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Refurbishment and uprating of hydro power plants—A literature review

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ABSTRACT

Refurbishment and uprating of hydro power plants has become an important issue for power generation experts and the utilities because of perennial shortage of power and slow pace in new hydro power addition programmes. As a result, in the recent years there has been great deal of interest in refurbishment and uprating of hydro power plants (HPP) for effective utilization of water potential. The concern about the issue has resulted from the large number of power houses in India which have outlived their useful life or are not operating optimally due to inadequacies in design. Hence, refurbishment and uprating of hydro power plants is the need of the day. To accomplish such a task various aspects of refurbishment and uprating of hydro power plants need to be reviewed. The present paper focuses on the research activities and practical experience in the area of refurbishment and uprating of hydro power plants. This exhaustive review consisting of about 214 research papers, reports, guidelines and standards will be of great help to the researchers, hydro power utilities and energy policy planners.

Contents

1. Introduction

The present paper shares the research work related to a problem area of refurbishment and uprating of hydro power plants. Electric utilities of today face unprecedented challenges. On top of our traditional goals of safety, efficiency and reliability, the modern utilities must address global environmental issues such as climate change, national security issues surrounding our dependence on foreign energy and a growing desire by customers to have greater control over their energy use decisions. Therefore, to meet the ever-increasing need of economical, clean and renewable energy for industrial growth and better quality of life there have been attempts to harness alternate

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energy sources. These alternatives include non conventional sources of energy like wind, solar, bio-mass, fuel cells, tidal power etc. Such sources of energy being intermittent in nature are cost prohibitive also. Therefore, the latest trend in the power generation industry is refurbishment and uprating of the existing power plants. Out of the refurbishment and uprating of different types of power plants, hydro power plants are considered best because of being renewable in nature, less capital intensive, low gestation period and above all cleanest and pollution free source of energy. The following aspects of HPP have been considered by different researchers and are reviewed in the present paper.

(i) Refurbishment and uprating of HPP.
(ii) Decision making for refurbishment and uprating of HPP.
(iii) Equipment wise refurbishment studies.
(iv) Power potential studies of existing HPP.
(v) Economic criteria for uprating and refurbish of HPP.

2. Refurbishment and uprating of HPP

Restructuring of power industry in India has pressurized power generating utilities to generate more power at minimum cost and to remain in competition. Refurbishment and uprating of existing power plants plays a crucial role in this direction. Srivastava and Shahidehpour have presented a detailed analysis of the current situation of the power sector in India [1].

Naidu has made an attempt to delineate India's hydro vision and its road map in which various strategies including RM&U of hydro plants have been discussed [2]. NHPC and CEA which are government agencies entrusted with the task for planning and execution of hydro plants have investigated into the power potential that can be obtained by RM&U activities and have put forward a plan in the Ministry of Power report on "National Hydro Power Policy in India" [3–5].

Singh and Srivastava have laid emphasis on status and future directions of electric power industry restructuring in India. Electricity Act 2003 has brought the element of competition in generation transmission as well as in distribution sector by unbundling the vertically integrated power utility structure of the country [6].

Kumar et al. have discussed the zonal congestion management approach in transmission system using real and reactive power scheduling for evacuation of power in restructured environment of power industry [7]. Khadkikar and Chandra have devised a novel structure for three phase four wire distribution system utilizing unified power quality conditioner (UPQC) [8].

The radical transformations in the electricity industry in Australia, Vietnam, Philippines, Thailand and India have played a significant role in introducing the element of competition in Electricity Supply Industry (ESI) and have proved more efficient, reliable, and more economical. The ownership of the industry is generally moving away from the public domain to the private domain [9–11]. Rajpurohit et al. have critically examined the relevance of wind generation and challenges associated with it [12].

Jamali et al. have discussed the importance of wind power as a RES and problems associated with such generation. The interaction of avian with wind turbines has become an important public policy issue and new techniques are required to monitor avian activities. The system designed is based on radar and Infra-Red (IR) techniques and has been capable of avian monitoring for an offshore wind turbine application [13,14].

Singh has illustrated the importance of Indian Electricity Industry by stating the provisions made for its safeguard in the Constitution of India [15]. Oberoi and Naidu have critically examined the need for refurbishment and uprating of Indian hydro power plants and have suggested the methodology for its implementation [16].

Fuhrmann and Mathias have devised a tool for refurbishment and uprating of hydro plants by evaluating health of sub-components of a various components of hydro power plants [17]. Telleschi and Wullimann have presented the refurbishment case study of the Lake Lungern Hydroelectric Scheme and have discussed about the deteriorating condition of the plant and had given brief introduction of its refurbished project including civil engineering works, electromechanical equipment, operating modes etc. [18].

Sahai has investigated the need of refurbishment and uprating of hydro power plants in India [19]. Lloyd and Stone have presented the online condition monitoring of generator by developing an analytical tool for on-line monitoring of rotors and stator windings [20]. Santos has discussed the major refurbishment programmes undertaken for the Ambuklao hydro power plant with an installed capacity of 75 MW which was commissioned way back in 1956 [21].

Hammons has focused on the present and future state of the electric power sector. It discusses the deregulation process and experience in Scandinavia, Hungary, and Germany [22].

According to Abdoo the prime focus is and will remain on reliability irrespective of the whether restructuring remains a decision of states or is taken by the federal governments [23].

Hammons et al. have discussed new realities in power development in developing countries. The paper goes on to discuss power system planning in deregulated environments and generalized representations to illustrate hydroelectric potential of the Central and East African regions [24].

Baker has depicted the objective of restructuring, deregulation and competition and with introduction of these elements in industry, the hydro power facilities have to either perform optimally or their existence in such an environment is threatened, and thus RM&U is the solution for such generating facilities [25].

Thakur et al. have introduced the salient features of Indian Electricity Act 2003 and how this act is going to boost Indian power industry in its all the three organs, i.e., generation, transmission and distribution [26].

Linsley et al. have introduced the techniques of dependability analysis for various applications in this book [27]. Taylor has proposed a methodology to extend the operating life of hydro equipment by proper upkeep and evaluation of various parts of power plant equipment [28].

According to Thakur, in India, out of 110 hydro power stations with total capacity of 14,030 MW about 60 of them are suitable for refurbishing and uprating with substantial gains in energy production [29].

Hartmann has demonstrated the methodology to improve the reliability of hydro power plants in USA [30]. Water has given emphasis on the importance of decision making in uprating of hydro power plants and proposed a methodology for same so as to avoid wastage of time and money [31]. Romo has proposed a tool for improved maintenance and upgrading decisions for carrying out RM&U of a hydro power plant [32].

3. Decision making for refurbishment and uprating of HPP

In the literature various researchers have suggested that it is always advantageous to use pattern of criterions to investigate a hydro power plant for refurbishment and uprating. The each significant component of the plant is examined to generate data about the health of equipment by assigning a value/points/weighting factor to each component for refurbishment and uprating. The refurbishment indicators can be condition of the component, age, operating conditions, trouble spots, time of breakdowns and maintenance charges, where as for uprating, the indicating parameters can be time of license, period of overflow and efficiency. The generated data are monitored by categorizing the equipment on the basis of point attained i.e., up to 49%, it is not justified at present, 50% to 70% advisable to consider and above 70% it is urgent for considering the equipment for refurbishment, similarly assessment can be made for uprating. The outages forced and planned may result in reduced availability, as well as, loss of energy production and revenue, maintenance cost tend to increase and plant efficiency decreases.

Nussli has introduced various factors like down time operation, maintenance cost, reduced reliability, licensing problems, investment cost, implementation time, generation loss which have been considered important parameters for decision making regarding RM&U of a plant [33].

Ridley has laid stress on the significance of the need of thorough investigations. The first and the foremost consideration is the availability of additional power from the water turbine [34].

Gummer et al. have proposed an expert analysis to decide upon the extent to which refurbishment is needed based on the maximum information available. To meet this end log books of machine performance, visual inspection and performance tests play important role [35].

A new methodology for the refurbishment of Nathpa Jhakri Hydro Power Station (NJHPS) which is badly damaged by excessive silt during monsoon period has been proposed. Both long time and short time measures have been proposed in these papers to tackle the menace of silt [36–38].

Lautala et al. have investigated about the expansion planning of hydropower systems representing a long-term investment problem, keeping in view the size and complexity of the system, which cannot generally be solved without the extensive models [39].

4. Equipment based refurbishment

Keeping in view the present requirements, lot of researches are going on, for better quality products, efficient decision making and production of the site specific equipment using latest technological advances. The review on the work published so far for the refurbishment and uprating of equipments and structures is given below:

4.1. Refurbishment of civil structures

The guidelines describing methods for assessing the conditions of civil works of hydroelectric plants has outlined some procedures available for power plants civil works rehabilitation and repair. In civil engineering part of the plant most of the assessment and rehabilitation works are centered on the components, such as, intake channel, fore way, intake, water conditions, power plant, and associated structures and tail race structure and channel.

Before going for the rehabilitation, the engineers on the job must learn as much as possible about the existing facilities. The learning process is based upon the visual inspection from site visits and review of available information [40].

Bull has explained that with the passage of operational life, the deterioration in the civil structures takes place, which may cause leakage, cracks in civil structures and failure of intake canal and even destruction of tail race structures [41].

Goudie has considered the thorough investigation into geology, hydrology and energy demand before going for the refurbishment of dam, intake, canal and tailrace of Tarabamba Small hydro project, Peru for maximization of benefits [42].

Dahlstrand et al. have presented a detailed report for rehabilitation of an 80-years old dam on the flat river country, Michigan, USA. The methodology proposed incorporated two type of approaches, repair and maintenance of dam and to equip the dam with modern instrumentation system like settlement gauges, lateral displacement gauges and piezometers etc. for life extension [43].

