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Review Article

An Overview of Hydroelectric Power Plant: Operation, Modeling, and Control

Ghazanfar Shahgholian[a,b]

[a] *Smart Microgrid Research Center, Najafabad Branch, Islamic Azad University, Najafabad, Iran.*
[b] *Department of Electrical Engineering, Najafabad Branch, Islamic Azad University, Najafabad, Iran.*

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ABSTRACT

Renewable energy provides twenty percent of electricity generation worldwide. Hydroelectric power is the cheapest way to generate electricity today. It is a renewable source of energy and provides almost one-fifth of electricity in the world. Also, it generates electricity using a renewable natural resource and accounting for six percent of worldwide energy supply or about fifteen percent of the world's electricity. Hydropower is produced in more than 150 countries. Hydropower plant producers provide energy due to moving or falling water. This paper presents and discusses studies on hydroelectric power plant fields, which have been carried out by different investigators. This work aims to study and provide an overview of hydroelectric power plants such as applications, control, operation, modeling and environmental impacts. Also, the hybrid power and efficiency of the hydroelectric power plants has been investigated. The applications of a flexible AC transmission system (FACTS) controller in the power system with the hydroelectric power plants are presented.

1. INTRODUCTION

Sustainability is one of the most important benefits of using renewable energy and, therefore, never disappears [1,2]. Vital renewable energies are one of the most interesting fields in engineering for numerous reasons [3,4]. Renewable energies such as wind energy [5,6], solar energy [7,8], and water power [9,10] vary widely in their cost effectiveness and are important in the world [11,12]. Even more importantly, renewable energy produces little or no waste products, hence minimal impact on the environment [13,14]. The nominal capacity of Iranian power plants by type of power plant in 2013-2014 and 2017-2018 is shown in Table 1.

Renewable energies have been widely adopted as alternatives to fossil fuels [15,16]. Instead of fossil fuels, renewable energies are used widely [17,18]. There is a world-wide requirement of hydropower turbines for peak load operation at increasing heads and for low head turbines operating with large head variations [19, 20].

Nowadays, hydropower has become the best source of electricity, which is widely utilized all over the world [21,22]. An installed capacity of supplied hydroelectric power is approximately 20 % of the world's electricity and accounts for about 80 % of electricity from renewable energy sources. Hydroelectricity, a clean and renewable energy source, has many economic, technical, and environmental benefits [23,24]. Basically, hydroelectric power generation is performed in compliance with the law of conservation of energy, where kinetic energy that results from the movement of the mass of water from the river is translated into electricity [25,26].

The main applications of a typical hydroelectric power plant include the generation of electric power, controlling of water flow in the rivers to create pondage, and storage of drinking water supply. Hydropower plants have essentially five major components: storage reservoir, intake tunnel, surge tank, penstock, and hydro turbine. A hydropower plant scheme is shown in Fig. 1 [27,28].

Many papers have been published in the field of applications and operation of hydroelectric power plants [29,30]. These are classified as (a) load frequency control in hydropower systems [31,32], (b) mathematical modeling of hydro turbine [33,34], (c) applications of FACTS devices in power system with hydropower plant [35], (d) hydropower plant control [36,37], (e) hydraulic turbine governing system [38], (f) coordination between the water energy and else renewable energy [39,40], and (g) impact on the environment [41,42].

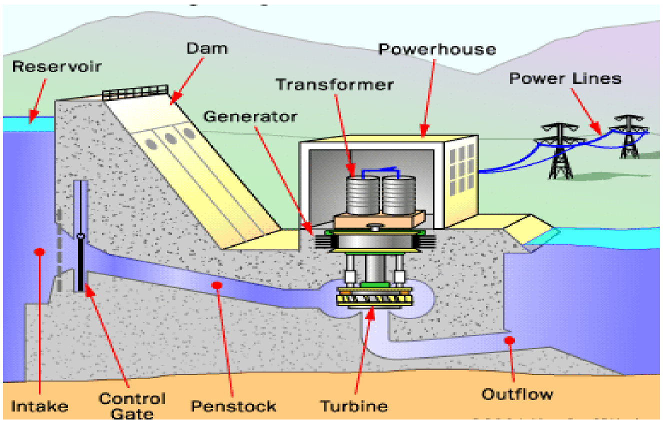

Figure 1. Components of a hydropower plant.

This paper reviews the operation and control of hydroelectric power plants. The present paper is organized in thirteen sections. Section 1 briefly reviews hydropower plants. Steps in the production of electricity in the hydropower plant are shown in Section 2. Section 3 briefly discusses the basic operating principles of the hydraulic turbine. Section 4 shows the model of the turbine. In hydro plants where the distance

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*Corresponding Author's Email: shahgholian@iaun.ac.ir (Gh. Shahgholian) between the reservoir and the turbine is quite large, a surge tank is usually utilized, as described in Section 5. One of the most important components of hydropower plant is hydraulic turbine regulating system (HTRS), which is explained in Section 6. Environmental impacts of hydroelectric power plants are shown in Section 7. Hydropower installations can have many environmental impacts by changing the environment and affecting land use, as described in Section 8. The differences between water and conventional power generations are given in Section 9. The efficiency of hydroelectric power plants is investigated in Section 10.

Table 1. Nominal capacity of Iranian power plants.

Plants	**2013-2014**		**2017-2018**	
	Manufacturing (MW)	**Total percentage**	**Manufacturing (MW)**	**Total percentage**
Steam	15830	22 %	15829	20.1 %
Combined cycle	17850	25 %	23166	29.4 %
Hydropower	10265	15 %	11942	15.1 %
Gas	24715	35 %	26200	33.2 %
Diesel - nuclear and renewable	1620	3 %	1761	2.2 %
Total	70280	100 %	78899	100 %

Hybrid power (combination of different technologies to produce power) is provided in Section 11. The applications of FACTS controller in power system with hydroelectric power plant are present in Section 12. The response of the hydraulic generating unit to a small change in load demand is shown in Section 13. The impact of the hydropower plant on the microgrid is shown in Section 14. Finally, concluding remarks are given in Section 15.

2. HYDROPOWER PLANTS CLASSIFICATION

In order to respond to the increasing demand for electricity, most countries give priority to its development and, accordingly, build many hydropower plants [43,44].

Hydropower plants based on quantity are classified as reservoir plants, pumped storage plants [45,46], and run-of-river plants.

According to the extent of water flow regulation, such plants may be classified into three categories: runoff river power plants without pondage, runoff river power plants with pondage, and reservoir power plants. The available head is an important determinant, and the head and capacity together largely determine the type of plant and installation. As per height of water or water head hydroelectric power plant can be divided into three categories: low head (Fig. 2), medium head (Fig. 3), and high head (Fig. 4) [47].

Generally, the grouping of hydroelectric power plants is shown in Fig. 5 [48,49].

