With the standard induction electric motor, it will be demonstrated how the performance of any electric motor "system" would be effectively doubled and the price halved, if simply converted to a patented electric motor circuit and control, or system architecture of Best Electric Machine (or B.E.M.), called SYNCHRO-SYM.

SYNCHRO-SYM's transformational leap in price-performance improvement is in addition to other price-performance improving techniques, that all electric motor manufacturers have strategically incorporated into the same century old electric motor circuit and control architecture as their competitors, such as off-the-shelf or advanced materials, packaging, manufacturing, winding, and design optimizing techniques.

To prepare the viewer for the demonstration, a short overview of basic electric motor or generator components and design fundamentals will now necessarily follow:

All rotating or linear electromagnetic motors and generators (traditionally called electric machines) are no different from this standard induction electric motor, which comprises four basic components:

First component, the stator (or stationary assembly), includes a balanced multiphase AC winding set that is excited with bidirectional multiphase AC electrical power directly through its terminals.

Only a balanced multiphase AC winding set, which is independently excited with multiphase bidirectional power directly through its terminals, i.e., active winding set, produces a rotating magnetic field relative to its frame that does real work (by actively contributing electrical power to the electrical to mechanical, or electromechanical, conversion process).

Second component, the rotor (or rotating assembly), which for this standard induction electric motor example, includes the so-called squirrel cage winding set:

Without an independent, bidirectional, multiphase electrical power connection to the terminals of the squirrel cage winding set, the cost, size, and electrical loss for a rotating electrical connection means are conveniently eliminated, but unlike the stator, the rotor cannot actively contribute electrical power to the electromechanical conversion process. Instead, the rotor squirrel cage winding power of the standard induction electric motor is a mutually inductive coupled component of the stator active winding power by a speed based asynchronous movement or slip phenomenon, called slip-induction. In effect, the rotor only "passively" participates in the electromechanical power conversion process by simply completing the magnetic circuit path across the air gap to establish the mutual air gap flux density.

Without violating basic motor operating principles, the passive squirrel cage winding is often replaced with other means that also have no direct bidirectional multiphase AC electrical power connection for independently contributing real electrical power to the electromechanical conversion process, such as passive rotor saliencies (for the reluctance electric machine), passive rotor direct current or D.C. electromagnets (for the D.C. field wound synchronous electric machine), or passive rotor permanent magnets (that replace the D.C. electromagnets for the coveted permanent magnet synchronous electric machine).

Note: It follows that the passive rotor consumes nearly half of the electric machine core real estate (as does the stator) with similar size, cost, electrical loss, or thermal dissipation as the stator, but unlike the stator, the passive rotor does not actively contribute additional electrical power to the electromechanical power conversion process. So, in effect, the passive rotor is worse than just wasted electric machine real estate.

Third component, the air gap separating the rotor from the stator, where the speed synchronized rotor and stator rotating magnetic field vectors superpose to establish the air gap flux density and to provide the electromechanical power conversion by pushing or pulling on the other's magnetic field in accordance with the electrical excitation frequency (and voltage) directly applied to the terminals of the balanced multiphase AC winding set of the stator.

Forth component, all other structural and mechanical components that do not actively contribute to the electromechanical power conversion process, but instead, provide air gap dimensional integrity under enormous magnetic and dynamic forces, such as the bearings, housings, endplates, and etc., provide thermal management, such as passive or active cooling, provide reduction of hysteresis and eddy losses, such as special electromagnetic and laminated materials, and provide high winding conductivity and voltage isolation, such as special insulated magnet wire and winding arrangements.

Note: Ironically, the structural and mechanical components add similar but significant size, cost, energy loss, thermal management, or design effort to any electric machine as does the electromagnetic design effort.

As a fifth and increasing critical component of any electric machine "system," electronic control of the current, voltage, and excitation frequency of the active winding set is now commonly used to at least implement practical operation of the electric machine, such as for the permanent magnet, reluctance, or doubly-fed electric machine, or to tune the performance of any electric machine between the dynamics of the application and the electrical environment.

Note: The electronic controller (or drive) of any electric machine compounds the loss, cost, and size of the electric machine system, and as a result, should be equitably included in the overall price-performance calculation of any electric machine (system). Still, it is expected that all electric machines will be electric machine systems in the near future because of significant improvement in application performance, such as varying the speed and torque to match the load, or ultrahigh speed operation for higher electric machine power and specific density.

