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Bar-wound versus wire-wound alternators

White Paper

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This white paper describes the differences in design between bar-wound (also called form-wound) and wire-wound (also called random-wound) alternators, and it provides recommendations for the use of each type by system designers.

While it is dangerous to make general characterizations about anything as complex as alternator design, and difficult to compare designs produced by different manufacturers, this paper also attempts to describe typical differences in performance between the two kinds of products.

Bar-wound alternator designs

Bar-wound alternators differ from wire-wound designs in that the copper windings of the stator are composed of individual copper bars, rather than wire bundles.

Figure 1 shows a section view of a typical stator slot in a bar-wound machine. Note that the stator windings are composed of bar assemblies that are laid in the slot in a precise mechanical configuration.

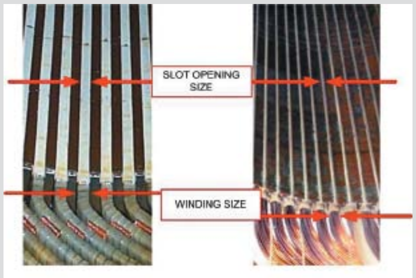

Figure 1 - Winding and slot size comparison shows that for similar winding size, the slot size of a wire-wound machine will be much smaller, resulting in lower harmonic distortion in voltage produced.

In order to lay the bars into the slot, the opening to the slot has to be quite large, and this leads to some of the most important differences in performance between bar-wound and wire-wound machines.

Wire-wound alternator designs

In a wire-wound design, the alternator windings are usually pre-formed wire bundles, which are inserted into the stator, often by machine processes. Note that with the wire-wound design the slot opening is significantly smaller, and the individual windings are composed of much smaller cross-section materials. Note also that the insulation space between the individual wires is less than with the bar-wound coils.

Performance differences

The differences in the physical designs between the two systems lead to some obvious performance differences that you can expect, and some that are less apparent.

- In general, you can expect that a copper bar is a more rigid object than a wire bundle. What you can't see in these illustrations is that it is probably easier to brace a bar-wound machine for mechanical stresses than it is a wire-wound machine. This being said, it should not be assumed that a wire-wound machine is always less durable than a bar-wound machine — it is simply easier to provide a mechanically rugged structure. Use of modern materials and design practices for wire-wound machines also will mitigate these differences. For example, all Cummins alternators larger than 100 kVA utilize a vacuum-impregnated design that includes mechanical bracing for the end turns, which results in the stator assembly being free of voids and mechanically very strong compared with designs from other suppliers that may use only a "dip and bake" type of insulation. Thus there is no significant difference in the mechanical strength between Cummins machines that are wire-wound versus bar-wound machines used in most applications.

- The bar-wound machine will generally have more space for insulation than there is available between the wires in a wire-wound machine. Added insulation is most important in medium-voltage alternators where the difference in voltage between the conductors is greater.

- On the other hand, the greater levels of insulation in the bar-wound design tend to make it more difficult to cool the machine, so more materials are needed to reach similar temperature rise goals.

- In general, the larger air gap and slot opening size will result in greater levels of inherent voltage waveform distortion (particularly at higher frequencies). So, bar-wound machines will typically exhibit poorer waveform quality than wire-wound machines of similar mechanical characteristics.

- Since the slot opening is greater in bar-wound machines, the magnetic circuit that exists between the rotor and stator is more efficient in the wire-wound design. Also, bar-wound designs tend to have longer end-turn arrangements. These two factors lead to better overall performance of the wire-wound design for similar material content. For example, the bar-wound machine will require more copper and steel to reach the same short circuit and motor-starting capability of a similarly rated wire-wound machine. Usually, the reactances of a wire-wound machine will be relatively lower than those of a similar-sized bar-wound machine, reflecting this physical distance.

- In addition to greater raw material content, bar-wound machines are typically more difficult to assemble, and they are sold in much smaller quantities. These factors lead to higher cost per kW for the bar-wound design, and greater difficulty in acquiring replacement parts.

To summarize, bar-wound alternator designs typically offer greater mechanical strength than wire-wound designs and greater dielectric strength, but they provide poorer performance in terms of voltage waveform quality, motor-starting performance and short circuit performance.

Application recommendations

The physical characteristics and performance differences in the two basic alternator designs lead to the following recommendations for their use:

Bar-wound designs are generally more desirable for medium-voltage applications. In these situations the ability to provide better turn-to-turn insulation will result in a more reliable machine, with relatively minor sacrifices in cost.

Bar-wound designs are also generally desirable for prime power applications that need the more rugged mechanical strength of the bar-wound design. In particular, applications that use continuous, repeated surge loads to the machine are usually best served with a bar-wound design. The surge loads result in magnetic reactions in the windings, particularly in the end turns of the stator, that tend to deform the windings, or even break them over time. With a rigid, heavily braced design, the impact of these mechanical stresses can be more easily mitigated.

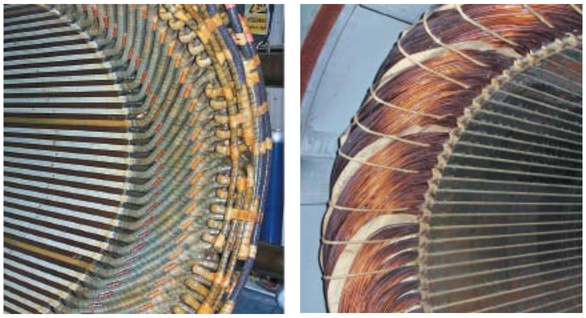

Figure 2 - Stator assembly of bar-wound machine (left) and wire-wound machine (right). Note the difference in slot size and bracing wiring on wire-wound machine.

A common situation of this type occurs in oil-field applications, where drilling operations put continuous sudden loads on the generator set.

Wire-wound designs tend to provide the best performance in terms of voltage waveform quality, resistance to waveform distortion, short circuit performance, and motor-starting performance. Thus they are almost always the best choice for line voltage applications in emergency/standby situations. This is particularly true in situations where there are large motor loads or when good waveform quality is important, such as due to the presence of non-linear loads in the system.

Applications such as uninterruptible power supply (UPS) for data centers, water treatment or sewage lift can often benefit from a wire-wound alternator. These applications have heavy concentrations of rectifier-based loads. They are different from, say, drilling applications in that loads are applied to the alternator in a relatively gradual process to minimize voltage sags and swells, whether operating on the utility service or generator set power.

For example, a UPS will ramp loads onto a generator set after a power failure, and it will draw reserve power from a battery supply when a sudden load is applied to its output. These loads on the generator set are much less mechanically stressful than those from drilling applications. Consequently, there is no clear need for the bar-wound design, and the greater efficiency of the wire-wound design may be desired.

Both bar-wound and wire-wound designs need special protection when used in harsh environments such as coastal areas or where they could suffer from corrosion.

Conclusion

The bottom line is that there are no applications that absolutely require one alternator design over another. In general, for similar-sized machines, the bar-wound machine is best suited to medium-voltage applications and cases where the loads subject the alternator to severe mechanical stresses. The wire-wound machine, properly constructed, will provide the best service in applications where motor-starting capability and the best resistance to waveform distortion are important.

About the author

Gary Olson graduated from Iowa State University with a BS in mechanical engineering in 1977, and graduated from the College of St. Thomas with an MBA in 1982. He has been employed by Cummins Power Generation for more than 25 years in various engineering and management roles. His current responsibilities include research relating to on-site power applications, technical product support for on-site power system equipment, and contributing to codes and standards groups. He also manages an engineering group dedicated to the design and development of next-generation power systems.

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PT-9013 (7/10)