Analytical Proof: SYNCHRO-SYM PROVIDES TWICE THE POWER DENSITY AT HALF THE COST AND LOSS!

Bottom Line Upfront (BLUF):

With *twice* the constant torque speed range (sometimes called maximum load speed (**MLS**)) for a *given* continuous torque, excitation frequency, and excitation voltage, a century of classic electric machine study has already proven the unique brushless, symmetric, and synchronous circuit and control architecture of SYNCHRO-SYM with dual "active" winding sets on the rotor and stator, respectively, provides twice the power (and octuple the peak torque) at half the cost, half the size, and half the loss within the same packaging as the familiar asymmetric circuit and control architecture of all other electric motor systems with a single "active" winding set and a "passive" rotor of rare-earth permanent magnets (**RE-PM**) (*i.e., synchronous*), DC field windings (*i.e., synchronous*), slip-induction dependent windings (*i.e., asynchronous*), or reluctance saliencies (*i.e., asynchronous or synchronous*).

For instance to achieve the same performance as an axial-flux SYNCHRO-SYM with the same custom selection of available optimizing material, winding, cooling, electronic control, and packaging techniques, which all electric machine system manufacturers leverage to improve their advertised performance that always result in similar performance if equally applied, all asymmetric axial-flux RE-PM electric machine system contestants with the same supply voltage and air-gap flux density design would have to: 1) include the additional loss, cost, and size of a controller with double the power and excitation frequency and a step-up transformer to double the supply voltage in order to double the MLS speed at the same continuous torque as SYNCHRO-SYM, or 2) mechanically couple the additional loss, cost, and size of another similar RE-PM electric machine "system" with its own controller in order to double the continuous torque at the same port voltage and MLS speed as SYNCHRO-SYM, or 3) design SYNCHRO-SYM to meet the same continuous torque at the same MLS and port voltage as the RE-PM electric machine system, which equates to twice the power, octuple the peak torque at half the cost, half the size, and half the loss *per unit of continuous power rating*.

In keeping with our mission statement, "Innovate for Our Clean, Efficient, and Sustainable Energy Future," BEM patented a whole new **Symmetric Dual Active Winding Axial-Flux** electric propulsion motor circuit and control architecture with "active" stator and rotor assemblies, called SYNCHRO-SYM, which is without the old problems and the unnecessary bells and whistles of all other electric propulsion motor systems with the same me-too asymmetric circuit and control architecture comprising a single active stator assembly and a "passive rotor assembly" of predominantly RE-PMs or instead, slip-induction dependent windings, DC field windings, or reluctance saliencies. SYNCHRO-SYM immediately provides:

THE ONLY GAME CHANGER FOR THE ELECTRIC PROPULSION WORLD:

- Twice the continuous power density per unit of continuous power rating
- Half the cost per unit of continuous power rating
- Half the loss (twice the efficiency) per unit of continuous power rating
- Half the cost per unit of continuous power rating
- Octuple the peak torque potential per unit of continuous power rating
- Always including the compounding loss, cost, and size of the electronic controller (*e.g., system*), SYNCHRO-SYM's System Power Density > 60KW/L, System Specific Power > 15KW/Kg, and System Efficiency > 98%.
- 50% less iron use (two "active" winding set in the same form and fit packaging)
- No permanent magnets with potential damage or life decay, such as expensive, environmentally unfriendly, and geopolitically sensitive rare-earth permanent magnets (RE-PM)
- Both rotor and stator assemblies actively contribute power (two "active" winding sets within the same form and fit packaging)
- "Effective" slot filling factor above 160% (two "active" winding set with orthocyclic packing within the same form and fit packaging)
- Simple construction (and the only additive manufacturing tooling)
- Small iron losses and double material utilization (two "active" winding sets within the same form and fit packaging)
- No torque ripple
- Simple but highly effective cooling concept with an inherent, highly efficient demand-based cooling method as only provided by the additive manufacturing of MOTORPRINTER under BEM-CAD
- Inherent Field Weakening for extended speed range to eliminate potential damage or decay to delicate permanent magnets, such as RE-PMs, winding insulation, or electronic control components.
- Octuple the peak torque potential for highly reliable less complex, and low maintenance gearless (direct drive) electric vehicles
- Leverages the same present or future performance enhancing techniques

ULTRA EFFICIENT INTEGRATED SIC CONTROLLER:

- The **Symmetric Dual Active Winding Axial-Flux Motor of SYNCHRO-SYM** effectively enhances the applied performance of SiC MOSFET by 2-3x at ½ the cost

HIGH QUALITY MANUFACTURING & PRODUCTION FACTS:

- On the road to perfection with a clear plan and a strong team
- Today: Fabricating our additive manufacturing tooling for high quality sample production and testing
- Tomorrow: Starting serial production in 2026
- Low cost, small footprint, and efficient additive, just-in-time manufacturing (i.e., only electric motor 3D Printer, called MOTORPRINTER, with non-crystalline metal ribbon)

- No permanent magnets to complicate the manufacturing process, tooling, and safety.

Introduction:

This whitepaper analytically proves the patented SYNCHRO-SYM, which is the only possible with brushless real time emulation control (**BRETC**), shows twice the power density (and octuple the peak torque) at half the cost, half the size, and half the loss per unit of continuous power rating as all other electric machine "systems," which include a derivative of field oriented electronic control (**FOC**), such as the rare-earth permanent magnet (**RE-PM**) electric machine system.

Common Electric Machine System (EMS) Design Trade Space for This Study:

Electric Motor, Electric Generator or Electric Machine System (**EMS**) design is a constant trade off within the following trade space, which shows the EMS circuit and control architecture is the only distinguishing performance differentiator when designing to the same MLS, supply voltage, excitation frequency, air-gap flux density, and continuous torque:

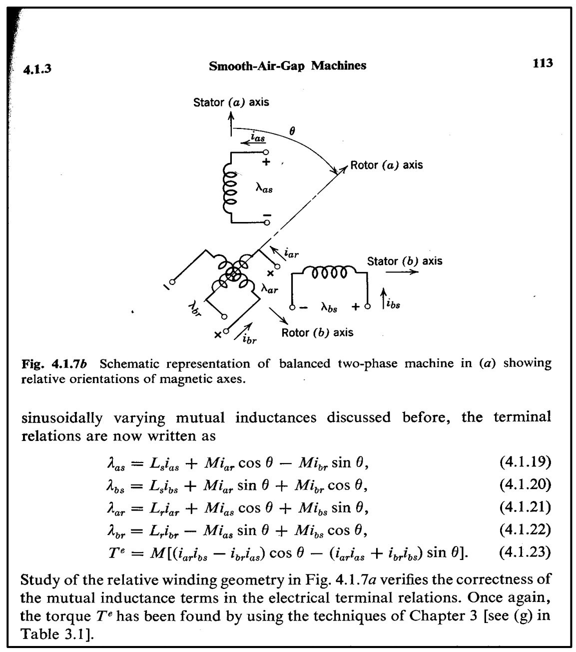
4.1.3 Smooth-Air-Gap Machines 113

Fig. 4.1.7b Schematic representation of balanced two-phase machine in (*a*) showing relative orientations of magnetic axes.

