DESIGN OF AN AUTO-BRAKING REGULATOR FOR A SMALL WIND GENERATOR

A. F. Fredericks, I. D. deVries

Abstract— **Wind generators require braking mechanisms to prevent serious damage in high wind speeds. This paper proposes an, automated, electronic solution to existing mechanical methods that are expensive and reduce reliability. The "soft" automatic braking system brakes the generator, by slowly decreasing the phase to phase resistance of the generator, allowing the generator to decelerate steadily until it is fully braked. Regulation is achieved by monitoring the charging voltage of the battery, braking the system when the battery is fully charged and releasing it when below fully charged. Synchronous rectification is also incorporated and results in an increase of output power from the system, by approximately 10%. High wind speed can also be sensed by monitoring the charging current or the current through the MOSFETs and the generator can be braked if necessary.**

***Index Terms*—. ELECTRONIC BRAKING; synchronous rectification; wind generators.**

I. BACKGROUND AND PROBLEM STATEMENT

IN South Africa and abroad, load/demand for electricity has increased steadily over the past few years, placing a heavy strain on energy suppliers. In South Africa, it has been found that demand for electricity has increased such that it will be at capacity by 2008 [1]. In the Cape region alone, the load/demand has increased at an average of 2,5% per year, since the year 2000 [2]. In addition to this, there are still households that do not have electricity, because they simply cannot afford it. As a result, a sustainable, yet affordable method of providing electricity is required to ease the load /demand on the electricity supplier, as well as making electricity available to everyone. Wind energy technology is more mature than any other renewable energy technology [3]. Thus, one method of solving the crisis mentioned earlier, is to implement small wind generator systems in households [4].

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However, when small wind generators are exposed to high winds, damage may be caused as design limitations are exceeded. Without a control mechanism, the wind generator could speed up immensely, presenting its full swept surface area to the wind and possessing enormous inertia. The combination of these forces could easily damage, if not destroy the generator. Usually, braking is achieved by mechanically furling the generator, which turns the generator out of high speed winds [5]. However, this increases cost and weight of the wind generator and mounting structures. It also increases the complexity of the system, reduces reliability and also increases the need for regular maintenance.

Another problem occurs when generators are used to charge batteries. Here, the batteries need to be protected from overcharging. When a battery is fully charged, it has to be disconnected from the wind generator. The next problem that arises, is that the wind generator now becomes unloaded, allowing it to spin at high speeds once again, reducing the life and reliability. Previous systems solved this problem by using a shunt regulator with a dump load. This meant that all the power, from the generator, was dumped into the dump load, which then dissipated the extra power as heat [6]. These dump loads have to be large enough to handle the power and safely dissipate the extra heat.

II. DESIGN FEATURES

A. Electronic Braking

Electronic braking is achieved by shorting out the three phases of the wind generator [5]. This can be done by modifying a three phase rectifier, where the bottom three diodes (low side diodes) are replaced by MOSFETs, as shown in fig. 1.

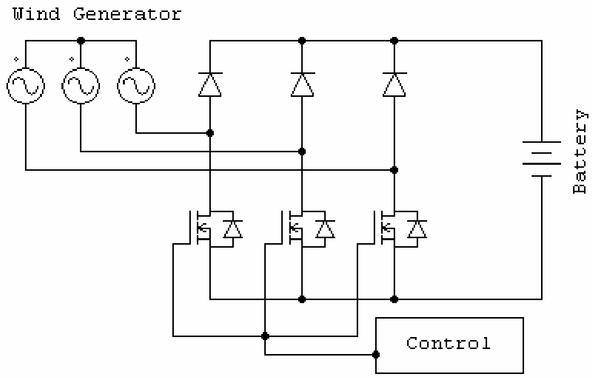

Fig. 1. Three phase Rectifier with built-in braking

If the MOSFETs are switched off, the internal-body diodes conduct in the same manner that the normal diodes would have. This means that the circuit still functions as a three phase rectifier. With additional control, the MOSFETs can now be triggered to switch on or off. When switched on, the low on resistance of the MOSFETs provide the generator with a phase to phase resistance, of less than 10 milliohms. This is as good as physically shorting the three wires of the generator together.