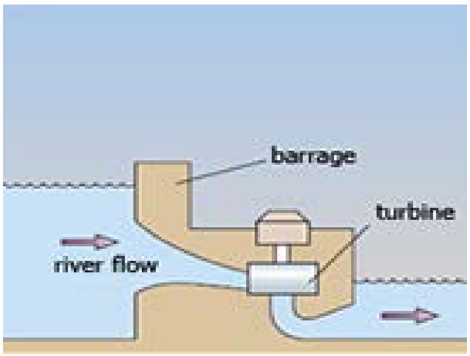

Figure 2. Low head power plant.

2.1. Based on head

There are three types of hydroelectric power plants based on the height of water available in the reservoir: low-head, medium-head, and high-head. The available water head in the low head is less than 30 m and in the medium head is more than 30 m, but is less than 300 m. However, the head of water available for producing electricity in high head is more than 300 m and can extend even up to 1000 m.

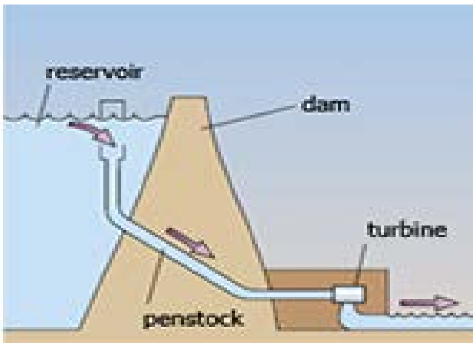

Figure 3. Medium head power plant.

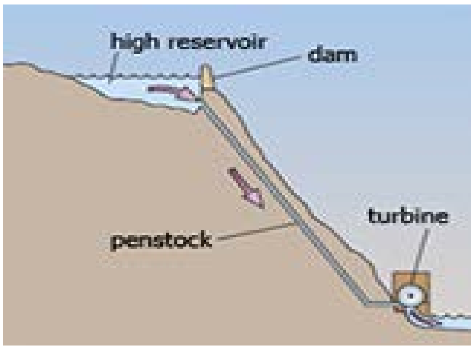

Figure 4. High head power plant.

A design technique based on optimal pole shift theory to control a low-head hydropower plant connected as a single machine to an infinite bus (SMIB) system was presented in [50], in which a state-space model with two-input and two-output variables was considered. The dynamic stability analysis of an islanded power system regarding the installation of a reversible hydropower plant for increasing renewable energy integration was shown in [51], in which these simulation results showed that the high-head hydropower installation provided a marginal contribution to system frequency regulation when explored in turbine operation mode, leading to a reversible power station with a single penstock.

2.2. Based on nature load

According to the nature of load, there are three types of hydroelectric power plants: base load plants, peak load plants, and pumped storage plant.

Base load plants are required to supply constant power to the grid. They are remotely controlled mostly and run continuously without any interruptions.

The supply of power during peak load is done through the peak load plant. They only work during certain hours of the day when the load is more than the average.

Pumped storage hydroelectric power plants are one of the most applicable energy storage technologies on large-scale capacity generation due to many technical considerations, thus maintaining the following loads in case of high penetration of renewables in the electrical grid [52].

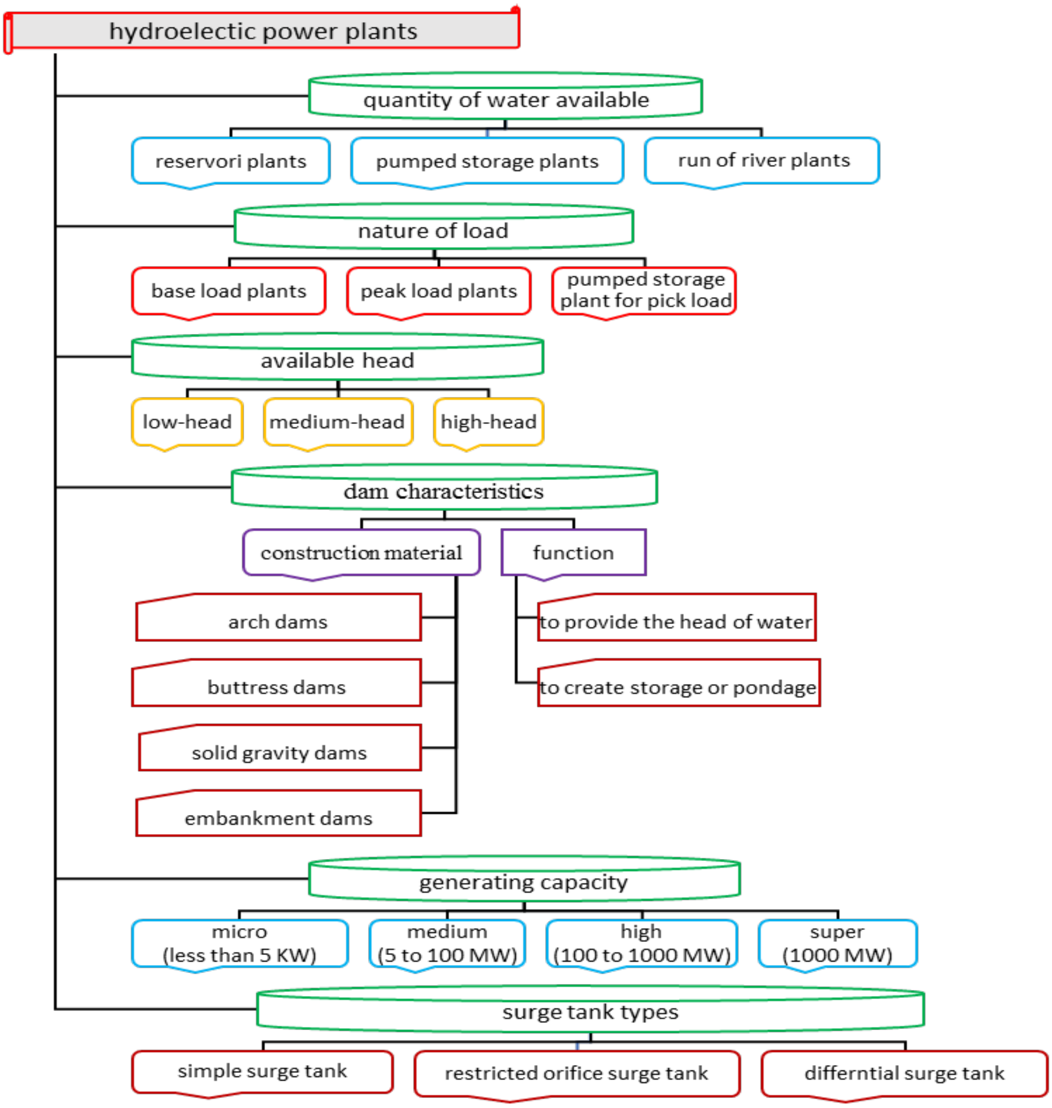

Figure 5. Showing the classification overview of hydroelectric power plants.

