Asynchronous Generators with Dynamic Slip Control

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Abstract — **This paper presents various systems for dynamic slip control of wound-rotor asynchronous generators. Particular systems are presented here and compared to each other. This paper thus yields a comprehensive overview of systems for converting wind energy to electrical energy using asynchronous generators with slip control.**

Keywords — *Asynchronous generator, dynamic slip control.*

I. INTRODUCTION

Asynchronous generators (AG) permit operation in the over-synchronous and under-synchronous range, i.e. above or below the synchronous speed. The speed of AG can be varied by:

- up to 10 % with dynamic slip control (Fig. 1a);
- approximately 30 % in over-synchronous operation using static Kramer system (Fig. 1b);
- around 40 % in under- and over-synchronous operation in double-fed systems, i.e. a total of 0.6 to 1.4 times the synchronous speed (Fig. 1c) [1].

Wound-rotor asynchronous machines give the opportunity of output branching. In this system, the majority of the converted energy is passed directly from the stator to the grid.

The rotor output which is usually much lower and is proportional to the slip is drawn off into additional resistors in the form of losses (dynamic slip control). On the other hand, the slip output is conditioned for transfer to the grid by a frequency converter in over-synchronous operation (static Kramer system, double-fed system). Furthermore, the power is taken from the grid via the frequency converter in under-synchronous operation (double-fed system) [2].

Although the dynamic slip control is uneconomical there is still rather big share on the market with these kinds of wind systems [3]. In this paper, various methods of dynamic slip control are described and compared to each other.

II. DYNAMIC SLIP CONTROL

AGs with wound rotor usually permit intervention via the slip rings [4]. Moreover, the energy induced in the rotor can be converted in the rotor system or inductively transferred to the stator. As well as the methods for converting slip energy and feeding it into the grid, there is also the option of its complete dispense in order to keep the cost of the conversion system low [5].
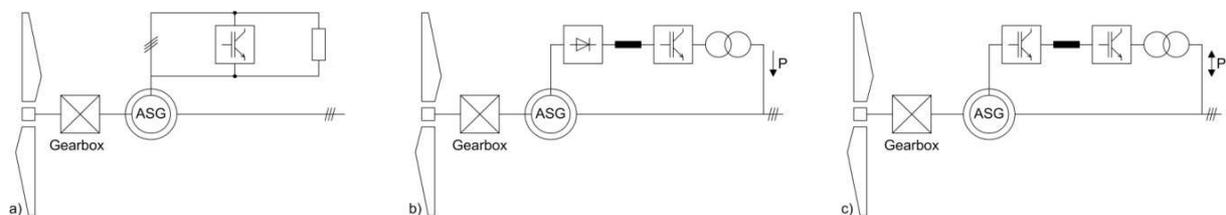

