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# SYNCHRO-SYM: THE ONLY SYMMETRIC MULTIPHASE WOUND-ROTOR SYNCHRONOUS DOUBLY-FED ELECTRIC MOTOR OR GENERATOR SYSTEM

Frederick W. Klatt, Chief Technology Officer  
[frederick.klatt@BestElectricMachine.com](mailto:frederick.klatt@BestElectricMachine.com)

SYNCHRO-SYM is a patented “synchronous” electric motor or generator (i.e., electric machine) system with the dual-ported symmetry of “directly excited multiphase winding sets” (or “active winding sets”) on the rotor and stator, respectively, the sum of which contribute working (or active) power to the electro-mechanical conversion process from sub-synchronous to super-synchronous speeds as only possible by the invention of an extraordinary brushless real time (*i.e., instantaneous*) emulation control (*i.e., sensorless and automatic*) means (**BRTEC**):

- Only SYNCHRO-SYM has BRTEC that unlike today’s state-of-art field oriented control (FOC) of electric machine systems, instantaneously (*i.e., real time*), automatically and sensorlessly (*i.e., emulation*), and contactlessly (*i.e., brushlessly*) phase locks synchronization between the rotor and stator rotating magnetic fields at any selectable value or speed from sub-synchronous to super-synchronous speeds, including at synchronous speed or zero speed, which eliminates the instabilities of relying on slip-induction that ceases to exist at synchronous speed and randomly introduces the effects of the rotor winding time constant, external excitation faults, external rotor shaft perturbations, etc;
- Only SYNCHRO-SYM has a rotor with another active winding set that “contributes” working (or active) power to the electromechanical energy conversion process in addition to the stator active winding set to uniquely utilize the entire electric machine real-estate (*i.e., both rotor and stator*), which is tantamount to twice the continuous active power rating in the same package as all other electric machine systems with only a stator active winding set;<sup>i</sup>
- Only SYNCHRO-SYM operates from sub-synchronous speed to super-synchronous speed, including zero or synchronous speeds, without motoring or generating regions of discontinuity or instability to uniquely provide twice the continuous constant-torque speed rang for a given torque, voltage, and frequency of excitation (*i.e., 7200 RPM with 60 Hz and two poles versus 3600 RPM for all other electric machine systems, after which constant-horsepower must be maintained with field weakening capability to stay within the safe operating area of any electric machine system*);
- Only SYNCHRO-SYM has a dual-ported transformer circuit topology, which in accordance with physics of conservation of energy, avoids core saturation by holding air-gap flux constant with increasing torque magneto-motive-force (MMF), to uniquely provide at least octuple the peak torque of the nominal frame continuous torque rating

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or at least quadruple the peak torque density as any other electric machine system, which is essential for eliminating the complexity, reliability, cost, maintenance, and physical size of the common electric vehicle gearbox expected by all other electric machine systems; <sup>ii</sup>

- Only SYNCHRO-SYM has BRTEC that acts like the simple, automatic, and instantaneous [electromechanical commutator](#) control means of the [universal electric machine system](#), which provided the highest peak torque and power density (including absolute zero speed) of any electric machine system, such as the ubiquitous rare-earth permanent-magnet (RE-PM) electric machine system, but in contrast, BRTEC uniquely provides speed-synchronized [multiphase AC](#) with significantly higher resolution of control and torque performance, while eliminating the formidable issues of electromechanical contacts or commutation, such as brushes, slip-rings, etc;
- Only SYNCHRO-SYM matchlessly provides direct, brushless, and individual phase, amplitude, and frequency control of the rotor and stator rotating magnetic fields (for implementing the ideal synchronous electric machine system, as only possible with BRTEC);
- Only SYNCHRO-SYM, which is without the size, cost, and inefficiencies of a DC Link Stage with large reactive components, such as large capacitors and chokes, can locate the highly integrated BRTEC in the otherwise wasted annulus space of its axial-flux symmetric multiphase wound-rotor doubly-fed electric machine entity to uniquely provide another level of power density and the overhead simplicity of duplicate rotor and stator assemblies;
- Only SYNCHRO-SYM brings the superconducting electric machine system closer to practical reality by conveniently relocating the DC superconductor field windings to the stator without electromechanical contacts for best superconductor logistics and with lower superconductor heating by virtually eliminating waveform harmonics with nearly pure sinusoidal electronic conditioning; and when AC superconductors become a practical reality, the fully electromagnetic SYNCHRO-SYM (with only winding sets) will be the electric machine system of choice;
- Only SYNCHRO-SYM inherently provides adjustable leading, lagging, or unity power factor correction for dynamic VAR compensation at the field application to dramatically improve electric distribution resiliency and electricity cost.
- Only SYNCHRO-SYM substitutes extravagantly costly, geopolitically volatile, environmentally unfriendly, supply chain limited, slave labor mined, unsafe handling issues of persistent magnetism, and “passive” RE-PMs instead with the electronics and high frequency magnetics of BRTEC and an active winding set.

