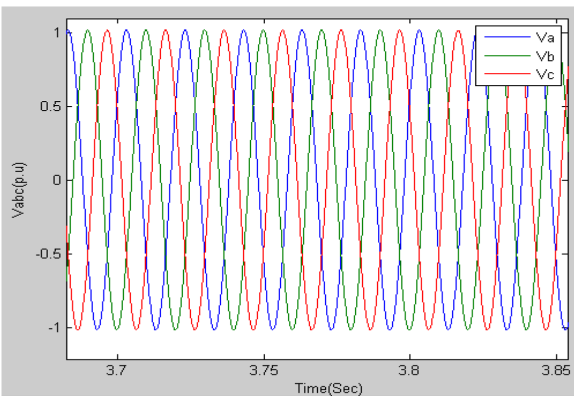

Fig. 9: Three Phase Voltages Vabc (P.U) of proposed SHP

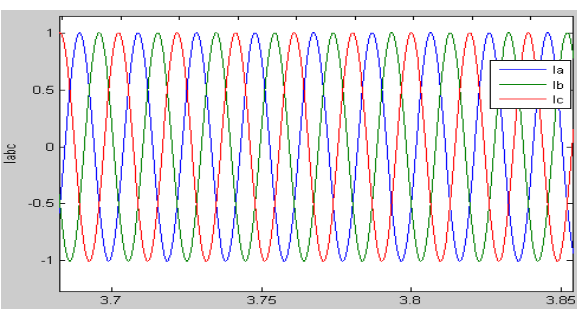

Fig. 10: Three Phase Currents of Generator Iabc (P.U) of Proposed SHP

system disturbances. The same disturbance of frequency control was implemented and the results were studied as shown in Fig. 11. The elaborative study of Fig. 11 shows that during the occurrence of system disturbance, the system frequency changes. It increases to 50.4 (positive side) to 49.7 (negative side) for the same interval of 2-4s. The results of Fig.11 show that the system frequency stabilizes for the interval from 2-6.5 second. The comparison of flow control scheme with the newly designed hybrid scheme was carried out and shown in Fig. 12. As obvious from the results of Fig. 12 that the proposed hybrid scheme is for better than the conventional flow control scheme. The response of the proposed scheme for the small hydropower system is compared with the traditional control scheme indicates that the response time of the proposed scheme is better than conventional scheme as depicted in Fig. 12**.** The comparison of both schemes is also shown in Table 3. As illustrated in Table 3, the proposed hybrid scheme response time is 2.1 second which is approximately 68% faster than that of conventional method. Similarly, the noise reduction in the proposed hybrid scheme is 90% as compared to that of traditional scheme. In conventional scheme the noise reduction is just a 30%. The power dissipation in the recommended hybrid scheme is 50% less as compared to that of traditional scheme. Table 3 illustrates the comparison of two schemes.

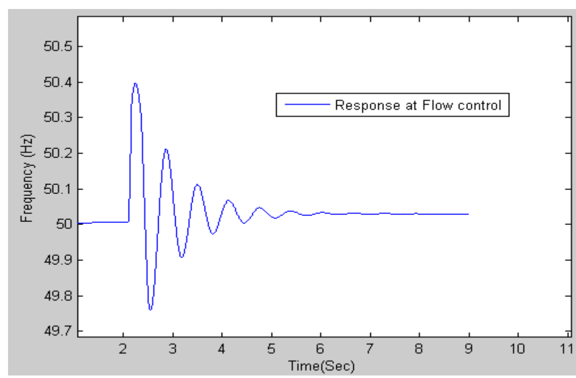

Fig. 11. Response of SHP System for Flow Control Scheme

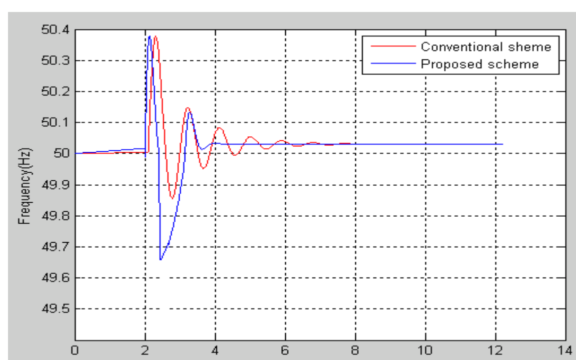

Fig. 12: Comparison of Designed Hybrid Technique with Conventional Technique applied for SHP

Table 3: Comparison of Proposed Hybrid and Conventional Scheme

Characteristics	Proposed hybrid Scheme	conventional Scheme
Response Time	2.1 Sec	6.5 Sec
Noise Reduction	90%	30%
Power dissipated	1/2	1

The elaborative simulation results show the successful implementation of advance control strategy design for frequency control of SHP. The proposed scheme is equally effective for isolated as well as for grid connected system. The design of control system is simple and cost effective. It is no negative impacts on the environment. The detail study of the results shown in Table 3 proves the supremacy of the proposed hybrid scheme over the traditional approaches used for frequency control of the SHP. The application of proposed scheme is effective. It application improve the response time, reduce the power consumption, minimizes the noise, keeps the frequency and voltage of the system within the permissible values.