sinusoidally varying mutual inductances discussed before, the terminal relations are now written as

$$\lambda_{as} = L_s i_{as} + M i_{ar} \cos\theta - M i_{br} \sin\theta, \quad (4.1.19)$$
$$\lambda_{bs} = L_s i_{bs} + M i_{ar} \sin\theta + M i_{br} \cos\theta, \quad (4.1.20)$$
$$\lambda_{ar} = L_r i_{ar} + M i_{as} \cos\theta + M i_{bs} \sin\theta, \quad (4.1.21)$$
$$\lambda_{br} = L_r i_{br} - M i_{as} \sin\theta + M i_{bs} \cos\theta, \quad (4.1.22)$$
$$T^e = M[(i_{ar} i_{bs} - i_{br} i_{as}) \cos\theta - (i_{ar} i_{as} + i_{br} i_{bs}) \sin\theta]. \quad (4.1.23)$$

Study of the relative winding geometry in Fig. 4.1.7*a* verifies the correctness of the mutual inductance terms in the electrical terminal relations. Once again, the torque T^e has been found by using the techniques of Chapter 3 [see (g) in Table 3.1].

Figure 1 - *Herbert H. Woodson and James R. Melcher, "Electromechanical Dynamics, Part 1: Discrete Systems," page 113, John Wiley & Sons, 1968.*

- All electric machine systems tightly follow the same electric machine physics in accordance with Ampere Circuital Law, Faraday's Law, and Lorentz Force Law, and as a result, leverage the same available optimizing "enabling techniques," such as packaging, winding, electromagnetic and structural materials, thermal management, construction, manufacturing, and electronic control enabling techniques, which always show similar performance improvement if equally applied across all contestants. With only the empirical selection of optimizing enabling techniques as the performance distinction, it is with wonder that today's motor manufacturers seemingly advertise their "me-too" electric motor system as significant electric motor invention or technology.

- Only a directly excited multiphase winding set (or "active" winding set) placed on the rotor or stator assembly (or active assembly) produces a moving magnetic field that independently contributes additional "active power" to electromechanical energy conversion process. In contrast by including the compounding windage and stray core losses and electronic control losses, a "passive" rotor or stator assembly reasonably *wastes* the other half of the electric machine size, loss, and cost by not independently contributing additional working power to the electromechanical energy conversion process. In accordance with Best Electric Machine, all electric machines need at least one active winding set (i.e., singly-fed) or at most two active winding sets (i.e., doubly-fed) because by definitions, DC field windings (not multiphase), slip-induction winding sets (not directly excited), or permanent magnets (no electric port) are not active winding sets.
- Maximum Load Speed (**MLS**) is the constant torque speed range of the electric machine for a given supply frequency of excitation, supply voltage of excitation, and continuous torque rating, and air-gap flux density design of the active winding set.
- In order to provide the most compact and lowest loss electric machine possible, Air-gap Flux density, β, of any EMS is generally designed to the highest flux density possible, since effective air-gap area and magneto-motive-force (**MMF**), which is the product of current and winding turns, are inversely proportional to β.
  - Constrained by the flux saturation limit of available core material and not by the bounded flux density potential of RE-PMs or the unbounded flux density potential of MMF, all optimized electric machines have similar air-gap flux density. Note: Futuristic superconductor EMSs are the exception, although SYNCHRO-SYM Technologies will bring Superconductor EMSs closer to practical reality and when AC superconductor EMS are available, the fully electromagnetic SYNCHRO-SYM will be the EMS of choice.
  - Without considering electrical loss, flux density production of an electromagnet is directly proportional to the winding MMF (A/M) and therefore, unlimited but in contrast, flux density production of permanent magnets is inversely proportional to coercivity (A/M) and therefore, limited. Without considering temperature degradation, expensive rare-earth permanent magnets (RE-PM) with the highest energy product are limited to air-gap flux density of about 1.25 Tesla (across a typical narrow air gap) before the thickness (amount) of the RE-PM is greater than the wire slot depth of an electromagnet. Ongoing Material Science research to improve the residual flux density of permanent magnet material will also, likely improve the core flux density of an electromagnetic.
- All electric machines must have groupings of so-called slots with the low permeability of air placed along the perimeter of the air-gap for holding windings and permanent magnets, which significantly increase the size of the air-gap surface area of all electric machines, including so-called coreless electric machines.
- Highly permeable electrical steel cores focus the magnetic flux directly across the air-gap in accordance to Ampere Circuital Law with non-crystalline metal ribbon cores, such amorphous or nanocrystalline metal ribbon cores, showing the highest permeability with the lowest loss. Even with the necessary intense computer aided

design mitigation, so-called coreless electric machine systems, such as Infinitum Electric PCB EMS, show detrimental low flux density with abnormally high amounts of RE-PM material and high winding conductor eddy losses.

- The current carrying capacity of the winding wire is proportional to its cross-sectional area, which in turn, affects the physical depth and width (*i.e., area*) of the so-called slot, which in turn affects the total physical area of the air-gap and the overall physical length and width (*i.e., size*) of the electric machine. As an example, half the current magnitude reasonably equates to half the electric machine wire cross-sectional area and with enabling design adjustments, such as slot size, number of slots, winding turns, structural, cooling, electromagnetic features, etc., equates to half the electric machine air-gap area, half the electric machine size, and twice the electric machine electrical resistance. As a result, the size of any electric machine is proportional to the current carrying capacity of the winding wire and the electrical loss is inversely proportional to current carrying capacity of the wire.
- All EMS use electronic excitation voltage and frequency control for practical performance optimization of the electric machine entity. Permanent magnet, reluctance, and doubly-fed electric machines require electronic control for practical functional operation. Any device that is connected in series with the electric machine, such as a transformer, an electronic controller, or a gearbox *compounds* the losses of the system. For instance, if the controller has an efficiency of 90% and the electric motor has an efficiency of 90%, the total system efficiency is 81% (i.e., 90% x 90%). As a functional "system," the loss, cost and size of the series connected device, such as electronic controller, transformer, or gearbox must be obviously included in the EMS specifications for equitable comparisons, which is generally not the case.
- Total Loss of any EMS should always include windage & stray losses, electronic controller (inverter) losses, core losses, such as hysteresis and eddy current losses, etc., with at least, windage & stray and core losses being directly proportional to at least the volume (size) of the electric machine system (*e.g., half the size provides half the windage, stray, and core losses*). Electrical Loss is associated with MMF. Therefore, the permanent magnet rotor of an electric machine has similar windage and stray losses but has no electrical loss (e.g., no windings) and very low core loss (without considering harmonics, such as from controlled excitation).
- Persistent magnetism (*i.e., permanent magnet*) or magnetizing MMF (current) are orthogonal to torque MMF (current). Magnetizing current magnitude is the result of inductive impedance and applied voltage and persistent magnetism magnitude is the result of the coercivity and permanent magnet physical thickness in the path of flux, of the permanent magnet. In contrast, torque MMF magnitude, which is against the very low permeability of the permanent magnets (air) or the neutralizing effects of rotor and stator torque currents of SYNCHRO-SYM (and to a limited degree of the induction EMS), follows Ohms Law (i.e., port voltage ÷ winding resistance) instead of inductive impedance. Of course, torque current produces electrical loss in the winding (*i.e.,* I^2R) of all electric machines and core loss (*i.e., hysteresis and eddy*

current) in the electrical steel core, such as SYNCHRO-SYM, Induction, and non-coreless permanent magnet machines.