2.3. Based on surge tank types

Various types of surge tanks used in the hydropower water conveyance system are given as follows: simple surge tank, restricted orifice surge tank, differential surge tank, gallery type surge tank, and inclined surge tank [53,54].

The setting condition of the downstream surge tank of hydropower station with sloping ceiling tailrace tunnel was studied in [55], in which the flow inertia of penstock corresponding to the endpoint of inequality interval is the allowable value of flow inertia where the downstream surge tank is not necessary to set. By using the second version of non-dominated sorting genetic algorithm, the closing law of wicket-gates and the surge tank position at a pumped storage power plant were optimized in [56], showing that the maximum rise and fall in the water level of surge tank decreased by 5.2 % and 7 %, respectively.

3. POWER PRODUCTION STEPS

Figure 6 shows the main energy transformation at the hydroelectric power plant.

At a hydroelectric power plant, water turns into electricity, which is carried to consumers along a transportation and distribution network. The power generation steps are illustrated in Fig. 7 [57].

1. HYDRAULIC TURBINE

A hydraulic turbine is the prime mover of hydropower development. It is a mechanical device that converts the potential energy of water into rotational mechanical energy. Hydro turbine plants exhibit complex dynamics, having parameters that vary significantly with changes in operating conditions. Classification of hydraulic turbines is shown in Fig. 8 [58].

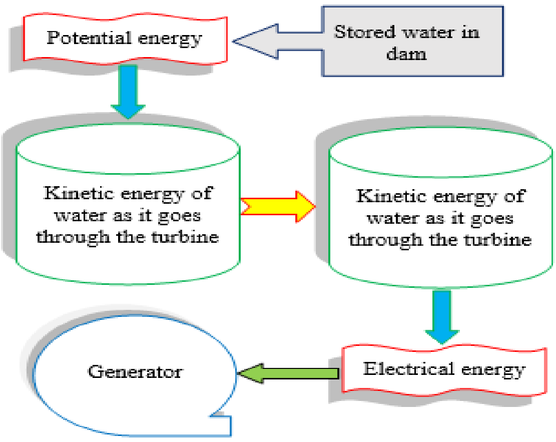

Figure 6. Main energy transformation.

4.1. Based on pressure change

Another common classification of hydro turbines is based on pressure change: impulse or reaction type that describes how the turbine transforms potential water energy into rotational mechanical energy [59,60].

The two main types of reaction turbine are the propeller (with Kaplan variant) and Francis turbines. Three main types of impulse turbine are in use: the Pelton, the Turgo, and the Crossflow.

4.2. Based on inelt head

Head is the height difference between where the water enters into the hydro system and where the former leaves the latter. Based on the head at the inlet of turbine, the hydraulic turbine is divided into low-head [61,62], medium head, and high-head [63]. Generally, for high heads, Pelton turbines are used, whereas Francis turbines are used to exploit medium heads [64,65]. For low heads, common Kaplan [66,67] and bulb turbines are applied [68]. The comparative results of the turbine performance based on head are summarized in Table 2.

4.3. Based on specific speed

The specific speed value of a turbine is the speed of a geometrically similar turbine, which would produce unit power (1 KW) under unit head (1 m).

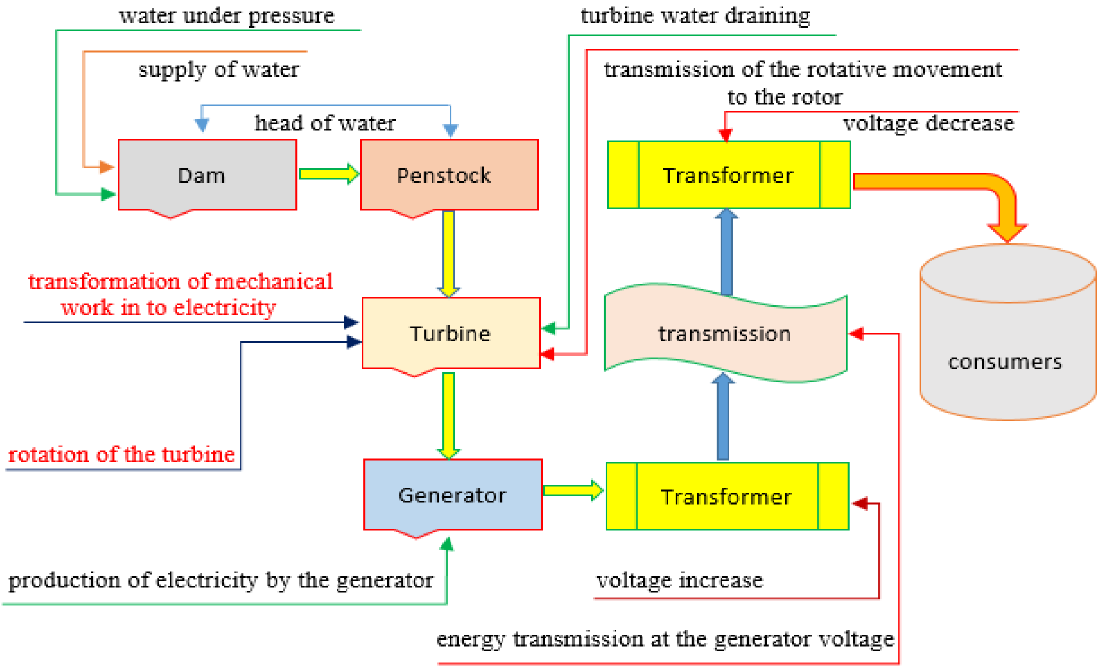

Figure 7. Steps in production of electricity at hydropower plant.

Turbine types can be classified by their specific speed, which always applies at the point of maximum efficiency. In the range of 1 to 20, impulse turbines are appropriate. In the range of 10 and 90, Francis-type runners should be selected. For up to 110, Deriaz turbines may be suitable. If speed ranges from 70 to the maximum of 260, propeller or Kaplan turbines are appropriate.

2. TURBINE MODEL

Several models of hydropower generation were investigated by scientists. Due to increasing the size and complexity of interconnected systems, hydraulic turbine generator units are applied increasingly to grant the control system needs. The block diagram of Fig. 9 shows the basic elements of a hydro turbine within the power system environment [69]. A number of different models for hydraulic turbines and their speed controllers were presented in [70].

Figure 10 shows the relationship between parameters in a hydropower plant.

The turbine and water channel characteristic is determined by assuming the rigidity of the gutter and the incompressible water flow regardless of the impact of the bump tank or the existence of a large bump tank based on the blocks shown in Figs. 11, 12, and 13.