All rotating (or linear) electric machines show the same basic operating principles and design fundamentals as follows:

Similar electric machine power rating design means similar synchronous speed and torque design under similar voltage, current, and air-gap flux density

Magneto-motive-force (or M.M.F.) of a winding is the scalar product of winding current and number of winding-turns with winding magnetic flux directly proportional to the product of the winding M.M.F. and the inverse of the airgap length.

In accordance with Faraday's Law, the winding terminal voltage is proportional to the product of the number of winding-turns and the time derivative of only the magnetic flux passing through the area of the winding (or magnetizing flux).

Magnetizing flux is proportional to the energy product of a permanent magnet assembly or the magnetizing M.M.F. of a winding or reluctance saliency assembly.

In accordance to Lorentz Law, torque is proportional to the cross product of the torque M.M.F. vector (of the active winding set) and the magnetizing flux vector (of the airgap), and as a result, torque M.M.F. is orthogonal to magnetizing flux (or magnetizing M.M.F.).

Total airgap magnetic flux is proportional to the vector sum of the torque M.M.F. vector and the magnetizing flux vector.

With all electric motor contestants optimally designed and without considering the extravagant expensive of rare earth permanent magnets, Magnetizing M.M.F. is the only cost, size, and loss distinction between permanent magnet electric machines and induction (or reluctance) electric machines. Since total MMF magnitude is the vector sum of the magnetizing M.M.F. and torque M.M.F. vectors, magnetizing M.M.F. adds less than 4%, worse case, to the total M.M.F. magnitude at full power, which is well within just the windage and material tolerance range between any electric machine design.

Magnetizing M.M.F. provides coveted field weakening capability for higher speed operation, for higher efficiency over broad speed range, and for electronic controller and insulation reliability. To leverage the attributes of field weakening, some permanent magnet electric machine systems ironically incorporate magnetizing M.M.F. with all the associated loss, cost, and size that were the original argument for migrating to permanent magnet motors in the first place.

The electrical excitation frequency versus speed of any electric machine must be in accordance to the so-called "synchronous speed relation" for useful torque production, which states, rotor speed and direction is directly proportional to the sum of the product of the stator multiphase winding excitation frequency and the inverse of the stator winding pole-pair count, and the product of the rotor multiphase winding excitation frequency and the inverse of the rotor winding pole-pair count; where speed and excitation frequency can be bipolar (i.e., positive or negative), and the excitation frequency would be zero for a rotor or stator without a multiphase winding set.

Increasing winding current, or M.M.F., beyond the flux saturation limit of the magnetic core would no longer contribute to torque production or electromechanical power conversion, but instead, dramatically contributes to electrical loss. Furthermore, by effectively squeezing the flow of magnetic flux about the essential slots for containing the windings or permanent magnets, or for forming the rotor saliencies, flux saturation is particularly critical near the air gap by effectively increasing air gap depth and magnetic leakage as more of the high core permeability transitions to the permeability of air as a result of saturation. Therefore, chiefly constrained to stay within the same flux saturation limit of the same available core material used by all, any practical, optimally designed electric machine with a given power rating will necessarily show similar air gap flux density and effective air gap area, regardless of the magnetic energy product of rare earth permanent magnets or the even higher magnetic flux potential of a winding set with magnetizing M.M.F. It follows that an "active winding set" of any practical, optimally designed electric machine with a given power rating is constrained by similar air gap flux density and effective area, and as a result, will show similar cost, energy loss, size, thermal dissipation, power to volume, and power to weight.

Linear electric machines are rotating electric machines with the chassis and electromagnetic core simply rolled out flat.

Lower electrical loss is directly related to higher efficiency, and higher power density is directly related to smaller size.

In accordance with the terms of this discussion, asynchronous (or induction) electric machines rely solely on the mutual induction of current onto the rotor winding set resulting from the asynchronous movement (or slip) between the passive rotor and active stator winding sets and as a result, slip induction shows discontinuity (or instability) about the synchronous speed region where slip induction is vague or ceases to exist. Opposite to asynchronous electric machines, synchronous electric machines do not rely on slip induction for operation (but may experience reluctance or slip induction) and as a result, do not show discontinuity or instability about synchronous speed.