4.2. Refurbishment of generator

Generator is also an important component of hydro power plant and is coupled to turbine and converts mechanical energy into electrical energy. Current technology advances in condition monitoring are employing an increasing number of techniques for condition monitoring and rehabilitation of generators. To improve reliability, availability and efficiency of generators the various researchers have suggested different approaches, like record of past operation, fault development, visual inspection, design and available technology etc. Correctly handling this information requires expertise in machine design and operating limits, sophisticated on-line monitoring instrumentation, and alarm processing and interpretation. The various contributions in this area are being presented here.

According to Mez, in condition monitoring of hydro generator and decision making for refurbishment and optimal energy generation the tests should be conducted after regular interval of time to assess the useful life of generator [44].

Dacier has stressed on the assessment of the condition of stator insulation. One of the major factor affecting the overall reliability of hydro power station is the reliability of its generators in general and their stator winding in particular [45].

Allegre has explained the stator winding failure which is the biggest single cause of major outages. It has been suggested that the most effective diagnosis of insulation must pin point the weakest point as well as, assessing the efficacy of complete winding after eliminating the weakest point [46].

Drommi and Maujean have emphasized the importance of on line diagnostics for large turbine generators. Such techniques help in early revealing of the most common defects in stator windings of large turbine generators with water cooling [47].

According to Poljakov and Tsvetkov the rise in temperature of the stator winding can be detected through the different resistance temperature detectors (RTD). In addition effective cooling of windings also needs to be monitored for safe and reliable operation [48].

Maujean has presented a study carried out by Electricite de France (EDF) for monitoring the hydroelectric power stations all over France. As per the analysis made by EDF the average life of generator winding has been determined as 35 years [49].

Ridley in his research papers has covered the various dimension of the generator condition monitoring. Some examples of old hydro plants in United Kingdom have been also presented [50–55].

Mahugan has addressed the common deterioration mechanisms and adverse generator maintenance conditions and suggested practical ways to reduce exposure to costly generator outages. There may also be efficiency improvements associated with these changes. On some units and in some situations the cumulative benefits from only a 0.3% improvement in efficiency have approached US$1000,000 a year which is not an insignificant amount. Yet another paper has discussed the application of the new class of rotor condition monitoring options using digital rotor telemetry technology to continuously monitor the health of rotor insulation systems in large generators [56–59].

4.3. Refurbishment of excitation system

Researchers have proposed techniques for modernization of control and excitation system. The automatic control system of a hydro power plant includes all sensor, actuators, such as, motor, valves etc. and all the automation units are required for fully automatic operation. It becomes difficult to achieve full automation of the old power plant due to lot of factors, such as, cost matching of components with existing one. Hence, it is, wise enough to go for partial modernization.

Stack and Reiman have proposed a simple adaptation to existing installation, besides the advantages of the modern thyristor or transistor technology for the refurbishment of excitation systems for hydro power generators. A planned uprating can also be carried out without any problems in the excitation systems [60].

Rao et al. have presented a renovation and modernization of Sharavathy hydro power station. The paper reveals that the losses in existing exciter were 52 kW (kW), where static excitation system full load losses were 22 kW, hence saving per year is $(30 \times 24 \times 365) = 262{,}800$ kW h (kW h). If tariff has been INR 1.00 per kW h then net saving per year has been INR 2.628 lacs per set, hence, while going for refurbishment of power plant, the refurbishment of excitation system with static excitation system can be thought of as a more suitable option [61].

4.4. Refurbishment of governor

Manjean et al. have illustrated about the governing system uprating of Roanoke Rapid hydro power plant. The new electro-hydraulic governor control installed on the said plant in place of mechanical governor has been fast in operation, more efficient and reliable than earlier mechanical one [62].

Doppler and Knoll have proposed the digital governor control. It has been observed that increased efficiency and reduced maintenance was recorded during the operation as per the observation of operating staff [63]. According to Ferme and Nicolas the outcome of the refurbishment of existing governing system of Vainden power plant by digital speed governor and it has been observed that the performance of governing system has been much better [64].

4.5. Refurbishment of control systems

Soeresen reports that by adopting modern control system through the refurbishment of old power plants, the supervisory control can be made more efficient. This improves advanced control and supervisory functions and improvement in diagnostic and maintenance functions [65].

Schenk and Schweizer have proposed that very old hydro-power plants are no longer economical because of lower availability, reliability and efficiency; increased maintenance, expensive operation due to staff requirements and non economical exploitation of the existing water power. The renewal of a plant by replacing or overhauling the main components such as gates, valves, turbines, generators, transformers and switchgear, by modernizing the control, instrumentation and information system, or both simultaneously have been suggested [66]. Bill and Smilovici have developed an assessment procedure for the refurbishment of control, instrumentation and information systems of existing hydropower plants with latest state of art related to refurbishment of instrumentation and control of power stations in South Africa [67].

J. G. Cripps has addressed the engineering considerations of refurbishment of control system and results obtained after implementing the new control system on the Munmorah Power Station which is located on the coast of New South Wales, Australia and has four generating units with an effective capacity of 300 MW [68].

Compson have proposed a planned programme of overhaul and maintenance to sustain the operation of major plant items in a power station during its operation. It has been shown that some of the good returns on investment can result from the replacement, upgrading or refurbishment of power station control and instrumentation systems [69].

Mackeown et al. have described the refurbishment, automation and remote control of the Tongland Power Station which has (3×11) MW synchronous generators [70]. Ham has shared his experiences with respect to the analog turbine electro hydraulic governor (EHG) systems and subsequent developments with digital systems [71].

Taylor and Ekwue have discussed the important issues associated with maximizing the use of capital assets, limiting down time, extending life and minimizing operational and support cost of power stations, and considers these as key areas which warrant continuous attention [72].

4.6. Turbine runners refurbishment

Naidu has mentioned that the space requirement for the same capacity turbine today is less than one third of what it used to be in 1920s. Naidu has considered design factors to be helpful in uprating and refurbishment [73,74].

IEEE has published the standards related to the recommended practice for preparation of equipment specifications for speed-governing of hydraulic turbines intended to drive electric generators. These are detailed guidelines to be followed during refurbishment of hydraulic turbines [75].

Johnson et al. have proposed the over speed control that has been achieved by reducing the feedback gains derived from frequency domain analysis and using an adaptive feed forward control to counter the transient over-frequency condition. Simulation results have shown the improved performance of the proposed control design [76].

Padhy et al. have investigated the effect of shape of silt particles on the erosive wear of Pelton turbine bucket. Sand was collected from the head work of one of the most silt affected power houses. Sand particles were mixed with the tank of water to be circulated through the Pelton turbine used for the experiment. Each test was conducted for different time periods and the sand particles were collected after each test. The shape of the sand particles was examined by using Image J software. The average value of ten particles was considered for analysis. From the analysis, it was observed that the sand particles were gaining circularity with the recirculation time of the sand water mixer. The wear rate decreased exponentially with the gain in circularity of silt particles and eroding capacity of angular particles was more than the circular particles [77].

Other investigators have proposed refurbishment and rehabilitation of turbine runners for improving reliability, efficiency, and plant life extension. According to researchers, these approaches have proved cost-effective solutions for ensuring power plant availability, improvement of operational integrity and life extension [78,79].

Fault diagnosis and condition monitoring techniques have been reported for hydro turbines in literature based on techniques based on support vector machine, condition monitoring system for hydro turbines based on LabVIEW and maintenance-oriented information digitalization of hydro turbine generator sets. The applications of digital information in condition monitoring, fault detection, and diagnosis have been discussed [80,81].

To meet the increasing requirements on the reliability and performance of hydro turbine governors, a highly reliable intelligent control strategy which combines reliable control and self-improving control using intelligent techniques has been proposed by Li [82].

Integrated maintenance features of hydro turbine governors and robust control of hydro turbine speed governor have been proposed in literature to meet the increasing requirements on the reliability and performance of hydro turbine governors. A highly reliable intelligent control strategy which combines reliable control and self-improving control using intelligent techniques has been simulated and results have shown that the proposed method is valid. The realization of the controllers doesn't involve extra cost to the control equipment in existence [83].

Thapa et al. have developed a new design program named as "Khoj" to facilitate the study of emerging solutions to prevent the erosion of hydro turbines by reducing the relative velocity inside the runner by improving hydraulic design. It has been established that the runner outlet diameter, peripheral velocity at inlet, and blade angle distribution have the highest effect on sediment erosion of Francis runner [84].

Other researchers have illustrated the refurbishing of turbine runners from the simple replacement of labyrinth seals to major overhauls, which can provide a very cost-effective investment for the owner and by developing the new runner designs by example of rehabilitation at Cabinet Gorge Power Station. The efficiency, output, and reliability have been considerably improved with the application of rehabilitation and refurbishment techniques [85,86].

Harisberger et al. have developed the device being applicable for investigations of turbine problems and was the reliable device which has been used for determining among other things, the pressures in the interior of oil circuit breakers at the time of opening the circuit and the stresses which are brought to bear upon bus insulators at times of short circuit [87].

Magureanu et al. have presented a solution for optimal operation of the Francis turbine. As the efficiency of this turbine is highly dependent on the water flow, which generally has a large variation, variable speed operation was chosen. Due to the fact that all hydro generators are AC machines, the connection to the 50 Hz power grid can be done only using static converters as interface. For higher than 1 MW power generators, front end three level inverters have been recommended. In addition, for higher than 1 kV voltage, double three level inverters has been used, as these were allowing their connection directly to the medium voltage grid, eliminating in this way the need of separation transformers [88].

Investigation of oscillatory problems and fatigue crack initiation of hydraulic generating units equipped with Francis turbine runners has been elaborated by the researchers. The vibration response of the unit to draft tube surges has been investigated and the risk of excessive oscillations was evaluated. This approach was developed for diagnosis of excessive vibrations of Kastraki hydro power station in Greece. Also an experimental investigation of the fatigue crack growth and the influence on the blade vibration has been presented which has helped to highlight mechanical damage and determining the fatigue life prediction of component [89,90].