Fig. 1. Systems for converting wind energy to electrical energy with wound-rotor asynchronous generator; a) dynamic slip control, b) over-synchronous Kramer system, c) doubly-fed asynchronous generator.
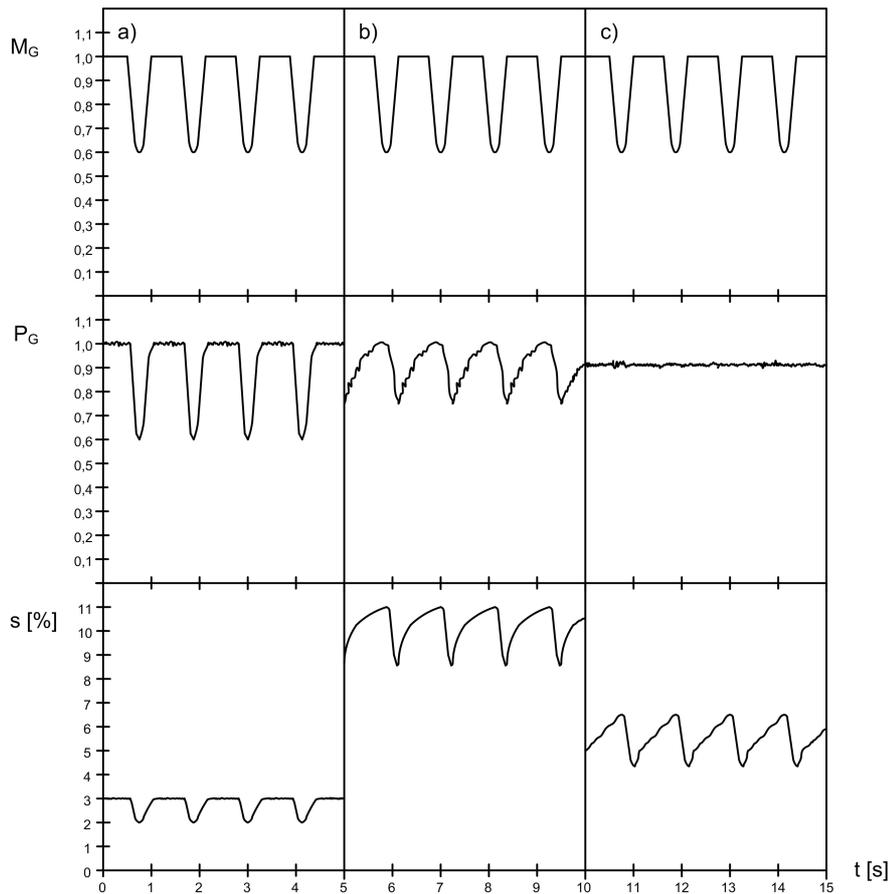
Fig. 2. System behavior of asynchronous generators for: a) the short-circuited rotor,
b) the rotor with fixed additional resistors and c) slip control.

Wind turbines are subjected to random and periodic output fluctuations due to wind-speed variation, tower-shadowing effects, natural resonances of components, etc. in a fixed-speed connection of the generator to the grid [6]. These fluctuations are passed into the grid at almost their full level via the drive train and the generator coils. Large slip values significantly reduce the load on the drive train and greatly reduce output fluctuations. However, if the slip energy is not recovered, high losses in the rotor circuit occur [1]. To achieve a high total efficiency, the rotor slip should be kept as low as possible in this relatively simple system. A favourable conversion system should therefore combine the two contradictory options of low slip energy losses and high dynamic speed and slip flexibility.

Wound rotor AGs permit three operating possibilities (Fig. 2). In the case of a short-circuited rotor winding, the generator operates at the lowest slip and thus achieves the best machine efficiency. However, this results in high drive-train loading and large output fluctuations (Fig. 2a). By connecting resistors in three phases of the rotor circuit, high slip values and thus high elasticity of speed can be achieved. Increase in slip brings better dynamic characteristics but poorer efficiency (Fig. 2b). With a continuous adjustment of slip to the prevailing wind and grid conditions a rapid change of the rotor circuit resistance aided by the alternating switching process between short-circuited rotor winding and full resistance in the rotor circuit can bring output-smoothed and efficient operating ranges. Thus, in the part-load range, low slip values can be set and adjusted slightly in order to achieve a high level of efficiency (Fig. 2c).

Figure 2 illustrates the characteristics of a system with slip control in comparison with the unregulated layout with short-circuited rotor and with additional resistors connected in the rotor circuit. This shows that a slip-controlled system can smooth output fluctuations caused by tower shadowing or similar effects. At the same time, average slip values (and thus losses) can be kept low.