In accordance with the terms of this discussion, an electric machine may have one (i.e., singly-fed) or at most two (i.e., doubly-fed) independently powered, bidirectional, balanced multiphase AC winding sets for collectively contributing power to the electromechanical conversion process. Any more than two active winding sets per electric machine is a duplication of the electric machine circuit topology. Singly-fed electric machines always have a passive rotor and an active winding stator, which forms a non-optimum, asymmetrical (or single ported) transformer circuit topology. In contrast, doubly-fed electric machines may form a non-optimum, asymmetrical transformer circuit topology that rely on slip induction or reluctance for functional operation, such as the so-called brushless doubly-fed electric machines with a passive rotor and dual active winding sets of unlike pole pairs on the stator, or instead, the wound-rotor "asynchronous" or induction doubly fed electric machine with an active winding set on the rotor and stator, respectively, and traditionally with known instability and a multiphase slip-ring assembly connection to the rotor winding set. As only enabled with an automatic and sensor-less (speed and position) to (frequency and phase) synchronizing control method in order to eliminate functional reliance on the discontinuity or instability of naturally occurring reluctance or slip-induction, doubly-fed electric machines may now form the optimum symmetrical (or dual ported) transformer circuit topology known as the wound-rotor "synchronous" doubly fed electric machine with an active winding set on the rotor and stator, respectively.

Note: The symmetrical, balanced multiphase, wound-rotor "synchronous" doubly fed electric machine and its symmetrical relationships becomes the classic theoretical study for all other electric machine types by de-optimizing its symmetrical relationships with asymmetry, such as setting the rotor winding excitation frequency to zero as expected with a permanent magnet, DC electromagnet, or reluctance electric machine rotor. But with means of automatically controlling the multiphase excitation of a rotor winding set over the entire speed range from zero to super-synchronous speeds, as customary in a theoretical study of the symmetrical relationships, a "synchronous" doubly-fed electric machine is born that does not rely on reluctance or slip induction for functional operation (but may experience reluctance or slip-induction) as defined by the synchronous definition of this discussion. Therefore, as a result of B.R.T.E.C., the synchronous-asynchronous hybrid study of the traditionally available wound-rotor doubly fed induction electric machine with a multiphase slip-ring assembly becomes old school.

Since electric machine torque is directly related to active winding current (or torque M.M.F.), which is orthogonal to the air-gap magnetic flux (or magnetizing M.M.F.), and electric machine speed is directly related to the active winding port voltage and excitation frequency in accordance to the synchronous speed relation, electronic excitation control of the current, voltage, and excitation frequency of the active winding set (as in an electric machine "system") is customarily used to at least tune the performance of any electric machine or to implement practical operation, such as for the permanent magnet, reluctance, or doubly-fed electric machines.

Note: The synchronous speed relation states that for average (or useful) torque production, the angular frequency of the rotor speed is proportional to the sum of the angular frequency of the rotor balanced multiphase AC winding set excitation and the angular frequency of the stator balanced multiphase AC winding set excitation, where angular excitation frequencies may be positive or negative and the angular excitation frequency of a rotor without a winding set is zero, such as a reluctance or permanent magnet rotor.

Note: There are three possible magnetic flux paths associated with electric machines, such as the very common radial-flux electric machine with the air-gap flux path perpendicular to the axle by a cylinder (rotor) inside cylinder (stator) form factor, the less common axial-flux electric machine with the air-gap flux path parallel to the axle by a disk (rotor) adjacent to disk (stator) form-factor, and the transverse-flux electric machine, which is virtually non-existent because of its extravagant complexity and cost. The Radial-Flux electric machine shows a forgiving frame and bearing assembly to the extreme magnetic forces and a power increase with length but could show rotor to stator contention with high speed centripetal force, limits rotor heat dissipation, and has a difficult inside-out winding approach. The Axial-Flux electric machine shows higher power and specific density, higher speeds without rotor to stator contention concerns, equally exposes the rotor and stator to thermal dissipation, and provides an easy outside-in winding approach but shows increasing power with increasing diameter and requires a robust frame and bearing assembly for the optimum single air-gap configuration.

Note: a balanced multiphase AC winding set has an even phase distribution of windings, such as 120 degrees between three phases, with a phase component of flux coupling between each phase winding, including between balanced phase windings across the air gap for a position dependent flux transformer.