Trivedi et al. have reviewed the available literature summarizing the experimental, numerical, and analytical investigations related to the effects of transients on Francis turbine. These effects shorten the runner life, increase cost of plant operation, and loss of power generation. The reviewed literature has shown that one start-stop cycle can shorten predefined refurbishment time up to 15 h. Turbine start-stop cannot be avoided, but runner life may be improved by minimizing the unfavorable pressure loading on the blades during transients through strategic movement of guide vanes [91].

4.7. Model testing for uprating of runner

Modification of an existing runner, and replacement of runner with new design, needs model testing. As every runner has a saturation limit caused by shock entry losses, mixing losses at the exit and frictional losses due to increased velocities.

Gass has explained about uprating of the Pelton wheel turbines of Holm power house in which the efficiency of the modified runner was enhanced to 92% at the 65% of full load, the efficiency of the existing runner was about 89% with respect to (w.r.t.) prevailing load conditions [92].

Vitvar has presented the case study of uprating of Kaplan turbine at Dahua power plant. The capacity of Dahua power plant was uprated from 103 MW to 117 MW with the modified runner [93]. Mombelli and Avellan have demonstrated that runner uprating can be achieved by increased efficiency of the turbine and by increasing the discharge. When a refurbishment project is scheduled, the most important decision for a power plant owner to make is whether or not to proceed with the rehabilitation of turbines, water conductor system, and other power house equipments [94].

Izena et al. have reported on practical hydraulic turbine models for Francis turbines and pumped-storage hydraulic turbines. The power system frequency during transient conditions greatly depends on governor control characteristics. Hence, some practical turbine models have been considered necessary to evaluate governor control characteristics satisfying quick response and stable operation [95].

Fang et al. have developed a simulation model for a typical hydroelectric power plant in a MATLAB/Simulink-based software environment. The digital simulations of a sudden full load rejection for an actual hydroelectric power plant in China were performed, and the results indicated that the proposed MATLAB/Simulink-based hydroelectric power plant simulation system is accurate and effective enough to represent and simulate hydroelectric power plant's nonlinear dynamics as well as to design hydraulic turbine speed control system. The proposed simulation system has also been proved to be useful for preliminary designs or assessments of hydropower projects [96].

Many researchers have proposed Computational Fluid Dynamics (CFD) based model for analysis of hydraulic transients in hydroelectric power plants, dynamic stresses analysis in a Francis turbine runner based on fluid-structure interaction, new runner designed by the latest CFD analysis, CFD aided hydraulic and structural design, geometry optimization, manufacturing and testing of hydraulic turbines, numerical study of Francis turbine flow field under small opening condition. The models have been validated and have proved to be useful for preliminary designs, optimization and/or assessments of hydropower projects [97–100].

Thorne and Hill have investigated the stability region of a hydraulic turbine and the associated governor control based on a proven model for the case of a single hydraulic unit connected to an equivalent system. In addition to the establishment of stability boundaries, practical operating boundaries have been also determined [101].

Safie and Hage have developed a simulation model to evaluate the risk of the Space Shuttle auxiliary power unit (APU) turbine wheels for a specific inspection policy. The simulation model represents a flexible tool to predict turbine wheel reliability and study the risk under different inspection policies [102].

Hydro Turbine Models have been developed for various investigations like the linearized model based on the prototype characteristics, nonlinear model for dynamic studies of hydro turbines, hydro turbine and governor (HTG) models to fulfil adequate modeling requirements for the representation of hydro power generation in the Nordic grid, hydro turbine-governor model validation in Pacific Northwest based on the measurements taken at the point of interconnection, modeling and control design for governing hydroelectric turbines with leaky wicket gates. Both the comparisons between simulation results and experimental data have been presented and results have been validated [103–107].

Kishor et al. have proposed a simulation of reduced order hydro turbine model to investigate its hydraulic transient characteristic. In this paper, turbine-penstock transfer function (TF) model has been reduced to an order $r=1$, 2, 3 & 4 using H-infinity approximant method. The gate position-turbine power nonlinear steady-state characteristic has been modelled for these reduced order transfer functions [108].

5. Menance of silt and its solution in power plants

According to Naidu, Indian rivers carry huge sediment loads during the monsoon period. In the Himalayan regions, concentration of silt is as high as 80,000 PPM which leads to accumulation of millions of tones of silt in the reservoirs. Despite of elaborate desilting arrangements, silt passes through the generating units at the rate of thousand of tones per day [109,110].

Chunhong has deliberated on the impact of sediment deposition on hydro power plants. The incoming percentage of sediments to the reservoir can be reduced by soil conservation measures, rational management of reservoir operation, proper impounding of reservoir, flood retention and sediment sluicing, storing clean water and sluicing muddy water and dredging of small reservoirs [111].

Alam in his research papers has stated that large dams and reservoirs are designed for an operational life of 100 years, but in fact more and more reservoirs around the world have been facing sediment problems within a much shorter period of time. Proper design giving adequate consideration to project sustainability, in particular sediment management, at the early design stage of a project has been suggested. Some of the areas requiring special attention include site selection, sediment transport characteristic in the river at the project site and in the reservoir after the dam is built. [112–116].

Ribeiro et al. have put forward two types of alternatives for sedimentation caused by turbidity currents in the Livigno reservoir on the Swiss-Italian border [117]. Sehgal et al. have discussed the structural failures of intake trash racks. In the paper, causes for structural failure have been investigated and solution methodology has been proposed based on the state-of-the art design for intake trash tacks [118].

Jacobsen has long experience in hydro plant and has presented a number of sediment handling technologies developed over the past two decades which include slotted pipe sediment sluicer, the sexophone sediment sluicer and an automatic sediment removal system. The author has presented practical experience of sediment handling in India and Norway known as hydro suction system to manage the problem of silt [119,120].

Singh and Durgunoglu have investigated the reduction in storage capacity of reservoir that takes place continuously with the passage of time due to silt deposition and a methodology has been developed for estimation of future reservoir storage capacities based on sediment deposition in the storage reservoirs considering trap efficiency, sediment compaction etc. [121].

6. Planning and design of hydro power plants

Hydro Electric Project forms an integral part of overall development of water resources of the river basin. The hydro schemes also form part of the complex integrated power generation system with diverse power generation resources.

Guthrie in Hydro-Electric Engineering Practice (vols. I, II and III) has exhaustively explained the all aspects of hydro power plant in his three volumes [122]. Nigam has explained the design aspects of hydro power plants [123]. Gulliver and Ardnt have elaborated the water resources developments of the river basin in the handbook [124]. Chaturvedi has given the detailed analysis of the progressive development of consumptive water use and new water resource based development projects in the river basin [125].

Kumar has presented the economical optimal design of hydropower plants by minimizing power losses and construction costs [126]. Sharma et al. have show-cased the difficulties in making full use of optimization, due to the great complexity of the optimization models [127].

Gingold has developed a model for the optimum size of small run-of-river hydro power plant Plants using conventional techniques of optimization [128]. Atteri has optimized the small hydro power potential of Himachal Pradesh considering all streams and based on their discharge data [129].

Jonas et al. have developed a computer model to design the power plant equipment based on economic analysis using cost data based on number of constructed projects [130]. Gordon and Penman have forwarded a methodology for quick estimation of the small hydro power plants [131].

Varshney has explained the technique of arranging raw data of a river/stream and to determine the dependability. The dependability has different value depending upon the type of utilization of water [132]. Mutereja has emphasized the importance of hydrological investigations [133].

ASCE has devised the methodology to arrange the hydrological data of a river available in a meaningful manner by using artificial neural network [134,135].

HPPCL has presented the methodologies for computing the flow series reported in literature depending on the type and extent of the available river flow data. 75% or 90% dependable years have been selected and depending upon this methodology, the capacity of power plant as well as energy to be generated is determined [136].

Jong has introduced a adaptive system design using genetic approach based on the principles of natural biological evolution and used the same for solution of engineering optimization problems [137]. Goldberg has extensively worked on the computer techniques, mathematical tools, and research results that have enabled both researchers and practitioners to apply genetic algorithms [138]. Goldberg and Rechardson have applied stochastic search methods for optimization based on the genetic algorithm [139].

Wang has introduced genetic algorithm based approach for tackling the problems of stochastic nature and has particularly applied to calibrate conceptual rainfall runoff model for different regions [140]. Adler in his paper titled "Genetic Algorithm and Simulated Annealing: A marriage Proposal," has applied Genetic Algorithm (GA) and Simulated Annealing (SA) for solving a problem based on a defined function with different constraints and has proved the usefulness of GA and SA techniques [141]. Dragen and Godfrey have applied genetic algorithm approach to find out the least cost option available out of a number of options available for design of water distribution network [142].

Hreinsson has considered the problem of obtaining the optimal design of hydroelectric power systems with respect to determining each project's optimal size or capacity. A mathematical model has been presented to examine project sizing in the general framework of expanding a purely hydroelectric system. The author has also discussed a recursive model to estimate the incremental cost of adding energy intensive industries (EII) to a hydro-based power system. Furthermore, Hreinsson and Eliasson have devised an optimal cost/benefit analysis model for hydroelectric power systems using GA technique [143–146].

Kirkpatrick et al. have explained SA as a compact and robust technique, which provides excellent solutions to single and multiple objective optimization problems with a substantial reduction in computation time [147]. Casotto et al. have presented a modification of the classical Simulated Annealing algorithm for the macro-cell placement problem for implementation on multiprocessor systems. Experimental results have shown that the new algorithm obtains results comparable in quality to those of the single processor version [148].

Greene and Supowit have considered the customary need for rejection of candidate moves in simulated annealing. The logic partitioning problem is used as an illustration; both simple moves and pair wise interchanges have been considered [149]. Grover has developed a new simulated annealing algorithm for standard cell placement and has shown better results as compared to classical simulated annealing algorithms [150].

