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Report on Discussions with Utility Engineers about Superconducting Generators

Conducted by Donn Forbes
as Part of the Superconductivity
Partnership Initiative under contract with
the National Renewable Energy Laboratory

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Preface

This report relates to a series of discussions with electric utility engineers concerning the integration of high-temperature superconducting (HTS) generators into the present electric power system. The current and future interest of the utilities in the purchase and use of HTS generators is assessed. Various performance and economic factors are also considered as part of this inspection of the utility prospects for HTS generators.

Integration of HTS generators into the electric utility sector is one goal of the Superconductivity Partnership Initiative (SPI). The SPI, a major part of the Department of Energy (DOE) Superconductivity Program for Electric Systems, features vertical teaming of a major industrial power apparatus manufacturer, a producer of HTS wire, and an end-user with assistance and technical support for the national laboratories. The SPI effort on HTS generators is headed by a General Electric Corporation internal team comprised of the Corporate Research Laboratories, Power Generation Engineering, and Power Systems Group. Intermagnetics General Corporation, which assisted in the development of the superconducting coils, is the HTS wire and tape manufacturer. Additional technical support is provided by the national laboratories: Argonne, Los Alamos, and Oak Ridge, and the New York State Institute on Superconductivity. The end-user is represented by Niagara-Mohawk and the Electric Power Research Institute.

Initial SPI awards for three cooperative programs were announced in 1993 by the DOE Golden Field Office, which provides contractual and technical oversight for the SPI programs. These three programs were directed at synchronous motors, fault-current limiters, and large synchronous generators. A fourth program on superconducting underground transmission was awarded in early 1995. The SPI programming thus covers the entire power delivery cycle from generation, transmission and distribution, to the end-user.

The intent of the SPI effort is to accelerate the development, introduction, and commercialization of HTS electric power components into the electric utility sector. These HTS components will show marked improvement in efficiency and improved system performance over conventional non-superconducting technology.

Additional information on the General Electric SPI program for HTS generators can be obtained directly from the principals involved:

• Trifon Laskaris, Superconductivity Manager, GE Corporate Research, **(518) 387-7744**

• George Cotzas, GE Power Generation Engineering, **(518) 385-5942**

• James Daley, DOE Superconductivity Program Manager, **(202) 586-1165**

• Jeff Hahn, DOE/GFO SPI Project Engineer, **(303) 275-4775**

• Richard Blaugher, NREL SPI Technical Support, **(303) 384-6518**.

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Introduction

This report summarizes the results of conversations with 16 generator engineers from 14 different U.S. utilities considering the usage of high-temperature superconducting (HTS) generators in a utility environment.

The following characteristics for an HTS generator were established by General Electric (GE) for comparison with a conventional generator.

Advantages

- 50% lighter
- 50% smaller
- lower synchronous reactance
- improved transient stability
- 50% lower electrical losses
- significantly reduced life-cycle costs.

Disadvantages

- lower rotor inertia
- higher field-time constants.

Other Characteristics

- lower transient reactance
- lower subtransient reactance.

Donn Forbes, a market researcher and business consultant for clients involved in superconductivity, and David Ephron, a graduate student in Applied Physics at Stanford, asked the engineers for their impressions of the importance of these advantages and disadvantages, and also for their opinions about the other characteristics.

The engineers were asked to respond to the Questionnaire in Appendix B which was followed by an interview.

Questions about Commercialization of HTS Generators

Forbes and Ephron asked the engineers the following questions during the interview:

- How many years of field tests would be required before commercial introduction of HTS generators?
- How many years after commercial introduction would HTS generators reach their maximum market share?
- What maximum market share would HTS generators attain?

- Is cryogenic cooling acceptable if the cryogenic system is sufficiently reliable?
- Are there any market barriers to the acceptance of superconducting generators?
- Assuming the generator has the advantages, disadvantages, and other characteristics described above, would you recommend that your utility purchase one?

Summary of Results

The respondents considered predicted low life-cycle costs of HTS generators a significant advantage; the other advantages were much less important to them. Not all were convinced that a superconducting generator would have lower life-cycle costs. They had different opinions about whether lower life-cycle costs would outweigh a higher initial cost. They agreed that reliability was crucial.

In general, the disadvantages and other characteristics described didn't seem very important to them. In many cases, the respondents acknowledged that they didn't have enough understanding of the engineering issues regarding design and performance of generators to render an educated opinion.

Most respondents thought 2 to 5 years of field testing would be required before commercial introduction. The number of years forecast from commercial introduction to maximum market share varied from 3 to 35, and the sample of respondents willing to make such a forecast was too small to be highly predictive. Regarding the maximum market share that HTS generators might eventually reach, respondents' answers ranged from 2% to 100%. About two-thirds of the respondents said cryogenic cooling is acceptable if the reliability is high enough. They described several market barriers to introduction, including lack of understanding, nervousness about cryogenics, the trend toward simpler machines, and the excess generation capacity in the United States. More than one-half of the respondents said they would recommend that their utility purchase a superconducting generator, provided that it had the properties we described and that it demonstrated good reliability. One respondent expressed interest in providing a demonstration site and in buying the first commercial unit.

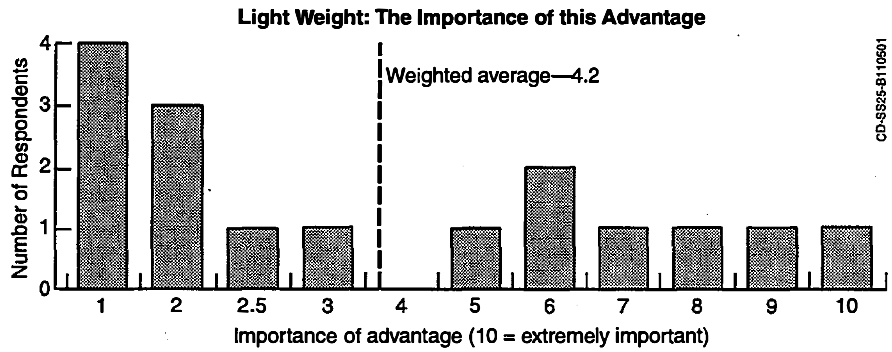
Because the United States is unlikely to represent a significant market for generators during the next 15 to 20 years, it would require too great an extrapolation to convert the engineers' comments into a market forecast; we would have to infer from their comments what their foreign counterparts will buy. If this study proves to have practical value, it will probably be in helping companies that are developing HTS generators to understand their customers' attitudes and states of awareness.