Note: Not considered in this discussion is the extremely high flux density potential provided by superconductor winding M.M.F., which, if ever practical, would be available to all electric machines with the same results.

In conclusion, the basic electric machine components and fundamentals show all conventional electric machine circuit and control architectures (i.e., systems) of similar power rating, that are optimally designed with similar structural and mechanical components, will have similar air gap flux density, and similar effective air gap area, with similar size, cost, energy loss, efficiency, and thermal dissipation. PERIOD.

Therefore, with power density inversely proportional to speed, electronic control of conventional electric machines is becoming the practical means of achieving higher power density with ultrahigh speed operation (of course, without considering the compounded size, cost, and loss associated with the necessary transmission for matching the high speed to the application).

The futuristic alternative to achieving higher power density, higher specific density, and higher efficiency (or lower loss) is the superconductor electric machine system. By typically providing twice the air gap field strength as a conventional electric machine, regardless of core saturation, with an ultralow resistive loss superconductor D.C. electromagnet of very high magnetizing M.M.F., the superconductor synchronous electric machine easily provides twice the power density and specific density with higher efficiency than conventional electric machines, but only by neglecting the formidable loss, cost, and size of ancillary enabling components for functional operation, such as electronic control, slip ring assemblies, cryogenic refrigeration, electromagnetic shielding, reliability, maintainability, safety, and etc. With the anticipation of significant improvement of electric machine price-performance, aggressive superconductor electric machine system research has continued with years of costly funding, but so far, with protracted success.

With an understanding of the basic fundamentals and the future of electric machine systems, now here comes what we have been waiting for, the SYNCHRO-SYM magic:

Simply retrofit the passive rotor element, such as the squirrel cage winding set of the standard induction electric motor, with a similar active balanced multiphase AC winding set as the stator, and replace the traditional multiphase slipring assembly and state-of-art electronic controller, such as any derivative of field oriented control, with a brushless real-time emulation controller to sensorlessly and automatically assure synchronized (speed and position) to (frequency and phase) multiphase excitation power supplied directly to the rotor active winding set in order to eliminate any functional reliance on reluctance or slip induction with known speed regions of discontinuity and instability, such as about synchronous speed where slip induction becomes vague or ceases to exist.

Replaced with a very compact, high frequency, position dependent flux rotating transformer of significantly higher power density inherently providing the analog processing for real-time emulation control, the multiphase slip ring assembly may well represent SYNCHRO-SYM's brushless real-time emulation controller assembly and accordingly, at least the following transformation leaps in price performance result:

<u>First Transformational Leap</u>: The new retrofitted electric motor system becomes the only practical, brushless, multiphase wound-rotor, doubly-fed, "synchronous," electric machine system that contiguously provides symmetrically stable motoring (and generating) operation from sub-synchronous to super-synchronous speeds, including about the unstable synchronous speed and zero regions.

Note: Practical operation of all other electric motors is only from sub-synchronous to synchronous speed because of conventional state-of-art control instability, such as any derivative of field-oriented control.

<u>Second Transformational Leap</u>: The new retrofitted electric motor system collectively shows the power of two active winding sets on the rotor and stator, respectively, (or twice the rated power) in the same package as the original standard induction electric motor, but also, with the same materials, the same volume of material, the same cost of materials, the same electrical loss, and the same thermal dissipation as the original standard induction electric motor (or system).

Note: By reasonably assuming SYNCHRO-SYM's active stator and active rotor occupy the same volume as the active stator and the passive rotor of an induction, reluctance, or permanent magnet electric machine (as expected with the axial flux formfactor).

Note: By reasonably assuming SYNCHRO-SYM's active rotor and stator show the same volume of core materials as the passive squirrel cage rotor and active stator of an induction electric machine (as expected with the axial flux formfactor).

Note: By reasonably assuming SYNCHRO-SYM's rotor or stator active winding set has the same loss as the rotor squirrel cage winding set or the stator active winding set of an induction electric machine appropriately designed with similar magnetizing magneto-motive-force (or M.M.F.).