7. Condition monitoring of hydro power plants

Prevention is better than cure, and continuous condition monitoring of the equipment or a plant enables problems to be resolved before these are escalated. Condition monitoring pertains to providing information on the condition of a plant so that it can be maintained properly.

Sumereder et al. have investigated the structure of the hydro power plants of the Austrian utilities many of which have reached a critical age. The focus of this procedure was to collect operational data; machine data and protocols of technical diagnosis measurements in order to form an objective analysis by weighing each factor [151]. Li et al. have developed a digital approach for condition analysis and diagnosis system for hydro turbine generator sets which has been successfully applied on 7 sets in Gezhouba Hydro Power Plant [152]. Zhaohui et al. have created a knowledge bank, which summarizes both the expert knowledge and the analytical knowledge on the failure modes and their manifestations as well as their effects [153]. Sedding et al. have developed a new diagnostic technique to improve condition monitoring of turbine generators. Improvements in assessment capability have been sought by better use of conventional sensor data by means of expert systems concepts [154].

In addition to above contributions the various professional organizations like Energy Development & Power Generation Committee of IEEE, Army Corp's of Engineers (USA), and International Energy Agency (IEA) have reported methodologies and guidelines for rehabilitations of hydro power plants to assist hydroelectric power plant owners, operators, and design engineers in economical as well as technically feasible manner. These standards/guidelines addresses conventional hydro power and have covered all equipments including generators, turbines, governors, exciters and other auxiliary equipments [155–159].

Taylor has applied an artificial intelligence technique known as fuzzy logic to develop a controller which can provide real time advice regarding load switching [160]. Sachs has presented a Fuzzy logic controls for operation of the run-of-river hydro power plant keeping in view the demand side management [161]. Bai and Tamjis have developed a fuzzy logic model using MATLAB Fuzzy logic toolbox for deriving optimal operational rules at the macro level for better performance and control of hydro-power generation [162]. Shrestha et al. have used the methodology for expressing operational rules of hydro-power generation in linguistic terms instead of mathematical equations. The case study of the Tenkiller Lake in Oklahoma has been illustrated this methodology [163].

8. Simulation of hydro power plants

Wangdi and Richards have developed a simulation model of the Chukha power plant in Bhutan. This project has been interconnected with a steam power plant at Farakka in India, consisting of four units of 100 MW each. The speed and load changes of the two plants have been simulated for a small step change of load applied and the effect of variation of the Chukha governor parameters on the speed and load changes have been investigated [164].

Weber and Prillwitz have contributed the most important steps for creation of mathematical models for hydro power plants of Macedonia and Yugoslavia. In the investigated hydro power plants measurements were performed to obtain step response time signals of all important functional parts of the plants to identify the most important parameters using the least-square-method with the Matlab-software [165]. Stokelj et al. have compared the various techniques for hydro power plants modeling [166]. Lai and Yuan have proposed methodology that enables to take the constraints and objectives specific to such a design problem in which most of the main dimensions of the existing turbine differ from the dimensions of a new design into account [167].

Yong et al. have presented simulation of a rotor dynamic model of radial vibrations. A novel algorithm, which can take account of both transient and steady-state analysis, is proposed to solve the model. Dynamic response for 125 MW hydro-units in Gezhouba Power Station has been simulated [168]. Welte et al. have developed a reliability model in which scheduling and optimization of maintenance and renewal have been utilized using Markov chain. Imperfect periodic inspection has been modeled by the proposed approach [169]. Ruzhekov et al. have investigated the dynamic behavior of a hydro turbine. The gain scheduling technique has been implemented in the software environment of *programmable logic controller* (PLC) [170].

Souza et al. have presented the study of hydraulic transients in hydropower plants specifically in hydraulic turbine units, with penstock, spiral case and draft tube. The comparisons between results of a theoretical simulation of a literature example using the characteristics method and the results obtained with the present method have been presented [171]. Puleva et al. have described the dynamic behavior of hydraulic turbine power control considering the water inertia effect. Simulation models of the hydro generator control system have been created and surge-free transition between different operational points has been accomplished [172].

Ion and Marinescu have worked on simulation of two micro hydro power plants on an islanded micro-grid. The model devised has ensured voltage and frequency regulation [173]. Jin et al. have proposed a nonlinear decentralized excitation and governor controller design for hydro power plants to enhance power system transient stability [174]. Vrancic et al. have suggested a new methodology to overcome the problems of precise tuning and noisy output by using the magnitude optimum and disturbance rejection magnitude optimum tuning method. The best controller performance versus activity ratio is achieved with the second or the third order filter at controller output [175].

IEEE Working Group on Prime Mover and Energy Supply Models for System Dynamic Performance Studies, IEEE Guide for the operation and maintenance of hydro-generators, Bureau of Indian Standards (BIS) guidelines for selection of hydraulic turbines, preliminary dimensions and layout of surface hydroelectric power plant have also recommended the hydraulic model suitable for a relatively wide range of studies related to speed control of prime movers as well as electromechanical stability [176–178].

Khodabakhshian and Hooshmand have simulated the stability of a hydraulic turbine-generator unit by linearized mathematical model on the basis of the performance equations and stability regions have been plotted that include the influence of certain key parameters identified as affecting the transient performance [179]. Jasmin et al. have conceptualized an electronic-analog-real-time-hydro-turbine simulator which can simulate both transient and steady state operation. Simulation of the Manicouagan hydro-turbine validates the approach in the transient as well as steady state operation [180].

Jasmin et al. have also developed an electronic-analog-real-time-hydro-generator simulator with static excitation. The simulator, based on the two axis representation of Park's equations has been analyzed [181]. Sanathanan has proposed a method for obtaining accurate reduced order models for hydro-turbines with long penstocks [182]. Murthi and Hariharan have investigated the influence of water column and shown that a modified water column compensator enhances the stability regions and dynamic performance considerably [183].

Ramamurthy et al. have covered the stability analysis of a Hydraulic Turbine-Generator Unit considering the influence of a Hydro-Mechanical Governor provided for control. The stability regions have been plotted that include the influence of certain key parameters identified as affecting-the transient performance [184]. Kishor et al. have presented state estimation of inelastic and elastic fifth-order state-space model of hydro plant. It has been observed that the state estimation of plant by this method outperforms to linear Kalman filter in terms of estimation [185].

Vournas and Papaioannou have investigated the interaction of the two surge tanks for the case of sudden opening or closure of the turbine gates. The stability of the frequency control loop has been assessed by using small signal analysis based on linearization [186]. Kishor et al. have presented extensive review in the area of hydro plant model development. In case of hydroelectric plant the hydro turbine is a non-linear, non-stationary multivariable system whose characteristics vary significantly with the unpredictable load on it and this presents a difficulty in designing an efficient and reliable controller [187].

Kumar et al. have discussed a simulation model for small hydro power plant for variations like inflow, head and storage. The model has been quite useful for plants in situations where discharge varies widely [188]. Dutt et al. have presented a review of simulation analysis in SHP simulator for medium head application which includes modeling of various components of hydro power plants [189].

Cozorici et al. have studied designing and simulation of a small wind-hydro power plant which will be located in the Didactical and Agreement Base Marisel belonging to the Technical University of Cluj Napoca, Romania and used in didactical and research purposes [190].

Puthumana and Jaleel have proposed a novel technique to reduce the size of the dump load, automatic generation control, and its simulation. A generalized transfer function model for the system is developed and finally, the transient performance of the system has been compared [191].

Kundur has discussed the development of detailed mathematical model of synchronous machine, hydro turbines, and briefly reviews its steady state and transient performance characteristics [192]. Anderson and Fouad have developed the mathematical models for a synchronous machine for stability. The simulation model for the machine has been developed using considerations including determination of initial conditions and determination of the parameters of the machine from available data [193]. Fritz has provided sufficient background about small hydro power plants [194]. Frick has depicted the dynamic behavior of reservoirs [195].

9. Economic criteria for uprating and refurbishment

The benefit cost analysis is standard procedure for reaching planning decisions. One reason for the difficulty of predicting future benefits and cost is that such decisions usually cannot be represented with sufficient reliability by accurate estimation, because of the many uncertainties that enters the analysis through assumptions on input and system parameters.

Bernhardt and Vapot have discussed different components of hydro power plant and have emphasized the importance of proper design of civil engineering structures with adequate safety margins to meet any unforeseen threat during long life span of the project [196].

James and Lee have presented the various investigating steps to be taken before actually taking up the construction of a power plant [197]. Varshney has introduced concepts of discount factors, rate of return, benefit cost ratio. BIS: I.S. 4877-1968 Code of Practice “Guide for preparation of estimate of river valley projects,” in an authentic reference for preparing the detailed estimates of a hydro power plant [198].

Gordon has proposed quick estimating technique with cost equations based on the analysis of 64 estimates prepared by more than 20 utilities and consultants [199]. Goicoechea et al. have developed an approach to risk and uncertainty analysis involved in benefit cost analysis of water resources projects [200]. Also, Gordon has demonstrated the development of mathematical formulae to estimate the cost of hydro-electric generating stations upto the capacity of 1000 MW [201]. In yet another paper, Gordon and Noel have demonstrated that many factors contribute for cost over-runs like underestimation of the rate of inflation, underestimation of the rate of inflation and an optimistic assessment of the site conditions. The requirement of an index which will reflect all these factors in the form of a constant has been advocated and has suggested a graphical technique to compute the value of constant [202].

Wood and Gulliver have presented the economic analysis of energy projects with uncertainty and have stated that the many factors contribute for cost over-runs like underestimation of the rate of inflation, and an optimistic assessment of the site conditions [203]. Castelli et al. have presented the technique for determining the cost of modernization of a power plant and to determine financial viability beforehand [204]. Schade and Scheil have proposed a cost-effective operation of generators by optimizing condition monitoring techniques and maintenance cycle to prolong the life and at the same time to minimize the scheduled an unscheduled outages [205].

