Abstract – By conceptually replacing the “passive rotor” of any “asymmetrical” axial-flux electric motor or generator system, such as rare-earth permanent magnet (RE-PM) rotors, with an “active rotor” as only provided by brushless real time emulation control, straightforward “qualitative observation” verifies that the resulting brushless, stable, and “symmetrical” multiphase wound-rotor doubly-fed “synchronous” electric machine system would show half the cost, half the size, half the electrical or core loss, and up to octuple the peak torque as the original asymmetrical axial-flux electric machine system with the same voltage, air-gap flux density, air-gap effective area, materials, manufacturing, winding, and electronic drive component techniques.

Index Terms—brushless, real-time, sensor-less, synchronous, wound-rotor, doubly-fed, electronic power transformer

I. INTRODUCTION

By conceptually replacing the “passive rotor” of any “asymmetrical” axial-flux electric motor or generator system, such as rare-earth permanent magnet (RE-PM) rotors, with an “active rotor” as only provided by brushless real time emulation control, straightforward “qualitative observation” verifies that the resulting brushless, stable, and “symmetrical” multiphase wound-rotor doubly-fed “synchronous” electric machine system would show half the cost, half the size, half the electrical or core loss, and up to octuple the peak torque as the original asymmetrical axial-flux electric machine system with the same electromagnetic construction and formfactor, such as the same packaging, the same effective airgap area, the same airgap flux density, the same voltage rating, the same electrical or core loss, the same amount and cost of materials (less any passive components, such as RE-PMs, saliencies, slip-induction windings, etc.), and the same manufacturing, winding, or electronic drive component techniques.

II. TECHNOLOGY BACKGROUND

All electric motors and generators (traditionally called electric machines) are polyphase alternating current (AC) electric machines because only a multiphase AC winding set “directly” excited at its terminals (or “active” winding set) independently establishes a “moving” magnetic field that pushes or pulls on the other magnetic field of the rotor or stator bodies for “active” participation (and power contribution) to the electrical to mechanical (or electromechanical) power conversion process. Today’s electric machine “systems” commonly employ electronic control of the “active” winding excitation waveform to tune the speed or torque for optimum performance or to at least provide practical operation, such as for permanent magnet and reluctance electric machine systems.

The rotor of virtually all electric machines comprises either slip-induction dependent windings that are fundamentally “leakage” winding extensions of the stator active winding set, a DC field winding that is generally connected through a single phase slip-ring assembly, permanent magnets, or reluctance saliencies in order to avoid the formidable complications of directly providing precision speed-synchronized multiphase AC electrical excitation power to the terminals of a rotating “active” winding set from sub-synchronous speeds, such as zero speed, to super-synchronous speeds, such as twice synchronous speed, including about synchronous speed. Without a directly excited multiphase AC winding set, the rotor assembly reasonably consumes half of the volume, half of the cost, and half of the electrical (or core) loss of the electric machine system but only “passively” participates in the electromechanical power conversion process, which asymmetrically leaves the entire “active” electromechanical power production and contribution exclusively to the “active” stator assembly (i.e., singly-fed).

With direct excitation of the terminals of multiphase winding sets on the rotor and stator, respectively, uniquely providing: 1) independent precision control of the position of the rotor and stator synchronized rotating magnetic fields, regardless of the rotor winding time constant, speed, or position, 2) freedom from relying on speed-based (or slip) winding current induction that ceases to exist about synchronous speed, and 3) a dual ported transformer circuit topology (i.e., doubly-fed), the resulting “symmetrical” electromagnetic circuit relations of the terminals of the symmetrical multiphase wound-rotor doubly-fed “synchronous” class of electric machine (see Figure 1) formulated more than a century ago become the classic study for all other classes of electric machines by deoptimizing the symmetry with the “asymmetry” of substituting the rotor “active” winding set with “passive” DC field windings or permanent magnets for synchronous electric machines, saliencies for reluctance electric machines, or slip-induction windings for asynchronous electric machines (or asymmetric electric machines).

