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Hybrid Synchronous Machine Capable Of High Output Power For Optimizing The Potentials In Nigeria's Extractive Industries

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Abstract

The economy of every nation is driven by electrical energy. However, the inadequacy of public supply affects industrial production output. For this reason, an alternative and reliable source of power is presented. This paper focuses on a hybrid source of power that will deliver a constant power to enhance industrial high production. The generator comprises a salient pole and round pole machines that are magnetically coupled together and integrally wound. The unique feature about this generator is that it is rugged, and while running at a synchronous speed, the effective quadrature axis reactance Xq can be adjusted by tuning the variable capacitance load of the auxiliary winding thereby delivering a high output power that will empower every equipment in an industry. When this type of generator is employed in extractive industry, production output will increase. The circuit diagram of the machine is presented and analyzed. It has a high output power and performance is better than every other conventional generator.
(Keywords: High voltage, Variable capacitance tuning)

INTRODUCTION

The delivering of a fixed electrical power generator, otherwise known as steady state machine has been reported [1-4]. This is hybrid synchronous generator and each has two stator windings. These windings are known as main and auxiliary windings. The machine comprises a round rotor and salient pole rotor that that are magnetically coupled together and integrally wound. The main winding is connected series and the auxiliary winding is transposed between the two sections of the machine. When this connection is carried out and by tuning the load capacitance of the auxiliary winding, it varies the operational q- axis reactance xq of the machine from zero to a very high output power value while the d- axis remains constant. Thus it is proven that varying Xd/Xq ratio is achieved from zero to a very high value. Hence, the output power of this coupled generator is directly proportional to Xd/Xq.

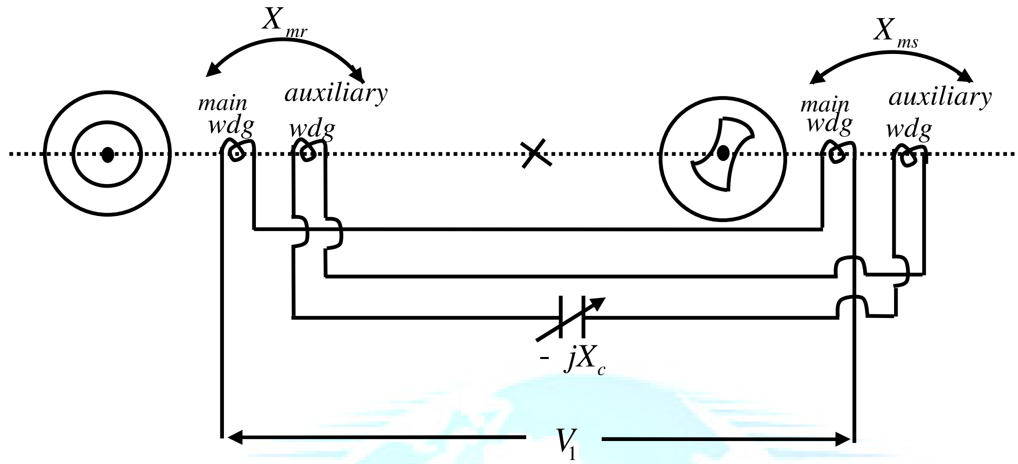

Figure 1: Per Phase schematic diagram of the coupled synchronous machine

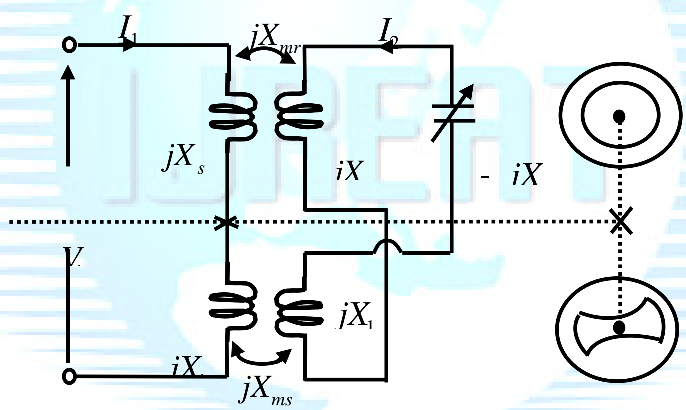

Figure 2: Equivalent circuit diagram of the above coupled machine

In analyzing Figure 2 the following assumptions are made:

(a) The synchronous reactance x_s of the round rotor section of the machine is matched to the d – axis reactance (X_d) of the salient pole by design. Therefore, $X_s = X_d$.