Evaluating the Advantages of Superconducting Generators

A. Light Weight

The respondents gave a broad distribution of opinions about light weight, but the most frequent answers were that it's not very important.

Editor's Note: *Generator siting for the most part is driven by the prime mover requirements. The generator size and weight is secondary.*



They pointed out that light weight is advantageous at the outset:

"It would be cheaper to install, and there isn't all the mass to move around." —*Hubert Smith, East Kentucky Power.*

"I question that 50% number, but if it's correct, you need less of a foundation, less expensive equipment such as cranes, hoists, etc." —*Jim Michalec, American Electric Power*

One respondent also suggested that a smaller machine might be less expensive:

"One would hope for lighter weight and smaller size leading to a lower cost." —*Les Ravenscroft, Nebraska Public Power District*

But apart from these considerations, light weight is irrelevant:

"The generator sits on the deck right next to the turbine, which is much heavier than the generator. You have to design the whole deck to support the turbine, so reducing the weight of the generator doesn't make much difference."—*Thomas E. Baker, Southern California Edison*

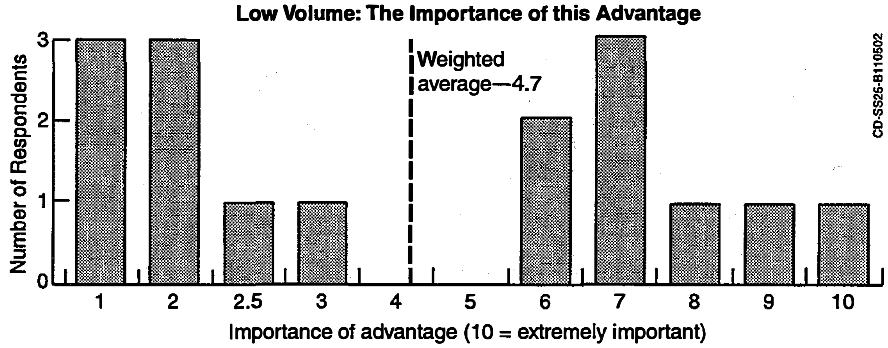
B. Small Volume

With respect to small volume, the distribution of responses was also broad, but the number of engineers who felt that this advantage is important was somewhat higher.

Several respondents felt that a small volume is irrelevant:

"Turbine cases are built like tanks. Space is not an issue for us. The main issues are improvements in efficiency and cost benefits." —*Thomas E. Baker, Southern California Edison*

Those who felt a small volume is important tend to think about space for doing hands-on work. Some emphasized that a small volume is more important in larger, higher-rated machines:



"Small volume is more important than light weight because space in the plant is at a premium." *—Virgil Rose, Pacific Gas & Electric*

"Small volume is very important to the maintenance crew because it gives us more room to work on the machine." *—Calvin Copeland, Maintenance Manager, Houston Lighting & Power*

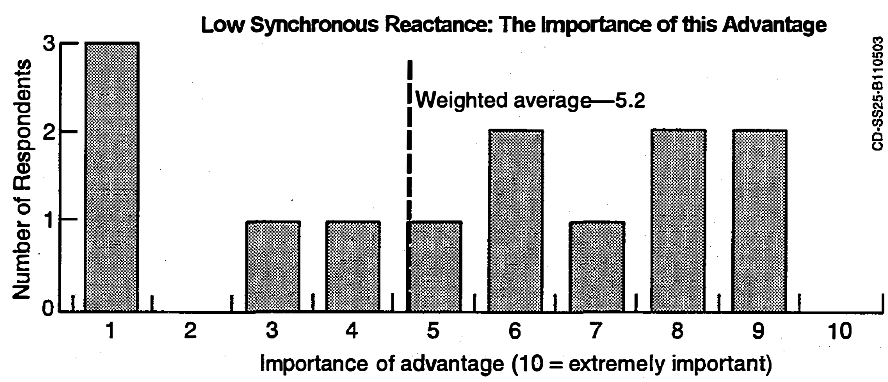
"For a 100-megawatt (MW) generator, size is not that important. You need to show a dramatic improvement at 1000 MW, where space becomes a critical issue. If we needed to upgrade capacity, we would be thinking in 200–300 MW increments. IPPs* are usually dealing with 600–800-MW installations." *—Noah Tai, Consolidated Edison of New York*

*independent power producers

C. Low Synchronous Reactance

The respondents were also divided about the importance of a low synchronous reactance.

The impact of lower synchronous reactances wasn't thought to be a factor for some of the utilities.



One engineer stated that a low synchronous reactance has no value for his utility:

"I think it's another nice technical advantage to discuss, but doesn't make much difference because even our oldest machines are handling any variation in VARs.*" *—Glenn Beckerdite, Kansas City Power & Light*

*volt amperes reactive

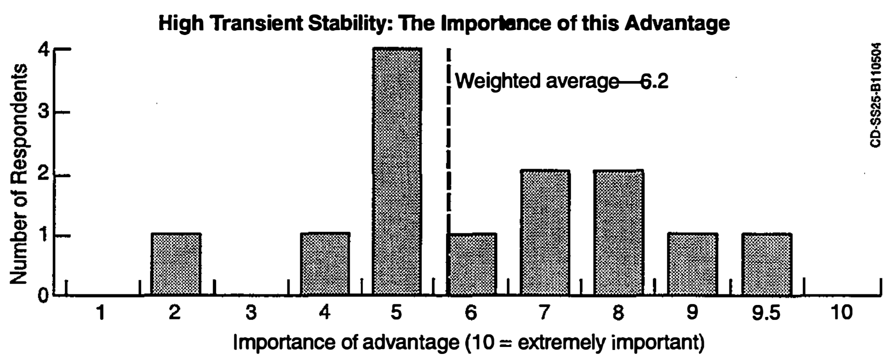
Another felt that it was a disadvantage:

> "The lower synchronous reactance results in a stronger short circuit. We have switchyards that are marginal on short-circuit duty. If you upgrade the duty, you have to buy more expensive breakers. With lower synchronous reactance and also lower subtransient and transient reactance, if you have a short circuit near the machine, then the short-circuit currents will be higher, and that affects the ratings of the switchyard. We at Edison have a very large project on cryogenic fault limiters because we want to limit the short-circuit current in order to keep running with present switch gear. Now you're talking about a generator that is going to defeat that purpose." *—Thomas E. Baker, Southern California Edison*

"There is always a need for more stability. What it normally lets you do is load up your transmission lines heavier, which allows you to import more low-cost power from outside your system."