III. DIFFERENT SYSTEMS FOR DYNAMIC SLIP CONTROL

A. Conventional designs

Figure 3 shows the conventional concept for wind turbines with slip control based upon the wound-rotor asynchronous generator. Using this system it is
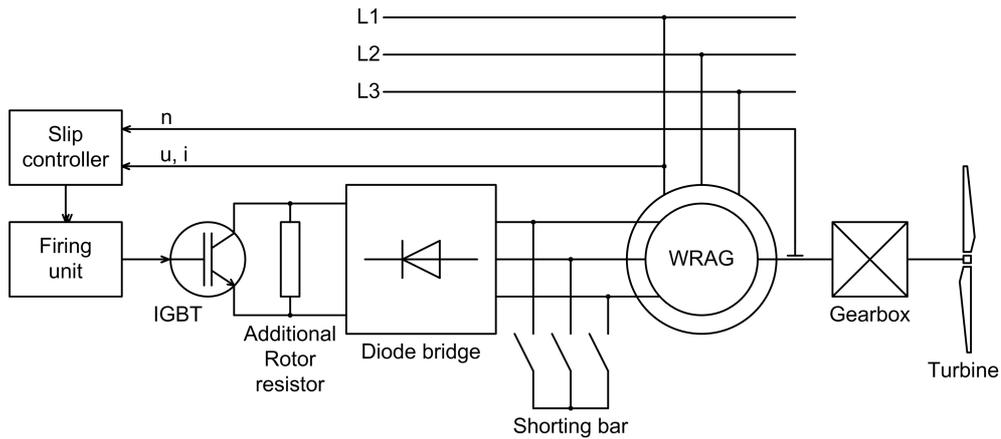
Fig 3. Dynamic slip control of wind turbine with WRIG for a rotor circuit with a rectifier bridge
and single-phase pulsing at the additional resistor.

possible to design the rotor circuit with a rectifier bridge and single-phase chopper at the additional resistor (Fig. 3) or to design the rotor system with additional resistors and chopper in all three phases (Fig. 4). The additional rotor resistors and the slip regulation and its drive are generally fitted as a separate unit outside the generator.

The works [7] and [8] have shown that a simple single-phase design, as shown in Figure 3, tends to cause mechanical vibrations in the drive train. These vibrations result from the rectification of rotor currents and due to the square-wave current in the case of the rectifier bridge take on values six times the slip frequency. This rotor current harmonics are also transferred to the stator and give rise to increased losses in the generator. Moreover, remedial measures are necessary to remove the vibrations. These disadvantages can be avoided by a symmetrical system with the three-phase rotor circuit design, as shown in Figure 4. However, due to the three-phase synchronized anti-parallel design of the frequency converter that this system calls for, the cost is considerably increased.

By a combination of the two variants, the design shown in Figure 5 with a three-phase resistor and single phase chopper can be used to build a relatively simple system which can achieve good operating results at a reasonable cost. Unlike the single-phase system in Figure 3, this configuration does not cause mechanical vibrations in the drive train. However, due to the lack of the resistor in parallel with the IGBT switch, an additional protective circuit is required to protect against the overvoltage that is created in the direct current circuit due to current pulsing.

According to the report [9], an annual running time of approximately 8000 hours must be assumed for generators in wind turbines. Components, particularly the slip-ring transmission system, are subjected to wear. Thus, regular maintenance and easy replacement of wearing elements must be ensured. In the recent years, particular attention was paid to elimination of the maintenance of the slip-ring transmission system. These efforts gave rise to the brushless design combining advantages of the dynamic slip control and brushless design.
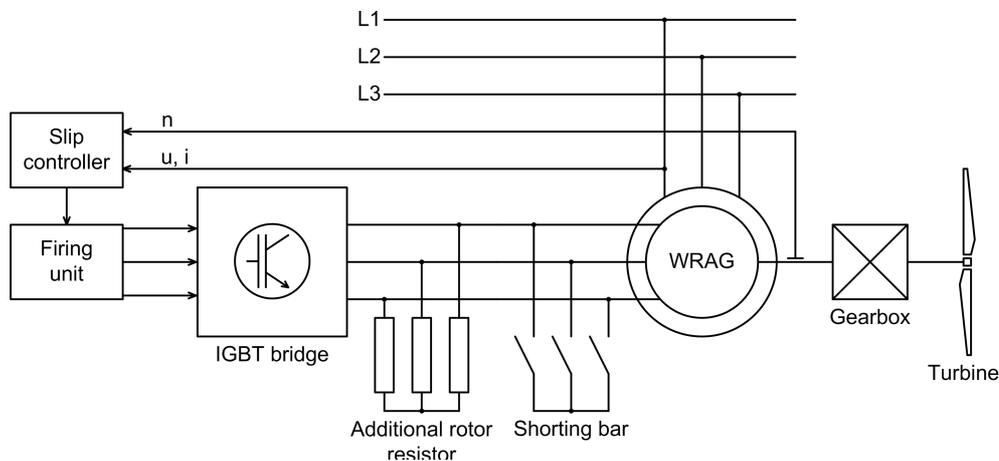