Note: If considering the retrofit of a permanent magnet electric machine, the additional extravagant cost and real estate associated with cartel controlled rare earth permanent magnets are conveniently eliminated, and thereby, leaving only relatively inexpensive copper and electrical steel as the remaining materials to consider.
For example:

Third Transformational Leap: Since efficiency, electrical loss, cost, size, and thermal dissipation are always normalized to the power rating of any electric motor, the new electric motor with the collective power of two similarly rated active winding sets on the rotor and stator, respectively, reasonably evaluates to half the size and weight, half the electrical loss, half the cost, and half the thermal loss (per power rating) as the original standard induction electric motor, with the collective power of only one similarly rated active winding set.

Fourth Transformational Leap: With contiguous and stable operation from sub-synchronous to super-synchronous speeds, including about synchronous speeds, the new electric motor system shows twice the speed of any other electric machine for a given pole-pair count, voltage, and excitation frequency of the active winding set (i.e., 7200 R.P.M. with 60 hertz and one pole-pair, versus, 3600 R.P.M. for the conventional electric machine system), which is a recognized characteristic associated with half the cost, half the electrical loss, twice the power density, and twice the specific density.

Fifth Transformational Leap: In accordance with the physics of a truly dual ported transformer circuit topology as provided by a fully electromagnetic electric machine system with the convenience of a balanced multiphase copper wound rotor that is actively and stably enabled by brushless real-time emulation control, including about zero speed and synchronous speed, "Conservation of Energy" dictates that the air gap flux density of the new electric motor system remains constant with increasing current (or torque) on each side of the air gap beyond magnetizing M.M.F. As a result, peak startup torque can increase substantially above all other electric machines without leading to magnetic core saturation (or higher port voltage), such as four times the peak startup torque of a similarly rated induction, reluctance, permanent magnet, or even universal electric machine system.

Note one: In addition to providing twice the steady state power density as all other electric machines, the new electric motor significantly increases peak startup torque potential, which conveniently alleviates the additional cost, size, loss, maintainability, and complexity of the common extraneous transmission for acceleration or deceleration in an electric propulsion application, such as an electric vehicle.

Note two: With the convenience of an inherent balanced multiphase copper wound rotor, the new electric motor, again, provides higher efficiency, cooler running, and lower ownership cost than even the copper rotor expectations of the induction electric motor industry struggling for its introduction for at least meeting upcoming efficiency standards.

Note three: Unlike all other electric machines, the steady state core flux density of the new electric motor can be designed closer to the saturation limit of the core without concern of reaching flux saturation with increasing torque current, which adds another level of lower cost, higher power density, and lower loss for the new electric motor. For all other electric machines with flux magnitude as the orthogonal vector sum of torque M.M.F. and magnetizing M.M.F., the steady state core flux density design must compensate for increasing flux magnitude leading to core saturation with increasing torque.

Note four: Shared between the rotor and stator active winding sets, magnetizing M.M.F. of the new electric motor adds less than 2% to the total M.M.F. magnitude at full power, worse case, if compared to the permanent magnet electric machine electromagnetic core, which is well within just the windage and material tolerance range between any electric machine design.

<u>Sixth Transformational Leap</u>: Only SYNCHRO-SYM may electronically control the power of the rotor winding set, or half the total rated power, for full power control of SYNCHRO-SYM, which is a recognized characteristic associated with additional levels of higher efficiency, lower cost, higher power density, and better thermal rating over a similarly power rated electric machine system with a passive rotor that needs full electronic power control, such as the permanent magnet electric machine system.

<u>Seventh Transformational Leap</u>: Only SYNCHRO-SYM (with a symmetrical fully electromagnetic architecture) conveniently accommodates the legacy or future investments in the plethora of electric machine designs, understanding, winding arrangements, packaging and manufacturing techniques, and their applications, because SYNCHRO-SYM is independent of costly and delicate exotic materials and methods, such as superconductor DC field windings, cartel controlled rare-earth permanent magnets, or unusual manufacturing and disposal procedures for persistently magnetized permanent magnets. Note: For the viewer's information but without details, SYNCHRO-SYM technology can actually bring superconductor electric machines closer to reality.

<u>Eigth Transformational Leap</u>: Only SYNCHRO-SYM (with a symmetrical fully electromagnetic architecture) conveniently supports any winding arrangement, such as distributed or concentrated windings, but more importantly, mitigates any resulting harmonic content introduced by the winding arrangement, slots, and saliencies (by mirroring the power flow through the stator and rotor active winding sets with symmetrical control of a fully electromagnetic architecture as only provided by a multiphase wound rotor synchronous doubly-fed circuit topology).