6. CONCLUSIONS

Small Hydro is a well-established technology, relying on non-polluting, renewable and indigenous resources. Small hydro has achieved great importance because it is an environment friendly. In a deregulated environment SHP can integrate easily the irrigation, water supply and onsite electric power generation. SHP is performing the significant role in the socio-economic development of underdeveloped countries for remote rural areas, particularly mountainous, where the access to the main grid is difficult. SHP can also provide power for small scale industrial, agricultural and other domestic application.

The hybrid technique proposed in this research study is simple, cheap, easy to apply, no burden of heavy computational work is necessary for its implementation. The controller design is modest, no load classification is required, high efficiency, and no assumptions are required for selecting its arbitrary values during its development. The analysis has been carried out in MATLAB software. The proposed methodology has better response time to that of conventional frequency control system. The design scheme has high noise reduction and power consumption is significantly less than that of traditional schemes. The proposed hybrid scheme efficiently establishes a balance between generation and loads, which is necessary to stabilize the frequency and voltage of power generation system at permissible value. Simulation results show that the presented methodology guarantees robust performance under a wide range of operating conditions and system uncertainties. Correct selection of system parameters and coefficient are essential for improved performance and efficiency. Wrong selection of various parameters may adversely affect the performance of the system. The designed technique saves water, does not waste power and has a smooth power output. The power consumption has been minimizes to 50% as compared to conventional schemes and easy to implement. The proposed algorithm incorporates the controller which performs two functions during its operation. It automatically either connects the dump load (switch ON) or disconnects the dump load (switch OFF) through solid state relay and handled the situation by controlling the flow of water and hence the system frequency. The proposed hybrid scheme also manages to control other system parameters like three phase voltage waveforms and current waveform within standard allowable values.

7. RECOMMENDATIONS

The proposed scheme is effectively applicable to distributed energy resources. Its implementation to bulk power generations is beyond the scope of this research work**.** Further elaborative work on newly proposed hybrid scheme may enable it to apply for bulk a power generation which is recommended as a future work on it.

8. LIST OF ABBREVIATION

AGC Automatic Generation Control
ANN Artificial neural network
A_p Area of cross section of the pipe
$b_p K_d k_i$ Coefficient of constants
C_d Coefficient of discharge
D Pipe inner diameter
DLC Direct Load Control
D Percent change in load by percent change in frequency
$D\Delta\omega$ Frequency sensitive load change

DER	Distributed energy Resources
DG	Distributed generation
f	Friction factor from Moody's chart
f	frequency
$\frac{df}{dt}$	Rate of change of frequency
E	Young's modulus of elasticity
EMR	Electromechanical Relay
EPDS	Electric power distribution system
EPS	Electric power system
FGPI	Fuzzy Gain Proportional Integral
F_{ref}	Reference signal
F_m	Measured signal
f_o	System frequency
GFR	Grid Frequency Regulation
g_s	Gravitational acceleration
H_s	Total head (meters)
H_g	Gross head
H_f	Head loss due to friction
H_{SYS}	Total System inertia
h_e	Effective head from the center line of intake
IG	Induction Generator
K	Bulk modulus of elasticity of water
K_r	Relative roughness
K_s	Equivalent sand grain roughness
LFC	Load Frequency Control
L_p	Length of penstock
MISO	Multiple input single output
MPC-LFC	Model Predictive Control based Load Frequency Control
M	rotating inertia of the rotor
PSO	Particle swam optimization
p_c	Given power
P_e	Electrical power
p_g	Generator power
P_i	Electrical load
P_m	Mechanical power
PFC	Primary Frequency Control
PID	Proportional Integral Derivative
PES	Power Electronic Switch
PI	Proportional Integral
PWM	Pulse Width Modulation
P	Actual power
P_{th}	Theoretical power
Q_p	Flow through the penstock pipe
Q_s	Water flow rate (cubic meters per second)
RESs	Renewable Energy Systems
R	speed regulation
ROCOF	Rate of Change of Frequency
R_e	Reynolds number
SHP	Small Hydel Power
S_B	Rotating power of the generator
SG	Synchronous Generator
SSR	Solid State Relay
SCR	Silicon Control Rectifier
STATCOM	Static Compensator
TVS	Transient Voltage suppressor
t	Thickness of the Pipe
V	Velocity of water flow through intake
VSHP	Variable Speed Heat Pump
V_p	Velocity of the flow through the pipe
VSC	Voltage Source Converter
VSI	Voltage Source Inverter
VSD	Variable Speed Drive
xf	Relative value of speed (frequency) deviation
Y	Guide van opening
y	Opening deviation after PID terms
y_c	Given opening
ΔF	Error signal
ΔP_e	Change in electrical power
ΔP_i	Change in electrical load
ΔP_L	Non- frequency sensitive load change
ΔP_m	Change in Mechanical power
$\Delta\omega$	Change of speed
Ω	Speed of turbine
$\eta_{genertor}$	Efficiency of generator
$\eta_{turbine}$	Efficiency of turbine
$\eta_{el\text{-}system}$	Efficiency of the rest of system

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