The turbine gain relating ideal gate opening (G) to real gate opening (g) is given by:

$$A_t = \frac{\overline{G}}{g} = \frac{1}{G_{FL} - G_{NL}} \tag{1}$$

where G_{FL} and G_{NL} are the gate opening at rated load and no load, respectively. q_{NL} is no-load flow.

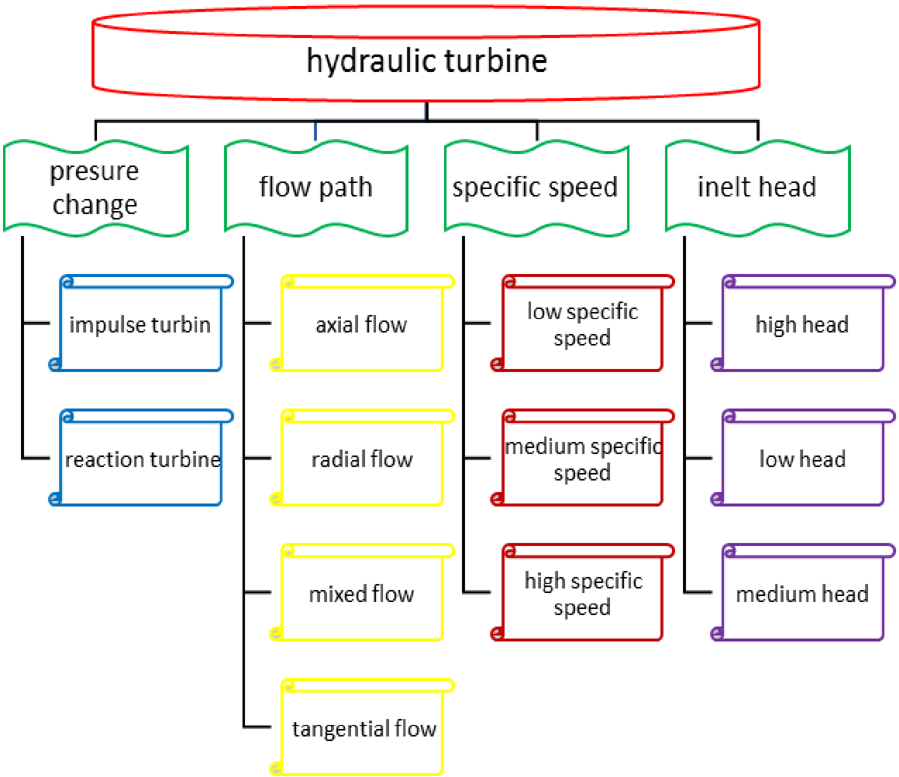

Figure 8. Classifications of hydraulic turbines.

Table 2. Characteristics of the turbine base on head.

Head	**High head** **(more than 50 m)**	**Medium head** **(between 15 m and 50 m)**	**Low head** **(less than 15 m)**
Turbines	Low-speed Francis, Pelton	Normal-speed Francis, Kaplan, fixed-blade propeller tubular turbine	Kaplan or fixed-blade propeller tubular turbine
Topographical conditions	Mountainous region	Hilly country (mountainous region)	Flat land
Character of storage	Seasonal annual or over-year storage	Daily or weekly poundage (storage)	No or daily pondage
Characterization of economies	Production cost being relatively low	Production cost being relatively moderate	Production cost being relatively high

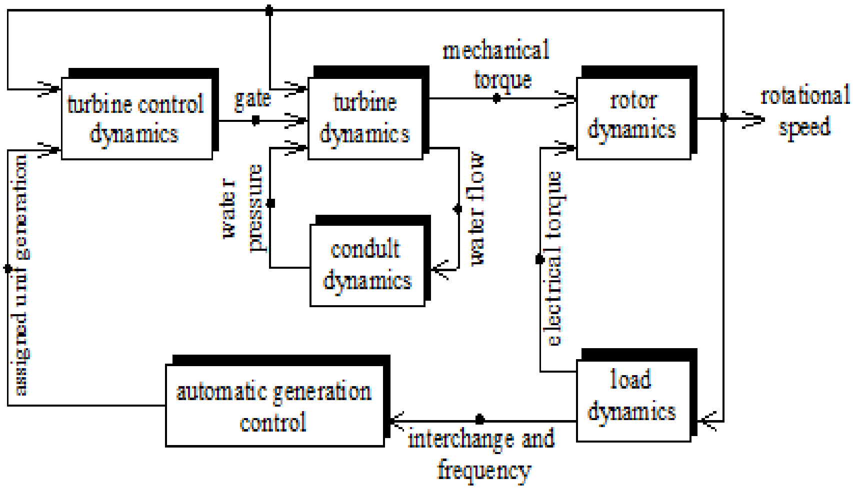

Figure 9. Functional block diagram showing the relationship between hydro prime mover system and controls to complete system.

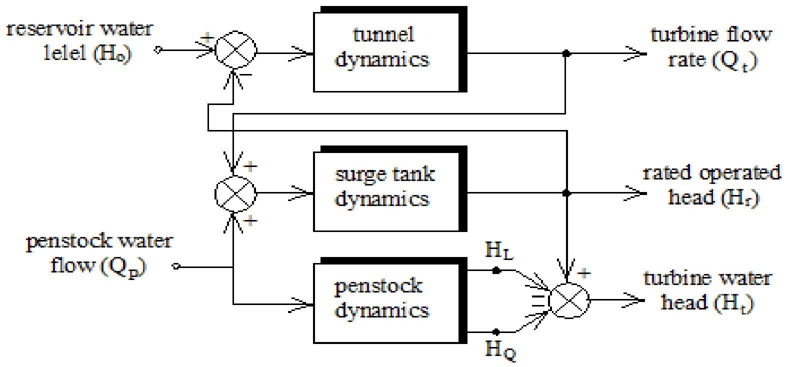

Figure 10. Relationship between parameters in hydropower plant.

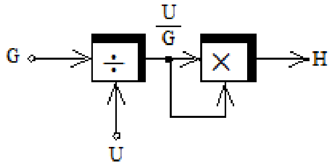

Figure 11. Block diagram based on water velocity equation.

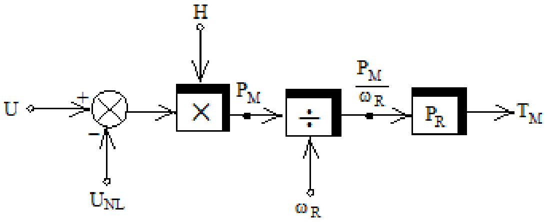

Figure 12. Block diagram based on blue turbine power equation.

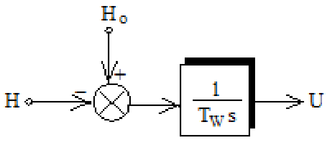

Figure 13. Block diagram based on water column acceleration equation.