D. High Transient Stability

The respondents spoke with more comfort about transient stability, and then tended to think it was a more important advantage than the three discussed above.



One respondent stated that higher transient stability is always an advantage:

> "There is always a need for more stability. What it normally lets you do is load up your transmission lines heavier, which allows you to import more low-cost power from outside your system. I don't know how to quantify that; we would have to run load-flow studies to see if it made a significant difference." *—John H. McKinley, Southern California Edison*

Others felt that the advantage of higher transient stability was highly dependent on the context:

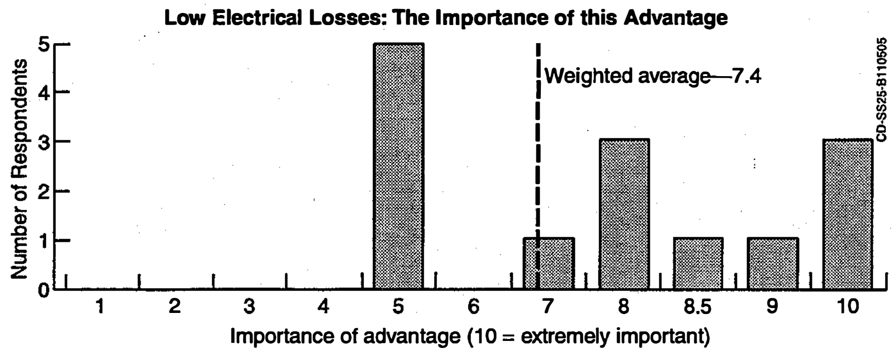
> "Our system is close knit. If you had long distances between power plants, higher transient stability would be important. It's not so important for us." *—Calvin Copeland, Houston Lighting & Power*

E. Low Electrical Losses

Not surprisingly, the respondents stated that low electrical losses are an important advantage.

In some sense, higher efficiency is always a plus:

> "Suppose you have an 800-MW machine. If you cut the losses in half, you have an extra 8 MW free. They are about 98% efficient to start with, and if you can make that 99%, you have another 1%, so you gain 8 MW. I'd say that was worth something." *—Thomas R. Wait, Pacific Gas & Electric*



One respondent pointed out that the generator may not be the best place to focus:

> "The extra 1% efficiency in the generator is not that exciting with turbines still at 30% efficiency."
> —*Lawrence Wall, Southern Company Services*

Another pointed out the need to consider efficiency as just one factor in the life-cycle-cost equation:

> "High efficiency has some value; you don't want to waste energy. But life cycle costs are more important to me. If the capital cost, maintenance cost, and operating cost overwhelmed the energy savings, then efficiency would not be so important." —*Virgil Rose, Pacific Gas & Electric*

F. Low Life-Cycle Costs

The respondents confirmed that low life-cycle costs are the most important issue:

> "It has to be cost competitive—the differences in the specs are not that important. We are going to need to be more cost competitive, especially with the deregulation of the industry." —*Jim Michalec, American Electric Power*

Some respondents felt that it was counterintuitive to suggest that a superconducting generator, even with higher efficiency, would have lower life-cycle costs:

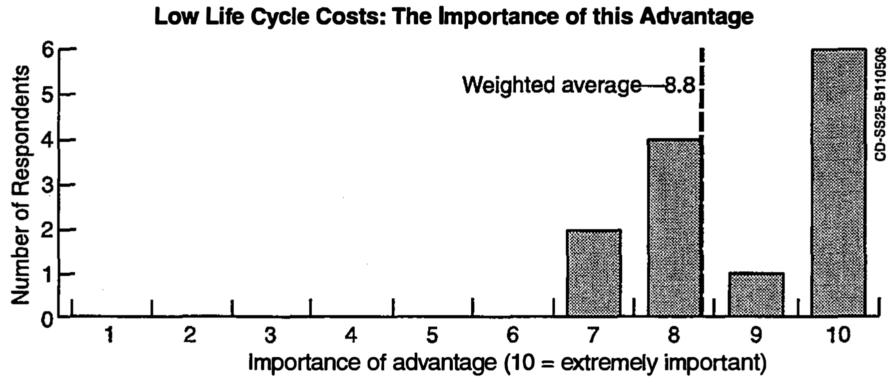
> "I don't believe it. The system is too complicated." —*Noah Tai, Consolidated Edison of New York*

Given the assumption that a superconducting generator would have lower life-cycle costs, some believed lower capital costs were not so important:

> "The cost-benefit calculation would have to show a substantial improvement over a 30-year period. We base our evaluation on the long-term costs. We have access to capital, so a high initial cost would not be a problem if it could be shown that the total long-term costs were lower. But how do we know that it won't cost double somewhere down the road? This would be a hard sell." —*Henry Henriksen, South Carolina Electric & Gas*

"Reliability, making sure this new technology works when you need it, would be extremely important . . ."