- With the exception of only SYNCHRO-SYM with torque current cancellation in accordance with dual ported transformer physics, electric machines with an iron core in the entire flux path (less air-gap), such as internally mounted permanent magnet and induction electric machines, can saturate with increasing torque current because of the high core magnetic permeability. In contrast, surface mounted permanent magnet or so-called coreless electric machines are less likely to saturate because of low core permeability but as a result of the low permeable core, require substantially more expensive, environmentally unfriendly, and geopolitically sensitive RE-PM material to obtain just satisfactory air-gap flux density. In all cases, peak torque current magnitude must be limited in permanent magnet electric machines to avoid potential permanent magnet, winding insulation, or inverter damage due to large uncontrolled back EMF (i.e., voltage) or current during faults.
- For comparative convenience in accordance with common EMS design trade space, Best Electric Machine categorizes all electric motor systems into two basic electric motor circuit and control architectures: 1) the familiar asymmetric EMS, which is controlled by a derivative field oriented electronic control (**FOC**), with the asymmetry of a single independently excited multiphase winding set (or "active" winding set) on the stator assembly and a "passive" rotor assembly of Slip-induction dependent windings (*i.e., asynchronous*), reluctance saliencies (*i.e., synchronous or asynchronous*), permanent magnets (*i.e., synchronous*), or DC Field windings (*i.e., synchronous*) and 2) the only (and patented) permanent magnet free, brushless symmetric multiphase wound-rotor "synchronous" doubly-fed EMS with the symmetry of two active winding sets on the rotor and stator assemblies, respectively, to preserve the same asymmetric electric machine form and fit, which is only possible with the stabilizing invention of brushless real time emulation control (**BRTEC**) as only provided by SYNCHRO-SYM. **Figure 1** shows a textbook two phase symmetric multiphase wound-rotor "synchronous" doubly-fed "electric machine" version to simplify study, which is taught in classic electric machine studies but only by hypothesizing the stabilizing invention of BRTEC to guarantee stable synchronous operation from sub-synchronous, synchronous, to super-synchronous speeds. The same classic electric machine study goes on to becomes the study for all asymmetric electric machine system by deoptimizing the symmetry of an active stator and rotor assembly under BRTEC with the asymmetry of a "passive rotor assembly" under a control derivative of FOC.
    - *Caveat*: Never realizing the enabling BRTEC invention (until SYNCHRO-SYM), the brushless symmetric multiphase wound-rotor *synchronous* doubly-fed EMS is always mistakenly confused with the antiquated asymmetric multiphase wound-rotor *asynchronous* (i.e., induction) doubly-fed EMS with the "asymmetry" of a passive rotor of slip-induction dependent windings, which is with the size, cost, loss, and reliability issues of a multiphase slip-ring assembly for electrical power connection to the rotor multiphase winding set, the instability issues associated with the loss of slip-induction *about* synchronous speed, and the instability issues

associated positive feedback of line or rotor shaft perturbations that were understood to only be resolved by applying the formidable invention of a brushless real time emulation controller.

- With stable operation from sub-synchronous to super-synchronous speed, SYNCHRO-SYM shows twice the MLS *with a given continuous torque, air-gap flux density, excitation frequency, and port voltage* of all other electric machine systems (*i.e., 7200 RPM for one pole-pair and 60 Hz excitation versus 3600 RPM for asymmetric electric machine systems*), which is tantamount to twice the continuous power for a given port voltage, excitation frequency, and optimizing packaging technique (less RE-PM) or twice *the power density* (and octuple the peak torque) at half the cost, half the size, and half the loss *per unit of continuous power rating* as analytically shown by this study.

Closer look at the RE-PM EMS:

The only competitively viable permanent magnet (PM) electric motor system (EMS) is the rare-earth permanent magnet (RE-PM) EMS by the enabling high BH energy product of dysprosium doped neodymium PMs. But because RE-PM production is controlled by a global adversary seeking world dominance without regard to the associated environmental, human suffering, or geopolitical consequences, today's efforts are focused on reducing or eliminating the amounts of RE-PMs in the EMS. One approach is to eliminate the high BH energy product RE-PM by substituting with the low BH energy product ferrite permanent magnet (FPM) but ironically, the FPM EMS cannot compete with an equally *optimized* slip-induction EMS, which seemingly suggests today's cultlike attraction to the PM EMS, regardless of price-performance. Another approach is to reduce the amount of RE-PM material by ironically introducing a high speed and therefore, compact RE-PM EMS while conveniently ignoring the extraneous *enabling* speed-reduction gearbox with additional *compounding* loss, cost, size, and reliability consequences. Without considering SYNCHRO-SYM or the futuristic superconductor electric motor systems, the basic advantages and disadvantages of RE-PM EMS over the slip-induction or reluctance EMS show the RE-PM EMS is not the total EMS solution as anecdotally thought:

- The RE-PM EMS has the *advantage* of no rotor windings and associated provisioning, such as slip-induction, slip-rings, magnetizing MMF, etc.;
- The RE-PM EMS has the *advantage* of no rotor core or electrical losses by neglecting the harmonic core and electrical loss associated with electric motor excitation and speed;
- The RE-PM EMS has the *advantage* of a larger than normal air-gap, which *may* simplify the structural integrity of the EMS;
- The RE-PM EMS has the *disadvantage* of safety, handling, cogging, and speed range issues associated with persistent magnetism;

- The RE-PM EMS has the *disadvantage* of limited life expectancy that is aggravated by back-EMF or by harmonic and conduction heating of the rotor;
- The RE-PM EMS has the *disadvantage* of a limited residual airgap flux density that unlike an electromagnet, is inversely proportional to coercivity of the PM and as a result, a larger than normal air-gap RE-PM EMS requires considerably more RE-PM material to reach the typical flux saturation limit of the core with the RE-PM size reaching beyond the size of a comparably performing electromagnet;
- Like any Asymmetric EMS that depends on slip-induction windings, reluctance saliencies, DC field windings, or PMs, the RE-PM EMS has the *disadvantage* of a "passive" rotor assembly, which has no directly excited power port for contributing additional working power to the electromechanical energy conversion process and as a result, effectively wastes half of the motor real-estate while concurrently consuming additional components of loss, cost and size.