Giri has investigated the reasons for high cost of electricity in India and has mentioned various factors responsible for it like high uptake of thermal generation, utility inefficiencies and revenue distortion due to cross subsidies [206]. Gordon has considered the approach of contract awarding in Canada. It has been demonstrated that there has been more litigation with a design-build contract as compared to the unit price contracts [207]. Wangensteen has proposed the estimation of social costs in addition to energy revenue earned from the commissioning of a project [208]. Newton and Hopewell have emphasized on the production of the hydro power energy which is main aim for building hydro power plants; however, there are lots of other aims who might be more valuable than produced energy like, flood control, environment consciousness, irrigation purpose, water navigation, saving fossil fuels etc. These factors have been considered and estimated as additional benefits [209].

Pakniat and Arbabian have chosen an optimized financial method for hydro power projects wherein numerous indirect benefits have been considered for financial study of a plant and cost of these benefits will definitely make any hydro power development quite attractive economically [210]. Salazar and Rudnick have presented the case study of Private investment in generation plants in Ecuador which reveals the failure of the existing competitive market model that has been in place for the last ten years [211]. Ancieta has presented an overview of available technical solutions. An economic analysis of the considered power plant has also been presented [212].

Roque et al. have demonstrated that the hydro power plants with generated power less than 10 MW are becoming more attractive considering technical economic aspects. Additionally, this type of energy production is environment friendly, contributes toward lesser gas emission and global warming reductions and can be used to regulate the watercourses [213]. Mishra et al. have presented costing of small hydropower projects with a case study in which costs of different components has been determined with regard to the various cost functions designed [214].

In all these contributions economic analysis using the principle of benefit cost ratio and rate of return have not been considered. However, both these methodologies are quite powerful for evaluating the techno-economic analysis of any project/ hydro plant.

10. Conclusion

The paper has presented exhaustive literature review encompassing various aspect related to refurbishment and uprating of hydro power plants. The contributions by the various researchers, experts, guidelines issued by professional organizations like, IEEE, BIS, American Army Corps of Engineers, ASCE, CEA, NHPC, HPSEBL, various reference books available related to hydro power, journals of high repute and proceedings of the international and national conferences have been critically reviewed, which has provided a sound footing for starting the research in this area or implementation of refurbishment and uprating of existing hydro power plants whose efficiency has deteriorated or have been running underrated. However, the significant and major contribution in this area have been cited again here as [1,2,6,16–19,20–25,40–45,63,65–68,72,74,80,83,88,89,97–100,102,106–108,122,131,151,158,172,181,192,193,203,206,214] for quick and ready reference for the field engineers and hydro power utilities.

References

[1] Srivastava A, Shahidehpour M. Restructuring choices for the Indian power sector. IEEE Power Eng Rev 2002;22(11):25–9 Nov.
[2] Naidu BSK. India's hydro vision for the 21st century. In Proc. of national conference on hydro power India: 2000, New Delhi; , 17–18 Oct. 2000. p. 15–30.
[3] National Hydro Power Corporation, Available: 〈http://www.nhpc.com〉; 1980.
[4] Central Electricity Authority Annual Report. Available: 〈http://www.cea.nic.in〉.
[5] National Hydro Power Policy in India. Available: 〈http://www.mop.nic.in〉.
[6] Singh SN, Srivastava SC. Status and future directions of electric power industry restructuring in India. CPRI J 2005;2(1):51–61.
[7] Kumar Ashwani, Srivastava SC, Singh SN. A zonal congestion management approach using real and reactive power scheduling. IEEE Trans. Power Syst 2004;19(1):554–62.
[8] Khadkikar V, Chandra A. A novel structure for three phase four wire distribution system utilizing unified power quality conditioner (UPQC). IEEE Trans. Ind Appl 2009;45(5):1897–902.
[9] Wattana S, Sharma D. Electricity industry reforms in Thailand: an analysis of productivity. Int J Energy Sect Manage 2011;5(4):494–521.
[10] Do TM, Sharma D. Vietnam's energy sector: a review of current energy policies and strategies. Elsevier J Energy Policy 2011;39(10):5770–7.
[11] Sharma D. The multidimensionality of electricity reform-an Australian perspective. Elsevier J Energy Policy 2003;31(11):1093–102.
[12] Rajpurohit BS, Singh SN, Erlich I. Wind power in electricity markets: key issues and challenges. Int J Energy Technol Policy 2008;6(3):196–211.
[13] Jamali MM, Snyder B, Williams J, Kindred R, John GS, Majid MW, Ross J, Frizado J, Gorsevski PV, Bingman VP. Remote avian monitoring system for wind turbines. In: IEEE international conference on electro/information technology (EIT); 15–17 May 2011. p. 1–5.
[14] Jamali MM, Bingman VP, Ross J, Mirzaei G, Majid MW, Gorsevski PV, Frizado J. Implementation of ant clustering algorithm for IR imagery in wind turbine applications. In: IEEE 55th international Midwest symposium on circuits and systems (MWSCAS); 5–8 Aug. 2012. p. 868–71.
[15] Singh MP. The constitution of India. Delhi: Delhi Law House; 2004.
[16] Oberoi BR, Naidu BSK. Uprating and refurbishing hydro plants in India. Water Power Dam Constr 1988:24–6 Oct.
[17] Fuhrmann C, Mathias HB. A tool for decision making in uprating and refurbishment. In: International conference on uprating and refurbishing hydro power plants, Water Power and Dam Construction; Oct. 1991; p. 26–46.
[18] Telleschi PL, Wullimann E. Refurbishment of the Lake Lungern hydroelectric scheme. Water Power Dam Constr 1993:31–7 Dec.
[19] Sahai IM. Refurbishment-the story so far. Water Power Dam Constr 2006:42–4 Feb.
[20] Lloyd BA, Stone GC. Developments for on-line monitoring of rotors and stator windings. Water Power Dam Constr 2008:32–4 Apr.
[21] Santos R. Major refurbishments for Philippine hydro. Water Power Dam Constr 2011:12–4 Feb.
[22] Hammons TJ. Eastern and Western European policy on electricity infrastructure, interconnections, and electricity exchange. IEEE Power Eng Rev 1998;18(no. 1):8–21 Jan.
[23] Abdoo RA. Industry restructuring deregulation and competition. IEEE Power Eng Rev 1999;19(7):16–8 July.
[24] Hammons TJ, Willingham M, Mak KN, Da Silva M, Morozowski M, Blyden BK. Generation and transmission improvements in developing countries. IEEE Trans. Energy Convers 1999;14(3):760–5 Sept.
[25] Baker GC. The wave of deregulation: operational and design challenges. IEEE Power Eng Rev 1999;19(11):92–7 Nov.
[26] Thakur T, Kaushik SC, Deshmukh SG, Tripathi SC. Indian Electricity Act 2003: implications for the generation, transmission and distribution sectors. In: IEEE international conference on electric utility deregulation, restructuring and power technologies (DRPT2004), Hong Kong; Apr. 2004. p. 54–9.
[27] Linsley RK, Wohler MA, Paulhus JL. Hydrology for engineers. New York, NY, USA: McGraw-Hill Co.; 1975.
[28] Taylor J. Extending the operating life of hydro equipment. Water Power Dam Constr 1988:28–37.
[29] Thakur TN. Rehabilitation of hydropower equipments. In: Third international conference of power development is Afro Asian Countries, Kathmandu, Nepal;1996. pp. 538–45.
[30] Hartmann O. Reliability improvements for hydro power plants in USA. Water Power Dam Constr 1984:43–56 Jan.
[31] Water N. Uprating your hydro power plants a methodology for decision making. In: International conference on uprating and refurbishing hydro power plants, Water Power & Dam Construction; 1987. p. 7–26.
[32] Romo. A decision tool for improved maintenance and upgrading decisions. Hydropower and Dams, Issue Two; 2001. p. 49–52.
[33] Nussli W. Upgrading your hydropower plant a methodology for decision making. In: International conference on uprating and refurbishing hydro power plants, Water Power and Dam Construction, Strasbourg, France; Oct. 1987. p. 9–26.
[34] Ridley GK. A case study for refurbishing and uprating of hydro generators. In: International conference on uprating and refurbishing hydro power plants, Water Power and Dam Construction; Oct. 1987. p. 133–47.
[35] Gummer JH, Barr DM, Sims GP. Evaluation criterion for upgrading hydro power plants. Water Power Dam Constr 1993:24–31 Dec.
[36] Singh RP. Silt damage control measures for underwater parts – Nathpa Jhakri hydro power station – case study of a success story. Water Energy Int 2009;66(1):36–42.
[37] Sharma HK. Power generation in sediment Laden Rivers: the case of Nathpa Jhakri. Hydro Power Dams 2010(6):112–6.
[38] Singh RP. Silt damage mitigation measures for underwater parts Nathpa Jhakri hydro power station—a success story. In: Proceedings of the national workshop on hydro power development in Himalayan Region—HYDRO-2010, National Institute of Technology, Hamirpur, HP, India; Dec. 6–7 2010. p. 15–30.
[39] Lautala P, Valisno H, Autti M. A planning model for optimal hydro system expansion. Water Power Dam Constr 1986:33–9 Oct.
[40] Task Committee, ASCE. Guidelines for rehabilitation of civil works of hydro-electric plants, ASCE, New York; 1992.
[41] Bull TW. Planning of uprating and refurbishment of hydro-electric generator Sets in Africa. In: International conference on uprating and refurbishing of hydropower plants, Water Power and Dam Construction, France; Oct. 1987. p. 154–77.
[42] Goudie RJ. Uprating and rehabilitation of Tarabamba small hydro project. In: International conference on uprating and refurbishing hydro power plants, Water Power and Dam Construction, Peru; Oct. 1987. p. 352–75.
[43] Dahlstrand KT, Donglas K, Sundquist J. Refurbishment of an 80-years old dam on the flat river, Kent country,. In: International conference on uprating and refurbishing hydro power plants, Water Power and Dam Construction, MI, USA; Oct. 1987. p. 335–52.
[44] Mez F. The refurbishment of hydro generator. Water Power Dam Constr 1987:14–6 Oct..
[45] Dacier J. Assessing the condition of stator insulation. Water Power Dam Constr 1990:12–4 Jan.
[46] Allegre J. Refurbishment of generators at EI Infierno Mexico. In: International conference on uprating and refurbishing hydro power plants, Zurich, Switzerland; 1989. p. 318–31.
[47] Drommi JL, Maujean JM. Hydro generator refurbishment and performance improvement. In: International conference on uprating and refurbishing hydro power plants. Water Power and Dam Construction 1991:319–30 Oct.
[48] Poljakov V, Tsvetkov V. Methods of stator winding on-line diagnostics for large turbine generator preventive maintenance, IEE Trans Energy Convers, 14, 4, 1646-1650, Dec. 1999.
[49] Maujean JM. EDF's experience in the repair and maintenance of hydro generators. Water Power Dam Constr 1989 28–23, Oct.
[50] Ridley GK. Refurbishment and uprating of hydro generators. In: IEE international conference on refurbishment of power station electrical plant; 7–8 Nov. 1988. p. 165–69.
[51] Ridley GK. Hydro generator design for refurbishment. Water Power Dam Constr 1992:29–32 May.
[52] Ridley GK. The impact of stator winding circulating current on EL CID results. Hydropower Dams Issue One 2004:68–73.
[53] Ridley GK. A deeper insight into EL CID. Hydropower Dams Issue Four 2005:87–91.