Fig. 4. Dynamic slip control of wind turbine with WRIG for a rotor circuit with three-phase additional resistor
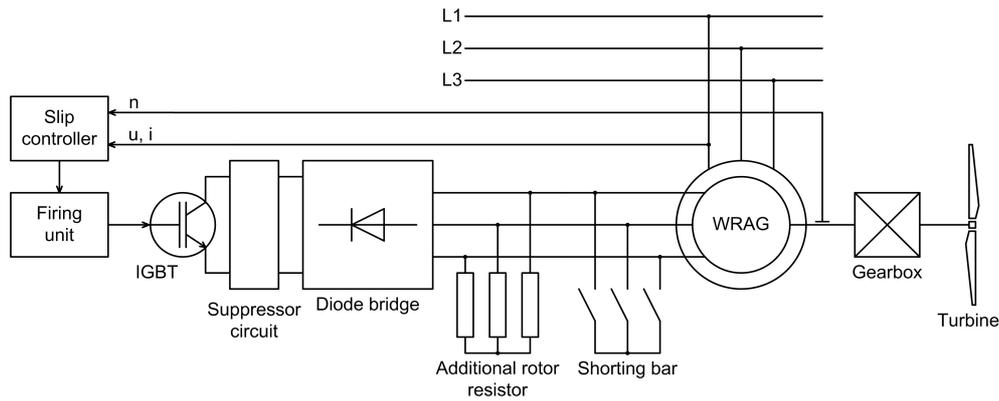
Fig. 5. Dynamic slip control of wind turbine by three-phase additional resistors with direct current pulsing.

B. Brushless designs

Brushless design is also possible in asynchronous machines. There are two systems that are used in the industry. The first is based on inductive transmission of the rotor-slip energy by secondary windings (Fig. 6) [10]. This is the simplest layout of brushless dynamic slip control design.

The other design is nowadays widely used in the multi-kilowatt range by the Danish producer VESTAS [11]. This system has the complete power section with additional resistors, power electronics and regulation in the rotating part of the generator (Fig. 7). The integrated current regulation is installed at the rear of the generator on the end of the shaft and consists of additional resistors, power electronics, current sensors and a microprocessor controller. The communication signals between the management system and the current-regulation device are carried via maintenance-free optical fibres.

IV. CONCLUSION

One of the biggest advantage of dynamic slip control of the wound-rotor AG is that unlike the other systems described in the chapter 1 (Fig. 1b, c), power electronic components used in this system do not affect the components electrically connected to the grid [1].

As mentioned in chapter 3, system with three-phase resistors and a single-phase chopper achieves best operating results at a reasonable cost reduced by reduction of power electronic devices. Therefore, this system is the best choice when consider conventional system with slip rings.

