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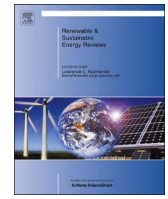

Present trends and future prospects of asynchronous machines in renewable energy systems

C. Carunaiselvane*, Thanga Raj Chelliah

Department of Water Resources Development and Management, Indian Institute of Technology, Roorkee, India

A R T I C L E I N F O

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A B S T R A C T

To fulfil the yearning of the majority population around the world and the need for environmental concerned energy conservation made renewable energy system (RES) as much obligatory among other energy systems. The asynchronous machines are particularly used in wind and hydro for creating more opportunities and challenges to have a control over them in order to create a stabilized RES. This paper extensively reviews on various types of asynchronous machines under different operating speeds and the existing control techniques deployed over them to aid a stabilized RES. In this context an analysis on the gradual development of machines and the role of power electronics over them to adopt with the up to date technology has been carried out. Additional benefits in terms of energy efficiency comparison between the synchronous and asynchronous machines in variable speed operation has also been premeditated. To a greater extent the paper advents the topical inclinations and imminent directions on asynchronous machines that can widely contribute to the growth of RES.

1. Introduction

The world's foremost energy sources can be characterized under conventional or non-renewable and non-conventional or renewable energy sources. In which the non-renewable based on oil, coal, and natural gas are being used expansively in such a way that their known reserves have been depleted and are expected to end in nearby future [41]. At the same time it is becoming difficult task to exploit their new deposits. The scarcity of conventional energy resources, rise in the fuel prices, concern for the environment and difficulties in accessing grid power to remote areas and the nonexistence of rural electrification have encouraged for never ending, non-polluting and widely available alternative sources of energy [5]. This search for alternative energy sources had forced the planners to end up with energy sources that can replenish naturally. Energy existing within nature is converted into a form which depends on the utilization say heat or electricity by a renewable energy system. These advantages, combined with the almost no emissions of both air pollutants and greenhouse gases made them very attractive energy systems among engineers as well as national interested common man also. However, global energy demand by this renewable energy is only 15–20% of total energy demand. Whereas, India, which is a developing country where most of the population lives in isolated rural areas ranks world's 6th largest energy consumer, accounting for 3.4% of global energy consumption are benefited by electrification in a decentralized mode by nearby available renewable energy resources [3] and [4]. The locally available renewable energy resources in remote rural areas, mainly include micro hydro power, biomass, wind and solar photo voltaic. The total renewable energy installed capacity (as of November 2015) in India is 38,283.59 MW in which, wind power capacity is 24,759.32 MW and hydro power is 4161.9 MW [105].

Though renewable energy sources have many advantages, those are gainful only if the sources are converted into proper and efficient form of electrical energy. In order to make a better renewable energy system (RES) from these sources, it is very necessary to couple a prescribed electrical machine along with these sources, depending on its application. The paper chooses the turbine related renewable energy sources i.e. wind power and hydro power and reviews about the asynchronous electrical machines coupled with them to achieve a better renewable energy system. This paper also suggests a suitable asynchronous machine from the available asynchronous machines as shown Fig. 1, for a particular operating condition and how these machines be controlled to have a better energy efficiency system.

Since the paper mainly focuses on the application of asynchronous machines it is very obligatory to have the following insight i.e. basic ideas on how asynchronous machines serves for mechanical to electrical energy conversion in RES (Section 2), the process by which different types of electrical machines are believed to have developed from earlier forms during the history of the RES (Section 3), a detailed state of the art on the influence of controllers and many other modern

* Corresponding author.
E-mail addresses: caruc.dwt2014@ittr.ac.in (C. Carunaiselvane), thangfwt@iitr.ac.in (T.R. Chelliah).

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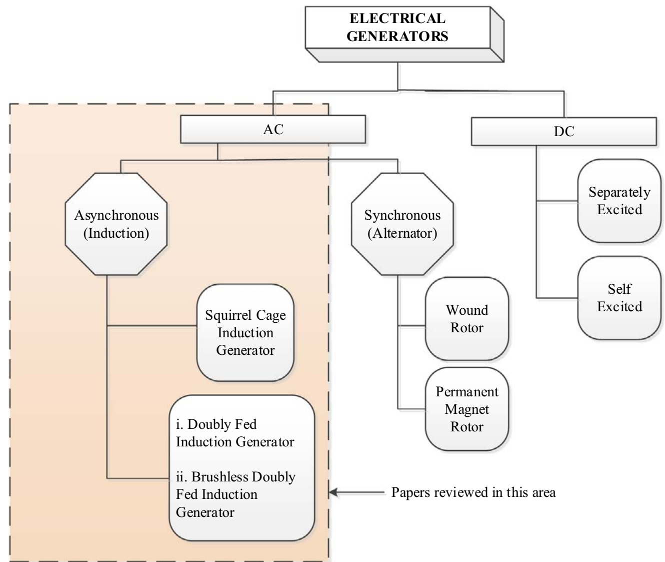

Fig. 1. Classifications of generators.

control techniques to improve the system stability under fixed speed (Section 4) and variable speed operation (Section 5), the role of power converters as an efficient interface between asynchronous machine and grid as well as for adjustable power transfer (Section 6), close to the present trends and the time regarded as still to come developments in asynchronous machines are discussed (Sections 7 and 9 respectively) and finally an illustrative example is done (Section 8) where synchronous and asynchronous machines are compared with a variable head hydro turbine and concludes (Section 10).

