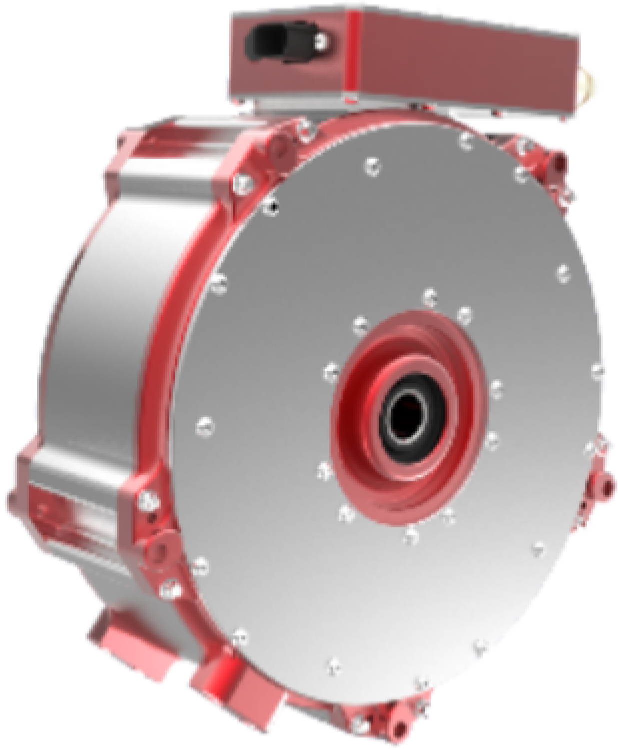
QUALITATIVE PROOF BASED ON EXPERT



SYNCHRO-SYM Technologies

– QUALITATIVE PROOF BASED ON EXPERT ANALYSIS –

Our Mission:

Innovate For Our Clean, Efficient, and Sustainable Energy Future!

QUALITATIVE PROOF BASED ON EXPERT ANALYSIS:

An Article by Evgeni Ganev, Ph.D., "[redacted]," IEEE Electrification Magazine, Dec. 2014, page 13-22, which was based on "High Performance Electric Generators for Aerospace More Electric Architectures," by Evgeni Ganev, Ph.D., Honeywell International, Aerospace Engineering & Technology, Torrance, CA, USA, comprehensively details the key performance criteria between all electric motors and generators:

"An optimal machine design process starts from a good understanding of the machine variables expressed by the output equation in formula (1). This equation represents the output power of a machine as a function of the basic geometry and electromagnetic characteristics.

$P = C \times B_L \times AC \times D^2 \times L \times N$ (1)

P is the electrical power generated at the EM terminals; N is the shaft speed; L is the length of the magnetically active machine; D is the rotor (or air-gap) diameter; ***AC*** *is the specific electric loading, which is the armature ampere conductors per unit length of armature periphery at the air gap;* B_L *is the machine magnetic loading, which represents the* *average flux density over the air gap; and C is a machine constant dependent on various factors such as rotor pole numbers and stator winding arrangements. The product D^2 x L represents the machine air-gap volume and is a measure of the used active magnetic materials. It is logical that the total weight and volume of an EM is proportional to the air-gap volume."*

NOTE: The table of key characteristics (**KC**s) from the article do not include the compounding cost, loss, and size effects of the essential electronic controller for practical application of the electric motor-generator (i.e., machine) "system," such as any derivative of *estimating* field-oriented control (**FOC**). Since equitable comparisons must be based on the same power rating and optimized packaging, the KCs are relative to "per unit of electric machine power rating." As a result, the *higher* the KC value in Table 1A, the better performance. Still, it is essential that the reader review Dr. Ganev's article to understand this abstract concept of KC (key characteristics). All of Dr. Ganev's contestants belong to the asymmetric electric machines with the asymmetry of a "passive" rotor assembly comprising rare-earth permanent magnets (**RE-PM**), slip-induction dependent windings, DC field windings, or reluctance saliencies.