[54] Ridley GK. Further development of EL CID vector diagram. Hydropower Dams Issue Four 2007:96–101.
[55] Ridley GK. Evaluating interlamination circulating current at core joints in large machine stators. Hydropower Dams Issue Six 2008:106–14.
[56] Maughan CV. Upgrading of generators to improve reliability, In: IEEE international electric machines and drives conference (IEMDC'03), vol. 2 pp. 885–94; 2003.
[57] Maughan CV. Monitoring of generator condition and some limitations thereof. Proc IEEE Electr Insul Conf Electr Manuf Expo 2005:50–3.
[58] Maughan CV, Emeritus PE. Generator condition monitor evolution and capability. Electr Insul Conf Electr Manuf Expo 2007:52–6.
[59] Maughan CV, Reschovsky JM. Advances in motor and generator rotor health. IEEE Int Symp Electr Insul (ISEI) 2010:1–4 6–9 June.
[60] Stack W, Reiman M. Modernization of excitation systems. Water Power Dam Constr 1991:49–57 Oct.
[61] Rao KR, Mohanty BN, Rajaram PN, Narayana TR. Renovation and Modernisation of Sharavathy hydro power station and introduction of micro processor based excitation control system, Electra India; Apr. 1994. p. 17–20.
[62] Manjean JM, Jouve J, Ferme JM. Electronic speed governing system for the Pierre Eybesse plant. Water Power Dam Constr 1990:8–11 Jan.
[63] Doppler R, Knoll E. Replacement of existing governing system by modern digital governors, In: International conference on uprating and refurbishing, Water Power and Dam Construction; p. 358–66, Oct. 1991.
[64] Ferme J, Nicolas J. Digital speed governor for Vainden. In: International conference on uprating and refurbishing hydro power plant-III, Water Power Dam Construction; Oct. 1991. p. 351–57.
[65] Soeresen E. Recent developments in hydro plant control systems. Hydro Power Dam Constr 1995:38–40 Jan.
[66] Schenk HA, Schweizer A. Refurbishment of control, instrumentation and information systems of existing hydropower plants—a possible procedure of assessment In: IEE international conference on refurbishment of power station electrical plant; p. 63–67, 7–8 Nov. 1988.
[67] Bill MR, Smilovici S. Refurbishment of control and instrumentation in power stations in South Africa, In: IEE international conference on refurbishment of power station electrical plant, p. 85-89, 7–8 Nov. 1988.
[68] Cripps JG. Munmorah power station life extension study control and instrumentation system, In: IEE international conference on refurbishment of power station electrical plant; p. 90-94, 7–8 Nov. 1988.
[69] Compson K. Control and Instrumentation systems in power station refurbishment schemes, In: IEE international conference on refurbishment of power station electrical plant; p. 95–9, 7–8 Nov. 1988.
[70] Mackeown J, Urquhart EB, Haining R. The refurbishment, automation and remote control of Tongland power station in the Galloay hydro scheme, In: IEE international conference on refurbishment of power station electrical plant; 115-119, 7–8 Nov. 1988.
[71] Ham PAL. Developments and experience in digital turbine control. IEEE Trans Energy Convers 1988;3(Issue. 3):568–74.
[72] Taylor A, Ekwue AO. Intelligent power plant control, for enhanced life management. Proc IEEE Int Conf Life Manage Power Plants 1994:61–5 12–14 Dec.
[73] Naidu BSK. Uprating of hydro turbines, hydraulic and mechanical factors. Water Power Dam Constr 1989:19–22 Oct.
[74] Naidu BSK. Field investigations for uprating hydraulic turbines. In: IAHR symposium, Norway; June 1988. p. 14–18.
[75] IEEE recommended practice for preparation of equipment specifications for speed-governing of hydraulic turbines intended to drive electric generators, IEEE Power & Energy Society, 10.1109/IEEESTD 125-1988.120259; Oct. 1988. p. 1–28.
[76] Johnson RM, Chow JH, Dillon MV. Pelton turbine deflector overspeed control for a small power system. IEEE Power Eng Soc Gen Meet 2003;19(2):1032–7.
[77] Padhy MK, Thatoi DN, Acharya AK. Effect of shape of silt particles on erosive wear of Pelton turbine bucket. Int Conf Adv Eng Sci Manage (ICAESM) 2012:19–24.
[78] Jackson RJ, Lawrence RA, Rudd SR. Refurbishment of turbogenerators for plant life extension, In: International Conference on Refurbishment of Power Station Electrical Plant; p. 160–64, 7–8 Nov., 1988.
[79] Hill R, Conroy RD, Hutchinson J. Welding solutions for turbine generator plant repair, upgrade and life extension. Int Conf Life Manage Power Plants 1994:85–92.
[80] Yang C, Tao J, Yu J. Fault diagnosis of a hydro turbine generating set based on support vector machine. WRI Global Cong Intell Syst 2009;3:415–8.
[81] Liu Z, Zou S, Zhou L. Condition monitoring system for hydro turbines based on LabVIEW. Asia-Pac Power Energy Eng Conf (APPEEC) 2012:1–4.
[82] Zhaohui Li, A highly reliable intelligent control strategy for hydro turbine governing systems. In: Second international conference on advances in power system control, operation and management (APSCOM), vol. 2; 1993. p. 751–56.
[83] Heng Q, Lu J, Lu Y. Robust control of hydro turbine speed governor. In: 10th world congress on intelligent control and automation (WCICA); 2012. p. 2680–84.
[84] Thapa BS, Gjosater K, Eltvik M, Dahlhaug OG, Thapa B. Effects of turbine design parameters on sediment erosion of Francis runner. In: Second international conference on the developments in renewable energy technology (ICDRET), Dhaka; 5–7 Jan. 2012. p. 1–5.
[85] Ligaard P. Hydro turbine refurbishment. Int Water Power Dam Constr 1987;39(10):37–40 Oct.
[86] Nichtawitz A. Development of new runner designs by example of rehabilitation at Cabinet Gorge P.S. In: Proceedings of the international conference on hydropower, San Francisco, CA, USA; Jul. 25–28 1995. , vol. 2, p. 1320–29.
[87] Harisberger Breed, Wilkins. Experience with bearings and vibration conditions of large hydroelectric units: waterwheel construction and governing: a study of irregularity of reaction in Francis turbines. J AIEE 1924;43(3):261–2.
[88] Magureanu R, Albu M, Bostan V, Dumitrescu AM, Pelizza M, Andreea F, Dimu G, Popa F, Rotaru M. Optimal operation of Francis Small Hydro turbines with variabiable flow. IEEE Int Symp Ind Electron 2008:1562–7 June 30–July 2.
[89] Konidaris DN, Tegopoulos JA. Investigation of oscillatory problems of hydraulic generating units equipped with Francis turbines. IEEE Trans Energy Convers 1997;12(4):419–25.
[90] Lecheb S, Djedid T, Chellil A, Nour A, Cherigui M, Kebir H. Fatigue crack initiation and vibration prediction life of turbine blade. In: Fifth international conference on modeling, simulation and applied optimization (ICMSAO); 2013. p. 1–6.
[91] Trivedi C, Gandhi B, Michel CJ. Effect of transients on Francis turbine runner life: a review (Review). J HydraulRes 2013;51(2):121–32 Apr.
[92] Gass ME. Modernisation and performance improvements of vertical Pelton turbines. Hydro Power Dams Issue Two 1998:25–9.
[93] Vitvar M. Kaplan turbine uprating at Orlik power plant. Water Power Dam Constr Oct. 1989:24–7.
[94] Mombelli HP, Avellan F. Model testing for upgrading and refurbishment projects. Hydro Power Dams 1995:63–5 July.
[95] Izena A, Kihara H, Shimojo T, Kaiichirou H, Furukawa N, Kageyama T, Goto T, Okamura C. Practical hydraulic turbine model. IEEE Power Eng Soc Gen Meet 2006:1–7.
[96] Fang H, Chen L, Shen NZ. Basic modeling and simulation tool for analysis of hydraulic transients in hydroelectric power plants. IEEE Trans Energy Convers 2008;23(3):834–41.
[97] Xiao R, Wang Z, Luo Y. Dynamic stresses in a Francis turbine runner based on fluid-structure interaction analysis. J Tsinghua Sci Technol 2008; 13(Issue 5):587–92.
[98] Nakamura K, Shigenobu T, Harada S, Muraki T. A high head pumped storage power plant rehabilitation project. Nagasaki. Int Conf Renewable Energy Res Appl (ICRERA) 2012:1–6 11–14 Nov.
[99] Kavurmaci B, Akin H, Ayli E, Celebioglu K, Aradag S. Design of an experimental test stand for Francis type hydraulic turbines. In: Fourth international conference on power engineering, energy and electrical drives (POWERENG); 2013. p. 876–80.
[100] Yaoyao Y, Wang H, Gong R, Wei X, Liu W. Numerical study of Francis turbine flow field under small opening condition. Int Conf Electron Mech Eng Inf Technol (EMEIT) 2011;4:1675–8.
[101] Thorne DH, Hill EF. Extensions of stability boundaries of a hydraulic turbine generating unit. IEEE Trans Power Apparatus Syst 1975;94(4, Part: 1):1401–9.
[102] Safie FM, Hage RT. A simulation model for risk assessment of turbine wheels. Proc Reliab Maintainabil Symp 1991:108–11.
[103] Gao H, Wang C. Effect of detailed hydro turbine models on power system analysis. In: IEEE power systems conference and exposition, (PSCE '06); 2006. p. 1577–81.
[104] De Jaeger E, Janssens N, Malfliet B, Van De Meulebroeke F. Hydro turbine model for system dynamic studies. IEEE Trans Power Syst 1994;9 (4):1709–15.
[105] Li Wei, Vanfretti L, Farrokhabadi M. Modeling of custom hydro turbine and governor models for real-time simulation. Proc Conf Complexity Eng (COMPENG) 2012:1–6.
[106] Kosterev DN. Hydro turbine-governor model validation in Pacific Northwest. IEEE Trans Power Syst 2004;19(2):1144–9.
[107] Doan RE, Natarajan K. Modeling and control design for governing hydroelectric turbines with leaky Wicket gates. IEEE Trans Energy Convers 2004;19 (Issue: 2):449–55.
[108] Kishor N, Saini RP, Singh SP. Simulation of reduced order hydro turbine models to study its hydraulic transient characteristics. in: Ninth IEEE international multitopic conference, (INMIC 2005); 2005. p. 1–6.
[109] Naidu BSK. Addressing the problems of silt erosion at higher plants. Hydropower Dams Issue Three 1997:72–7.
[110] Naidu BSK. Silt erosion problems in hydropower stations. CBIP Seminar on silting problems in Hydropower stations, WRDTC, Roorkee, India; May 1997.
[111] Chunhong HU. Controlling reservoir sedimentation in China. Hydro Power Dams 1985:50–2 March.
[112] Alam S. The influence and management of sediment at hydro projects. Hydropower Dams Issue Three 1999:54–7.
[113] Alam S. A critical evaluation of sedimentation management design practice. Hydropower Dams Issue One 2001:54–9.
[114] Alam S. Improving sedimentation management using multiple dams and reservoirs. Hydropower Dams Issue One 2002:63–8.
[115] Alam S. Essential design features for efficient sediment management. Hydropower Dams Issue Six 2005:80–3.
[116] Alam S. Site selection and layout for efficient sediment management. Hydropower Dams Issue Five 2006:150–3.
[117] Ribeiro ML, Cesare GD, Schleiss AJ. Sedimentation management in the Livigno reservoir. Hydropower Dams Issue Six 2005:84–8.
[118] Sehgal CK, Saxena H, Morgan MJ, Kirchen GF, Kraftwerke E. Recommendations for the design of intake trashracks. Hydropower and Dams, Issue Six 2005:90–4.

