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Energy Saving Concepts Relating to Induction Generators

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ENERGY SAVING CONCEPTS RELATING TO INDUCTION GENERATORS

INTRODUCTION

Recent development of the energy saving Power Factor Controller (PFC) for induction motors, U. S. Patent No. 4,052,648, resulted in numerous inquiries to the Marshall Space Flight Center (MSFC). Two of these inquiries led to brief investigations by MSFC which resulted in the demonstration of two additional energy saving technologies applicable to the induction machine when used as a generator.

Although the induction motor has been the "workhorse" of home and industry for the greater part of this century, with close to a billion in use daily in the U.S. alone, there has been, until recently, very little interest in their application as generators.

This paper first describes a technique for using an induction machine as a variable load for prime movers or load coupling mechanisms under test. This technique provides a means for recovering most of the test energy, which is usually dissipated as heat. Second, it describes a technique for reducing the losses in an induction machine being used as a wind driven generator.

REGENERATIVE VARIABLE LOAD

In the performance testing and in the life testing of prime movers and load coupling mechanisms such as electric motors, internal combustion engines, transmissions, belts, etc., the mechanical output energy of the test specimen, in most applications, is absorbed and dissipated as wasted heat in such standard devices as dynamometers and prony brakes. Rising energy costs have created a demand for a system which can provide the variable load while recovering most of energy output of the mechanism being tested. The direct current (dc) generator, for example, is ideal for providing a variable load. However, the electronics required for converting the dc to alternating current (ac) are complex and expensive.

By using a conventional ac induction machine as the load for the drive mechanism and a variable transformer as a means of varying the load, most of the output power of the drive can be converted to electrical energy and returned to the line. If an induction machine is connected to an ac line and driven at higher than synchronous speed in the same direction that it runs as a motor, it becomes an induction generator. It will convert mechanical energy applied to its shaft to electrical energy which it returns to the ac line. The ac line regulates the frequency and output voltage of the induction generator, eliminating the need for expensive and complex electronic conversion equipment.

When used in this application, the induction generator must be driven at a speed a few percent higher than synchronous speed as shown in Figure 1. This might be done by coupling it to the drive mechanism with a belt and selecting the proper pulley ratio. Typically, if an induction motor has a name plate rating of 1725 rpm (75 rpm below synchronous speed), it should be driven at approximately 1875 rpm when used as a generator.

To obtain a variable load, the induction generator is connected to the ac line through a variable transformer (variac) as shown in Figure 2. The load provided by the generator will vary with the applied voltage and can be precisely controlled from zero to rated load by varying the setting of the variac. Since the losses in the variac are low, the energy returned to the ac line will essentially be equal to the energy applied to the shaft of the induction generator multiplied by its efficiency. Its efficiency versus torque as a generator is essentially the same as its efficiency versus torque as a motor. Although the system shown is for a single phase motor, it is also applicable to three-phase motors by using a three-phase variac. Typically, a reasonably loaded three-phase motor will return 80 to 90 percent of the energy applied to its shaft back to the line.

In a specific application where the prime mover is an induction motor that is either larger than or equal in size to the load machine, the variac can be used to vary the applied voltage to both machines. In addition to varying the load, this also will reduce the losses in the drive motor at the lighter loads. The variac, however, has to be sized to supply the vector sum of the motor and the generator currents.

A second method of obtaining a variable load is shown in Figure 3. Instead of using a variac for varying the voltage, a triac or two silicon controlled rectifiers (SCR) may be used. The triac is turned on for only a portion of each half cycle and the load provided by the generator will vary as the length of the on-time of the triac varies. The firing angle control circuit varies the on-time of the triac to provide the desired load. The energy returned to the line is essentially the same as with the variac method. For three-phase motors, a triac (or two SCR) would be required in each leg with appropriate control circuitry.

There are two potential disadvantages with the above described technology. First, in the testing of certain types of equipment, it may be required to vary the speed over a broad range. The induction generator concept is valid only for speeds greater than synchronous speed. This requirement could be accommodated to a degree by the selection of pulley ratios, gearing, or a variable speed transmission. For providing a variable load at speeds significantly greater than synchronous speed, an induction machine with a high inherent slip characteristic can be used as the generator. In this way a broad torque-speed range in the generator can be achieved. This will, however, result in a sacrifice of efficiency.