(b) The main winding and auxiliary winding of the machine have the same number of poles as the rotor and they occupy the same slot space, and thus perfectly coupled. Hence, $X_{mr} = X_1 = X_d$ and = $X_{ms} = X_1$

(c) The resistance of the windings is ignored.

Taking the above assumptions, therefore, for a distributed stator winding and a salient pole structure, the winding reactance X_1 is a function of rotor position and well known as [6]:

$$X_1 = \frac{X_d + X_q}{2} + \frac{X_d - X_q}{2}\cos 2\delta + j\frac{X_d - X_q}{2}\sin 2\delta \qquad (1)$$

(Where δ is the phase angle between the direct axis reactance and the rotating *mmf)*

The machine is analyzed as a magnetically coupled circuit. Applying KVL equation in the two meshes of Figure 2 and noting the positive and negative couplings in the respective halves of the machine, it can readily be seen that

$$V_1 = j2X_d I_1 + j(X_1 - X_d)I_1 - j(X_1 - X_d)I_2 \qquad (2)$$

And

$$0 = j2X_d I_2 + j(X_1 - X_d)I_1 - j(X_1 - X_d)I_2 - jX_c I_2 \qquad (3)$$

Equations (2) and (3) lead directly to the equivalent circuit as shown in Figure 3.

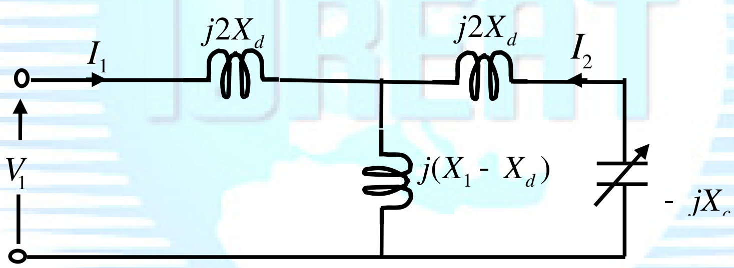

Figure: 3 Per-phase steady-state equivalent circuit of hybrid synchronous machine

From Figure 3,

$$V_1 = j(X_d - X_1)I_1 - j(X_1 - X_d)I_2 \qquad (4)$$

And from equation (3),

$$0 = j(X_1 - X_d)I_1 + j(X_d - X_1 - X_c)I_2 \qquad (5)$$

Solving equations (4) and (5) simultaneously using MATLAB

$$I_1 = j*(-\frac{3}{2}*X_d - \frac{1}{2}*X_q - (\frac{1}{2}*X_d - \frac{1}{2}*X_q)*esp(2*j*del) + X_c /(-4*(\frac{1}{2}*X_d$$
$$+\frac{1}{2}*X_q + (\frac{1}{2}*X_d - \frac{1}{2}*X_q)*esp(2*j*del))*X_d + (\frac{1}{2}*X_d + \frac{1}{2}*X_q$$
$$+(\frac{1}{2}*X_d - \frac{1}{2}*X_q)*esp(2*j*del))*X_c + X_d*X_c)*V_1$$

$$I_2 = j*(-\frac{1}{2}*X_d + \frac{1}{2}*X_q + (\frac{1}{2}*X_d - \frac{1}{2}*X_q)*esp(2*j*del))/(-4*(\frac{1}{2}*X_d + \frac{1}{2}*X_q + (\frac{1}{2}*X_d - \frac{1}{2}*X_q)*esp(2*j*del))*X_d + (\frac{1}{2}*X_d + \frac{1}{2}*X_q + (\frac{1}{2}*X_d - \frac{1}{2}*X_q)*esp(2*j*del))*X_c + X_d*X_c)*V_1$$

The resulting impedance matrix is given below

$$\begin{bmatrix} V_1 \\ 0 \end{bmatrix} = \begin{bmatrix} j(X_d + X_1) & -j(X_1 - X_d) \\ -j(X_1 - X_d) & j(X_1 + X_d - X_c) \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} \quad (6)$$