Design Constraints for This Study:

With the previous common electric machine system trade space understanding, all EMS contestants are normalized to the following design physics without deviation with the Singly-fed (**SF**) designator referring to the ubiquitous asymmetric EMS and with the Doubly-fed (**DF**) designator referring to the symmetric multiphase wound-rotor "synchronous" doubly-fed EMS, as only provided by SYNCHRO-SYM:

1. In this study, $\mathbf{P_{DF}}$ (*i.e., number of pole-pairs of the two active winding sets on the rotor and stator for DF*), $\mathbf{P_{SF}}$ (*i.e., number of pole-pairs of the stator active winding set for SF*), $\mathbf{N_{DF}}$ (*i.e., number of pole-pairs of the two active winding sets on the rotor and stator for DF*), $\mathbf{N_{SF}}$ (*i.e., number of winding-turns of the stator active winding set for SF*), $\mathbf{I_{DF}}$ (*i.e., port current for the rotor and stator active winding sets of the DF*), $\mathbf{I_{SF}}$ (*i.e., port current of the stator active winding set for SF*), $\mathbf{A_{DF}}$ (*i.e., Area per winding pole coupling the air-gap flux in accordance to Lorentz Law of DF*), $\mathbf{A_{SF}}$ (*i.e., Area per winding pole coupling the air-gap flux in accordance to Lorentz Law of SF*), $\mathbf{(I_{DF})}$ (*i.e., the cross-sectional area of the winding wire in accordance with port current magnitude of DF*), & $\mathbf{(I_{SF})}$ (*i.e., the cross-sectional area of the winding wire in accordance with port current magnitude of DF*) are normalized to their ratio between SYNCHRO-SYM (**DF**) and Singly-fed (**SF**) counterparts.

2. Faraday Law (*per active winding set, slip induction dependent windings, reluctance saliencies, or DC field windings*) or permanent magnet depth and coercivity (*per permanent magnets*):
   $V \propto N * P * A * B * Freq$ (or speed) $\propto N_{DF} * P_{DF} * A_{DF} * Freq_{DF} = N_{SF} * P_{SF} * A_{SF} * Freq_{SF}$;

   Note: *B (flux density) is the same amongst all optimized electric machine categories and therefore removed as a differentiator between EMS contestants.*

Where N is winding-turns, P is the number of pole-pairs, A is the effective area of the air-gap (per pole) that cuts the air-gap magnetic field in accordance to Lorentz Law, Freq (or speed) is the frequency of excitation or speed of the rotor, and * is the scalar product.

3. Lorentz Force Law (per active winding set):
   Force α N * P * L * B * I;
   Torque α F * W;
   Torque α N * P * A * B * I α N_{DF}* P_{DF} * A_{DF} * I_{DF} α N_{SF} * P_{SF} * A_{SF} * I_{SF};

   Note: *B (flux density) is the same amongst all optimized electric machine categories and therefore removed as a differentiator between EMS contestants.*

   Where I is the force (or torque) current in the winding, L is the Length of wire that cuts the air-gap magnetic field in accordance to Lorentz Force Law (vector cross product) with the other opposing winding sides (e.g., end turns) with a length of W, neutralizing each other and L x W = A (Area per pole). As W increases, so does diameter, which is proportional to torque.

4. Maximum Load Speed (MLS) is the speed for a given frequency of excitation, excitation voltage, and continuous torque of the directly excited multiphase winding set (i.e., active winding set):

   MLS_{DF} α 2 * $Freq_{DF}/P_{DF}$;
   or $Freq_{DF}$ α MLS_{DF} * P_{DF} /2;

   MLS_{SF} α $Freq_{SF}/P_{SF}$;
   or $Freq_{SF}$ α MLS_{SF} * P_{SF};

5. Total Electrical and mechanical power:

   Total Electrical (or Mechanical) $Power_{SF}$ = V_{SF} * I_{SF}; (single active winding set)

   Total Electrical (or Mechanical) $Power_{DF}$ = 2 * V_{DF} * I_{DF}; (double active winding sets)

   Where V_{SF} = V_{DF} (port voltages) and I_{SF}, I_{DF} are the port currents at the active winding sets with the DF electric machine having two active winding sets.

6. Winding resistance (per active winding set):

   Resistance α (N * P * A * (1/I))

   Where the product of the number of winding-turns, N, the number of pole-pairs, P, the length of the wire wind-turn directly related to airgap surface area, A, and the resistance of the winding, which is inversely proportional to the current, I, that is proportional to the wire cross-sectional area of the active winding set;

$Resistance_{SF} = N_{SF} * P_{SF} * A_{SF} * (1/I_{SF})$;
$Resistance_{DF} = N_{DF} * P_{DF} * A_{DF} * (1/I_{DF})$;

(I_{SF}) & (I_{DF}) is the cross-sectional area of the winding slot, which is directly related to the current magnitude. (*i.e., if the current is halved, the cross-sectional area of the conductor is halved, the size is halved and the resistance is doubled.*)

7. Total Electric Loss in all active winding sets:

Total Electrical Loss = I^2R;

Total Electrical $Loss_{DF} = 2 * I_{DF}^2 * Resistance_{DF}$; (SYNCHRO-SYM has two active winding sets)

Total Electrical $Loss_{SF} = I_{SF}^2 * Resistance_{SF}$; (One active winding set with a RE-PM rotor)

Where I is the current in the active winding set and R is the resistance of the active winding set.

Note: RE-PM electric machines (without field weakening design assets) have no rotor winding electrical loss. In contrast, induction electric machines (with inherent field weakening) have rotor slip-induction dependent windings sets with similar electrical loss, cost, and size as the stator active winding set. In reality, all rotors have windage losses, core losses, etc., which are not an obvious part of this analytical study.

8. Size of the active winding set:

Size α P * A * (I) of the rotor and stator assemblies;

Where (I) represents the slot cross-sectional area of the winding, which is directly proportional to the current magnitude in the active winding set, directly affects the airgap surface area and the depth of the electric machine core (i.e., size of the electric machine), and directly affects the winding resistance;

$Size_{DF}$ α $P_{DF} * A_{DF} * (I_{DF})$; Of the active winding set
$Size_{SF}$ α $P_{SF} * A_{SF} * (I_{SF})$; Of the active winding set

Size indicates the amount (and cost) of material, such as permanent magnet material, aluminum, steel, copper, etc. (I_{SF}) & (I_{DF}) is the slot area.