A second potential disadvantage that results with the induction generator concept is poor power factor. The power input to a motor is equal to the product of the line voltage, the current, and the cosine of the phase angle between voltage and current ($EI\cos\theta$). The cosine of θ is defined as the power factor of the system. In an idling motor, the current may lag the voltage as much as 75° to 80°. If an external torque is applied to the shaft and increases the speed to synchronous speed, the phase lag will increase to 90°. At that point the losses in the machine are being supplied by the external force and the net electrical energy is zero since the cosine of 90° is zero. As the external force increases to drive the machine at higher than synchronous speed, the phase lag exceeds 90°. The cosine of angles greater than 90° is negative indicating negative power flow, or that energy is now being returned to the line. As the driving force continues to increase to where full load current is being returned, the phase lag may be as much as 150°. It can be seen from the previous discussion that, in typical applications, large phase angles and hence poor power factors may result, even though energy is being returned to the line. The significance of this would have to be evaluated for the specific application in conjunction with the method used by the utility company to penalize the user for poor power factor loads.

The previously discussed scheme for providing a regenerative variable load has been successfully demonstrated on single-phase and three-phase motors. In a recent test, an integral horsepower three-phase drive motor was coupled by a belt to a second integral horsepower three-phase load motor. Information received from this test indicated successful variable loading and a maximum energy return of approximately 70 percent of the energy input to the drive motor. Based on this test, the payback time for the purchase of a load motor, a variac, and power factor correction equipment could be well under one year.

WIND DRIVEN GENERATORS

Although induction generators are well documented in textbooks, there has been very little interest in their usage, since the magnetization current has to be supplied by the ac line to which it is connected. There was little need for a generator if the power source was already available. However, because of the rapid rise in energy costs and in tax credits provided for energy conservation schemes, induction generators are being applied as the energy converter in certain co-generation systems such as wind driven generators. Approximately 40 domestic firms now build wind driven generators, and many of these use induction generators as the energy converter.

In this application, the propeller attempts to overspeed the generator, but is limited by the retarding torque produced by the generator to a speed a few percent higher than synchronous speed (Fig. 1). The system is designed for a given maximum wind velocity, and the motor must either be decoupled or disconnected from the line above that velocity to prevent damage. It can also be seen from Figure 1 that a minimum wind velocity is required to drive the generator to synchronous speed to supply the inherent losses in the generator. Hence, the generator is disconnected from the line at a minimum wind velocity to prevent consuming power as a motor and is again disconnected at a maximum wind velocity to prevent damage. The generator design is compromised to minimize low load losses while obtaining good high load performance. Minimizing low load losses allows the system to be turned on at a lower wind velocity and hence broadens the operating range.

The aforementioned patent No. 4,052,648 describes a technique for reducing losses in an induction motor. It was shown in that disclosure that high currents flow in a lightly loaded induction motor which cause a significant power loss. By reducing the applied voltage to that necessary for a given load, the losses can be minimized. A similar technique, though simpler than that of the PFC, can be applied to induction generators to reduce losses, allow the system to be energized at a lower wind velocity, and improve overall operating efficiency.

It was previously shown that the phase lag between voltage and current increases as the force driving the generator increases. This is compatible with the inherent turn-off characteristics of triacs and SCR. Once these devices are gated on, they will remain on until the anode current goes to zero. Hence, unlike the variable load application previously described, where the control circuitry advances the firing angle to increase the load, the wind driven generator requires only a fixed predetermined firing angle as shown in Figure 4.

A minimum on-time of the triac is required to supply the magnetizing current, and is determined by test. This minimum on-time occurs at the lowest wind velocity at which the generator is energized. As the wind velocity increases, the external energy causes the current and its phase lag with respect to the voltage to increase. The increased phase lag inherently causes the triac to remain on longer allowing energy to be returned to the line as shown in Figure 4. If the wind is sufficient to drive the generator to full load, the triac remains on continuously, resulting in no sacrifice in high output performance.