Without violating the “basic electric machine design axioms,” which will follow, [an implementation of SYNCHRO-SYM is conceptually demonstrated](#) by simply replacing the rotor slip-induction winding set (e.g., squirrel cage winding) of the common induction (or

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asynchronous) electric machine system with a similar active winding set as found on its stator and by simply replacing the common FOC with BRTEC for “brushless and synchronous” operation (instead of asynchronous operation). While utilizing the same packaging as the original induction electric machine but with the performance multiplying feature of two similarly rated active winding sets on the rotor and stator, respectively, simple “*qualitative observation*” shows the SYNCHRO-SYM retrofit provides at least the following, particularly in an axial-flux form factor:

- Half the physical volume (and equivalent amount of material) or twice the continuous power density (*per KW of power rating*) of the original slip-induction electric machine system because the “passive rotor slip-induction winding set” becomes an “active rotor synchronous winding set” that contributes power to electromechanical conversion process in addition to the stator active winding set;
- Half of the cost (*per KW of power rating*) of the original slip-induction electric machine system by reasonably assuming the same amount of material and manufacturing complexity but with twice the power;
- Half of the electrical or core loss (*per KW of power rating*) of the original slip-induction electric machine system by reasonably assuming the same balanced rotor and stator winding MMF (and core dissipation) for highest efficiency but with twice the power;
- Quarter of the electrical loss of magnetizing MMF (*per KW of power rating*) of the original slip-induction electric machine system by uniquely sharing the Magnetizing MMF (and  $I^2R$  loss) between the rotor and stator active winding sets;
- Quadruple the peak torque density (*per KW of power rating*) of the original slip-induction electric machine system because the core saturation avoiding physics (i.e., conservation of energy) of a symmetric or dual-ported transformer circuit topology holds air-gap flux density constant, regardless of increasing torque current (and torque).
- Elimination of the size, cost, and loss of the passive rotor assembly while doubling the power rating.

### **BASIC ELECTRIC MACHINE DESIGN AXIOMS:**

With superconductor electric machine systems as the exception, the following “basic electric machine design axioms” for any reasonable electric machine system comparison, as taken from “[Electric Machine Design Distinctions & Constraints](#),” but more importantly, show that the loss and size between any optimally designed electric machine system contestant are within close margins, particularly in an axial-flux form factor:

1. All electric motor or generator systems (i.e., electric machine systems) must satisfy three basic laws of physics in order to obey the natural law of conservation of energy, which are Ampere Circuital Law, Faraday’s Law, and Lorentz Law;