[119] Jacobsen T. Sediment handling technologies: experience from case studies, India. Hydropower Dams Issue Six 2003:84–6.
[120] Jacobsen T. Sediment removal at the Malana reservoir, India. Hydropower Dams Issue One 2006:74–7.
[121] Singh KP, Durgunoglu A. A new method for estimating future reservoir storage capacities. Water Resourc Res Apr. 1989:263–74.
[122] Guthrie BJ. Hydro-electric engineering practice. . London: Blackie & Son Ltd.; 1984.
[123] Nigam PS. Hand book of hydro electric engineering. Roorkee, India: Nem Chand and Brothers; 1985.
[124] Gulliver JS, Ardnt REA. Hydro power engineering hand book. USA: McGraw Hill; 1991.
[125] Chaturvedi MC. Water Resources Planning and Management. New Delhi: Tata McGraw-Hill Publishing Ltd; 1992.
[126] Kumar LV. Economic evaluation of micro hydel projects in hilly areas. Indian J Power River Valley Dev 1978:33–7 July.
[127] Sharma DP, Verma GL, Bahadur AK. Selecting installed capacity for a run-of-river plant. Water Power Dam Constr 1980:23–7 Mar.
[128] Gingold PL. The optimum size of small run-of-river plants. Water Power Dam Constr 1981:50–8.
[129] Atteri VK. Optimized development of small hydro in H. P. ME dissertation. Roorkee, India: Water Resources Development Training Centre, University of Roorkee; 1995.
[130] Jonas E, Pall J, Ludvigsson. Optimal design of hydro power plants. Hydro Power Dam 1997 661-618.
[131] Gordon JL, Penman AC. Quick estimating techniques for small hydro potential. Water Power Dam Constr 1979:46–51 Sept.
[132] Varshney RS. Engineering hydrology. Roorkee India: Nem Chand and Brothers; 1979.
[133] Mutereja KN. Applied hydrology. New Delhi: Tata McGraw-Hill; 1982.
[134] ASCE Task Committee. Artificial neural network in hydrology: preliminary concept. In: ASCE J Hydrol Eng; Apr. 2000. p. 115–20.
[135] ASCE Task Committee. Artificial neural network in hydrology: hydrologic applications. In: ASCE J Hydrol Eng; Apr. 2001. p. 124–37.
[136] HPPCL. Detailed project report of 100 MW Sainj Power House, General Manager Designs, HPPCL, Sunder Nagar (HP), India; 2005.
[137] Jong KA. Adaptive system design: a genetic approach. IEEE Trans Syst Man Cybern 1980;10(3):556–74.
[138] Goldberg DE. Genetic algorithm in search, optimization and machine learning. Harlow England: Addison Wesley Longman; 1999.
[139] Goldberg DE, Rechardson J. Genetic algorithm with sharing for multi model function optimization. In: Proceedings of second international conference on genetic algorithm; 1987. p. 41–49.
[140] Wang QJ. Genetic algorithm and its application to calibrate conceptual rainfall runoff model. Water Resourc Res 1991;27(9):2467–72.
[141] Adler D. Genetic algorithm and simulated annealing: a marriage Proposal. In: Proceedings of IEEE international conference on neural networks; Mar. 1993. p. 1104–09.
[142] Dragen AS, Godfrey AW. Genetic algorithm for least cost design of water distribution network. J Water Resourc Plann Manage ASCE 1997:67–77 Apr.
[143] Hreinsson EB. Optimal sizing of projects in a hydro-based system. IEEE Trans Energy Convers 1990;5(no. 1):32–8 Mar.
[144] Hreinsson EB. Incremental cost and allocation of hydro-resources for energy intensive industry In: IEEE IAS 35th annual meeting and world conference on industrial application of electrical energy, Rome, Italy; 8–12 Oct. 2000. p. 917–23.
[145] Hreinsson EB. Optimal short term operation of a purely hydroelectric system. IEEE Trans Power Syst 1988;3(3):1072–7 Aug.
[146] Hreinsson EB, Eliasson J. Optimal design and cost/benefit analysis of hydro-electric power systems by genetic algorithms. In: VIII symposium of specialists in electrical operations and expansion planning, Brasilia, Brazil; 19–23 May 2002. p. 1–7.
[147] Kirkpatrick S, Gelatt Jr. CD, Vecchi MP. Optimization by simulated annealing. Sci J 1983;220(4598):671–80 13 May.
[148] Casotto A, Romeo F, Vincentelli S. A parallel simulated annealing algorithm for the placement of macro-cells. IEEE Trans. Comput-Aided Des Integr Circuits Syst 1987;6(issue 5):838–47.
[149] Greene JW, Supowit KJ. Simulated annealing without rejected move. IEEE Trans Comput Aided Des Integr Circuits Syst 1986;6(issue 1):221–8.
[150] Grover LK. A new simulated annealing algorithm for standard cell placement. In: Proc. of IEEE international conference on computer-aided design, Santa Clara; 1986. p. 378–80.
[151] Sumereder C, Rupp C, Muhr M, Egger H, Marketz M. Condition evaluation of hydro generators. In: Eighth IEEE international conference on properties and applications of Dielectric Materials; June 2006. p. 285–88.
[152] Li ZH, Yang XB, Niu SQ, Malik OP. Maintenance-oriented information digitalization of hydro turbine generator sets, In: IEEE power & energy society general meeting (PES '09); p. 1–7, 2009.
[153] Zhaohui L, Yitao C, Jiang G. Integrated maintenance features of hydro turbine governors, In: Proc of international conference on power system technology (Power-Con 2002) vol. 3; p. 1984–88, 2002.
[154] Sedding HG, Lloyd BA, Stone GC, Braun JM, White JC. Development of novel instrumentation and expert system concepts in turbine generator condition monitoring, In: Proc. fourth international conference on electrical machines and drives; p. 177–181, 89.
[155] Hydro Performance Processes, Inc. Condition assessment manual hydropower advanced project (HAP); 2012. p. 1–7.
[156] Energy Development & Power Generation Committee. IEEE guide for the rehabilitation of hydroelectric power plants, IEEE Standard 1147^{TM}-2005; 22 Mar. 2006.
[157] Army Corp's of Engineers "Hydro Plant Risk Assessment Guide: Generator Condition Assessment"; 2004.
[158] International Energy Agency (IEA). Guidelines on methodology for hydroelectric Francis turbine upgrading by runner replacement; 2001.
[159] International Energy Agency (IEA). Guidelines for hydroelectric generator upgrading; 2001.
[160] Taylor P. Fuzzy logic take control. Water Power Dam Constr 1999:24–5 Nov.
[161] Sachs R. Fuzzy logic controls run-of-river hydro. Water Power Dam Constr 2000:40–2 Aug.
[162] Bai VR, Tamjis MR. Fuzzy logic model on operation and control of hydropower dams in Malaysia. In: IEEE international conference on computer engineering & systems, (ICCES '07); 2007. vol. 4, no.1, p. 31–9.
[163] Shrestha BP, Duckstein L, Stakhiv EZ. A fuzzy rule based reservoir operation. J Water Resour Plann Manage 1996;122(3):262–8.
[164] Wangdi Y, Richards EF. Modelling and simulation of the Chukha hydro power plant, Bhutan and the nearby Indian power system, In: Proc. of the IEEE twenty-second annual North American power symposium; p.398–404, 1990.
[165] Weber H, Prillwitz F. Simulation models of the hydro power plants in Macedonia and Yugoslavia. Bologna, Italy. IEEE Power Tech Conference 2003;3 June 23-26.
[166] Stokelj T, Golob R, Gubina F. Accuracy assessment of hydro power plants models. PowerTech Budapest. Int Conf Electr Power Eng 1999:47.
[167] Lai XD, Yuan H. Numerical simulation-driven hydrodynamic optimization for rehabilitation & upgrading of hydro turbines, In: Asia Pacific Power and Energy Engineering Conference (APPEEC 2009); p. 1–8, 2009.
[168] Yong X, Zhaohui L, Xide L. Simulation model of radial vibration for a large hydro-turbine generator unit and its application. IEEE Power Eng Autom Conf (PEAM) 2011;3:191–5.
[169] Welte TM, Vatn J, Heggest J. Markov State model for optimization of maintenance and renewal of hydro power components, In: International Conference on Probabilistic Methods Applied to Power Systems (PMAPS 2006); p.1–7, 2006.
[170] Ruzhekov G, Slavov T, Puleva T. Modeling and implementation of hydro turbine power adaptive control based on gain scheduling technique. In: 16th international conference on intelligent system application to power systems (ISAP); 2011. p. 1–6.
[171] Souza Jr. OH, Barbieri N, Santos AHM. Study of hydraulic transients in hydropower plants through simulation of nonlinear model of penstock and hydraulic turbine model. IEEE Trans Power Syst 1999;14(4):1269–72.
[172] Puleva T, Garipov E, Ruzhekov G. Adaptive power control modeling and simulation of a hydraulic turbine. In: 16th international conference on intelligent system application to power systems (ISAP); 2011. p. 1–6.
[173] Ion CP, Marinescu C. Control of parallel operating micro hydro power plants. In: 16th international conference on optimization of electrical and electronic equipment (OPTIM); 2010. p. 1204–09.
[174] Jin MJ, Hu W, Liu F, Mei SW, Lu Q. Nonlinear decentralized excitation and governor coordinated control for hydraulic power plants, In: International Conference on Power System Technology (PowerCon 2004); vol. 1 p. 918–23, 2004.
[175] Vrancic D, Kristiansson B, Strmcnik S, Oliveira PM. Improving performance/activity ratio for PID controllers. Int Conf Control Autom 2005:834–9.
[176] Working Group on Prime Mover and Energy Supply Models for System Dynamic Performance Studies. Hydraulic turbine and turbine control models for system dynamic studies, IEEE Transaction on Power System, vol. PWRS-7; Feb. 1992. no. 1, p. 167–79.
[177] IEEE Guide for the Operation and Maintenance of Hydro-Generators' IEEE Standard 492^{TM}-1999; 1999.
[178] Guidelines for selection of hydraulic turbines, preliminary dimensions and layout of surface hydroelectric power plant, BIS Standard IS-12800, Part (I, II, III); 1991.
[179] Khodabakhshian A, Hooshmand R. A new PID controller design for automatic generation control of hydro power systems. Electr Power Energy Syst 2010;32:375–82.
[180] Jasmin G, Bowles JP, Mukhedkar. Electronic Simulation of a Hydro Generator with Static Excitation. IEEE Trans Power Apparatus Syst 1981;PAS 100 (9):4207–15.
[181] Jasmin G, Leroux A, Mukhedkar. Electronic simulation of a hydro turbine with its penstock, speed regulator and damping unit. IEEE Trans Power Apparatus Syst 1983;PAS-102(no. 9):3023–9.
[182] Sanathanan CK. Accurate low order models for hydraulic turbine-penstock. IEEE Trans Energy Convers 1987;EC-2(2):196–200 June.
[183] Murthi MSR, Hariharan MV. Analysis and improvement of the stability of a hydro-turbine generating unit with long penstock. IEEE Trans Power Apparatus Syst 1984;PAS-103(no. 2):360–6 Feb.
[184] Ramamurthy V, Ramchandram K, Kodandarmaswamy PS. Transient performance and control of hydraulic turbine-generator units. IEEE Trans Power Apparatus Syst 1981;PAS-100(1):288–94 Jan.
[185] Kishor N, Singh SP, Saini RP. Dynamic simulation of hydro turbine and its state estimation based LQ control. Energy conversion and management, vol. 47. UK: Elsevier Science; 2006. p. 3119–37 Nov.

