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

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SYNCHRO-SYM is the only "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 as only possible by the invention of an extraordinary brushless real time emulation control 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 the synchronization between rotor and stator rotating magnetic fields at any selectable value or speed, including at synchronous speed or zero speed, without the instabilities of relying on slip-induction with stochastic 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;[i]

- 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, 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 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; [ii]

- Only SYNCHRO-SYM has BRTEC that acts like the simple, automatic, and instantaneous electromechanical commutator control means of the universal electric machine system, which has 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 electronically controls its full power by electronically controlling only the power of rotor or stator active winding set, which is half of the electronic controller power rating of other electric machine systems, with similar reductions in associated cost, size, and loss;[iii]

- 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 provides a “new” symmetric electric machine circuit and control architecture of a truly symmetric multiphase wound-rotor “synchronous” doubly-fed electric machine system, which was routinely hypothesized during classic academic studies but proven impractical to implement without the invention of a brushless real time emulation control means to overcome stochastic instabilities. In contrast, today’s state-of-art or so-called invented electric machine systems are simply the same century old asymmetric electric machine circuit and control architecture, comprising rotor RE-PMs, slip-induction windings, reluctance saliencies, or field windings, with the optimized application of available high performing packaging art. But if retrofitted with the symmetric circuit and control architecture of SYNCHRO-

SYM, the original performance claims of today's state-of-art or so-called invented electric machine systems would again be doubled;

- Only SYNCHRO-SYM substitutes extravagantly costly, geopolitically volatile, environmentally unfriendly, supply chain limited, and "passive" RE-PMs with the electronics and high frequency magnetics of a new electric machine circuit and control architecture.

- Only SYNCHRO-SYM comprises a copper and electrical steel electromagnetic core with rotor and stator "active" winding sets, which is without extravagantly costly, geopolitically volatile, environmentally unfriendly, supply chain limited, and "passive" RE-PMs; and without the safety and handling issues of persistent magnetism of RE-PM electric machine systems, SYNCHRO-SYM can be conveniently shipped in duplicate, small diameter, low weight rotor and stator components for field assembly, such as desired for low speed, large power wind turbine generators.

- 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.

Without violating the "universal basis" for electric machine systems, 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 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 for a truly equitable comparison 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:

- 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 density;

- 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 density;

- 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).

The "universal basis" for any electric machine system, as taken from "Electric Machine Design Distinctions & Constraints," should be asserted for reasonably equitable comparisons between electric machine systems but more importantly, demonstrate that the loss and size of any electric machine can be optimally designed to be within ten percent of each other:

1. 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 torque rating of the electric machine system with the sum of at most two active winding sets (*i.e., doubly-fed or double directly excited multiphase winding sets*) determining the total power rating of the electric machine system;
2. 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 but also, while contributing additional active (or working) power to the electromechanical energy conversion process;
3. 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 MMF between the rotor and stator at continuous power rating for best efficiency, and c) together with the mounting assembly, such as the rotor or stator, reasonably consume half of the volume, cost, and loss of the electric machine system but also, while not contributing additional active power to the electromechanical energy conversion process;
4. Without the unlimited MMF of the futuristic superconducting electric machine system as the only exception, air-gap flux density is determined by the saturation limits of the electrical steel core material and not by the residual flux density of RE-PM or the unbounded flux density potential of winding MMF and as a result, all optimized electric machines have similar air-gap flux density;
5. Similar air-gap flux density determines similar effective air-gap area (and physical volume) in accordance with the active winding set for any multiphase electric machine system with a given continuous torque, speed, and voltage rating;
6. Today's so-called invented 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 optimized application of off-the-shelf "packaging art," such as winding, material, frame, construction, or thermal management techniques;
7. Without considering other optimizing techniques, such as copper rotor windings, Magnetizing MMF of an optimally designed slip-induction electric machine system

(which is with coveted field weakening capability) shows about 5-10% more physical volume and electrical loss than a similarly rated RE-PM electric machine system (which is without field weakening capability);

8. Only a brushless, sensorless, automatic, and instantaneous multiphase control means implements a continuously active rotor that is necessary for a truly practical symmetric multiphase wound-rotor "synchronous" doubly-fed electric machine system.

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[i] "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, 2nd column, paragraph 3]*

[ii] 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]*

[iii] "Evaluation of Current Control Methods for Wind Turbines Using Doubly-Fed Induction Machines," Andreas Petersson, Lennart Harnefors, and Torbjorn Thiringer, IEEE Transactions On Power Electronics, Vol. 20, No. 1, January 2005, pp. 227-235. *[See page 227, column 1, 1st paragraph]*