B. Slow Brake Initiation

If a hard electrical short is applied instantly to all three phases while the wind generator was rotating at high speeds, it would likely cause serious damage to the generator. This would be due to the huge forces generated trying to stop the angular momentum instantly. As a result, the electronic braking system applies the short in a slow, "soft" manner. This is achieved by progressively decreasing the resistance applied across the three phases over a period of 4 – 5 seconds. This allows the wind generator to decelerate slowly, reducing the stress on it. All the rotational kinetic energy is dissipated into the regulator. Here, the braking MOSFETs have been very well heat sunk with good thermal inertia to absorb this energy. Once fully braked, the wind generator will turn very slowly in a stalled mode, generating very little power.

C. Auto-Braking

When charging a battery, the device will automatically brake the generator once the battery is fully charged. When the battery voltage falls below fully charged, the brake is released, causing the battery to start charging again as the generator starts to produce power. The controller monitors the voltage across the battery, as shown in fig. 2.The sensing uses a comparator with an additional hysteresis circuit. The hysteresis prevents the device from fluctuating in and out of regulation mode.

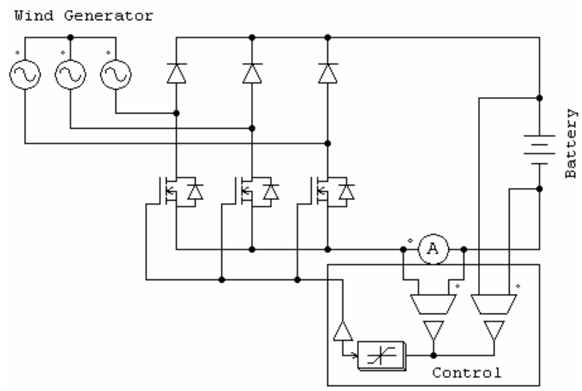

Fig. 2. Auto braking concept, with battery monitoring.

This system has settings for 12V, 24V and 48V. For a 12V set device, the turbine will brake (stop/shutdown) once the battery is fully charged at 14.1V. The turbine only starts up again once the battery voltage drops to below 12.75V.

The system also senses high speed winds, by detecting the charging current, also shown in fig. 2.The brake is then activated when high wind speeds are reached. When the brake is activated, high wind speeds can be sensed by monitoring the current through the mosfets. This is easily accomplished by monitoring the rms voltage from the MOSFET's drain to source (V_{DS}). Once the wind speed has dropped, the brake can be released and power can be generated once again.

D. Synchronous Rectification

1) Problem with Diode Rectifiers: Traditionally, three phase rectifiers make use of diode bridges. Here, two diodes are used for each phase, resulting in a total of six diodes. In such a circuit, there are always two diodes conducting at any given instant. The problem with this design is the power loss within the rectifier. For example: if we consider using a 120W generator to charge a battery at 10A and a diode forward voltage of 0.7V for each diode, then the total power dissipated at any given time amounts to: $Pd = (2*V_F*10) = 14W$. This means approximately 12% of the power, from the generator, is lost in the rectifier.

2) A More Efficient Solution: Currently MOSFETs are readily available with on resistances in the region of 3 – 4 milliohms [7]. If we replace all six of the diodes with MOSFETs, and these MOSFETs have an on resistance of 4 milliohms, then power dissipated: $Pd = (2* I^2 *R_{DS(ON)}) = 1.6W$. In such a system only 1.3% of the output power, from the generator, is lost in the rectifier. Since the rectifier is operating at a low frequency, switching losses are insignificant and can be ignored. Thus, only on state losses are taken into account. By replacing the diodes with MOSFETs, that are switched synchronously, the output power of the system can be improved by approximately 10%.

3) How Synchronous Rectification is achieved: Switching the MOSFETs on synchronously necessitates that the MOSFETs should be switched on at the same time that the internal diodes would normally conduct. This means that when the voltage at the source (Vs shown in fig. 3) of the MOSFET, is greater than that of the voltage at the drain (Vd shown in fig. 3), the MOSFET should be turned on. The opposite is also true, where the MOSFET has to be turned off when the voltage at the source, is smaller than the voltage at the drain.

