Best Electric Machine
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THE SIMPLE TRUTH (PART 2)

- SIMPLE TRUTH (PART 1) -
- SIMPLE TRUTH (PART 3) -

SYNCHRO-SYM IS THE PINNACLE OF ELECTRIC MOTORS

BOTTOM LINE UP FRONT

BEM leveraged the patents of the *only* electric motor technology, called **SYNCHRO-SYM**, with a practical brushless real-time emulation controller (**BRTEC**) for enabling the "synchronous" symmetric doubly-fed circuit and control architecture, which is employed in the classic introductory study of electric motor, generator, and transformer theory *(i.e., electric machine theory*) (*see a two-phase version in 4.1.19 – 4.1.23 of Figure 1*) by *hypothesizing* the invention of a BRTEC means that electric machine researchers reasoned essential to eliminate the reliance on slip-induction for *contiguously* "synchronous" stability from sub-synchronous to super-synchronous speeds, including at (or about) synchronous speed, where slip-induction ceases to exist. At least a half century of classic electric machine study and research proved that the circuit and control architecture of SYNCHRO-SYM, which is without permanent magnets, is the pinnacle of electric motor systems (**EMS**) by providing twice the power density and octuple the peak torque at half the cost and half the loss per unit of power rating of any other EMS with the same packaging, construction, electronic component, and manufacturing techniques and the same "operational design specification," such as voltage, excitation frequency, torque, synchronous speed, and air-gap flux density. Until SYNCHRO-SYM, the pinnacle of electric motor circuit and control architecture has never materialized in practice because of the formidable challenges of realizing the invention of a practical BRTEC of BEM. Most importantly**, l**ike the "DC field-wound-rotor" synchronous EMS from **ZF, Mahle, Vitesco, and BMW's 5th generation e-drive (2022)**, SYNCHRO-SYM is ethically without the harmful environmental and geopolitical consequences of rare-earth permanent magnets (**RE-PM**) but also, *with just one simple additional assembly step***,** the resulting SYNCHRO-SYM *drop-in replacement* will brushlessly provide twice the power density and octuple the peak torque with half the cost and half the loss per unit of electric motor power rating.

DESCRIPTION

For nearly 150 years, the performance improvement in efficiency, cost, and power density of the electric motor system (**EMS**) has been the result of specialized construction, manufacturing, packaging, and control techniques (Part 1 and Part 2 by Mr. Jeffrey Jenkins) but the actual *electric motor circuit and control architecture* hasn't fundamentally changed from the non-optimal "electromagnetic *asymmetry*" of a "passive rotor assembly," which always comprises slip-induction dependent windings, permanent magnets, reluctance saliencies, or DC field windings, that reasonably consumes half of the electric motor system real-estate, cost, and loss, particularly when including all associated frictional, controller, and assembly components, but without synchronously, stably, contiguously, and independently (*i.e., no slip-induction*) contributing additional "working power" to the electromechanical energy conversion process along with the *universally essential* "active stator assembly," which comprises the single directly-excited multiphase winding set or "active winding set" for actual "working power" production (*i.e., singly-fed*). As examples, with no *directly-excited* multiphase electrical port for contributing working power, permanent magnets are obviously "passive" devices and likewise slip-induction dependent winding sets are passive devices, because any working power is mutually coupled between the *secondary* and *primary* windings with *compounding* loss, cost, and size effects on the rotor and stator. In consideration, the basic purpose of the rotor is to establish the air-gap magnetic flux density by closing the magnetic circuit of the core.

