A power generating system for adjustably coupling an induction motor, as a generator, to an A.C. power line wherein the motor and power line are connected through a triac. The triac is regulated to normally turn “on” at a relatively late point in each half cycle of its operation, whereby at less than operating speed, and thus when the induction motor functions as a motor rather than as a generator, power consumption from the line is substantially reduced.

1 Claim, 2 Drawing Figures
AC LINE FIRING ANGLE CONTROL

FIG. 2

A. LOW WIND VELOCITY

B. LOW WIND VELOCITY

C. HIGH WIND VELOCITY
ELECTRICAL POWER GENERATING SYSTEM

ORIGIN OF THE INVENTION

The invention described herein was made by an employee of the U.S. Government and may be manufactured and used by or for the Government of the United States for governmental purposes without the payment of any royalties thereon or therefor.

TECHNICAL FIELD

This invention relates to electrical power generation, and particularly to an auxiliary generating system for coupling an induction motor type generator to an A.C. power line for adding power to that line.

BACKGROUND ART

In the past few years, there has been a considerable effort to develop new sources of electrical power. Included has been the development of systems primarily designed for providing power to a single enterprise, for example, a household, with any excess generated power being fed back to a power line of a public utility providing a primary source of power for that household. Frequently, the auxiliary or local power generating unit is in the form of a windmill, and there are times when little or insufficient power is available from it alone. Thus, as a matter of convenience, in order to preserve a continuous interconnection of power to on-site electrical devices to be powered, the windmill and public utility power lines are connected together.

Windmill generators have typically been of the direct current type, and thus in order to achieve compatibility with public power lines, which are of alternating current type, and thus in order to achieve compatibility between the generated output and the power lines, there must be both voltage amplitude and phase compatibility between the generated output and the power line voltage. All in all, such a coupling system is necessarily complex and costly.

As an alternate to the direct current generator, induction motor/generator units are sometimes used with windmill generating systems. While the induction motor/generator has not seen great use as a generator in the past, it is perhaps the most widely used type of motor, and thus is widely available and at a reasonable cost.

The power input to an induction motor is given by the product of the applied voltage, the current, and the cosine of the phase angle between the voltage and current (E I Cosine a). In a heavily loaded motor, the current will tend to be in phase with the voltage. When unloaded, the current will typically lag the voltage 70° to 80°. If an external force tends to drive the shaft higher than synchronous speed, the phase lag will continue to increase. When the force is sufficient to cause the phase lag to be 90°, the power input to the motor is zero since cosine 90° = 0. At this point, the mechanical energy applied to the shaft is exactly equal to the magnetizing losses, and there is no net energy being returned to the A.C. buss. As the driving force continues to increase, the phase angle becomes greater than 90°. The cosine of angles greater than 90° is negative, indicating negative power flow. The motor is now generating and returning energy to the A.C. buss. Further increase in driving force causes the phase lag to approach 180° as the full generating capacity of the machine is reached.

Significantly, the induction generator requires no synchronization or voltage regulation circuitry to couple its output to a power line. It inherently functions as a generator when it is driven above its synchronization speed, a speed equal to the frequency of the power line divided by the number of pairs of poles that it contains, typically the speed being 1,800 rpm in the case of a 4-pole device. It, like a direct current generator, is typically connected to a power line when its speed is sufficient for the production of power which, in the case of the induction motor/generator, is at sync speed. Beyond this speed, and in the range of approximately five percent of the sync speed, this type device provides increasing power output to a power line, this increase occurring as the phase lag of current with respect to voltage increases above 90°, an angle which persists at the sync speed.

Despite the obvious advantages of the induction motor/generator over a D.C. generator as described, the former has one significant disadvantage. It must draw field excitation power from the power line that is connected to it. This excitation current is drawn during a portion of each half cycle of the A.C. line voltage when current and voltage are of the same polarity, which, in the case of a lightly driven generator, is only slightly less than one-half of each half cycle. Thus, in such case, it can only function as a generator during the remaining slightly more than one-half of each half cycle, and thus its net output as a generator is essentially slight. At higher speeds, the ratio of power drawn to power delivered improves.

It is the object of this invention to effectively reduce the portion of each half cycle where current is drawn by the generator, and thus substantially improve its efficiency, particularly at low velocity drive levels which, in the case of windmill operation, may persist for a substantial portion of the time of operation.