Total $Size_{DF}$ α 2* P_{DF}* A_{DF} * (I_{DF});
Total $Size_{SF}$ α P_{SF}* A_{SF} * (I_{SF}) + Passive Rotor Assembly, which effectively = 2 * P_{SF}*A_{SF} * (I_{SF});

9. Total Electrical Loss (per unit of continuous power rating) IAW 7. & 5.:

   Total Electrical $Loss_{DF}$ / Electrical (or Mechanical) $Power_{DF}$;

   Total Electrical $Loss_{SF}$ / Electrical (or Mechanical) $Power_{SF}$;

10. Total Size (per unit of continuous power rating) or power density IAW 8. & 5.:

    $Size_{DF}$ / Electrical (or Mechanical) $Power_{DF}$;

    $Size_{SF}$ / Electrical (or Mechanical) $Power_{SF}$;

11. Voltage is fixed and the same amongst all electric machine systems (V_{DF} =V_{SF}).

12. B is fixed and the same amongst all electric machines (B_{DF} =B_{SF}).

Study Results:

There are three axial flux electric machine designs for comparative purposes with the RE-PM electric machine system: MLS_{DF} = 2 * MLS_{SF} with I_{DF} = I_{SF}, which is the classic two stator disk retrofit (*i.e., another active stator disk replacing a form fit passive rotor disk of RE-PMs, slip-induction windings, reluctance saliencies, or DC field windings*) providing twice the MLS speed with the same continuous torque, MLS_{DF} = MLS_{SF} with I_{DF} = I_{SF}, which is the same MLS speed but twice the continuous torque, and MLS_{DF} = MLS_{SF} with I_{DF} = ½ * I_{SF}, which is a direct torque and speed fit to the asymmetric electric machine system.

A SIMPLE SWAP EXAMPLE OF AN PASSIVE ROTOR DISK WITH AN ACTIVE STATOR DISK OF AN AXIAL-FLUX RE-PM ELECTRIC MOTOR

2 * MLS_{SF} = MLS_{DF}, ($Freq_{SF}$ = $Freq_{DF}$), (V_{DF} = V_{SF}), & **I_{DF} = I_{SF}**:

IAW 4.:
Let 2 * MLS_{SF} = MLS_{DF} = 2 * $Freq_{SF}$/P_{SF} = 2 * $Freq_{DF}$/P_{DF}; $Freq_{SF}$/P_{SF} = $Freq_{DF}$/P_{DF};

P_{SF} = P_{DF};

With the exception of the bearing assembly, the axial-flux rotor disk with RE-PMs, slip-Induction dependent windings, reluctance saliencies, or field windings is reasonably the same core loss (e.g., stator winding) and windage and stray losses, cost, and form fit (size) as the stator disk with the active winding sets and as a result, $P_{DF} = P_{SF}$, $N_{DF} = N_{SF}$, $I_{DF} = I_{SF}$ & $A_{DF} = A_{SF}$, & $(I_{DF}) = (I_{SF})$.

IAW 5. with $(I_{DF} = I_{SF})$, $(V_{DF} = V_{SF})$, & $(P_{SF} = P_{DF})$:

- Electrical (or Mechanical) $Power_{DF} = V_{DF} * 2 * I_{DF} = 2 * V_{SF} * I_{SF}$;
- Electrical (or Mechanical) $Power_{SF} = V_{SF} * I_{SF}$;

Electrical (or Mechanical) $Power_{DF}$ = 2 * Electrical (or Mechanical) $Power_{SF}$;

With $A_{DF} = A_{SF}$, $P_{DF} = P_{SF}$, & $(1/I_{DF}) = (1/I_{SF})$, SYNCHRO-SYM is the same size (α P x A) as the SF electric machine and as a result has the same amount and cost of winding and structural materials (less RE-PMs), but with twice the power rating (*i.e., Electrical (or Mechanical) $Power_{DF}$ = 2 * Electrical (or Mechanical) $Power_{SF}$*), SYNCHRO-SYM shows half the amount of material per unit of continuous power rating of the electric machine system, which again equates to half the cost per unit of continuous power rating of the electric machine system.

IAW 6. with $(P_{DF} = P_{SF})$, $(N_{DF} = N_{SF})$, $(A_{DF} = A_{SF})$, & $(I_{DF}) = (I_{SF})$:

- $Resistance_{DF} = N_{DF} * P_{DF} * A_{DF} * (1/I_{DF})$;
- $Resistance_{SF} = N_{SF} * P_{SF} * A_{SF} * (1/I_{SF})$;

$Resistance_{DF} = Resistance_{SF}$;

IAW 7. with $P_{DF} = P_{SF}$, $N_{DF} = N_{SF}$, & $A_{DF} = A_{SF}$, & $(I_{DF}) = (I_{SF})$:

- Total Electrical $Loss_{DF}$ α $2 * I_{DF}^2 * (N_{DF} * P_{DF} * A_{DF} * (I_{DF})) = 2 * I_{SF}^2 * (N_{SF} * P_{SF} * A_{SF} * (I_{SF}))$;
- Total Electrical $Loss_{SF} = I_{SF}^2 * (N_{SF} * P_{SF} * A_{SF} * (1/I_{SF}))$;

Total Electrical $Loss_{DF}$ = Total Electrical $Loss_{SF}$; (not induction motor)

With Total Electrical $Loss_{DF}$ = Total Electrical $Loss_{SF}$, SYNCHRO-SYM shows the same loss as the singly-fed RE-PM electric machine system with rotor RE-PMs showing no electrical loss (but half the loss of the Induction electric machine with the rotor showing similar loss to the stator). With twice the power per unit of continuous power rating of the electric machine system (Electrical (or Mechanical) $Power_{DF}$ = 2 * Electrical (or Mechanical) $Power_{SF}$), SYNCHRO-SYM equates to same loss per unit of continuous power rating of the RE-PM electric machine system and half the loss per unit of continuous power rating as the Induction electric machine system. But when considering the electronic controller (BRTEC), which only controls half the current, and the friction losses, such as windage losses, SYNCHRO-SYM will show half the loss as the RE-PM electric machine system.

IAW 8. & with $P_{DF} = P_{SF}$, $N_{DF} = N_{SF}$, & $A_{DF} = A_{SF}$, & $(I_{DF}) = (I_{SF})$:

- $Size_{DF}\ \alpha\ P_{DF} * A_{DF} * (I_{DF}) = P_{SF} * A_{SF} * (1/I_{SF})$;
- $Size_{SF}\ \alpha\ P_{SF} * A_{SF} * (I_{SF})$;
- Total $Size_{DF}\ \alpha\ 2 * Size_{DF}$;
- Total $Size_{SF}\ \alpha\ 2 * Size_{SF}$;

$Size_{DF} = Size_{SF}$;
Total $Size_{DF}$ = Total $Size_{SF}$;

IAW 7. & 5. with $P_{DF} = P_{SF}$, $N_{DF} = N_{SF}$, $A_{DF} = A_{SF}$, & $(I_{DF}) = (I_{SF})$, Total Electrical $Loss_{DF}$ = 2 * Total Electrical $Loss_{SF}$**,** & Electrical (or Mechanical) $Power_{DF}$ = 2 * Electrical (or Mechanical) $Power_{SF}$:

Total Electrical Loss Per Unit of Continuous power rating:
Total Electrical $Loss_{DF}$/ Electrical (or Mechanical) $Power_{DF}$ =
2 * Total Electrical $Loss_{SF}$/(2 * Electrical (or Mechanical) $Power_{SF}$) =
Total Electrical $Loss_{SF}$/Electrical (or Mechanical) $Power_{SF}$;

SYNCHRO-SYM shows the same electrical Loss per unit of continuous power rating as the RE-PM electric machine system
[or half the electrical loss per unit of continuous power rating of the induction electric machine systems; When considering the electronic controller (BRTEC), which only controls half the torque current, SYNCHRO-SYM shows half the cost and half the loss as the RE-PM electric machine system. With half the current, BRTEC is shows half the cost of FOC of the Induction or RE-PM EMS.]