In a demonstration of the previously described system, the idling losses in a 1/2-horsepower single phase motor were reduced from 220 W to 75 W with no sacrifice in full load performance. It should be also noted that the net cost of adding the triac and its control circuitry to a wind driven generator can be minimized if the triac also serves as the disconnect switch for the generator.

CONCLUSIONS

Rising energy costs and tax incentives granted for energy conservation measures have created new interest in co-generation systems. The induction generator, because of its ruggedness and inherent voltage and frequency regulation, is ideal for supplementing existing power systems. Two energy saving technologies relating to induction generators, though not fully developed, have been successfully demonstrated.

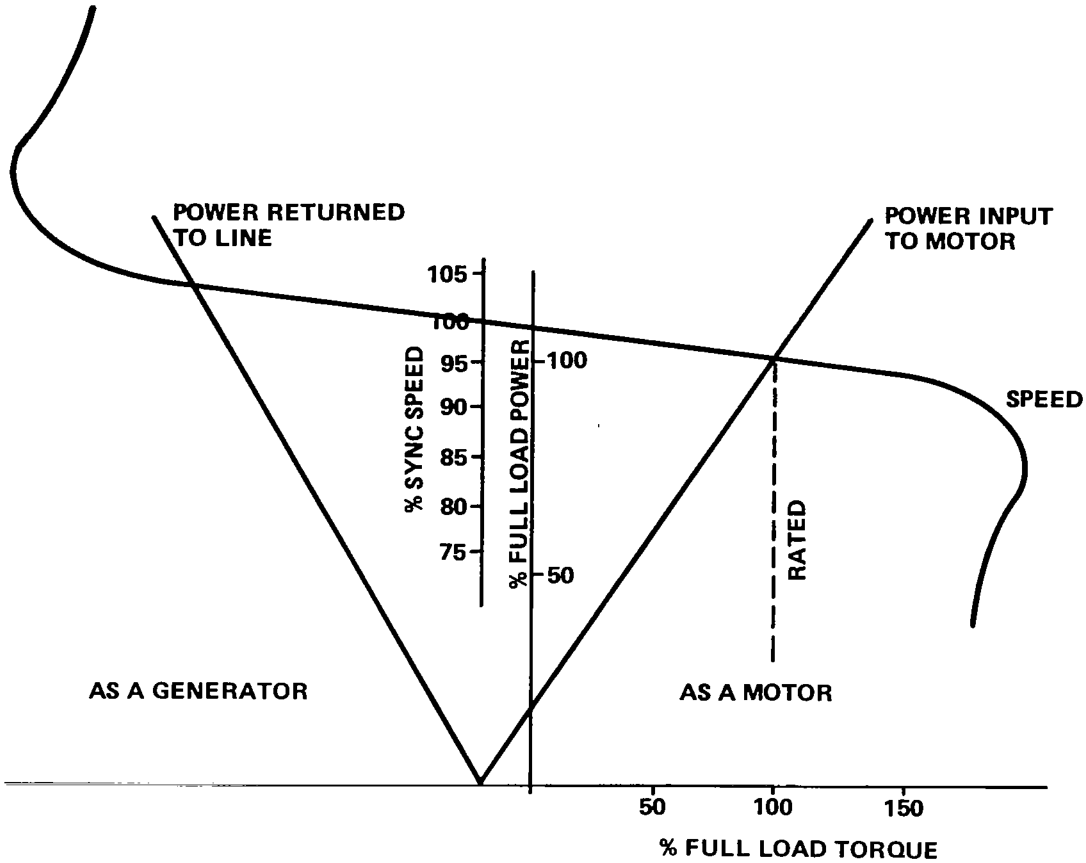

Figure 1. Typical torque versus speed and power for induction motor/generator.

