SYNCHRO-SYM Elevator Speech:

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Market Bottom Line Up Front:

Although constrained by the immaturity of the electric vehicle (EV) support infrastructure, such as recharging stations, and the uncertainty of the rare-earth permanent magnet (RE-PM) supply chain, such as the hostile adversary control of its limited global minable supply, the emerging EV traction motor market, alone, is conservatively estimated to reach nearly $40B by 2028 with a compounded annual growth rate (CAGR) of 35.32%. Other reports estimate the entire commercial and passenger electric propulsion motor market with electronic control will reach as high as $1.4T by 2028.

All electric motor manufacturers are serving this market focus with the same century-old *asymmetric* electric motor circuit and control technology comprising the asymmetry of a *passive rotor assembly* with either rare-earth permanent magnets (RE-PM), slip-induction dependent windings, reluctance saliencies, and conventional or superconductor DC field windings and an *active stator assembly* that determines similar power rating, performance, and size between optimally designed electric motors with only minor performance distinction provided by the same strategic application of available material, winding, packaging, and manufacturing techniques.

BEM has leveraged the patent of a *symmetric* electric motor circuit and control technology, called SYNCHRO-SYM, which is commonly hypothesized to be the absolute pinnacle of electric motor-generator technology during the century of classic electric motor study. *In accordance with the governing Law of Conservation of Energy*, SYNCHRO-SYM with two active winding sets of similar power rating provides twice the power density at half the cost, half the loss, and octuple the peak torque *per unit of power rating (e.g., $/KW)* within the same packaging of materials, winding, and manufacturing techniques as the other century-old *asymmetric* electric motor circuit and control architecture with a single active winding set of similar power rating but more importantly, without relying on the uncertainty of the rare-earth permanent magnet (RE-PM) supply chain.

Technology Bottom Line Up Front:

All electric motors have a stationary assembly (called a stator) and a rotating assembly (called a rotor) that comprise:

- An "active stator" with a directly excited multiphase winding set that contributes power to the electrical to mechanical conversion process.
- *But* a "passive rotor" with the *asymmetry* of either permanent magnets, slip induction dependent windings, reluctance saliencies, or DC field windings with no directly excited power port that reasonably consumes the other half of the size, cost, and loss

of the electric motor but cannot contribute additional power to the electrical to mechanical conversion process.

Only BEM has a patented *symmetric* electric motor circuit and control technology, called SYNCHRO-SYM, with the symmetry of a directly excited "active rotor" that can stably contribute additional power to the electrical to mechanical conversion process over its entire speed range. With both the stator and rotor contributing "active" power to the electrical to mechanical conversion process:

- *Only* SYNCHRO-SYM *halves* the *size*, *cost*, and *loss* per unit of power rating of all other electric motors with the same application of performance enhancing material, winding, packaging, electronic control, and manufacturing techniques.
- *Only* SYNCHRO-SYM *octuples the peak torque potential* per unit of power rating of all other electric motors.
- *Only* SYNCHRO-SYM *doubles the performance gain* per unit of power rating of all other electric motors. For example, if wide bandgap semiconductors (WBG) are expected to improve the applied performance of the century old asymmetric electric machine system by 10%, then SYNCHRO-SYM with WBG would comparably improve applied performance by 20%!

Show Me SYNCHRO-SYM Is the Pinnacle of Electric Motor-Generator Technology:

All rotating electric motors and generators have a rotating assembly (or rotor) and a stationary assembly (or stator). The stator is attached to the frame (or chassis) and the rotor is attached to the shaft and isolated from the frame by bearings. Also:

- Only a directly excited multiphase winding set (*or active winding set)* produces a rotating magnetic field that synchronously pushes or pulls on either the rotor or stator, which contributes active electrical power to the electrical to mechanical energy conversion process when excited with a rotor speed synchronized frequency of alternating current (AC):
  - An "active winding set" is generally placed on the active stator (*i.e., active stator*) to avoid the obvious challenges of *rotating* multiphase electrical connections with automatic speed synchronized excitation.
- In contrast, without an electrical power port for direct multiphase excitation, slip-induction dependent windings, reluctance saliencies, permanent magnets, or conventional or superconductor DC field windings are passive devices, which cannot contribute active electrical power to the electromechanical conversion process in conjunction with the "active stator":
  - "Passive devices" are generally placed on the rotor (*i.e., active rotor*) to avoid the challenges of rotating *multiphase* electrical connections.