Although the inherently unique and attractive attributes of the symmetrical multiphase wound-rotor doubly-fed “synchronous” electric machine system were easily hypothesized long ago from its “symmetrical” electromagnetic circuit relations, such as half the size, half the electrical and core loss, and half the cost as any asymmetrical electric machine system with the same electromechanical construction and formfactor, a hypothetical but necessary enabling inventions of a practical real time emulation control means that sensorlessly, automatically, and immediately reacts to any instability, such as the result of external rotor perturbation, particularly about synchronous speed where slip-induction ceases to exist, or a
practical brushless means to propagate “multiphase AC excitation power” directly to the rotor “active winding set” were inconceivable until the 1960’s with the advent of high speed electronic power semiconductor switching, high frequency electromagnetics, and electronic control technologies for electric machines, which triggered a renaissance of pioneering research, such as by the University of Wisconsin.[1],[2],[3],[4]

Although a practical means of brushless real time emulation control was never fully realized, research revealed that the fully electromagnetic (or without RE-PM) brushless and symmetrical multiphase wound-rotor doubly-fed “synchronous” electric machine system would be the ideal electric machine system. Accordingly, all of today’s so-called new, advanced, or invented classes of electric machine systems are actually the same century old electric machine circuit and control architectures with the asymmetry of a “passive” rotor assembly of saliencies, permanent magnets, DC field winding, or a slip-induction winding set that are only enhanced with refined selections of off-the-shelf but better performing materials, manufacturing, winding, packaging or electronic control technologies.

III. TECHNOLOGY ATTRIBUTES BY QUALITATIVE OBSERVATIONS

By conceptually modifying any available “asymmetrical axial-flux electric machine system,” which comprises a “passive” rotor disk adjacently separated by an airgap from an “active” stator disk (instead of the cylinder-inside-cylinder radial-flux formfactor), such as the most advanced rare-earth permanent-magnet electric machine systems of today, a “symmetrical” multiphase wound-rotor doubly-fed “synchronous” axial-flux electric machine system is conveniently realized by simply replacing the “passive” rotor disk(s) and bearing assembly with another “active” stator disk from the original asymmetrical axial-flux electric machine system (but fitted with the rotor bearing assembly) and by simply replacing the usual field-oriented controller derivative with the hypothetical “brushless real time emulation controller” to guarantee symmetrical stability. Since the resulting “symmetrical” multiphase wound-rotor doubly-fed “synchronous” axial-flux electric machine system brushlessly incorporates the cumulative power of two “active” stator disks or twice the continuous power rating of the original asymmetrical axial-flux electric machine but keeps the same electromechanical construction and formfactor, such as the same packaging, the same effective airgap area, the same airgap flux density, the same voltage rating, the same electrical (or core) loss, the same amount and cost of materials (less any passive components, such RE-PMs, saliencies, slip-induction windings, etc.), and the same manufacturing, winding, or electronic component techniques, a few of its inherently unique and attractive attributes are reasonably verified by straightforward qualitative observation or analysis:

- **Twice the “constant torque speed range” with a given torque, air-gap flux density, effective air-gap area, voltage, and frequency of excitation** clearly doubles the “continuous power density” of the original asymmetrical electric machine (i.e., 7200 RPM with two poles and 60Hz excitation versus 3600 RPM).
- **Twice the power rating with the same packaging, the same material, the same electrical (or core) loss, and the same electronic controller loss** clearly doubles the continuous power density as the original asymmetrical electric machine system or halves the cost and halves the electrical (or core) loss per continuous power rating of the original asymmetrical electric machine system.
- **Up to octuple more peak torque** before reaching the core saturation of the original asymmetrical electric machine system because only the “symmetry” of directly excited multiphase winding sets on the rotor and stator, respectively, provides a true dual ported transformer circuit topology, which in accordance with electromagnetic physics, air-gap flux density ideally remains constant with increasing active (or torque) current beyond magnetizing current.
- **Elimination of the “extraneous” cost, size, inefficiency, environmental impact, limited life expectancy and handling safety of persistent magnetization, safe operating regions, or global volatility introduced by “passive” permanent magnets, rotor saliencies, slip-induction dependent windings, or DC field windings of the original asymmetrical electric machine system.**
Also, brushless real time emulation control (BRTEC) brings superconductor electric machine systems closer to practical reality by relocating the superconductor DC field winding to the stationary body without brushes or sliprings and by isolating exposure to the high harmonic content of electronic field-oriented control power conditioning. If AC superconductors become a practical reality, the fully electromagnetic, brushless and symmetrical multiphase wound-rotor doubly-fed “synchronous” superconductor electric machine system would be the holy grail of electric machine systems.

REFERENCES