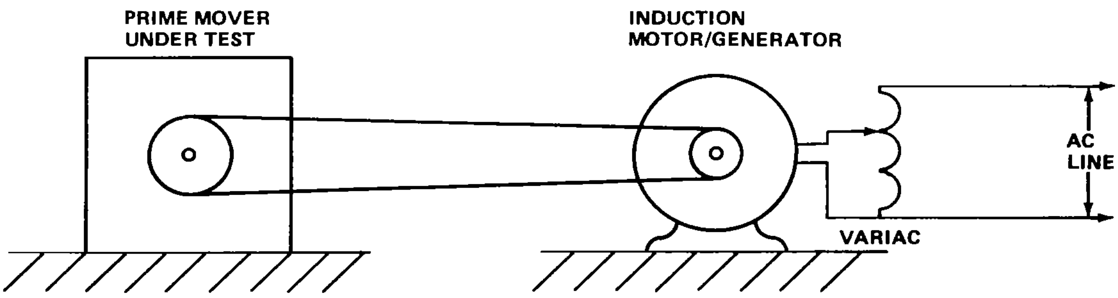

Figure 2. Variable regenerative load – variac method.

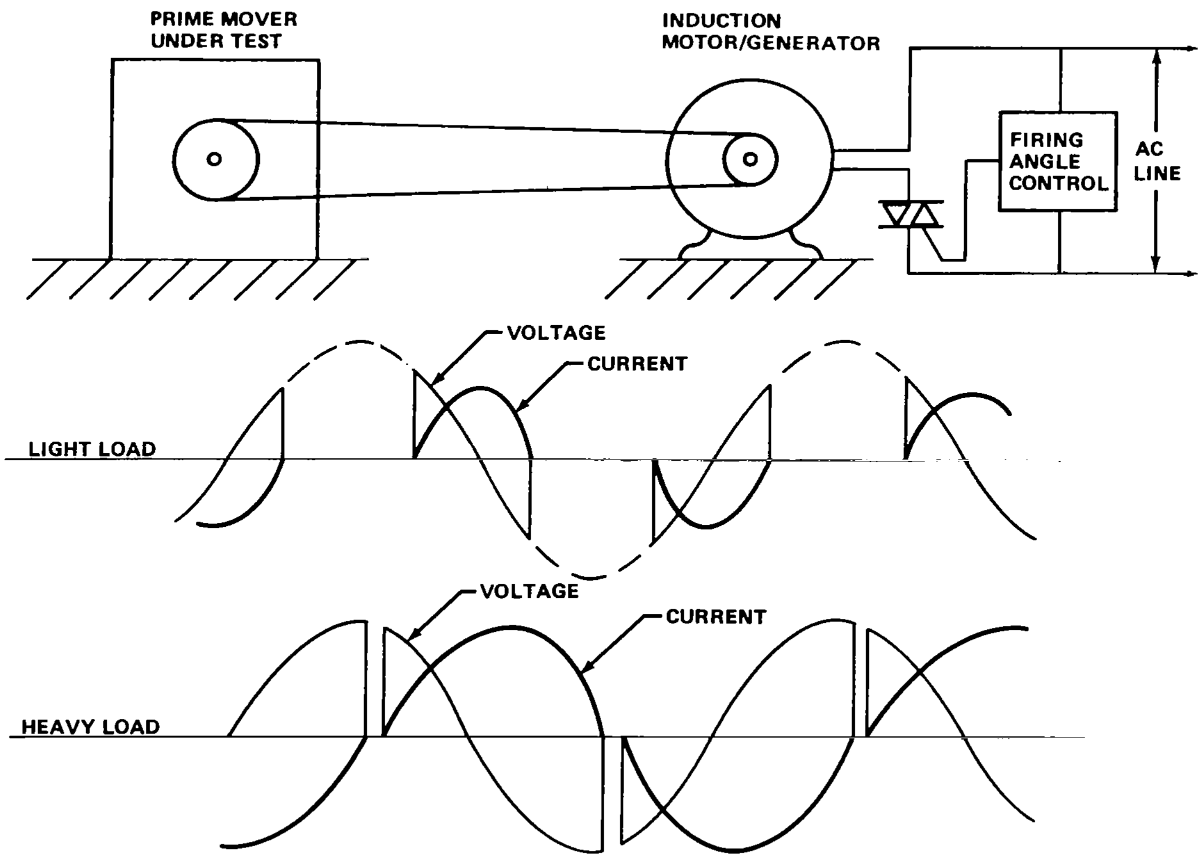

Figure 3. Variable regenerative load and waveforms – triac method.