Figure 14 shows the block diagram of the hydraulic turbine. Transfer function F(s) that represents the hydraulic system is the water velocity to head at turbine. F(s) represents a distributed parameter system. The complete hydraulic system conversion function that determines the relationship between water speed and turbine height is:

$$F(s)=\frac{U_t(s)}{H_t(s)}=-\frac{1+\dfrac{F_1(s)\,F_2(s)}{Z_P^2}}{\phi_p+F_1(s)+F_2(s)} \qquad (2)$$

where ϕ_p is the channel friction coefficient, and Z_p is the channel hydraulic impedance.

The conversion function of the tunnel and bump tank shows the ratio of the bump tank height (H_S) to the water velocity of the upper channel (U_P):

$$F_1(s)=-\frac{H_S(s)}{U_P(s)}=\frac{\phi_C+T_{WC}s}{1+T_S\varphi_C s+T_{WC}T_S s^2} \qquad (3)$$

where T_S is the bump tank lift time, T_{WC} is the tunnel start time, and ϕ_C is tunnel friction coefficient. If there is no bump tank, the function $F_1(s)$ is zero.

The $F_2(s)$ in terms of channel elastic stretching time (T_{ep}) and channel hydraulic impedance is given by:

$$F_2(s)=Z_P\,\tanh(T_{ep}s) \qquad (4)$$

The application of a nonlinear controller based on a feedback linearization scheme to the multi-input multi-output model of a system consisting of a synchronous generator and a hydraulic turbine was described in [71].

3. SURGE TANK

A surge tank is a stand pipe or storage reservoir at the dam to absorb sudden rises of pressure and to quickly provide extra water during a brief drop in pressure [72]. The surge tank mitigates pressure variations due to rapid changes in the velocity of water. Surge tanks are usually provided at high or medium-head plants when there is a considerable distance between the water source and the power unit, necessitating a long penstock [73,74].

The main functions of a surge tank are given below: (a) it reduces the amplitude of pressure fluctuations by reflecting the incoming pressure waves and (b) it improves the regulation characteristic of a hydraulic turbine. Some of the most common different types of surge tanks that are possible to be installed are simple surge tank, restricted orifice surge tank, and differential surge tank.

The surge tank model is shown in Fig. 15, in which T_W is water starting time, C_S is the storage constant of the surge tank, h_S is surge tank head, q_S is flow into the surge tank, q_T is flow down the upper tunnel, and q_P is flow to turbine [75].

A model of a hydro-turbine system with the effect of surge tank based on state-space equations to study the nonlinear dynamical behaviors of the hydro-turbine system was presented in [76], in which both theoretical analysis and numerical simulations show chaotic oscillations. The simulation of a hydroelectric power plant equipped with a Francis turbine, which has a high-water head and a long penstock with upstream and downstream surge tanks, was given in [77].

4. HYDRAULIC TURBINE GOVERNING SYSTEM

A crucial control system of hydropower plant is the hydraulic turbine governing system (HTGS) [78,79]. It plays a key role in maintaining safety, stability, and economic operation of hydropower generating units [80,81].

The HTGS is a complex nonlinear, multivariable, time-variant system in nature, and non-minimum phase system that involves the interactions among hydraulic system, mechanical system, and electrical system [82,83]. The modeling of HTGS is an important and difficult task [84,85].

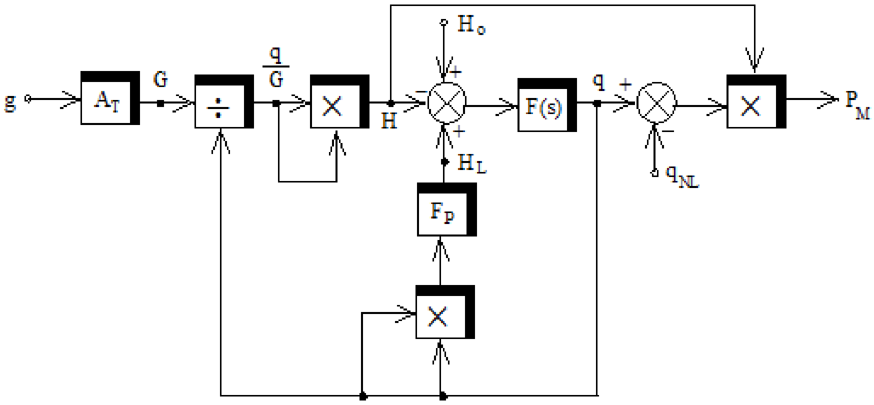

Figure 14. Hydraulic turbine block diagram.

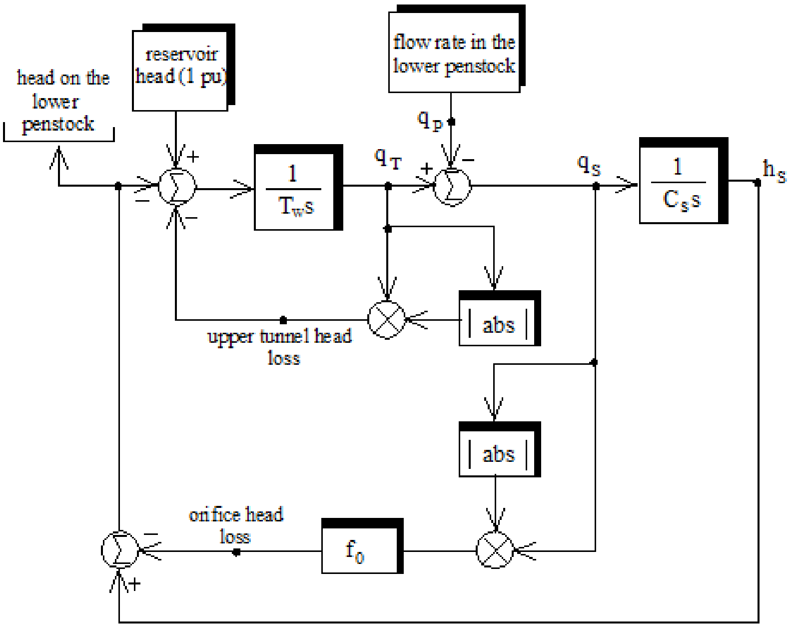

Figure 15. Surge tank model.

The main task of the HTGS system is to adjust the power output to the grid and track the frequency of the grid in general [86,87]. It consists of five parts, that is, conduit system, hydro-turbine, governor, electrohydraulic servo system, and power generator [88,89]. In this system, turbine governor is the controller and hydroelectric generating unit is the controlled object [90,91]. The main difference between the hydroturbine governing system and the gas and steam turbine governing systems is that a higher force is required to move the control gate, since the water pressure and the frictional forces are high. To provide this force, two servomotors are used. A functional diagram of the HTGS is shown in Fig. 16 [92,93].