IAW 8. & 5. with $P_{DF} = P_{SF}$, $N_{DF} = N_{SF}$, & $A_{DF} = A_{SF}$, & $(I_{DF}) = (I_{SF})$, $Size_{DF} = Size_{SF}$, Total $Size_{DF}$ = Total $Size_{SF}$, & Electrical (or Mechanical) $Power_{DF}$ = 2 * Electrical (or Mechanical) $Power_{SF}$;

Total Size (per unit of continuous power rating) or power density:
Total $Size_{DF}$/Electrical (or Mechanical) $Power_{DF}$ =
Total $Size_{SF}$/(2 * Electrical (or Mechanical) $Power_{SF}$) =
½ * Total $Size_{SF}$/Electrical (or Mechanical) $Power_{SF}$;

SYNCHRO-SYM shows half the size per unit of continuous power rating;
[or half the size per unit of continuous power rating of the RE-PM or induction electric machine systems, which equates to half the amount of material (e.g., copper and electrical steel), particularly with MOTORPRINTER, per unit of power rating, which equates to half the cost of materials. With the material,

environmental, geopolitical costs of RE-PMs, SYNCHRO-SYM is considerably less expensive than a RE-PM EMS.]

With twice the constant torque speed per continuous torque, excitation frequency, and excitation voltage, the **$2 * MLS_{SF} = MLS_{DF}$**, **$P_{DF} = P_{SF}$**, & **$I_{DF} = I_{SF}$** version of SYNCHRO-SYM will need the additional compounding loss, cost, and size of a gearbox to halve the MLS speed and as a result, provides the same MLS speed as the RE-PM electric machine system contestant (but will double the continuous torque output). In contrast to provide the same speed and power as SYNCHRO-SYM (without the gearbox), the RE-PM electric machine system would need the additional "compounding" loss, cost, and size of a voltage and power step-up transformer to double its port voltage and power, and an electronic controller (such as FOC) with double the power and frequency of excitation. Unlike RE-PM electric machine systems with potential damage to winding insulation, permanent magnets, or electronic components with speeds beyond MLS, particularly during back EMF faults, SYNCHRO-SYM can advance to speeds beyond MLS without damaging to winding insulation or electronic components with inherent field weakening.

Since SYNCHRO-SYM is half the size of any electric machine system per unit of continuous power rating with at least windage, core & stray losses directly proportional to size, and unlike all other electric machine systems with BRTEC controlling only half the current of the electric machine system for another degree efficiency, **SYNCHRO-SYM provides half the loss, half the size, and half the cost (per unit of continuous power rating) of any electric machine system**, including RE-PM electric machine systems. Also, with MOTORPRINTER additive manufacturing, which is the only 3D Printer of electric machines, with low loss, high permeability non-crystalline metal ribbon, such as amorphous or nanocrystalline metal ribbon, for deeper slot potential, provides another level of size, loss, and cost reduction.

A REDESIGNED SYNCHRO-SYM EXAMPLE THAT RUNS AT THE SAME MLS AS AN AXIAL-FLUX RE-PM ELECTRIC MOTOR

$MLS_{SF} = MLS_{DF}$, ($Freq_{SF} = Freq_{DF}$), ($V_{DF} = V_{SF}$), & **$I_{DF} = I_{SF}$**:

IAW 4.:
Let $MLS_{SF} = MLS_{DF} = Freq_{SF}/P_{SF} = 2*Freq_{DF}/P_{DF}$;

$2 * P_{SF} = P_{DF}$;

With $2 * P_{SF} = P_{DF}$, SYNCHRO-SYM has twice the number of poles in an active winding set for the same speed.

IAW 5. with ($I_{DF} = I_{SF}$), ($V_{DF} = V_{SF}$), & ($2 * P_{SF} = P_{DF}$):

- Electrical (or Mechanical) $Power_{DF} = V_{DF} * 2 * I_{DF} = 2 * V_{SF} * I_{SF}$;

- Electrical (or Mechanical) $Power_{SF} = V_{SF} * I_{SF}$;

Electrical (or Mechanical) $Power_{DF}$ = 2 * Electrical (or Mechanical) $Power_{SF}$;

With $A_{DF} = ½ * A_{SF}$, $2 * P_{SF} = P_{DF}$, & $(1/I_{DF}) = (1/I_{SF})$, SYNCHRO-SYM is the same size (α P x A) as the SF electric machine and as a result has the same amount and cost of winding and structural materials (less RE-PMs), but with twice the power rating (*i.e., Electrical (or Mechanical) $Power_{DF}$ = 2 * Electrical (or Mechanical) $Power_{SF}$*), SYNCHRO-SYM shows half the amount of material, which again equates to half the cost per unit of continuous power rating of the electric machine system.

IAW 6. with $2 * P_{SF} = P_{DF}$, $N_{DF} = N_{SF}$, & $A_{DF} = ½ * A_{SF}$, & $(I_{DF}) = (I_{SF})$:

- $Resistance_{DF} = N_{DF} * P_{DF} * A_{DF} * (1/I_{DF}) = N_{SF} * 2 * P_{SF} * ½ * A_{SF} * (1/I_{SF}) = N_{SF} * P_{SF} * A_{SF} * (1/I_{SF})$;
- $Resistance_{SF} = N_{SF} * P_{SF} * A_{SF} * (1/I_{SF})$;

$Resistance_{DF} = Resistance_{SF}$;

IAW 7. with $2 * P_{SF} = P_{DF}$, $N_{DF} = N_{SF}$, & $A_{DF} = A_{SF}/2$, & $(I_{DF}) = (I_{SF})$:

- Total Electrical $Loss_{DF}$ α $2 * I_{DF}^2 * (N_{DF}* P_{DF}* A_{DF} * (1/I_{DF})) = 2 * I_{SF}^2 * (N_{SF} * 2 * P_{SF}* A_{SF}/2 * (1/I_{SF})) = I_{SF}^2 * (N_{SF} * P_{SF}* A_{SF} * (1/I_{SF}))$;
- Total Electrical $Loss_{SF} = I_{SF}^2 * (N_{SF} * P_{SF}* A_{SF} * (1/I_{SF}))$;

Total Electrical $Loss_{DF}$ = 2 * Total Electrical $Loss_{SF}$; (not induction motor)

With Total Electrical $Loss_{DF}$ = 2 * Total Electrical $Loss_{SF}$, SYNCHRO-SYM shows the same loss as the singly-fed RE-PM electric machine system with rotor RE-PMs showing no electrical loss (but half the loss of the Induction electric machine with the rotor showing similar loss to the stator). With twice the power per unit of continuous power rating of the electric machine system (Electrical (or Mechanical) $Power_{DF}$ = 2 * Electrical (or Mechanical) $Power_{SF}$), SYNCHRO-SYM equates to same loss per unit of continuous power rating of the RE-PM electric machine system and half the loss per unit of continuous power rating as the Induction electric machine system. But when considering the electronic controller (BRTEC), which only has to control half the current, and the friction losses, such as windage losses, SYNCHRO-SYM will show half the loss as the RE-PM electric machine system.