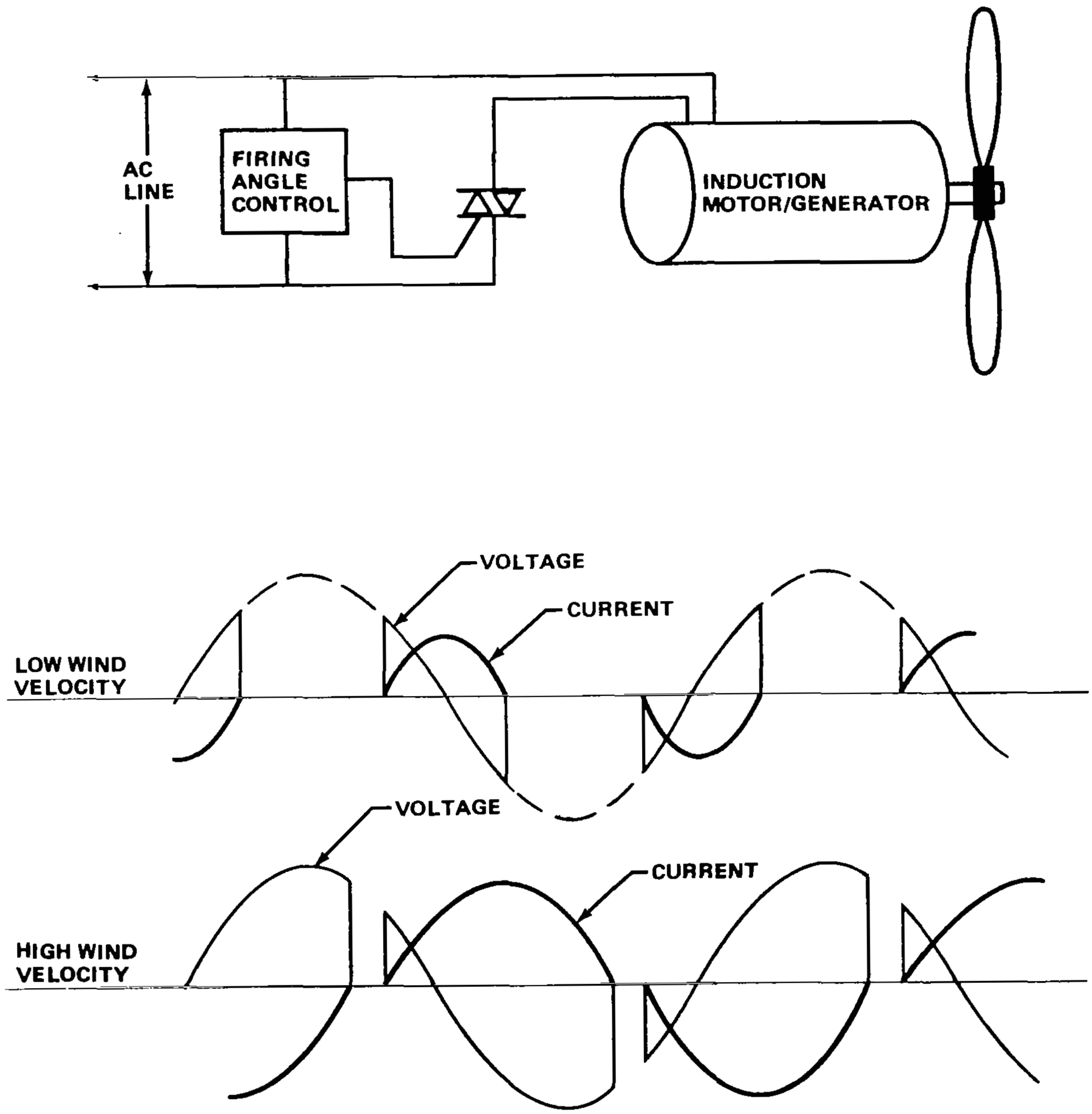

Figure 4. Triac controlled wind driven generator and waveforms.

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16. ABSTRACT

Two technologies relating to energy saving concepts for induction generators are presented in this paper. The first describes a regenerative scheme using an induction generator as a variable load for prime movers under test. The second describes a method for reducing losses in induction machines used specifically as wind driven generators.

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