Only BEM has leveraged the patents of a new EMS technology, called **SYNCHRO-SYM**, that fundamentally changes the *electric motor circuit and control architecture* with the optimal "electromagnetic *symmetry*" of an "active rotor assembly," which brushlessly comprises a similar "active winding set" as the stator's (*i.e., doubly-fed*), that reasonably consumes half of the electric motor system real-estate, cost, and loss but *unlike* the "passive rotor assembly" of the singly-fed asymmetric EMS, the "active rotor assembly" brushlessly, synchronously, stably, contiguously, and independently contributes an additional increment of "working power" to the electromechanical energy conversion process along with the universally essential "active stator assembly." The "active rotor assembly" is only possible with *automatic* brushless real-time emulation control (**BRTEC**), which eliminates: a) the size, loss, and cost of the multiphase slip-ring assembly, b) unstable delays of measuring shallow (low frequency) signal slopes, c) *estimating* response to *random* line and rotor shaft perturbations, d) the need for rotor permanent magnets, DC field windings, or reluctance saliencies, and e) reliance on slip-induction to contiguously guarantee stable "synchronous" operation from sub-synchronous to super-synchronous speeds, including at (or about) zero speed and synchronous speed, where slip-inductions ceases to exist. Without BRTEC, the circuit and control architecture revert to the so-called "wound-rotor slip-induction doubly fed electric machine," which is an asymmetric slip-induction EMS that is predominantly used in wind turbine generators.

With the electromagnetic symmetry of two similarly rated active winding sets on the rotor and stator, respectively, which conveniently preserves the same footprint as the asymmetric EMS, particularly in an axial flux formfactor with similar adjacent disks, at least a half century of electric machine research have proven SYNCHRO-SYM provides *twice* the maximum load speed (**MLS**) range (or constant-torque speed range) with a given frequency of excitation, port voltage, synchronous speed, and torque, which *calculates* to double the power density, half the cost, and half the loss (*per unit of continuous power rating*) with the same packaging, construction, manufacturing, thermal management, and control techniques under the same "operational design specification," such as voltage, excitation frequency, torque, synchronous speed, and air-gap flux density, as the asymmetric EMS with a single active winding set. For example, a two-pole SYNCHRO-SYM provides an MLS of 7200 RPM with 60 Hz excitation *versus* an MLS of 3600 RPM for a two-pole asymmetric EMS with the same torque design, which is a clear indication of double power density at half the cost and loss per unit of continuous power rating with the same design torque. Also, unlike the asymmetric EMS, the physics of a symmetric dual-ported transformer circuit topology with little magnetizing MMF, as only realized by SYNCHRO-SYM, automatically neutralizes the stator torque flux by the rotor torque flux and as a result, air-gap flux density (and associated core loss) remain constant with changing torque current, which avoids core saturation and allows at least octuple (8x) peak torque potential over the asymmetric EMS with increasing torque current, without considering the universal thermal management means to dissipate electrical loss during short bursts of high torque acceleration or deacceleration. It follows that BEM correctly challenges the multiple EMS categories of customary electric motor practice with the simplicity of just two distinct EMS categories for easy trade space assessment: 1) the electromagnetically "symmetric" EMS, as only realized by SYNCHRO-SYM, and 2) the electromagnetically "asymmetric" EMS of all others.

BEM is basing all of its performance calculation on the axiom, "*Premise 1:* w*ith the same effective air-gap area determined by the same "operational design specification," such as port voltage, excitation frequency, torque, synchronous speed, and air-gap flux density, and Premise 2: with electric motor size directly proportional to the effective air-gap area, Conclusion: any asymmetric EMS will show similar size, cost, and loss with the same "operational design specification" and with the same optimized packaging, construction, control, and manufacturing techniques, particularly by including all associated frictional, essential electronic control, and essential assembly components.*" As the result of having two active winding sets with the power rating of the single active winding set of the asymmetric EMS, the axiom can be restated as, "*SYNCHRO-SYM will always show double the power density and octuple the peak torque at half the cost and half the loss with the same packaging, construction, manufacturing, electronic component techniques (less RE-PM) under the same "operational design specification" of any other EMS.*" Seemingly a change to the axiom would depend on: 1) the advancements in permanent magnet (**PM**) energy product but BEM argues that any material science to improve PM energy product at the molecular level would likely provide similar performance improvement in electrical core materials or 2) the advancement in a practical superconductor (*i.e., so-called super*

permanent magnet), but BEM argues that any advancement in superconductors will bring AC superconductors closer to reality, which would make the fully electromagnetic SYNCHRO-SYM the EMS of choice, although the brushless, automatic, precision control of BRTEC would bring the superconductor EMS closer to practical reality, today. All other packaging, construction, manufacturing, control advancements are seemingly compatible with either the asymmetric or the symmetric EMS.