Recent years have shown that the maintenance cost in multi-kilowatt range is the crucial condition and thus mainly the brushless design is widely used. Due to the simple construction of dynamic slip regulation of wind turbine with power section and regulation in the rotor, only this system is practically used. It combines
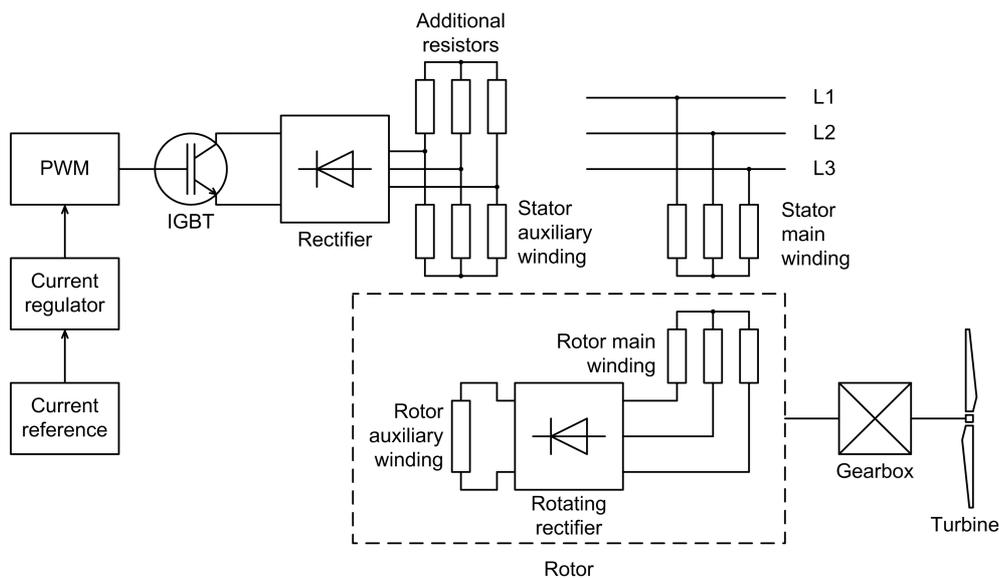
Fig. 6. Brushless dynamic slip control of wind turbine with slip energy transmission by secondary windings.
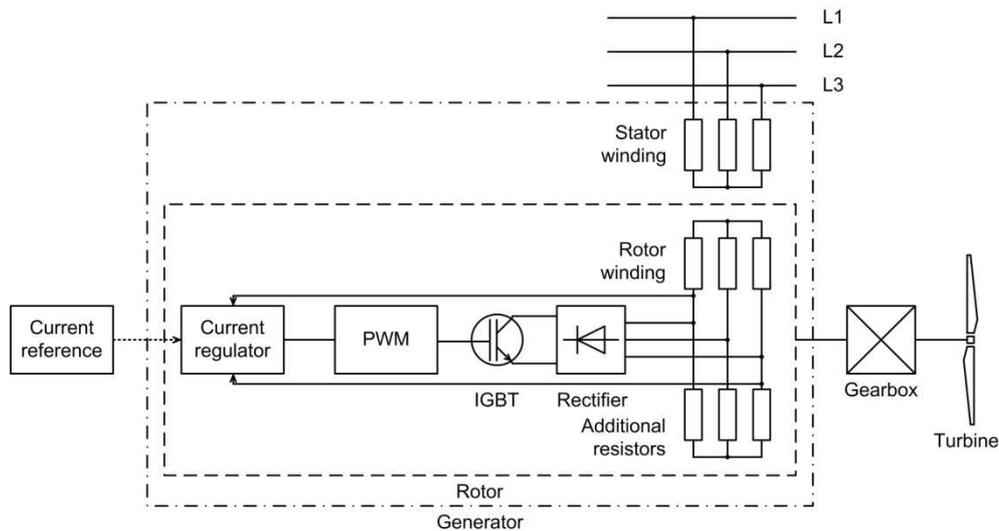
Fig. 7. Brushless dynamic slip control of wind turbine with power section and regulation in the rotor.

the brushless design and best performance of brushes system possibilities. This is the reason why this system nowadays has the biggest share on the market [3].

V.   ACKNOWLEDGMENT

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