A number of papers have improved the behavior of the HTGS. In [94], the design and analysis of a robust PID controller for a hydraulic turbine generator governor using a frequency response technique was presented. In [95], an improved gravitational search algorithm was proposed and applied to solve the identification problem for HTGS under load and no-load running conditions, in which HTGS is modeled by considering the impact of turbine speed on water flow and torque. The Hamiltonian mathematical modeling and dynamic characteristics of multi-hydro-turbine governing systems with sharing common penstock under the excitation of stochastic and shock load were presented in [96] for improving the stability of hydropower stations. A gravitational search algorithm was introduced and applied in parameter identification of an HTGS in [97], where the developed optimization algorithm GSA was improved by a compound search strategy of particle swarm optimization. A fractional order mathematical model of an HTGS to analyze the nonlinear dynamic behaviors of the HTGS in the process of operation was presented in [98]. A grey prediction control method for turbine speed control system to solve the stability problem of power system in various perturbations was presented in [99]. The stability for the primary frequency regulation of the hydro-turbine governing system with surge tank was given in [100], where the nonlinear dynamic performance of the system under opening control mode and power control mode was investigated. A mathematical model of an HTGS was presented in [101], and the nonlinear dynamical behaviors of the system considering the process of load rejection transient were studied.

When the water valve opens to compensate for the increase in load by initially reducing the turbine pressure, a short initial change in the turbine occurs, which is opposite to changing the valve position. However, by accelerating the water and increasing its velocity in the water-conducting pipe, the water pressure increases, increasing the generator's output power and ultimately the active power balance. Therefore, blue turbine governors must have significant transient loss, and to ensure optimal and sustained speed control performance, the blue unit governor needs a transient compensator.

Figure 17 shows a block diagram of the governor of the blue turbine system for sustainability study. Two limiters are considered for the position of the water valve and the magnitude of its variations.

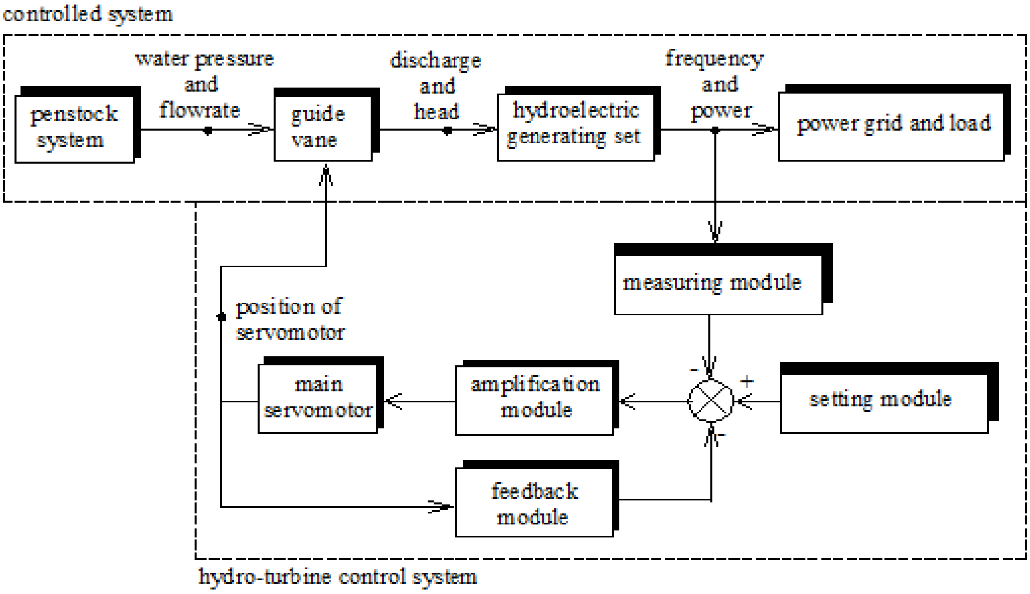

Figure 16. Block diagram of hydroelectric generating regulating system.

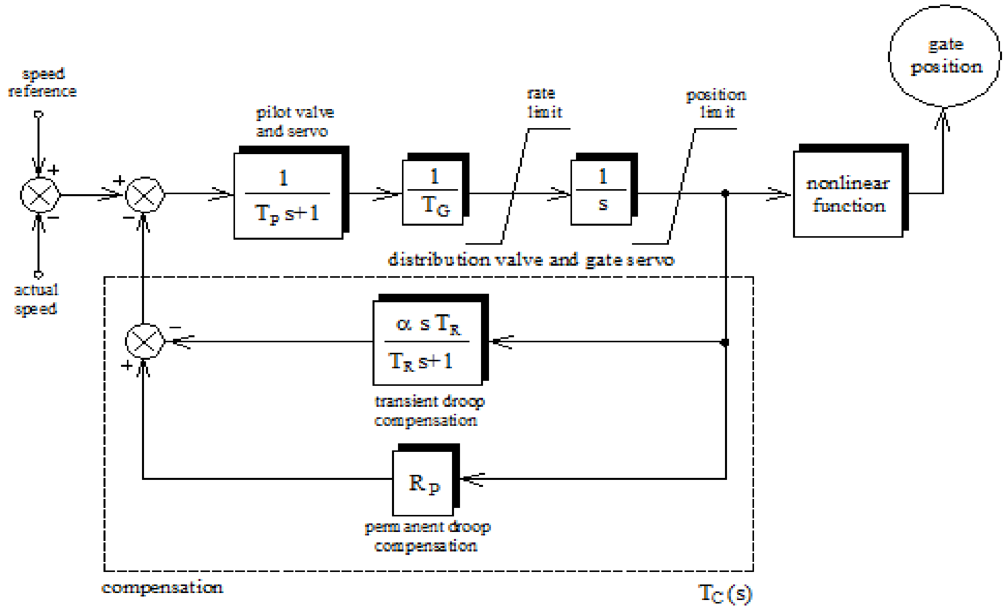

Figure 17. Block diagram Governor model of hydro turbine.

5. ENVIRONMENTAL IMPACTS

Hydropower does not pollute the water or the air. Water has a critical role in all environmental, social, and economic systems. Ecological impacts of hydroelectric power plants are large. They change natural watercourses and movement paths of wildlife around the plant and, thus, alter the ecosystem [102]. Hydropower plants can have positive and negative impacts on the socio-economic development of regions. Hydropower is clean. It prevents the burning of 22 billion gallons of oil or 120 million tons of coal each year. Hydropower does not produce greenhouse gasses or other air pollution. Hydropower leaves behind no waste. Reservoirs formed by hydropower projects in Wisconsin have expanded water-based recreation resources, and they support diverse, healthy, and productive fisheries. In fact, catch rates for game fish like walleye and smallmouth bass are substantially higher on hydropower reservoirs than natural lakes. Negative impact of dams are as follows: in flat basins, large dams cause flooding of large tracts of land, destroying local animals and habitats; people have to be displaced, causing a change in lifestyle and customs of -about 40 to 80 million people that have been displaced physically by dams worldwide; large amounts of plant life are submerged and decay anaerobically; the migratory patterns of river animals like salmon and trout are affected; dams restrict sediments that are responsible for the fertile lands downstream; saltwater intrusion into the deltas means that the saline water cannot be used for irrigation; large dams are breeding grounds for mosquitoes and cause the spread of disease; dams serve as a heat sink, and the water is hotter than the normal river water. This warm water when released into the river downstream can affect animal life [103].