IAW 8. with $2 * P_{SF} = P_{DF}$, $N_{DF} = N_{SF}$, & $A_{DF} = A_{SF}/2$, & $(I_{DF}) = (I_{SF})$:

- $Size_{DF}$ α $P_{DF}* A_{DF} * (I_{DF}) = 2 * P_{SF}* A_{SF}/2 * (I_{SF}) = P_{SF}* A_{SF} * (I_{SF})$;
- $Size_{SF}$ α $P_{SF}* A_{SF} * (I_{SF})$;
- Total $Size_{DF}$ α $2 * Size_{SF}$;

- Total $Size_{SF}$ α 2 * $Size_{SF}$;

$Size_{DF}$ = $Size_{SF}$;
Total $Size_{DF}$ = Total $Size_{SF}$;

IAW 7. & 5. with 2 * P_{SF} = P_{DF}, N_{DF} = N_{SF}, & A_{DF} = A_{SF}/**2**, & (I_{DF}) = ½ * (I_{SF}), Total Electrical $Loss_{DF}$ = 2 * Total Electrical $Loss_{SF}$**,** & Electrical (or Mechanical) $Power_{DF}$ = 2 * Electrical (or Mechanical) $Power_{SF}$:

Total Electrical Loss Per Unit of Continuous power rating:
Total Electrical $Loss_{DF}$/Electrical (or Mechanical) $Power_{DF}$ =
2 * Total Electrical $Loss_{SF}$/(2 * Electrical (or Mechanical) $Power_{SF}$) =
Total Electrical $Loss_{SF}$/Electrical (or Mechanical) $Power_{SF}$:

SYNCHRO-SYM shows the same electrical Loss per unit of continuous power rating as the RE-PM electric machine system
[or half the electrical loss per unit of continuous power rating of the induction electric machine systems; When considering the electronic controller (BRTEC), which only controls half the torque current, SYNCHRO-SYM shows half the cost and half the loss as the RE-PM electric machine system. With half the current, BRTEC is shows half the cost of FOC of the Induction or RE-PM EMS.]

IAW 8. & 5. with 2 * P_{SF} = P_{DF}, N_{DF} = N_{SF}, & A_{DF} = A_{SF}/2, & (I_{DF}) = (I_{SF}), $Size_{DF}$ = $Size_{SF}$, Total $Size_{DF}$ = Total $Size_{SF}$, & Electrical (or Mechanical) $Power_{DF}$ = 2* Electrical (or Mechanical) $Power_{SF}$:

Total Size (per unit of continuous power rating) or power density:
Total $Size_{DF}$/Electrical (or Mechanical) $Power_{DF}$ =
Total $Size_{SF}$ /(2 * Electrical (or Mechanical) $Power_{SF}$) =
½ * Total $Size_{SF}$/Electrical (or Mechanical) $Power_{SF}$;

SYNCHRO-SYM shows half the size per unit of continuous power rating;
[or half the size per unit of continuous power rating of the RE-PM or induction electric machine systems, which equates to half the amount of material (e.g., copper and electrical steel), particularly with MOTORPRINTER, per unit of power rating, which equates to half the cost of materials. With the material, environmental, geopolitical costs of RE-PMs, SYNCHRO-SYM is considerably less expensive than a RE-PM EMS.]

With twice the constant torque speed per continuous torque, excitation frequency, and excitation voltage, the **MLS_{SF} = MLS_{DF}**, **P_{DF} = 2 * P_{SF}**, & **I_{DF} = I_{SF}** version of SYNCHRO-SYM shows the same MLS speed as the RE-PM electric machine system but with double the continuous torque output. In contrast to provide the same MLS speed and continuous torque as SYNCHRO-SYM, the RE-PM electric machine system contestant would have to mechanically couple the shaft with the additional loss, cost, and size of another similar RE-PM electric machine "system" contestant with its own controller to double the torque with the same port voltage. Unlike RE-PM electric machine systems with potential damage to winding insulation, permanent magnets, or electronic components with speeds beyond MLS, particularly during back EMF faults, SYNCHRO-SYM can advance to speeds beyond MLS without damaging to winding insulation or electronic components with inherent field weakening.

Since SYNCHRO-SYM is half the size of any electric machine system per unit of continuous power rating with at least windage, core & stray losses directly proportional to size, and unlike all other electric machine systems with BRTEC controlling only half the current of the electric machine system for another degree efficiency, **SYNCHRO-SYM provides half the loss, half the size, and half the cost (per unit of continuous power rating) of any electric machine system**, including RE-PM electric machine systems. Also, with MOTORPRINTER additive manufacturing, which is the only 3D Printer of electric machines, with low loss, high permeability non-crystalline metal ribbon, such as amorphous or nanocrystalline metal ribbon, for deeper slot potential, provides another level of size, loss, and cost reduction.

DIRECT REPLACEMENT SYNCHRO-SYM EXAMPLE TO RE-PM ELECTRIC MOTOR SYSTEM EXAMPLE

$\mathbf{MLS_{SF} = MLS_{DF}}$, ($Freq_{SF} = Freq_{DF}$), ($V_{DF} = V_{SF}$), & $\mathbf{I_{DF} = ½ * I_{SF}}$:

IAW 4.:
Let $MLS_{SF} = MLS_{DF} = Freq_{SF}/P_{SF} = 2*Freq_{DF}/P_{DF}$;

$\mathbf{2 * P_{SF} = P_{DF}}$**;**

With $2 * P_{SF} = P_{DF}$, SYNCHRO-SYM has twice the number of poles in an active winding set for the same speed.

IAW 5. with ($I_{DF} = ½ * I_{SF}$), ($V_{DF} = V_{SF}$), & ($P_{DF} = 2 * P_{SF}$):

- Electrical (or Mechanical) $Power_{DF} = 2 * V_{DF} * I_{DF} = 2 * V_{SF} * ½ * I_{SF} = V_{SF} * I_{SF}$;
- Electrical (or Mechanical) $Power_{SF} = V_{SF} * I_{SF}$;

Electrical (or Mechanical) $\mathbf{Power_{DF}}$ = Electrical (or Mechanical) $\mathbf{Power_{SF}}$;

With half the total current at each port $\mathbf{I_{DF} = ½ * I_{SF}}$ for the same total current at the same continuous power as RE-PM electric motor system and with $A_{DF} = ½ * A_{SF}$, $2 * P_{SF} = P_{DF}$, & $(1/I_{DF}) = (2/I_{SF})$, SYNCHRO-SYM is half the size (α P x A) of the SF electric machine with the same power rating (*i.e., Electrical (or Mechanical) $Power_{DF}$ = Electrical (or Mechanical) $Power_{SF}$*), which equates to half of the amount of winding and structural materials (less RE-PMs), which again equates to half of the cost per unit of continuous power rating of the electric machine system.