> "These machines last a long time. Higher initial costs would not pose a serious problem if the long-term economics worked out." —*Hubert Smith, East Kentucky Power.*



Others felt that lower capital costs were very important:

> "Lower initial capital costs are important. People will use higher up-front costs as an excuse not to buy one. If the costs really are lower, then it is an offer people cannot refuse." —*Noah Tai, Consolidated Edison of New York*

> "The initial cost is extremely important. The capital is hard to come up with. It will not be easy to convince our customers that we should invest in something that is more expensive now based on projected cost savings 40 years from now." —*Lawrence Wall, Southern Company Services*

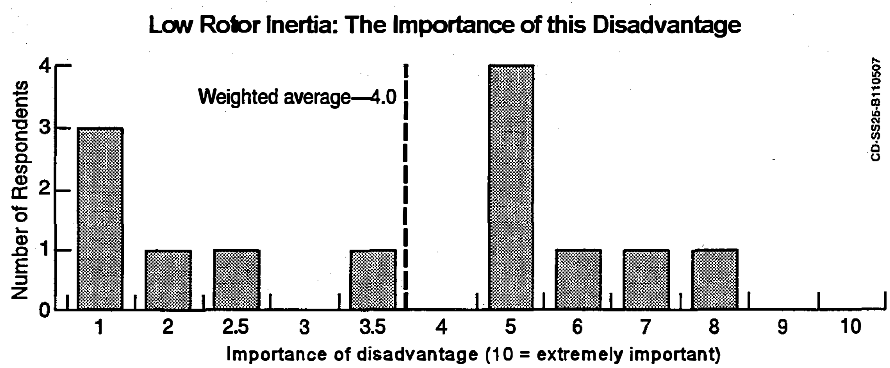
Another common theme was that reliability is extremely important:

> "Reliability, making sure this new technology works when you need it, would be extremely important. Even if it's cost effective, it must be dependable, or you wouldn't buy it." —*Virgil Rose, Pacific Gas & Electric*

Evaluating the Disadvantages of Superconducting Generators

A. Low Rotor Inertia

In general, the respondents seemed to think that the lower rotor inertia of a superconducting generator is at worst only a moderately important disadvantage.



The following responses were typical:

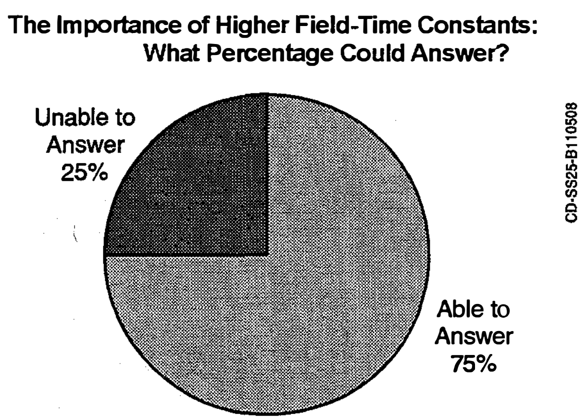
"The lower rotor inertia is not important, provided that the other characteristics add to the stability of the system." —*Rik Nilsson, Ohio Edison*

"I don't see that as a serious problem. The turbine is going to dictate the system." —*Lawrence Wall, Southern Company Services*

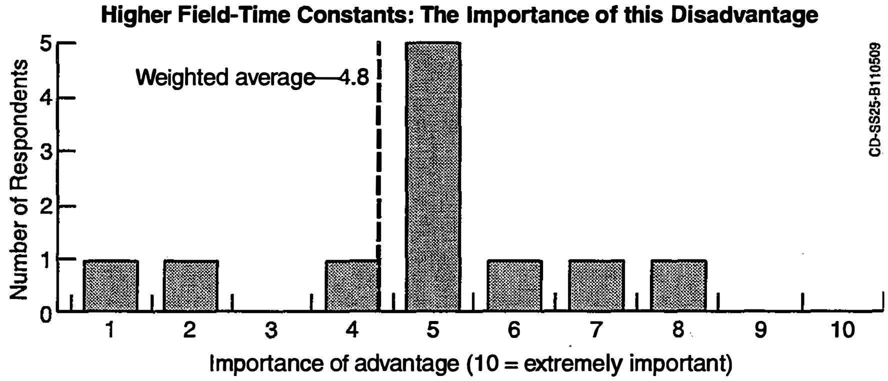
"During a transient, the inertia in a machine tries to keep the system stable. A lower rotor inertia would be a negative element. It would be somewhat balanced by the lower synchronous reactance. We can't give you an answer about what the result would be until you run a study because there are some positives and some negatives in the equations." —*Thomas E. Baker, Southern California Edison*

B. High Field-Time Constants

As Leon Richardson of GE noted, some of the utilities do not have engineers who fully understand all the engineering issues associated with the design and performance of generators. One-fourth of the respondents were unable to comment on the importance of higher field-time constants.



The respondents who felt competent to comment on higher field-time constants tended to think it was a moderately important disadvantage.



A representative of Southern California Edison said that the higher field-time constants would aggravate their problem of protecting auxiliary transformers:

"We have trouble protecting our auxiliary transformers. The auxiliary transformer is fed off the generator bus. When a unit trips, the generator has all the trapped flux in it. You feed fault current for an external fault, and it takes out the auxiliary transformer. We have high-speed relays that will see a fault external to the transformer, it will trip everything in six cycles, but the machine is still rotating and still has trapped flux in it, and so it continues to feed fault current during the generator coastdown, and when it is all over with, usually we lose the auxiliary transformer. The higher field-time constants would aggravate that condition. It's a problem now, and longer field-time constants would make it more of a problem. If you increase the time constant, it will see fault current for a longer period of time, would be my assumption. We're running a research program in order to alleviate this situation. This superconducting generator would make it even tougher." *—Thomas E. Baker, Southern California Edison*

Another respondent stressed that the importance was situation-specific:

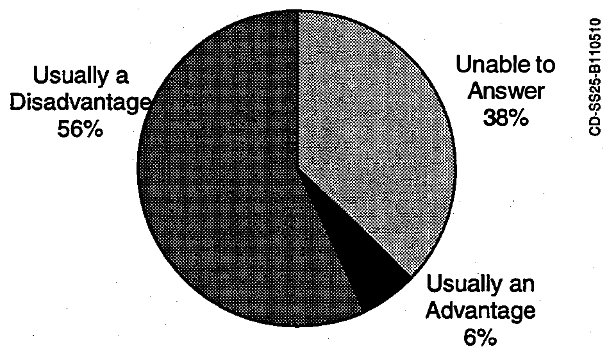
"High field-time constants could be a problem. It all depends on what parameters you are designing to and what your system requires. In one system, it would make no difference; in another, it might—you have to look at the system where you are applying the unit and see what you want to get done, other than just producing power. You have to see how the generator would behave in steady-state and transient conditions, and that would determine what those constants ought to be." *—Shalom Zelingher, New York Power Authority*

Evaluating the Lower Transient and Subtransient Reactance

Regarding the significance of lower transient and subtransient reactance, 56% (nine respondents) said those characteristics were usually a disadvantage, 6% (one respondent) said they were usually an advantage, and 38% (six respondents) were unable to answer.