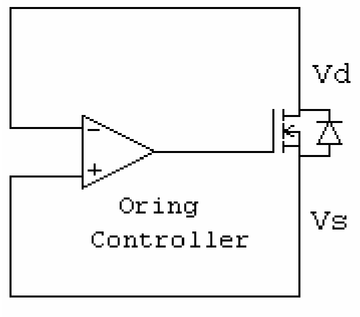

Fig. 3. Shows how the MOSFET is switched synchronously by an or-ing MOSFET controller.

For this design, an or-ing MOSFET controller (IR1167) was used to sense the drain and source voltages of the MOSFETs After the controller determines which of the two voltages are greater, the gate of the MOSFET is driven so that the MOSFET is switched to the required on or off state. This device was chosen because of its low turn-on and turn-off times of 80 and 60ns respectively [8]. A fast turn-off time is especially important, because the MOSFET has to turn off before the one in the next branch/bridge starts to conduct.

The electronic breaking system discussed earlier, can easily be adapted to incorporate synchronous rectification by replacing the diodes with MOSFETs, each with its own or-ing MOSFET controller, as shown in fig. 4.

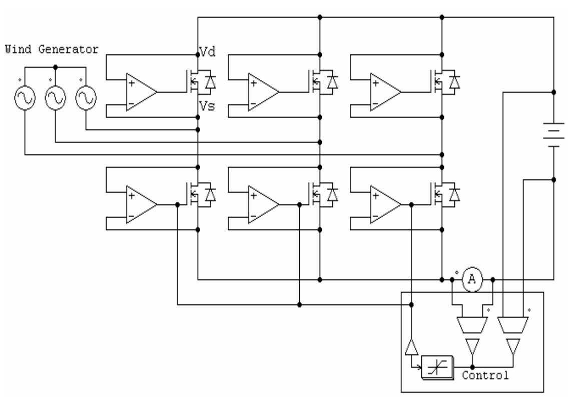

Fig. 4. Shows a simplified diagram of the synchronous rectifier with electronic braking.

III. Results

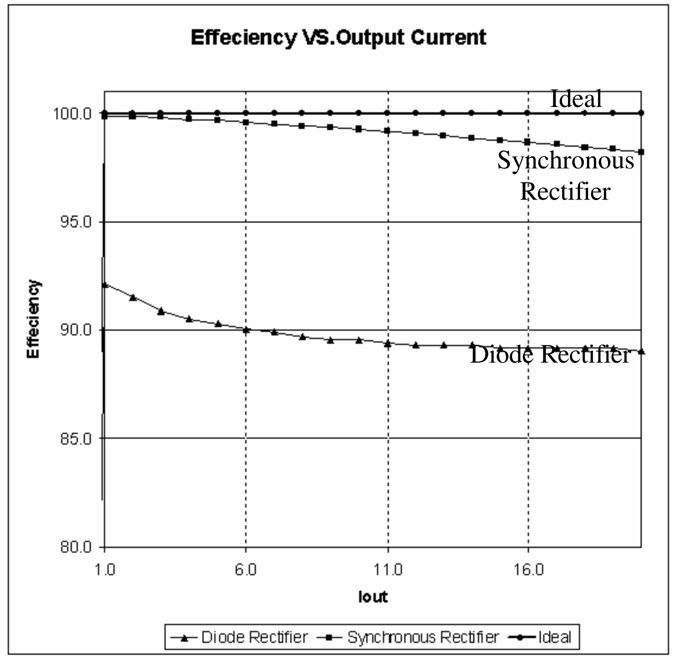

Fig. 5. Compares the efficiency of the synchronous rectifier with diode rectifiers and an ideal rectifier.

The data in fig. 5 was obtained by driving the rectifier current into a 12V battery. It shows that the synchronous rectifier is approximately 9 – 10% more efficient than a three phase rectifier, using schottky diodes.

IV. Conclusion

The objective of this paper was to develop a method of braking/stalling wind generators without the use of mechanical methods that are large, high maintenance and difficult to install.

This objective was achieved by braking the generator electronically. This was accomplished by slowly decreasing the phase to phase resistance of the generator, thus slowing it down. In addition, by switching MOSFETs synchronously, the efficiency of the three-phase was improved by approximately 10%. This occurs as a result of less on-state losses when replacing traditional diodes, with MOSFETs that are synchronously switched.

By increasing the overall efficiency of wind generator systems, decreasing maintenance and increasing reliability, this design makes it possible to implement small-scale wind generators systems in all communities and making electricity available to everyone, a reality.

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