<u>Ninth Transformation Leap</u>: Only SYNCHRO-SYM (with a symmetrical fully electromagnetic architecture) can efficiently utilize the slotted core and winding topology by symmetrically tuning both the rotor and stator excitation with electronic control.

<u>Tenth Transformational Leap</u>:

SYNCHRO-SYM conveniently accommodates the axial-flux form factor, which is proven to have higher torque and power density, better heat removal, adjustable air gap depth, and stackable machines for power stacking lengthwise, for series stacking low voltage SYNCHRO-SYM machines to high voltage low current machine in a series circuit connection or vice versa, high voltage SYNCHRO-SYM machines to high current low voltage machines in a parallel circuit connection.

Eleventh Transformational Leap: Only SYNCHRO-SYM (with a symmetrical fully electromagnetic architecture) reduces manufacturing variances and inventory when constructed in an axial flux form-factor, because the rotor and stator assembly with brushless real-time emulation control (or B.R.T.E.C.) are exact duplicates and as a result, only SYNCHRO-SYM can place the REG is in annulus of axial flux electric machine.

Twelfth Transformation Leap: Only SYNCHRO-SYM (with the symmetry of a symmetrical multiphase wound rotor synchronous doubly-fed circuit topology under brushless real-time emulation control or B.R.T.E.C.) provides nearly pure sinusoidal waveforms to the windings and the DC or single or multiphase AC power supply.

Thirteenth Transformation Leap: Only SYNCHRO-SYM (mirrors the power flow through a fully electromagnetic architecture with symmetrical control) to provide comprehensive leading, lagging, and unity power factor, including variable air-gap field control (or field weakening) at any speed.

Note: Without the capability of airgap flux density adjustment (or field weakening) by controlling the magnetizing M.M.F. in an electrical winding set, permanent magnet electric machines with a persistent magnetic field must be speed limited to avoid over-voltage damage. Ironically, some permanent magnet electric machines incorporate extraneous methods to provide the benefits of field weakening by introducing magnetizing M.M.F. with associated size, electrical loss, cost, and thermal management that were the original motive for replacing DC field or squirrel cage windings (for instance) with high cost rare earth permanent magnets.

Fourteenth Transformation Leap: Only SYNCHRO-SYM (with the symmetry of a symmetrical multiphase wound rotor synchronous doubly-fed circuit topology under B.R.T.E.C.) can share magnetizing M.M.F. between the rotor and stator winding sets to provide a quarter of the magnetizing current electrical loss of an induction electric machine.

Note: Since the air-gap flux density is established by the magnetizing M.M.F. vector (or the permanent magnet persistent field vector), which is orthogonal to the torque current vector and by correctly using vector addition instead simple arithmetic, magnetizing M.M.F. adds between 0.4% to 4.4% to the total current magnitude (i.e., magnetizing and torque current magnitude) in an induction electric motor with a respective 10% to 30% magnetizing M.M.F. design criteria and between 1% to 9% to the total electrical loss at full torque (normalized to 1), if compared to an optimally designed rare earth permanent magnet electric machine without field weakening capability. However, magnetizing current provides the coveted field weakening for higher speed operation, higher peak torque, and efficiency tuning, if magnetizing M.M.F. varied across the design criteria to optimize operation various speeds and torque. In contrast, a symmetrical multiphase synchronous doubly fed electric machine that evenly shares the magnetizing M.M.F. between the rotor and stator M.M.F., as only provided by SYNCHRO-SYM, only adds between 0.2% to 2.2% to the total current magnitude and between 0.5% to 4.5% to the total electrical loss (while "doubling" the normalized power rating).

Fifteenth Transformation Leap: Only SYNCHRO-SYM (with symmetrical control of a fully electromagnetic architecture) shows virtually no cogging at low speeds, and full torque control, at zero speeds and synchronous speeds.

Sixteenth Transformation Leap: Only SYNCHRO-SYM (with symmetrical control of a fully electromagnetic architecture showing constant air gap flux density and resulting magnetic forces with increasing torque current) requires a less robust structural support for accommodating the coveted single air-gap axial flux form factor, which has been shown to provide another level of power density and specific power.