"In most cases, it would not be an issue. These parameters determine the amount of current that would flow into a fault, a short at the machine's terminals. With today's protective relays and fast breakers, not many utilities would have a problem with this." *—Jim Michalec, American Electric Power*

Significance of Lower Transient and Subtransient Reactance



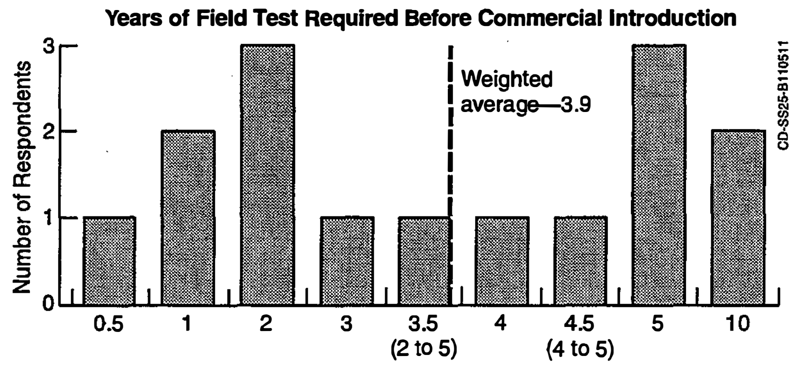
One respondent suggested that the problem would be more severe for larger machines:

"These factors would not be a serious concern in a 100-MW machine, but in a 500–600-MW generator it could be a problem if the short-circuit levels go up too high." *—Lawrence Wall, Southern Company Services*

Commercialization of Superconducting Generators

A. Years of Field Tests Required before Commercial Introduction

The responses about how much field testing would be required before commercial introduction ranged from 6 months to 10 years. The most frequent responses were 2 years and 5 years.



The following comments are typical:

> **" . . . One or two years of field trial doesn't say anything about the life of the winding, so people will look very carefully at how you insulate the wire, what type of wire you have, and they would like to see many aging tests on the wire . . ."**

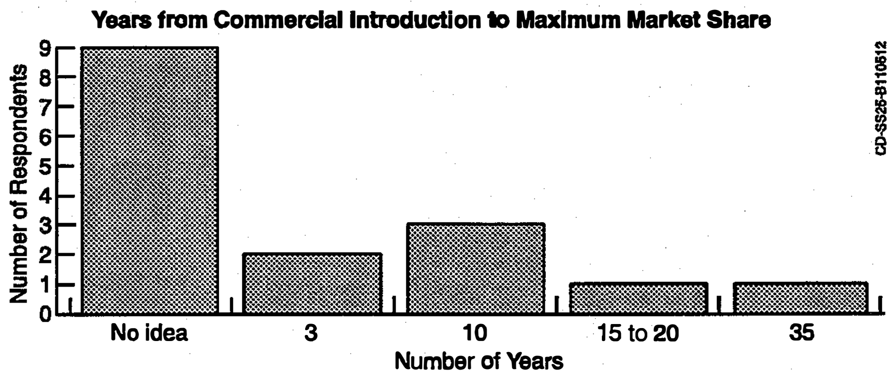
"If you tried to send that machine to me, I would spend a lot of time looking at the winding. One or two years of field trial doesn't say anything about the life of the winding, so people will look very carefully at how you insulate the wire, what type of wire you have, and they would like to see many aging tests on the wire before they go on. If you have to rewind this machine twice over its lifetime, your $5 million is more than lost. I think that would be a crucial issue, the reliability of the winding... From an operating perspective, 1 year is plenty to see how it will behave for system disturbances, but when you get into the credibility of that design, you probably need 5 years. The overhaul interval is normally 5 years. We have a lot of experience at how insulation systems behave in 5-year intervals. Run it for 5 years and then have a thorough inspection and see how it has really held up. It's not going to be a quick sell."
—Thomas E. Baker, Southern California Edison

"We are a smaller utility, so we would be looking for a larger utility to do it first. It would have to operate at least 1 year subject to real conditions: short circuits, surges, cycling, and starts and stops."
—Henry Henriksen, South Carolina Electric & Gas

"There would have to be several units with 3–5 years of experience before we would even consider it."
—Bob Schukai, Union Electric

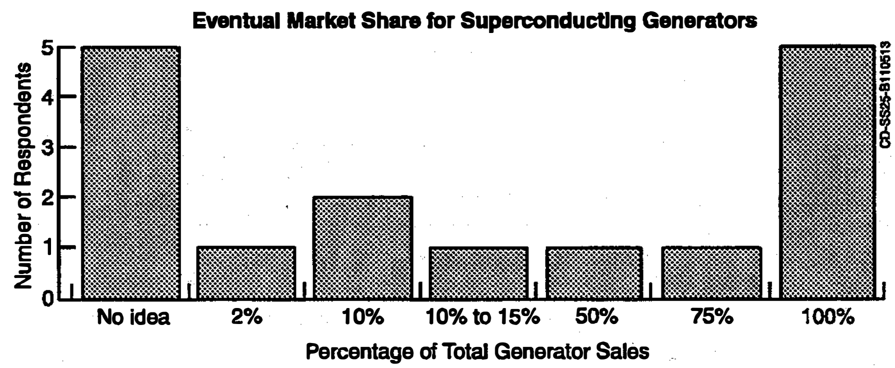
B. Years from Commercial Introduction to Maximum Market Share

Only seven respondents would guess the duration of time from commercial introduction to maximum market share. Their responses ranged from 3 to 35 years.



C. Eventual Market Share for Superconducting Generators

The estimates about what market share superconducting generators might eventually achieve ranged from 2% to 100%.