Substituting the value of I_2 in equation (4) into equation (5)

$$V_1 = (X_d + X_1)I_1 + \frac{(X_1 - X_d)(X_d - X_1)I_1}{X_1 + X_d - X_c} \quad (7)$$

$$V_1 = \frac{(X_d - X_1)(X_1 + X_d - X_c) + (X_1 - X_d)(X_d - X_1)I_1}{X_1 + X_d - X_c} \quad (8)$$

$$V_1 = \frac{X_1X_d + X_d^2 - X_cX_d + X_1^2 + X_1X_d - X_1X_c - X_1X_d - X_1^2 - X_d^2 + X_1X_d)I_1}{X_1 + X_d - X_c} \quad (9)$$

$$V_1 = \frac{(4X_d - X_c)X_1 - X_cX_d)I_1}{X_1 + X_d - X_c} \quad (10)$$

Impedance $Z_{in} = \frac{V_1}{I_1} = j[\frac{(4X_d - X_c)X_1 - X_cX_d}{X_1 + X_d - X_c}]$ (11)

Substituting $X_1 = \frac{X_d + X_q}{2} + \frac{X_d - X_q}{2}\cos 2\delta + j\frac{X_d - X_q}{2}\sin 2\delta$ into equation (11) gives

$$Zin = j[\frac{4X_d - X_c)(\frac{X_d + X_q}{2} + \frac{X_d - X_q}{2}\cos 2\delta + j\frac{X_d - X_q}{2}\sin 2\delta) - X_cX_d}{\frac{X_d + X_q}{2} + \frac{X_d - X_q}{2}\cos 2\delta + j\frac{X_d - X_q}{2}\sin 2\delta + X_d - X_c}] \quad (12)$$

$$Z_{in} = j\left[\frac{(4X_d - X_c)[X_d + X_q + (X_d - X_q)\cos 2\delta + j(X_d - X_q)\sin 2\delta] - 2X_c X_d}{X_d + X_q + (X_d - X_q)\cos 2\delta + j(X_d - X_q)\sin 2\delta + 2X_d - 2X_c}\right] \quad (13)$$

Equation (13) can be simplified as follows:

Let $(4X_d - X_c)(k-1) - 2kX_c + (4X_d - X_c)\cos 2\delta = a$ (14)

$$(4X_d - X_c)(k-1)\sin 2\delta = b \quad (15)$$

$$3k + 1 - 2k\frac{X_c}{X_d} + (k-1)\cos 2\delta = c \quad (16)$$

$$(k-1)\sin 2\delta = d \quad (17)$$

(Where $k = \frac{X_d}{X_q}$)

However,

$$Z_{in} = j\frac{a + jb}{c + jd} \quad (18)$$

Rationalizing equation (18) gives

$$Z_{in} = j\left[\frac{ac - jad + jbc + bd}{c^2 + d^2}\right] \quad (19a)$$

$$Z_{in} = \left[\frac{ac + bd}{c^2 + d^2} + \frac{ad - bc}{c^2 + d^2}\right] \quad (19b)$$

$$Z_{in} = \left[\frac{ad - bc}{c^2 + d^2} - j\frac{ac - bd}{c^2 + d^2}\right] \quad (19c)$$

Therefore,

$$Z_{in} = -R_e + jX_e \quad (20)$$

(Where R_e and X_e are the effective resistance and reactance of the machine).

AXIS REACTANCE OF THE MACHINE

Considering the reactive component of Z_{in} (Equation 20) leads directly to the direct axis and quadrature axis reactance.

Direct axis reactance X_D when $\delta = 0$

$$X_D = \frac{(2X_d - X_c)(\frac{X_d + X_q}{2} + \frac{X_d - X_q}{2} - X_d) + 2X_d(X_d - X_c + \frac{X_d + X_q}{2} + \frac{X_d - X_q}{2})}{X_d - X_c + \frac{X_d + X_q}{2} + \frac{X_d - X_q}{2}} \quad (21)$$

$$X_D = (2X_d - X_c)(0 - X_c) - 2X_d \quad (22)$$

Therefore, $X_D = 2X_d$ (23)

When $\delta = \pi/2$, quadrature axis reactance X_Q

$$X_Q = \frac{(2X_d - X_c)(\frac{X_d + X_q}{2} - \frac{X_d - X_q}{2} - X_d) + 2X_d(X_d - X_c + \frac{X_d + X_q}{2} - \frac{X_d + X_q}{2})}{X_d - X_c + \frac{X_d + X_q}{2} - \frac{X_d + X_q}{2}} \quad (24)$$

$$X_Q = \frac{(4X_d - X_c) - kX_c}{k + 1 - k\frac{X_c}{X_d}} \quad (25)$$

(Where $k = \frac{X_d}{X_q}$)

From equations 23 and 25, the fixed values of X_d and k determine by the geometry of the salient pole section of the generator, the quadrature axis reactance X_Q is dependent on the variable X_c. Hence for appropriate value of X_c, X_Q takes values between 0 and infinity while X_Q remains constant and therefore, a variable of X_D / X_Q ratio which varies from zero to a very high value output power is obtained.