Seventeenth Transformation Leap: Only SYNCHRO-SYM (with the symmetrical transformer circuit topology that exhibits low harmonic content and constant flux density regardless of increasing torque current) can simply leverage legacy off the shelf core and slot designs. In contrast, all other electric machines exhibit high harmonic content and increasing flux density with increasing torque current that nearly always require intensive computer aided design, such as finite element analysis, to at least optimize the slot design to reduce harmonic content and concentrated flux density.

Eighteenth Transformation Leap: Only SYNCHRO-SYM is a copper rotor motor or generator by the nature of a balanced multiphase AC winding set, with higher efficiency, cooler running, and lower ownership cost than even the copper rotor expectations of industry striving for its introduction.

Note: Easily calculated, SYNCHRO-SYM comprises no passive rotor assembly (with a normalized component cost of 0 and a normalized component power rating of 0), two active copper winding assemblies on the rotor and stator, respectively, (with a normalized component cost of 2 and a normalized component power rating of 2), and similar structural and frame components as any electric machine. In contrast, the common induction electric motor comprises a passive rotor assembly (with a normalized component cost of 1/2 for the squirrel cage winding of the induction electric motor and 2 for the rare-earth permanent magnets of a permanent magnet electric motor, and a normalized component power rating of 0), one active copper winding assembly on the stator (with a normalized component cost of 1 and a normalized component power rating of 1), and similar structural and frame components as any electric machine. Since the normalize system cost is the sum of the normalized component costs divided by the sum of the normalized component power rating, SYNCHRO-SYM has a normalized system cost of 1 (or 2/2) compared to the induction electric motor with a normalized system cost of 3/2 (or 1.5/1) even with a copper rotor and 3 (or 3/1) for the rare earth permanent magnet electric motor.

Nineteenth Transformation Leap: Only SYNCHRO-SYM incorporates a brushless, sensor-less and automatic control method, called Brushless Real-Time Emulation Control or B.R.T.E.C., which comprises a compact position-dependent-flux high frequency transformer to act as real-time analog computer, an inherent absolute and precise speed-position resolver, and a brushless power propagator of multiphase power, that provides sensor-less and automatic frequency and phase control to eliminates the undesirable reliance on reluctance or slip-induction and the extreme difficulties, delays and inaccuracies of measuring or synthesizing vague slow signals, particularly in speed regions of instability, such as about synchronous speed, eliminates the errors of estimation, eliminates the untimely delays of sequential offline processing, and eliminates the associated issues of a multiphase slip-ring-brush assembly (or radial rotary transformer) of all other state of art control methods, such as flux oriented control and its derivatives.

Note: During generating, the stability of the multiphase wound-rotor synchronous doubly-fed is dependent on the damping and stability of the prime mover dynamics. In contrast during motoring, stability of the multiphase wound-rotor synchronous doubly-fed is dependent on the speed and precision of the feedback response to shaft perturbations, which are further aggravated by slip-induction and reluctance, which only a sensor-less automatic control means can satisfy.

Twentieth Transformational Leap:

With a Brushless Real-Time Emulation Controller of a multiphase AC rotor winding, frequency and phase is automatically synchronized to the power grid while providing comprehensive leading to lagging power factor adjustment at any speed, including zero speed. As a fully electromagnetic electric machine with field weakening, the rotor multiphase winding set and control can be designed to a lower startup power rating at startup for self-starting with associated lower loss, cost, and size.

Twenty-first Transformational Leap:

With a Brushless Real-Time Emulation Control, SYNCHRO-SYM operates on DC and single or multiphase AC.

SYNCHRO-SYM is the only practical, brushless, balanced multiphase wound-rotor, "synchronous," doubly-fed electric machine system that is symmetrically stable while motoring and generating. Surprisingly, SYNCHRO-SYM's transformational improvement in price-performance just demonstrated was already theoretically substantiated and published in the 1960s by academia, but the development of a practical synchronous doubly fed electric machine system was essentially abandoned, after realizing the necessary enabling invention of a brushless, sensor-less, and automatic control means to eliminate instability, particularly about zero or synchronous speed or during motoring (as only provided by SYNCHRO-SYM's brushless real-time emulation control or B.R.T.E.C.), was beyond the technology of that time.