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2. All electric machine systems have at least one active winding set (*i.e., singly-fed or single directly excited multiphase AC winding set*) that determines the continuous torque rating of the electric machine system or at most two active winding sets (*i.e., doubly-fed or double directly excited multiphase winding sets*) with the sum of the active winding sets determining the total power rating of the electric machine system;
  3. The classic study of all electric machines begins with the study of a doubly-fed electric machine with the symmetry of two active winding sets on the rotor and stator respectively, which provides twice the Maximum Load RPM (*i.e., constant-torque speed range*) for a given torque, frequency and voltage of excitation (or twice the power in the same package) but only by postulating a brushless real-time (*i.e., instantaneous*) emulation (*i.e., sensor-less and automatic*) control means (BRTEC) to guarantee continuously stable operation throughout the constant-torque speed range from sub-synchronous to super-synchronous speed, including synchronous speed where slip-induction ceases to exist, by eliminating reliance on slip-induction excitation. The classic study becomes the study for all other electric machines by de-optimizing the symmetry of two active winding sets on the rotor and stator respectively, with the asymmetry of a passive rotor with slip-induction dependent winding set, reluctance saliencies, permanent magnets, or DC field windings and a constant-torque speed range of up to synchronous speed for a given torque, frequency and voltage of excitation.
  4. Compared to the common radial-flux electric machine form factor with a rotor cylinder inside the annulus of stator cylinder providing a radial flux path direction perpendicular with the axle, the axial-flux electric machine form factor with a rotor disk adjacent to a stator disk (*i.e., so-called pancake form*) providing an axial flux path direction parallel to the axle uses 13% less copper and 21% less steel, while providing: 1) higher efficiency and torque (see axial-flux whitepaper with MAGNAX marketing remarks), 2) equally exposed rotor and stator cooling surfaces for improved thermal management, 3) convenient outside-to-inside winding approach, 4) non-contending and therefore, adjustable air-gap surfaces, and 5) rotor and stator disks of virtually similar size:<sup>iii</sup>
  5. An active winding set, together with its mounting assembly, such as the rotor or stator bodies, reasonably consumes half of the volume, cost, and loss of any electric machine system, particularly in an axial-flux form factor, but also, while contributing additional active (or working) power to the electromechanical energy conversion process;
  6. Permanent magnets, DC field windings, reluctance saliencies, or slip-induction dependent windings are: a) passive components, b) optimally designed with balanced PM coercivity or winding magneto-motive-force (MMF) between the rotor and stator at continuous power rating for best efficiency, and c) together with their mounting assembly, such as the rotor or stator bodies, reasonably consume the other half of the volume, cost, and loss of the electric machine system, particularly in an axial-flux form factor, but also, while not contributing additional active power to the electromechanical energy conversion process;
  7. Air-gap flux density is determined by the saturation limits of the electrical steel core material and not by the bounded residual flux density potential of RE-PM or the unbounded flux density potential of winding MMF and as a result, all optimized electric machines show similar air-gap flux density;

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8. Similar air-gap flux density determines similar effective air-gap area (and physical volume in accordance with the active winding set) for any electric machine system designed with a given continuous torque, frequency excitation, and voltage rating;
  9. Today's so-called invented or performance electric machine systems are actually the same century old asymmetric circuit and control architecture with a "passive rotor" of slip-induction windings, RE-PMs, reluctance saliencies, or DC field windings but with the strategic application of off-the-shelf "packaging art," such as winding, material, frame, construction, or thermal management techniques;
  10. Without considering other optimizing techniques, such as copper rotor windings, Magnetizing MMF of an optimally designed slip-induction electric machine system (with the coveted field weakening capability) shows more physical volume and electrical loss (in proportion to the percentage of slip) than a similarly power rated RE-PM electric machine system (which is without field weakening capability). Ironically, the loss, cost, and size of Magnetizing MMF is being reinstated into high performance RE-PM electric machine systems to leverage field weakening capability;
  11. The Max Load RPM (or constant torque speed range) for a given torque, frequency and voltage of excitation must be known or accurately surmised between competing electric machine systems to minimize performance variations as a result of strategically applying different material, winding, electronic control components, or packaging techniques, which are convenient available to all electric machine systems.

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<sup>i</sup> "Direct Torque and Frequency Control of Double-Inverter-Fed Slip-Ring Induction Motor Drive," Gautam Poddar and V. T. Ranganathan, VOL. 51, NO. 6, December 2004, pp 1329-1337. [See page 1329, 2<sup>nd</sup> column, paragraph 3]

<sup>ii</sup> Norbert L. Schmitz and Willis F. Long, "The Cycloconverter driven Doubly-fed Induction Motor," IEEE Transactions on Power Apparatus And Systems, Vol. PAS-90, No. 2, March/April 1971, pp. 526-531. [page 526, column 1, paragraph 6]

<sup>iii</sup> The Advantages of axial flux are: 1) high torque and less copper and steel; 2) easier for automated winding (equal advantage of SMC) by an outside-in approach to winding. Theoretical considerations by Polard [Zahra Nasiri-Gheidari, Hamid Lesani, "A Survey on Axial Flux Induction Motors," PRZEGLAD ELEKTROTECHNICZNY (Electrical Review), ISSN 0033-2097, R.88 NR 2/2012] show the axial-flux electric machine can reduce copper utilization by 13-14% and iron utilization by 21.5-32.5% compared to the traditional radial-flux electric machine. Furthermore, amorphous metal can reduce core loss, which is 15% of the total loss of any electric machine, by up to 80%, but show properties that make manufacturing difficult (e.g., no practical amorphous metal EMS is available to date).