The respondents who felt the eventual market share would be low cited a variety of reasons:

> "It would get only about 10% of the market because it would be a more complex machine. There is a level of skepticism. You need proof before people would consider it." *—Shalom Zelingher, New York Power Authority*

> "Application of this machine is somewhat limited. It is really only suitable as a baseload unit. You couldn't use this as a peaking unit because the cool-down time for the rotor is presumably too long. Peaking units must be ready to come on line within a matter of minutes." *—Rik Nilsson, Ohio Edison*

> "Most of the added capacity in the next 15 years will be peaking capacity. Because of the higher initial costs and the risks of not being able to cover those costs due to the current regulatory climate, this is a negative."
> *—Bob Schukai, Union Electric*

> "Most utilities today are more concerned about getting the most out of existing systems to be better positioned to compete against IPPs than with new technology for entirely new systems." *—Lawrence Wall, Southern Company Services*

> "If it is an IPP, my understanding is they don't care, they just want it to last for their commitment; they can trash it afterwards. Utilities want something that lasts longer." *—Glenn Beckerdite, Kansas City Power & Light*

"If some big manufacturer waved its hands and said, 'We have this generator that is half the size and weight and saves you $40 million,' I would imagine that people would want to start today, and I imagine 50% of their fleet would be that way. It just depends on how sophisticated the utility wants to get... When you ask how big a market these will have over the years, it has to do with who will buy them. The way deregulation is going now, the utilities seem to be heading out of the generation business. Small companies are getting into it, and they are going to go away from sophistication, not towards it. My guess is, if superconducting generators work out really well and do everything you hope they would, due to the unsophisticated owners, you will probably see just 10% of the total generation in the country (using them). That would not be the case if we were going to stay in the generation business. If utilities stayed in the generation business and this worked out well, the next round of generators to be purchased would probably be a good percentage of them, 40% or 50%. But our newest generator went on line 22 years ago. We have no plans to ever buy a new one." *—Thomas R. Wait, Pacific Gas & Electric*

Even so, some respondents saw the possibility of a big win for superconducting generators in the most important markets and, over the long term, in the United States:

"Cryogenics puts another link in the chain of reliability. You would have to demonstrate that it would work in the field, not just in the laboratory."

"We have an excess of generation. When people have excess generation, I don't see them changing an existing machine for a new one because of higher efficiency. I'm not optimistic about market penetration unless you are selling them where there is a big increase like in China. Every year they install 50 to 60 gigawatts of power. Different utilities in different countries have different ideas about how much money up front to spend to get life-cycle cost benefits. If capital cost is not much higher and benefits are greater, they will go for it. I don't see why not."*—Thomas E. Baker, Southern California Edison*

"I don't think it would be economical to do retrofitting. A superconducting generator would be strictly for new units. For our grid, you are talking out to the year 2005 and beyond before we need any new generators... The factors that might influence the market are complexity, how much complexity it's adding. The cooling system, how big it is or how many man-hours it takes to operate or maintain it. Frankly, most of the new generation in the future will come in as a packaged unit. You will deal with someone like General Electric that would sell you both a turbine and generator as a package, so the vendor of the superconducting generator would have to convince the supplier of the turbine to put it into his package. If you did that, it would get a very large percentage of the market; there's no limit, basically. I don't know why it couldn't get 100% if it is reliable and proven and economical." *—John H. McKinley, Southern California Edison*

"One hundred percent, if it becomes state of the art. Even if these generators were 75% of the weight of a conventional machine and 75% the volume, they could still capture the market. Any new generator would be a cryogenic machine. The average on our systems is 20-something years old. Some are nearly 50 years old. Electricity really became popular in this country in the 1910s and 1920s. That means in the next few years, we will see many generators approaching 60 years of age. They will deteriorate, and it will not be economical to repair them; they will need to be replaced. I see a marked need in 10 to 15 years."*—Jim Michalec, American Electric Power*

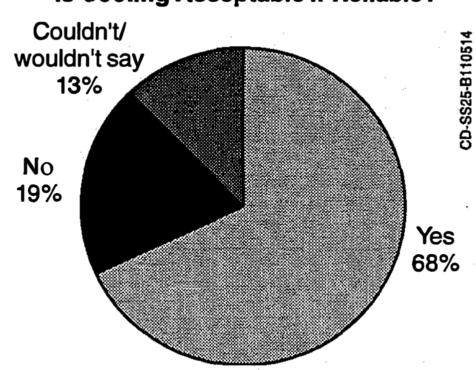
D. Cryogenics

About two-thirds of the respondents commented that cooling is acceptable if the cryogenic system is sufficiently reliable.

Some respondents assume cryogenics will be reliable, others doubt it, some simply don't know about cryogenics:

"Cryogenics is a proven technology by itself." *—Henry Henriksen, South Carolina Electric & Gas*

"It depends on how reliable your cryogenic system is. I would see problems selling the concept. Cryogenics puts another link in the chain of reliability. You would have to demonstrate that it would work in the field, not just in a laboratory." —*Les Ravenscroft, Nebraska Public Power District*



"Not being well informed about the issues relating to cryogenic cooling, I would be concerned about potential safety problems for personnel if there were a major leak, for example. This is more a question of the unknown than anything else." —*Lawrence Wall, Southern Company Services*

"There are a lot of unanswered questions. What does the cryogenic cooling do to the windings? Can you have a leak inside the machine? How do you connect it up? How large is the auxiliary cooling equipment?"—*Tom Higgins, Alabama Power*

One respondent pointed out that all generators are cooled and expressed the opinion that cryogenic cooling is a natural progression:

"We have so many different ways to cool generators: air, water, hydrogen, water and hydrogen, and now we have three new gas turbine generators that use glycol pumped out to a large cooling tower. Cryogenic cooling is the next step. I think it would be a great step forward. I remember when the first hydrogen-cooled plant was installed in Dayton, Ohio, in the late 30s. The technology has made many steps forward since then, and generators have gotten much smaller as a result."—*Hubert Smith, East Kentucky Power*

Another respondent said that a cryogenically cooled generator will last longer:

"The only thing that typically goes wrong with generators is the insulation, and the insulation breakdown is usually temperature related. If you could run at a lower temperature, that would make the insulation last longer, which would make the generator live longer. The 30-year life cycle might be inaccurate; it might last a lot longer. But if they put in thinner insulation, all of that is canceled. I mean electrical insulation in the windings that keeps the windings from shorting to ground and to each other, in both the stator and the rotor. The stator is the more critical one because it is operating at higher voltages... I like running it cooler. There are other advantages because heat from the generator has to go someplace, and if you are talking about power cooling, that means less heat into the lake, and that means more cooling available for the condenser, and I think a utility would like that. It would also mean equipment savings of smaller heat exchangers, and depending on how it's set up, with a separate cooling-water pump, they could get by with a smaller one." —*Glenn Beckerdite, Kansas City Power & Light*

For better or for worse, however, utilities are moving toward simpler cooling systems and large air-cooled machines:

"The cryogenic package would be really simple to run and trouble free, equivalent to any air-cooled machine. We have a hydrogen-sealed system now, but the trend is to go to larger air-cooled machines to get rid of hydrogen. This superconducting generator goes the other way. Especially with cogens, I don't think they are going to run a complicated system. They're in the business of doing it cheap and dirty and not getting too complicated. The level of skills is not very high. We don't like air-cooled machines, because they can be very dirty, depending on how their air system is designed. You have some maintenance expense with an air-cooled machine, cleaning the generator during overhauls. Like a motor, it gets extremely dirty. The hydrogen-cooled generator has a benefit of being a cleaner machine. However, the trend, especially if you look overseas, is to go to bigger and bigger air-cooled machines to get rid of the hydrogen. That is the trend, like it or not." *—Thomas E. Baker, Southern California Edison*

"The conventional generators we use today have stator water-cooling systems that are complex. They have hydrogen seals that are rather complex. They run on hydrogen gas. You have to keep the gas from leaking out past the bearings. So we have elaborate oil seals at both systems to keep gas in and air out. They have a rather complicated system of pumps and valves and regulators.

"The stator windings themselves, some of them are hollow, and just as you would pump liquid helium through the windings, we would pump water through the windings of the stator. The system like that is complicated. We are adding a third system that pumps something else. It has its own problems with maintaining it and getting people to operate it.

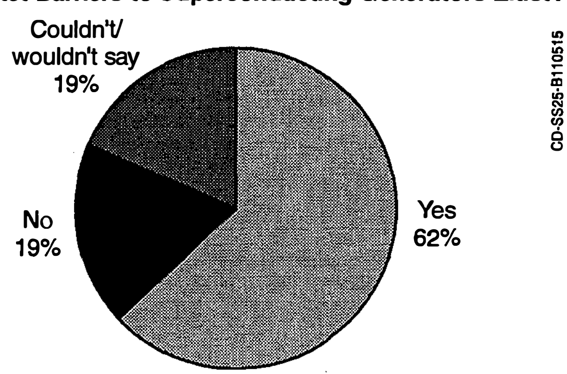
"I am looking today at all the little cogen plants going up around the country. I hate to say this, but people are going the wrong way—not utilities, but cogenerators; they are scared stiff of hydrogen or anything exotic. They want to get away from hydrogen, and they don't use stator water-cooling systems, either. The generators they are buying are about the same level of sophistication as those made in the 1920s.

"I was talking to GE recently, and they are making 200-MW air-cooled generators. Those cost a little less, and they aren't very sophisticated, and the maintenance cost is a little lower. You could pack a lot of dirt around the windings, but there is no oil or hydrogen system to worry about. GE is making the largest air-cooled turbogenerators anybody has ever made, and they keep making bigger ones because people want them no matter how inefficient they are."*—Thomas R. Wait, Pacific Gas & Electric*

E. Market Barriers

Most of the respondents said that market barriers to the introduction of superconducting generators definitely exist.

Do Market Barriers to Superconducting Generators Exist?



The respondents mentioned the need to cool the generators and to train personnel. They pointed out that many regions of the United States have excess generation capacity. One respondent also said that funding for the research is a significant issue:

"There are a lot of barriers with any technology that is new. It just doesn't happen overnight. Those barriers take years to overcome. There may not be a market because there is an overabundance of generation at this point, at least on the East Coast. There is more generation than we know what to do with. Utilities will not be buying generation, not in New York State, until at least 2010 or 2015."
—Shalom Zelingher, New York Power Authority

"The main barriers involve feeling familiar with the technology, knowing what it is and isn't, and being comfortable that the manufacturer can support new equipment. Superconducting material has to be cooled, and that might create additional reliability problems. A lot of this would be worked out in the testing phase... It would be better to market these generators as high-efficiency generators; if superconductivity were the way you accomplished that, then fine. Superconductivity doesn't sell that well; it's a sexy technology label, but people immediately develop images of reliability problems or unproven things."*—Virgil Rose, Pacific Gas & Electric*

"We have excess generation now. We have no plans for new units." *—Thomas E. Baker, Southern California Edison*

"A superconducting generator means a lot of extra training for maintenance personnel. The equipment will be more technical than conventional equipment. We don't have any cooled equipment in a conventional power plant." *—Calvin Copeland, Houston Lighting & Power*

"Who is going to pay the research costs? The trend has been for utilities to drop research. EPRI* came on the horizon because individual utilities could not afford their own research departments. Now utilities are dropping out of EPRI. They can't even afford to pay their membership costs. It's the least painful way to cut costs. No one should expect the utilities to foot the bill. It's appropriate for DOE** to be funding this. GE and DOE should publicize this effort more in the trade journals."
—Henry Henriksen, South Carolina Electric & Gas Co.

*The Electric Power Research Institute
** U.S. Department of Energy

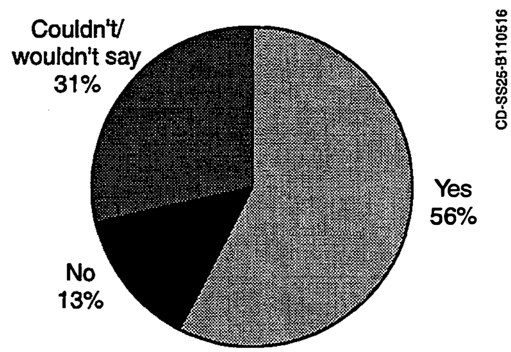
F. Would You Recommend Purchase?

More than half of the respondents said they would recommend that their utilities purchase superconducting generators if they had the properties described.