[186] Vournas CD, Papaioannou G. Modelling and stability of a hydro plant with two surge tanks. IEEE Trans. Energy Convers 1995;10(no. 2):368–75 June.
[187] Kishor N, Singh SP, Saini RP. A review of hydropower plant models and control. Renewable and sustainable and energy review, vol. 11. UK: Elsevier Science; June 2007. p. 776–96.
[188] Kumar DL, Singhal MK, Khatod DK. Simulation of small hydro power plant, In: International conference on advances in renewable energy (ICARE-2010), Bhopal (Madhya Pradesh); June 24–26, 2010.
[189] Dutt N, Singhal MK, Khatod DK. Review of simulation analysis in SHP simulator for medium head application In: International conference on advances in renewable energy (ICARE-2010), Bhopal (Madhya Pradesh); p. 250–260. 24-26 June 2010.
[190] Cozorici F, Vadan I, Munteanu RA, Cozorici I, Karaissas P. Design and simulation of a small wind-hydro power plant. Int Conf Clean Electr Power (ICCEP) 2011:308–11.
[191] Puthumana LJ, Jaleel JA. Performance evaluation of AGC of SHP with multi-area power system. Int Conf Power Energy Syst (ICPS) 2011:1–5.
[192] Kundur P. Power system stability and control. McGraw-Hill; 1994.
[193] Anderson PM, Fouad AA. Power System Control and Stability. 2nd ed.. USA: IEEE Press, Wiley Interscience; 2003.
[194] Fritz JJ, *Small and mini hydro power systems,* McGraw-Hill Book Company, USA.
[195] Frick PA. Automatic control of small hydro-electric plants. IEEE Trans Power Apparatus Syst 1981;PAS-100(5):2476–85 May.
[196] Bernhardt GA, Vapot WA. Power station engineering and economy. New Delhi: McGraw-Hill Publishing Company Ltd.; 1964.
[197] James LD, Lee RR. Economics of water resources planning. New Delhi: McGraw-Hill Publishing Company Ltd.; 1970.
[198] Varshney RS. Water resources systems planning and economics. Roorkee, India: Nem Chand and Brothers; 1990.
[199] Gordon JL. Estimating hydro station costs. Water Power Dam Constr 1981:31–3 Sept.
[200] Goicoechea A, Krouse R, Antle LG. An approach to risk and uncertainty in benefit cost analysis of water resources projects. Water Resourc Res 1982:791–9 Aug.
[201] Gordon JL. Hydropower cost estimates. Water Power Dam Constr 1983:30–7 Nov.
[202] Gordon JL, Noel RCR. The economic limits of small and low-head hydro. Water Power Dam Constr 1986:23–6 Apr.
[203] Wood J, Gulliver JS. Economic Analysis of Energy Projects with Uncertainty. Journal of Energy Engineering 1990;116(no. 1):1–16 Apr.
[204] Castelli B, Hartman O, Ravinisi L. Cost and economics of hydro plant modernization. Water Power Dam Constr 1993:47–55 Dec.
[205] Schade H, Scheil H. Cost-effective operation of generators by optimizing maintenance cycle. Hydropower Dams Issue Four 1997:83–7.
[206] Giri AB. The key to low cost electricity. Water Power Dam Constr 2001:45–6 June.
[207] Gordon JL. Unit price contracts or design-build? Water Power Dam Constr Issue Five 2001:99–102.
[208] Wangensteen I. The hydro connection. Water Power Dam Constr 2002:34–5 Apr.
[209] Newton MJ, Hopewell PD. Costs of sustainable electricity generation. Power Engineering Journal 2002:68–74.
[210] Pakniat P, Arbabian M. "Choosing an optimized financial method for hydro power projects," International Symposium on Water Resources & Renewable Energy Development in Asia, Bangkok, Thailand, pp. 7.07-7.10, Dec. 2006.
[211] Salazar G, Rudnick H. Hydro power plants in Ecuador: a technical and economical analysis. IEEE Power Energy Soc Gen Meet 2008:1–5.
[212] Ancieta CA. Estimating E&M powerhouse costs. Water Power Dam Constr 2009:21–5 Feb.
[213] Roque A, Sousa DM, Casimiro C, Margato E. Technical and economic analysis of a micro hydro plant—a case study. In: Seventh IEEE international conference on the European energy market (EEM); 23–25 June 2010. p. 1–6.
[214] Mishra S, Singal SK, Khatod DK. Costing of small hydropower projects. In: 2011 IEEE international conference on prudent development and renewable energy resources (ICPDRE 2011), (Chennai) India; Feb. 19–20 2011. p. 22–5.