The electromagnetically asymmetric RE-PM EMS for electric vehicles (**EVs**), which are expensive with harmful environmental and geopolitical consequences, are operating at very high speeds to seemingly reduce the amount of RE-PM materials because paradoxically, high speed operation requires the additional "compounding" loss, cost, size, reliability, and maintenance consequences of: i) a large speed reduction gearbox, ii) a high frequency electronic controller, iii) a high frequency winding set, and iv) a high frequency core. For example, if the gearbox component is 98% efficient and the electric motor component is 95% efficient, the *compounded* efficiency for a useful system of systems (**SoS**) is reduced to only 93.1% (98% x 95%) while also, negatively impacting SoS complexity, maintenance, and reliability, all of which are never made obvious by the gearbox/EMS manufacturer. Also, the RE-PM EMS has efficiency draining cogging torque and is being non-optimally retrofitted with the additional loss, cost, and size of magnetizing MMF for enabling coveted field weakening capability, which ironically, was already more optimally provided by the self-induction EMS being replaced. As a fully electromagnetic EMS with field weakening capability for optimal performance at different speeds, with octuple (8x) the peak torque potential, and without cogging torque, SYNCHRO-SYM provides the only practical gearless or direct drive EMS for another level of EV efficiency, low cost, small size, high reliability, low maintenance, and extended range.

SYNCHRO-SYM is best implemented in an axial-flux formfactor because unlike the asymmetric EMS with a derivative of estimating field-oriented or direct-torque control, only the compact, highly integral BRTEC, which has a unique AC-to-AC conversion method that is without a DC Link Stage for suitable partitioning between the rotor and stator, can be conveniently merged into the otherwise unoccupied annulus area: 1) to provide another level of power density, efficiency, and cost by correctly allowing the size, cost, and loss of BRTEC to be inherently included in SoS calculations and 2) to reduce component assembly inventory and design with similar rotor and stator assemblies. To conveniently provide an axial-flux SYNCHRO-SYM, BEM has leveraged the patents of the only practical 3D Printer of electric machines, called **MOTORPRINTER**, which implements a *unique* laminated object *additive* manufacturing (**LOM**) *method*, that uniquely layers off-the-shelf feedstock materials *without altering* their premanufactured properties, which were specifically optimized for the performance of the electric motor being manufactured instead of the performance of MOTORPRINTER, such as amorphous or nanocrystalline metal ribbon, structural materials, and magnetic wire. In complete contrast, customary 3D Printers layer feedstock materials *by altering* their premanufactured properties, such as sintering, which were specifically optimized for the

performance of the 3D printer without specific regard to the performance of the product being manufactured. BEM has already orchestrated the original successful experimental studies with several companies, such as IPG-Photonics and Metglas, which proved the MOTORPRINTER method of layering premanufactured feedstock material without damaging the delicate electromagnetic and structural properties. Presently, BEM is fabricating MOTORPRINTER for the rapid, scalable (*e.g., portable*), low cost, inhouse additive manufacture of axial-flux SYNCHRO-SYMs for at least meeting anticipated customers' specified needs just-in-time. Also, under the control of BEM's CAD tool (**BEM-CAD**), MOTORPRINTER provides a unique high performance thermal management means to meet the power density potential of SYNCHRO-SYM. For instance with BEM-CAD and MOTORPRINTER, BEM has a competing design to the Koenigsegg Quark E-Motor, which is RE-PM free but shows an extraordinary 66 KW/L @ 4000 RPM and 1.25T air-gap flux density.

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