One respondent pointed out that the purchasing decision is based on economics, not technology:

"My answer is, right now we don't have the beginning of enough information. It is not concern over the technology. If you demonstrate the technology, that is not an issue. It is an issue of capital cost vs. payback. HTS generators are strictly a question of economics, and if the economics are there, it makes sense. The purchasing decision should be reduced to an economic study. . . How many components are required to support the superconducting technology? Five million dollars in lifetime cost savings due to efficiency doesn't strike me as a lot of money. Say you have a winding failure for that technology. You could easily eat up the $5 million over the 30 year life, if repair for the windings required a lot of extra work and expense. To reinsulate a rotor, which is a weak link, a rotating part, you are pushing $1 million. What does it cost to reinsulate the proposed rotor, if that part is superconducting? What if you had a stator winding failure? What would it cost to repair that or rewind the generator, compared to a standard design? Assume one field reinsulation and one stator rewind in your life. We assume that for a conventional machine." *—Thomas E. Baker, Southern California Edison*

Would You Recommend Purchase?



Another respondent described simultaneously his receptivity and his reasons to be cautious:

> "I like the technology if it's proven. We have had some bad experiences going with new technology. We went with a Westinghouse generator and turbine, the largest at the time, a supercritical boiler cyclone burning local coal with a scrubber on the back. All of that was cutting-edge technology at the time, especially for the size. We got it in 1970. It went into service in 1974. It has been a pain in the rear. It only recently ran well. Took 20 years to make it run. It is just now starting to have really nice reliability. It took quite a while to get things sorted out on the scrubber. It is a darn good unit now. It's becoming economical with some of the coal they found to burn on it." *—Glenn Beckerdite, Kansas City Power & Light*

One respondent sounded like a champion for the technology and expressed interest in buying the first unit:

> "It would be foolish not to consider a cryogenic machine. We've done a lot of innovation at AEP. I would be comfortable installing a superconducting generator after seeing one work for 1 year. I would even feel comfortable about being the first. Let's beat the Japanese out of it. We have the talent here and we have plenty of places that we could put one in. I'm all for it. Let's be the first one on the block. I'd like to see my tax dollars go to work here." *—Jim Michalec, American Electric Power*

List of Figures

Appendix A. Respondents

Thomas E. Baker, Southern California Edison Company (Rosemead, CA)
Glenn Beckerdite, Kansas City Power & Light Company (Kansas City, MO)
Calvin Copeland, Houston Lighting & Power Company (Houston, TX)
Henry Henriksen, South Carolina Electric & Gas Company (Columbia, SC)
Tom Higgins, Alabama Power Company (Birmingham, AL)
John H. McKinley, Southern California Edison Company (Rosemead, CA)
Jim Michalec, American Electric Power Company, Inc. (Columbus, OH)
Rik Nilsson, Ohio Edison Company (Akron, OH)
Les Ravenscroft, Nebraska Public Power District (Columbus, NE)
Virgil Rose, Pacific Gas & Electric Company (San Francisco, CA)
Bob Schukai, Union Electric Company (St. Louis, MO)
Hubert Smith, East Kentucky Power Cooperative, Inc. (Winchester, KY)
Noah Tai, Consolidated Edison of New York, Inc. (New York, NY)
Thomas R. Wait, Pacific Gas & Electric Company (San Francisco, CA)
Lawrence Wall, Southern Company Services, Inc. (Birmingham, AL)
Shalom Zelingher, New York Power Authority (New York, NY)

Appendix B. Generator Questionnaire*

Advantages

The table below lists six probable advantages of these generators (compared to conventional generators). Please assess the importance of these advantages to your utility by assigning to each a number between 1 and 10 (1 = not important; 10 = extremely important).

Parameter	Advantage	Importance of this Advantage to Your Utility (1 to 10) (1 = not important; 10 = extremely important)
Weight	50% lower	
Volume	50% lower	
Synchronous Reactance	much lower	
Transient Stability	more stable	
Electrical Losses	50% lower	
Life-Cycle Costs	significantly lower	

Disadvantages

The table below lists three probable disadvantages of these generators (compared to conventional generators). Please assess the importance of these disadvantages to your utility by assigning to each a number between 1 and 10 (1 = not important; 10 = extremely important).

Parameter	Disadvantage	Importance of this Advantage to Your Utility (1 to 10) (1 = not important; 10 = extremely important)
Capital Cost	higher	
Rotor Inertia	somewhat lower	
Field Time Constants	much higher	

*Used as a guideline for telephone interviews.

Characteristics

The probable characteristics listed in the table might be advantages in some settings and disadvantages in other settings. Please tell us your perspective by completing the table below.

Parameter	Characteristic	% of All Installations Where This Characteristic Would be an Advantage	Importance of This Advantage on a Scale of 1 to 10 (10 = most important)	% of All Installations Where This Characteristic Would be a Disadvantage	% of All Installations Where This Disadvantage Would Rule Out This Generator
Transient Reactance	somewhat lower	%		%	%
Subtransient Reactance	somewhat lower	%		%	%

Miscellaneous Questions

1. These generators will require cryogenic cooling. We assume you won't object to cryogenic cooling, provided that it doesn't decrease reliability or increase maintenance requirements. Is that assumption true?

   _______ Yes, cryogenic cooling is acceptable provided that it doesn't decrease reliability or increase maintenance requirements.
   _______ No, cryogenic cooling is not acceptable because ____.

2. How long would these generators have to operate successfully in a field test before you would consider them reliable enough to purchase?
   _______ (length of time)

3. Do you buy equipment on the basis of initial capital cost or life-cycle costs?
   _______ Initial Capital Cost
   _______ Life-Cycle Cost

4. Would you buy a superconducting generator on the basis of its lower life-cycle costs?
   _______ Yes
   _______ No

5. What percentage of the total U.S. generator market would these generators eventually capture? __________%

6. How many years after their introduction would it take them to capture that percentage? _______ (years).

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This report relates to a series of discussions with electric utility engineers concerning the integration of high-temperature superconducting (HTS) generators into the present electric power system. The current and future interest of the utilities in the purchase and use of HTS generators is assessed. Various performance and economic factors are also considered as part of the analysis of utility prospects for HTS generators.

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