6. DIFFERENCES BETWEEN WATER AND CONVENTIONAL POWER GENERATIONS

A power plant can be of several types based mainly on the type of fuel used. Based on power generation, three major classifications of power production on a reasonably large scale include hydroelectric power generation, thermal power generation, and nuclear power generation. Hydropower produces electricity twenty-four hours a day and has little environmental impact not like solar and wind energy which is not functional twenty-four hours per day [104,105]. The primary disadvantage of solar power is that it obviously cannot be created during the night. The power generated is also reduced during times of cloud cover (although energy is still produced on a cloudy day).

At a hydropower plant, in the frequency control mode, it is possible to save power, which is not the case for a wind power plant [106,107]. Compared with steam turbines, hydro turbines are easier and cheaper to control. Hydropower enjoys high efficiency. Conventional hydropower efficiency is about 80 %. The thermal efficiency of thermal power plants is only 30 %-50 %.

7. HYDROPOWER PLANTS EFFICIENCY

The conversion efficiency of a hydroelectric power station depends mainly on the type of water turbine. In general terms, efficiency is the output of a process compared to the input [108].

In the context of a hydroelectric power plant, there are three types of efficiencies: operational efficiency, economic efficiency, and energy efficiency. The electricity is generated by moving water comes from large hydroelectric power plants and also from smaller ones such as mini-power and micropower plants. It is worth mentioning that more than 90 % of the total hydropower generated in the European Union comes from large hydro. The installed capacity of a small hydroelectric power plant is generally a few MW (<5 MW with an efficiency between 80 and 85 %). The conversion efficiency of a hydroelectric power plant depends mainly on the type of water turbine employed and can be as high as 95 % for large installations. Smaller plants with output powers less than 5 MW may have efficiencies between 80 and 85 % [109,110].

A method to calculate the cost of efficiency losses using a unit commitment dispatch in hydroelectric generators was presented in [111], demonstrating that costs can be comparable to the income of the generator in the short-term market.

8. HYBRID POWER SYSTEM

The output power of a renewable energy generator is highly affected by atmospheric conditions [112,113]. Therefore, a hybrid power system (including two or more input sources) has become the design trend for renewable energy processing, in which a constant output voltage and sustained power supply can be completed [114,115]. As mentioned earlier, hybrid systems can minimize the intermittency problem of renewable systems, which is important. Hybrid power system may or may not be in connection with the grid; therefore, they usually are not dependent on centralized grids and can be used in rural places [116,117].

The load frequency control of an interconnected two-area power system under deregulated environment was presented in [118], where Area 1 is a thermal system having two generating companies and Area 2 is the hydrothermal system. A coordination methodology for wind and pumped-storage hydro units in the day-ahead operation planning of power systems was proposed in [119], where the pumped-storage unit can offset intra-hour wind energy imbalances with coordination and minimize wind energy curtailments. The wind market value in power systems where hydroelectric stations with large reservoirs prevail was assessed in [120]; when moving from 0 % to 30 % wind penetration, hydropower mitigates the value drop by a third. The competitive interactions between an autonomous pumped-storage hydropower plant and a thermal power plant in order to optimize power generation and storage were studied in [121], where each type of the power plant individually tries to maximize its profit by adjusting its strategy.

9. FACTS EFFECTS ON HYDROELECTRIC POWER PLANT

FACTS controllers are static power-electronic devices installed in AC transmission networks to stability, increasing power transfer capability and controllability of the networks through series and/or shunt compensation [122,123]. They are used in the energy system [124].

The analysis of automatic generation control of a two-area interconnected power system under the open market scenario in the presence of thyristor controlled phase shifter-based hydrothermal system in the continuous mode using the fuzzy logic controller was presented in [125]. The LFC of the interconnected two-area system with one area as multi-unit of all-hydro power system and the other as all thermal/ thermal-hydro mixed were investigated in [126]. The authors presented a coordinated control between TCPS and SMES, with the gains of the integral controller in AGC loop and parameters of TCPS/ SMES being optimized by craziness-based PSO. A static synchronous compensator along with a variable frequency drive for voltage and frequency control of a small-hydro turbine-driven self-excited induction generator system was proposed in [127], where the FACTS devices were used to control the terminal voltage through variable reactive power injection.

10. RESPONSE GENERATING UNIT

The governors of hydraulic units require transient droop compensation for stable speed control performance. The nature of the responses of generating units with a hydraulic turbine with reheat steam turbine and without reheat steam turbine when subjected to a step change in load is shown in Figs. 18, 19, and 20.

The simulation results show that the steady state speed deviation is the same for all three units considered, and there are significant differences in their transient response.

11. HYDROPOWER PLANT IN MICROGRID

A microgrid is a localized grouping of distributed energy resources, loads, energy storage devices, inverters, and protection devices [128-131]. There are different approaches in the operation of microgrids [132-134]. A simplified microgrid system with (a) controllable generation like the generation diesel generators and load bank, (b) not controllable generation (limited) like the photovoltaic cell and wind turbine, and (c) distributed energy storage like batteries and supercapacitors is shown in Fig. 21 [135,136].

A number of studies have investigated the application of the heyroplant power plant in the microgrid [137,138].

A microgrid topology with two generators, one of which is driven by a small-hydro turbine and other driven by a small-scale wind turbine, was studied in [139], demonstrating that the voltage and frequency of the system were regulated and the power-quality-related issues were also resolved in this microgrid. A control system to improve the parallel operation of two microhydro power plants, equipped with fix-speed turbines that drive induction generators, on an islanded microgrid was presented in [140], in which the proposed control method is a combination between active elements and passive ones. The modeling and control of a small hydro-power plant for a DC microgrid based on passivity theory was presented in [141], where the electrical, mechanical, and hydraulic dynamics in the mathematical model of the plant were considered.