SYNCHRO-SYM's doubling of price-performance improvement over all other practical electric machine systems was verified by modeling and simulation with a computer aided design tool specifically developed by B.E.M. for the new dual ported electric motor transformer circuit topology and brushless real-time emulation control architecture of SYNCHRO-SYM. Also, B.E.M. complemented modeling and simulation verification of the SYNCHRO-SYM architecture with multiple stages of production prototyping for functional validation of the SYNCHRO-SYM architecture.

Now, consider SYNCHRO-SYM versus the futuristic superconductor electric machine system:

SYNCHRO-SYM is the only practical and stable electric machine system that replaces the wasted passive rotor found in all other electric machines, including the superconductor electric machine system, which reasonably consumes half of the real estate of the electric machine but without contributing to electromechanical power production, with an active rotor to effectively achieve similar power density, specific density, and efficiency as the superconductor field wound synchronous electric machine system, but with proven off-the-shelf technology, and without the significant ancillary loss, cost, size, reliability, maintainability, and complexity of cryogenic support.

Ironically, SYNCHRO-SYM's brushless real-time emulation controller (or B.R.T.E.C.) can bring the traditional superconductor electric motor system closer to reality by at least conveniently relocating the superconductor D.C. field winding to the stator for simpler cryogenic support, for brushlessly relocating the active multiphase winding set to the rotor, for eliminating the slip ring assembly, and for reducing costly harmonic heating as only provided by B.R.T.E.C. with inherently pure multiphase sinusoidal drive waveforms for

variable speed control.
Much more beneficial than just the substantially higher flux density provided by passive D.C. superconductor electromagnets, superconductor alternating current (or A.C.) multiphase winding sets, which also provide significantly lower overall electrical loss, are being aggressively researched; and when practical, a brushless, fully electromagnetic A.C. machine (as only provided by SYNCHRO-SYM) would be the obvious choice for the A.C. superconductor electric machine application, particularly, after realizing that today, the induction electric motor (with a passive rotor) is industry's best consideration for implementing the fully electromagnet A.C. superconductor electric motor.

As the only symmetrical, fully electromagnetic architecture, SYNCHRO-SYM provides many more transformational leaps in price-performance that are too numerous to list here. So B.E.M. invites you to visit our website at bestelectricmachine.com to learn more about SYNCHRO-SYM Technologies or to submit your questions, comments, suggestions, or requests.

If you like the simplicity and innovation of SYNCHRO-SYM, Best Electric Machine (or B.E.M.) has also leveraged several additional patents, such as the only 3D Printer, called MOTORPRINTER, for laminated, object manufacturing of the preferred adjustable airgap, axial flux electric machines or the smart grid, high frequency, high power transformer, which B.E.M. is developing to democratize the high speed, just-in-time, low waste, universal additive manufacture of axial-flux electric machine cores with integral frame and bearing bezel assembly, and for the inhouse, additive manufacture of the axial-flux form of SYNCHRO-SYM, which includes an integral high frequency, high power transformer.

In a small footprint, MOTORPRINTER builds from relatively inexpensive pre-processed, high performance optimized electrical steels, such as amorphous metal ribbon, and off-the-shelf structural materials, such as aluminum, steel or composite bar-stock, without adversely affecting their coveted but delicate preprocessed magnetic or structural performance properties, which is very different from the few contemporary ongoing 3D Printing approaches for manufacturing electric machines, that are still in heavily funded research under guarded expectations of actual success; but worse, these 3D Printing approaches utilize pre-processed materials with more stringently controlled removal waste that are specifically manufactured and optimized for compatibility and consistency with the 3D Printer, itself, instead of for the electric machine core and frame assembly.

With MOTORPRINTER, Best Electric Machine again distinguishes itself from all other electric machine manufacturers with innovated manufacturing tooling, instead of simply applying better available packaging techniques and performance materials for price-performance enhancement of the same traditional century old electric machine circuit and control architecture. Furthermore, highly reliable, adjustable air-gap, axial flux, amorphous metal transformer cores provide even flux distribution and isolated, high frequency, high power, low loss, direct AC-to-AC conversion (with SYNCHRO-SYM Technologies) for the future of smart grid power distribution and conversion (instead of traditional method of DC Link Stage conversion with bulky, expensive, and delicate capacitors).