IAW 6. with $2 * P_{SF} = P_{DF}$, $N_{DF} = N_{SF}$, & $A_{DF} = ½ * A_{SF}$, & $(I_{DF}) = (½ * I_{SF})$:

- $Resistance_{DF} = N_{DF} * P_{DF} * A_{DF} * (1/I_{DF}) = N_{SF} * 2 * P_{SF} * ½ * A_{SF} * 2 * (1/I_{SF}) = 2 * N_{SF} * P_{SF} * A_{SF} * (1/I_{SF})$;
- $Resistance_{SF} = N_{SF} * P_{SF} * A_{SF} * (1/I_{SF})$;

$Resistance_{DF} = 2 * Resistance_{SF}$;

IAW 7. with $2 * P_{SF} = P_{DF}$, $N_{DF} = N_{SF}$, & $A_{DF} = A_{SF}/2$, & $(I_{DF}) = ½ * (I_{SF})$:

- Total Electrical $Loss_{DF}$ α $2 * I_{DF}^2 * (N_{DF}* P_{DF}* A_{DF} * (1/I_{DF}))$; $= 2 * ¼ * I_{SF}^2 * (N_{SF} * 2 * P_{SF}* A_{SF}/2 * 2 * (1/I_{SF})) = I_{SF}^2 * (N_{SF} * P_{SF}* A_{SF} * (1/I_{SF}))$;
- Total Electrical $Loss_{SF} = I_{SF}^2 * (N_{SF} * P_{SF}* A_{SF} * (1/I_{SF}))$;

Total Electrical $Loss_{DF}$ = Total Electrical $Loss_{SF}$; (not induction motor)

With Total Electrical $Loss_{DF}$ = Total Electrical $Loss_{SF}$, SYNCHRO-SYM shows the same loss as the singly-fed RE-PM electric machine system with rotor RE-PMs showing no electrical loss (but half the loss of the Induction electric machine with the rotor showing similar loss to the stator). With twice the power per unit of continuous power rating of the electric machine system (Electrical (or Mechanical) $Power_{DF}$ = 2* Electrical (or Mechanical) $Power_{SF}$), SYNCHRO-SYM equates to same loss per unit of continuous power rating of the RE-PM electric machine system and half the loss per unit of continuous power rating as the Induction electric machine system. But when considering the electronic controller (BRTEC), which only has to control half the current, and the friction losses, such as windage losses, SYNCHRO-SYM will show half the loss as the RE-PM electric machine system.

IAW 8. with $2 * P_{SF} = P_{DF}$, $N_{DF} = N_{SF}$, & $A_{DF} = A_{SF}/2$, & $(I_{DF}) = (I_{SF})$:

- $Size_{DF}$ α $P_{DF}* A_{DF} * (I_{DF}) = 2 * P_{SF}* A_{SF}/2 * ½ * (I_{SF}) = ½ * P_{SF}* A_{SF} * (I_{SF})$;
- $Size_{SF}$ α $P_{SF}* A_{SF} * (I_{SF})$;
- Total $Size_{DF}$ α $2 * Size_{DF}$;
- Total $Size_{SF}$ α $2 * Size_{SF}$;

$Size_{DF} = ½ * Size_{SF}$;
Total $Size_{DF}$ = ½ * Total $Size_{SF}$;

IAW 7. & 5. with $2 * P_{SF} = P_{DF}$, $N_{DF} = N_{SF}$, & $A_{DF} = A_{SF}/2$, $(I_{DF}) = ½ * (I_{SF})$, Total Electrical $Loss_{DF}$ = Total Electrical $Loss_{SF}$**,** Electrical (or Mechanical) $Power_{DF}$ = Electrical (or Mechanical) $Power_{SF}$:

Total Electrical Loss Per Unit of Continuous power rating:
Total Electrical Loss$_{DF}$/Electrical (or Mechanical) Power$_{DF}$ =
Total Electrical Loss$_{SF}$ /Electrical (or Mechanical) Power$_{SF}$;

SYNCHRO-SYM shows the same electrical Loss per unit of continuous power rating as the RE-PM electric machine system
[or half the electrical loss per unit of continuous power rating of the induction electric machine systems; When considering the electronic controller (BRTEC), which only controls half the torque current, SYNCHRO-SYM shows half the cost and half the loss as the RE-PM electric machine system. With half the current, BRTEC is shows half the cost of FOC of the Induction or RE-PM EMS.]

IAW 8. & 5. with 2 * P_{SF} = P_{DF}, N_{DF} = N_{SF}, & A_{DF} = A_{SF}/2, & (I_{DF}) = ½ * (I_{SF}), Size$_{DF}$ = ½ * Size$_{SF}$, Total Size$_{DF}$ = ½ * Total Size$_{SF}$, & Electrical (or Mechanical) Power$_{DF}$ = Electrical (or Mechanical) Power$_{SF}$:

Total Size (per unit of continuous power rating) or power density:
Total Size$_{DF}$/Electrical (or Mechanical) Power$_{DF}$ =
½ * Total Size$_{SF}$/Electrical (or Mechanical) Power$_{SF}$;

SYNCHRO-SYM shows half the size per unit of continuous power rating;
[or half the size per unit of continuous power rating of the RE-PM or induction electric machine systems, which equates to half the amount of material (e.g., copper and electrical steel), particularly with MOTORPRINTER, per unit of power rating, which equates to half the cost of materials. With the material, environmental, geopolitical costs of RE-PMs, SYNCHRO-SYM is considerably less expensive than a RE-PM EMS.]

With twice the constant torque speed per continuous torque, excitation frequency, and excitation voltage, the **MLS$_{SF}$ = MLS$_{DF}$**, **P_{DF} = 2 * P_{SF}** & **I_{DF} = ½ * I_{SF}** version of SYNCHRO-SYM competes directly with the same MLS speed and continuous torque of RE-PM electric machine system contestant but with half the size, cost, and loss. Unlike RE-PM electric machine systems with potential damage to winding insulation, permanent magnets, or electronic components with speeds beyond MLS, particularly during back EMF faults, SYNCHRO-SYM can advance to speeds beyond MLS without damaging to winding insulation or electronic components with inherent field weakening.

Since SYNCHRO-SYM is half the size of any electric machine system per unit of continuous power rating with at least windage, core & stray losses directly proportional to size, and unlike all other electric machine systems with BRTEC controlling only half the current of the electric machine system for another degree efficiency, **SYNCHRO-SYM provides half the loss, half the size, and half the cost (per unit of continuous power**

rating) of any electric machine system, including RE-PM electric machine systems. Also, with MOTORPRINTER additive manufacturing, which is the only 3D Printer of electric machines, with low loss, high permeability non-crystalline metal ribbon, such as amorphous or nanocrystalline metal ribbon, for deeper slot potential, provides another level of size, loss, and cost reduction.