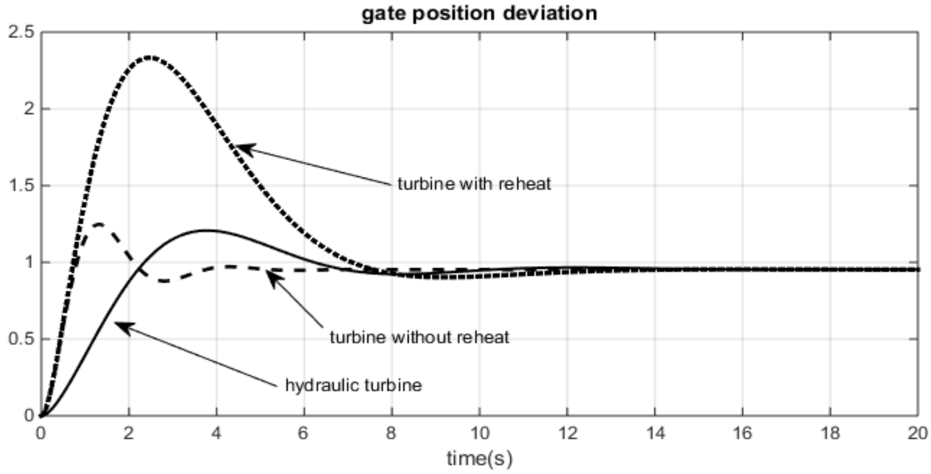

Figure 18. Turbine valve/gate position.

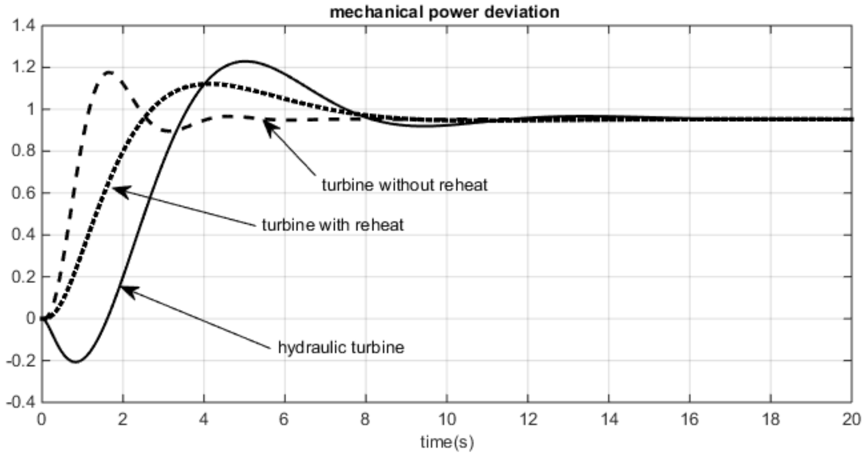

Figure 19. Mechanical power.

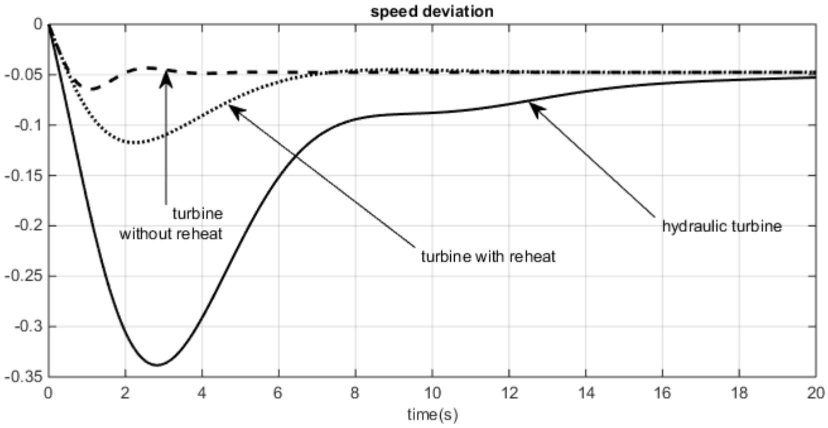

Figure 20. Speed deviation.

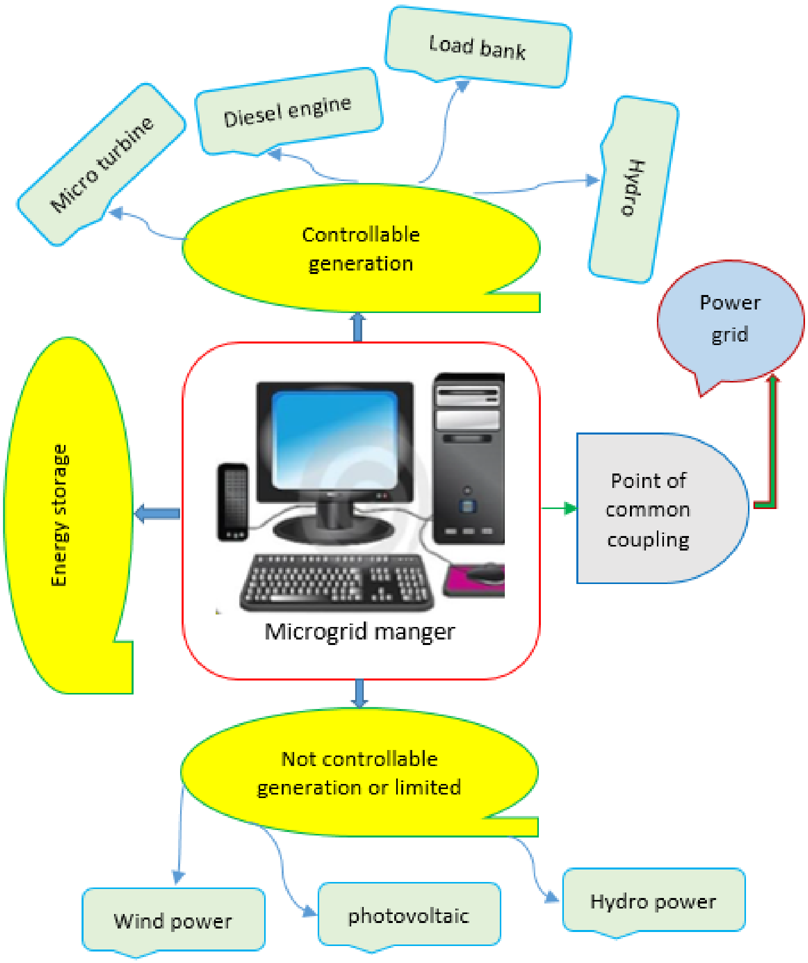

Figure 21. Schematic of a microgrid with different connected energy sources.

15. CONCLUSIONS

Hydropower is generally available in remote areas. It is a major energy source among the renewable energy sources. Worldwide, about 20 % of all electricity is generated by hydropower. Most of the countries now have hydropower as the source of major electricity producers. Hydropower schemes are classified according to installed capacity, how dependent energy production is on available flow, head conditions, and potential for the scheme to be multi-purpose.

In this paper, an extensive literature review of the research of hydroelectric power plants was carried out. Therefore, hydropower is a sustainable and long-lasting source of energy. It produces a great amount of electricity. Dams can also be used for other purposes such as fishing and sports. All these advantages show the importance of hydropower electricity, which gives us a solution to the problems of this boom and gloom economy.

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