2. Electrical generating equipments in renewable energy system

To culminate the complete renewable energy system the mechanical force from the turbine has to be converted to exploitable electrical energy and it is evident that generators are the only rotating machines that can convert a mechanical energy to electrical energy. The general and complete electrical generation process in a renewable energy system is shown in Fig. 2.

The conversion of mechanical to electrical energy is a complicated task because it involves not only a mechanical and electrical system, but apart from that there is also another system that connects both these systems called the magnetic system. As illustrated in Fig. 3, an electromechanical system entails a magnetic system with magnetic flux, flux density, and field strength as their fields. All these field quantities are governed using Maxwell's equations [2]. The magnetic system fits as a “ferry” between the electrical and mechanical systems in an energy conversion system. When this magnetic system coupled with a mechanical system, the rotation of moving parts of the machine varies the magnetic flux linkages. These magnetic flux linkages induce an electromotive force (emf) in the electric circuit and current which are the active components of the electrical system. The products of these active components are equalized by the product of torque and speed. On the other hand, when coupled with an electrical system, the magnetic flux interrelating with the current in the circuit would produce a torque on a mechanically movable part. Therefore, the mechanical energy and the electrical energy are interconverted through the magnetic field [1].

The magnetic system purely depends on the design features of a machine [2]. From these discussions it is very evident that unless otherwise the design features match with the requirement that particular machine cannot be used for all operating conditions. Hence, this paved the way for the perception to be based suggestion of asynchronous machine based on applications. The turbines are operated under two major operating conditions, one is fixed speed operation and the other is variable speed operation as shown in Fig. 4.

The available AC generators can be classified under synchronous and asynchronous machines, in which asynchronous machines can be self-started whereas synchronous machines requires external resources to run it in synchronous speed. Since synchronous machine runs at only synchronous speed, the power generation is possible only at that speed range, which has been demonstrated with an illustrative example in Section 8, however asynchronous machine generates power possibly on super and sub synchronous speed along with synchronous speed [5]. These advantages combined with economic feasibility made intended the review to focus on asynchronous generators, they lack more in absorbing the reactive power from the utility grid and performing voltage regulation which is the major source of voltage fluctuations. When the same is done on synchronous generators experiences stability problem due to voltage regulators [6]. Therefore, it is very necessary to observe the responses of the generator in the renewable energy system during faulty conditions to improve the system stability [44]. These key points made mandatory the perception to be based on system stability under different operating conditions as shown in Fig. 5.

3. Evolution of generators in renewable energy system

The power generation in renewable energy systems started with the co-ordination of squirrel cage induction generators with standard layout of generator coupled with gear boxes. Since the generators were limited to operate at a fixed speed their stator was connected directly to the grid. During this era, both synchronous and induction generators served the renewable energy system equally. Later growing demand in role of renewable energy power in the overall power system and precise methodological requirement for coordinating grid, the alternate and advanced technology for variable speed operation was developed. As variable speed operation came into existence the change in the design of existing synchronous and induction generator were prerequisites. To change the design of synchronous generator to support variable speed operation was quite tedious and more advanced researches were required then. Similarly, in the case of an induction generator, the rotor were not accessible through external circuits. Therefore, the induced currents that are responsible for torque generation are firmly a function of the slip speed. In-order to make induction generator a variable speed machine the rotor circuits are to be made externally accessible so that the rotor currents can be manipulated and therefore the electromagnetic torque production. This type of induction machine where the three isolated rotor windings can be electrically accessible via slip rings on the shaft of the machine was popularly named as wound-rotor induction machine. The variable speed technology was becoming more popular by the wound–rotor induction machine as similar to the field of power electronics. Though the wound–rotor induction machine was serving variable speed technology healthier the slip power was not utilized efficiently by this machine. As power electronics started spreading widely during this era, they were involved in wound-rotor induction machine to recover the slip power. When power converters were collaborating with the wound-rotor induction machine, it was able to meet the requirements of grid, as the machine was able to provide frequency support and reactive power besides active power. After this development the variable speed renewable energy system can be basically divided into types. The first type is equipped with a wound-rotor induction generator whose stator is directly connected to the grid and rotor with a small size back-to-back power converter, they are popularly called as a doubly fed induction generator (DFIG). The second type is equipped with a conventional synchronous generator which is connected to the grid via power converters in between [69], [7] and [8].

A schematic diagram of all types of generators associated with renewable energy systems is shown in Fig. 5. In the figure, the generators are primarily classified into synchronous and asynchronous