For more than a century, the classic study of electric motors and generator begins with the symmetric electric motor circuit and control technology with an active winding set on both the rotor and stator, respectively, by hypothesizing the invention of a brushless, instantaneous (*i.e., real time*), sensor-less & automatic (*i.e., emulation*), and bi-directional

control means (*or brushless real time emulation excitation control or* **BRTEC**^{TM}) that guarantees speed-synchronized and phase-locked multiphase excitation to the rotor active winding set from sub-synchronous to super-synchronous speeds without the asymmetric dependency on slip-induction, which ceases to exist about synchronous speed, and without regard to random rotor shaft and line perturbations:

- Ironically, the classic century old study of the symmetric electric motor circuit and control technology becomes the study of the asymmetric electric motor circuit and control technology by deoptimizing the relational symmetry of an active rotor and stator with the relational asymmetry of a passive rotor and an active stator.
- Without a practical **BRTEC**^{TM} for realizing a symmetric electric motor until the patented invention of **SYNCHRO-SYM**, the rare-earth permanent-magnets (**RE-PM**) asymmetric electric motor is anecdotally considered to be today's most optimum electric motor, particularly for electric vehicle propulsion.

All of today's electric motor manufacturers apply the same century-old electric motor circuit and control technology with the "asymmetry" of an "active stator" and a "passive" rotor" with the total loss, cost, or size of the electric motor determined by the combined sum of the loss, cost, or size of the active stator and passive rotor but with the total working power of the electric motor solely determined by the active stator:

- Therefore, the only cost-performance distinction between today's asymmetric electric motor manufacturers is different strategic application of the same available material, winding, packaging, and electronic control techniques, such as rare earth permanent magnets, wide bandwidth semiconductor switches, or superconductors.

By simply retrofitting the asymmetry of a "passive rotor" with the symmetry of a form fit "active rotor," which has another "directly excited multiphase winding set" that contributes an additional increment of working power production in conjunction with the active stator, the original asymmetric electric motor or generator becomes a symmetric electric motor or generator with the symmetrical power of two active winding sets on the rotor and stator, respectively, providing twice the power capacity within the same packaging of material cost and power loss as the original asymmetric electric motor. With the reasonable trade space assumption that the rotor or stator each consumes half of the loss, cost, or size of the electric motor, the following performance gains become obvious:

- The symmetric electric motor provides twice the power density *per unit of electric motor power rating*.
- The symmetric electric motor provides half the total cost *per unit of electric motor power rating*.
- The symmetric electric motor provides half the total loss *per unit of electric motor power rating*.
- The symmetric electric motor doubles the expected performance gain from applying the same performance enhancing techniques to the original asymmetric electric motor.
- The symmetric electric motor effectively eliminates the entire loss, cost, and size of the "passive" rotor assembly of the original asymmetric electric motor.
- The symmetric electric motor provides octuple the peak torque *per unit of electric motor power rating* with the balanced mutual coupling between the symmetry of two active winding sets on the rotor and stator, respectively, that prevents the core flux

saturation experienced by the original asymmetric electric motor with increasing torque current.

- The symmetric electric motor provides coveted field weakening and comprehensive leading to lagging power factor, including unit power factor at any speed, by selectable phase-locked adjustment.

SYNCHRO-SYM Accomplishments:

The symmetric electric motor leap in performance has been consistently studied and analytically verified by postulating *brushless real time emulation excitation control* during a century of classic electric motor study. In addition, BEM has leveraged several patents on SYNCHRO-SYM technologies and verified **SYNCHRO-SYM** with the only practical **BRTEC^{TM}**: a) by comprehensive analytical study, b) by developing several progressive stages of prototyping, including retrofitting off-the-shelf electric motors, c) by developing pre-production prototyping, and more importantly, d) by developing a computer aided design tool for SYNCHRO-SYM, called **BEM-CAD**, that simultaneously provides true side-by-side designs of the RE-PM and Induction electric machine system with absolute comparative fairness by applying the same electrical and mechanical parameters without different winding, material, packaging, thermal management, and control techniques while interfacing to the only 3D Printing method of axial-flux electric machine systems with high performance electrical, amorphous or nanocrystalline metal ribbon, called MOTORPRINTER. Also, with simple retrofitting examples, **SYNCHRO-SYM** is typically routine electric motor engineering, packaging, and manufacturing ready for power scaling to any customer specification.