Unlike the asymmetric electric machine systems with a "passive" rotor assembly that consumes precious motor real-estate, cost, and loss but cannot produce "working" power, only the brushless symmetric multiphase wound-rotor synchronous doubly-fed electric machine system, known as SYNCHRO-SYM, has the symmetry of an "active" rotor assembly comprising another directly excited multiphase winding set for providing synchronous stabilization at any speed between sub-synchronous and super-synchronous speeds, including zero and synchronous speeds, which is only possible with the relatively recent enabling invention of *automatically exact* brushless real time emulation control (**BRTEC**). As a result, SYNCHRO-SYM provides twice the constant-torque speed range (*i.e., double Maximum Load RPM*) as the asymmetric electric motor system with the same torque, frequency and voltage of excitation, and packaging (*i.e., 7200 RPM with 1 pole-pair @ 60 Hz of excitation versus 3600 RPM*). Tantamount to effectively providing double the power density, half the loss, half the cost, octuple the peak torque, and twice the armature ampere conductors per unit length of armature periphery at the air gap with similar "active" winding sets strategically positioned on each side of the airgap (and all based on "per unit of electric machine power rating" for power scaling), the specific loading term, "AC," of equation (1) for SYNCHRO-SYM is twice the specific electric loading as asymmetric electric motors and as a result, the KCs (*per unit of power rating*) of SYNCHRO-SYM is twice the KC rating of the Induction motor (IM), which also has winding sets on the rotor and stator, respectively, albeit a passive and an active winding sets. As shown in Table 1A, which is Table 1 of Dr. Evgeni Ganev's article with the *additional* column for SYNCHRO-SYM's KCs, SYNCHRO-SYM has 184 total KCs (or double the IM KCs per unit of power rating), which is nearly twice the 120 total KCs for the best case, toothless, multi-pole PMM, as theoretically expected by at least 60 years of classic electric machine study and research.

Table 1A. Electric Machine Key Characteristics (KC) [*leveraged from Table 1 of the Article*]

Note 1. Higher numbers are better
Note 2. Rotor thermal limitation for PMM is typically 200°C.
Note 3. KC 1-14 Descriptions can be found in the Article, scaled to per unit of power rating
Note 4. Induction Electric Machine (**IM**), Synchronous Reluctance Electric Machine (**SRM**), Rare-earth Permanent Magnet Electric Machine (**PMM**)

	Machine Type Key Characteristics	SYNCHRO-SYM	IM	SRM	PMM Tooth, 2-Pole	PMM Tooth, Multi-pole	PMM Toothless, 2-Pole	PMM Toothless, Multi-pole
KC 1	***Rotor losses***	**12**	**6**	**6**	**10**	**10**	**10**	**10**
KC 2	***Stator losses***	**16**	**8**	**8**	**9**	**10**	**8**	**9**
KC 3	***Windage losses***	**10**	**5**	**1**	**9**	**9**	**10**	**10**
KC 4	***Rotor thermal limitations***	**16**	**8**	**10**	**4**	**4**	**4**	**4**
KC 5	***Cooling options***	**10**	**5**	**5**	**9**	**9**	**10**	**10**
KC 6	***Rotor mechanical limitations***	**10**	**5**	**7**	**9**	**9**	**10**	**10**
KC 7	***Torque-to-inertia ratio***	**10**	**5**	**7**	**9**	**9**	**10**	**10**
KC 8	***Torque Pulsation***	**18**	**9**	**3**	**6**	**6**	**10**	**10**
KC 9	***Compatibility with bearings***	**10**	**5**	**5**	**9**	**9**	**10**	**10**
KC 10	***High-speed capability***	**10**	**5**	**7**	**9**	**9**	**10**	**10**
KC 11	***Short-circuit behavior***	**20**	**10**	**10**	**4**	**4**	**3**	**3**
KC 12	***Machine complexity***	**14**	**7**	**10**	**9**	**9**	**8**	**8**
KC 13	***Current density***	**14**	**7**	**7**	**10**	**10**	**8**	**8**
KC 14	***Power density***	**14**	**7**	**8**	**10**	**10**	**8**	**8**
	TOTAL KC WEIGHT	**184**	**92**	**92**	**116**	**117**	**119**	**120**

By extrapolation, the detailed analysis of a well-known electric machine expert shows SYNCHRO-SYM is 1.3x (best asymmetric RE-PM electric machine system) to 2x (asymmetric slip-induction electric machine system) better without including the significant performance advantages of BRTEC over FOC. For instance, operating under the same port voltage for equitable comparison, the full rated electronic controller of the asymmetric electric machine system would require full current control to meet full power rating in contrast to the half-rated (and half current) BRTEC, which provides SYNCHRO-SYM a significant I^2R loss advantage. Also, the electric machine entity power loss would be compounded as it passes through the controller.

Electric Machine Systems	**Key Characteristic (KC) Weight**
SYNCHRO-SYM	**184**
Best Asymmetric RE-PM	**120**
Asymmetric Slip-Induction	**92**