Disclosure of the Invention

In accordance with this invention, an induction motor/generator is mechanically driven and electrically coupled to an A.C. power line through a thyristor or thyristors operated to retard the time of interconnection to a relatively late point in each half cycle of the A.C. line voltage, whereby the energizing power supplied by the line to the motor/generator may be decreased, and thereby the net power delivered to the line may be increased. Typically, a triac would be employed as the thyristor. Alternately, two SCR devices connected in antiparallel may be employed instead.

Brief Description of the Drawings

FIG. 1 is a schematic illustration of an embodiment of the invention.

FIG. 2 is a graphical presentation of characteristics of operation of the invention.

Best Mode For Carrying Out the Invention

Referred to the drawings, an A.C. induction motor/generator 10 is mechanically driven through shaft 12 by a propeller 14 of a windmill 16. In this illustration, a 115-volt (or other voltage) A.C. power line 18 is coupled to terminals 20 and 22 and thence to the circuit of this invention. Thus, terminal 20 is connected to one...
terminal 24 of generator 10, and a second power termi-
nal 22 is connected through triac 28 to terminal 26 of
generator 10, connection being via conventional triac
power terminals MFI and MT2. The firing angle for
triac 28 is set by a conventional firing angle control 30,
which is connected to power line 18 and supplied a
trigger voltage to the gate terminal 32 of triac 28.

As a feature of this invention, triac 28 is controlled to
be turned “on” at a selected point, a relatively late
point, in each half cycle of the A.C. voltage cycle as
supplied by line 18. Typically, this voltage is at approxi-
mately 150° into each half cycle. From this point, and
until the 180° point when the line voltage passes
through zero, the power line actually supplies an ener-
gizing field current to generator 10 to enable immedi-
ately following operation as a generator during a por-
tion of the next half cycle. The turn “on” point is set no
later than needed to effect generator operation for the
particular generator used. Thus, power drain by the
generator is minimized.

Most significant in the present invention is the appli-
cant’s utilization of the characteristic of the triac to turn
“off” only after current goes through zero following a
turn “on” of the triac as described. Significantly, this
zero crossing by the current occurs when the generator
ceases to deliver power to the line after which point the
generator would consume power. Thus, there has been
achieved an automatic optimum control of the period of
coupling between the line and generator.

The operation described will be better appreciated by
reference to the waveforms shown in FIG. 2 illustrative of
the employment of induction motor/generator 10 with and
without the present invention. Waveforms A, which will be first examined, are illustrated of windmill
operation for a relatively low wind velocity and for the
conventional case where triac 28 is omitted and genera-
tor 10 and power line 18 are directly connected. Curve
e1 is representative of line voltage of A.C. power line
18. Curve i1 is illustrative of current flow between an
A.C. power line and an induction motor/generator.

Waveform B of FIG. 2 illustrates, comparatively, the
electrical operation of the system constructed in accor-
dance with the present invention as illustrated by the
circuit of FIG. 1, and wherein operation is for a like
(low) wind condition to that depicted by waveforms A.
Waveform C illustrates by voltage curve e3 and cur-
rent waveform i3 operation of the system shown in FIG.
1 for a relatively high wind velocity condition. Here, as
will be noted, the energization period for the windmill
is the same as shown in waveforms B, from time point
t1 to time point t5, but the power generation portion
from t5 to the end of the current half cycle t2 is signifi-
cantly expanded.

The applicant has not attempted to detail require-
mements for driving an induction motor/generator at a
range just above its synchronization speed, as such ar-
rangements may vary substantially. It is to be under-
stood, however, that depending upon the optimum op-
erating speed of the drive element, e.g., propeller 14,
there would be appropriate gearing between the drive
element and the shaft of the induction motor/generator.

The present invention has its principal effect in im-
proving efficiency when the generator is driven, in the
lower portion of its speed range, as in the case of wind-
mill operation depicted in waveforms B. It enables a
lower threshold of windmill speed for power genera-
tion, and in its lower velocity range of operation, it
enables a greater electrical output. Considering now
that in many installations environmental winds are less
than maximum most of the time, it is to be appreciated
that the present invention provides a valuable contribu-
tion to the art.

I claim:

1. An electrical generating system comprising:
a windmill having a power shaft and a pair of power terminals;
a motor/generator having a power shaft and a pair of power terminals;
an alternating current power supply having a pair of power terminals;
the triac means, including at least one triac, having a control input and a pair of power terminals;
said power terminals of said device and power line being interconnected through said power terminals of
said triac, and
control means connected between one of said power terminals and said control input of said triac for delaying the turn “on” point of said triac with respect to the period of each half cycle of alternat-
ing current power to normally limit the power transfer from said power line to said device;
whereby a higher net transfer of power from said device to said power line may be obtained.