The loci of Zn of equation 20 as δ varies from 0 to infinity to π are family of circles of radius $\frac{1}{2}(X_D - X_Q)$ and center $\frac{1}{2}(X_D + X_Q)$, 0) for various values of X_c as shown in Figure 4

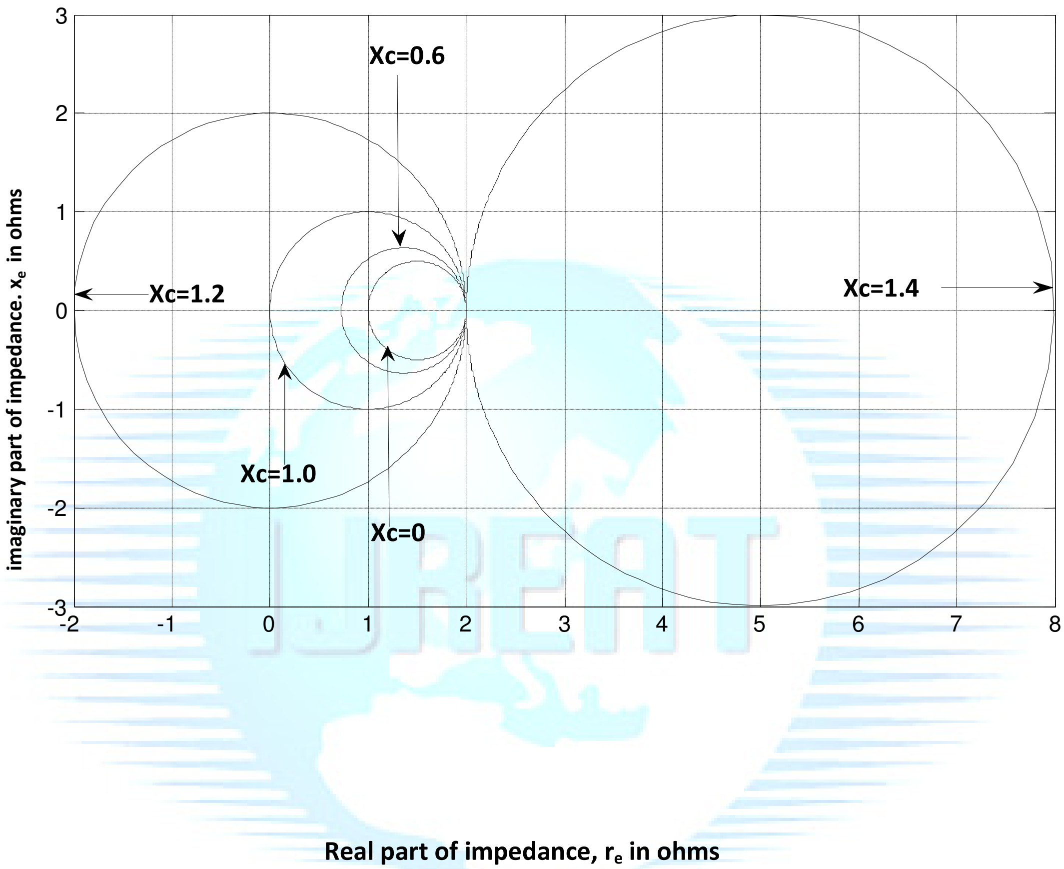

Figure 4: Impedance loci of the hybrid machine at various values of X_c

In Figure 4, all the family of circles are tangential to the straight line passing through 2 p.u for X_d, = I p.u. When X_d, = abs $- X_q$, the machine will draw or supply the same current irrespective of load in refractive industries.

For a constant applied voltage, the current loci which are the inverse of the impedance loci are family of circles tangential to the line 0.5 p.u as shown in Figure 5

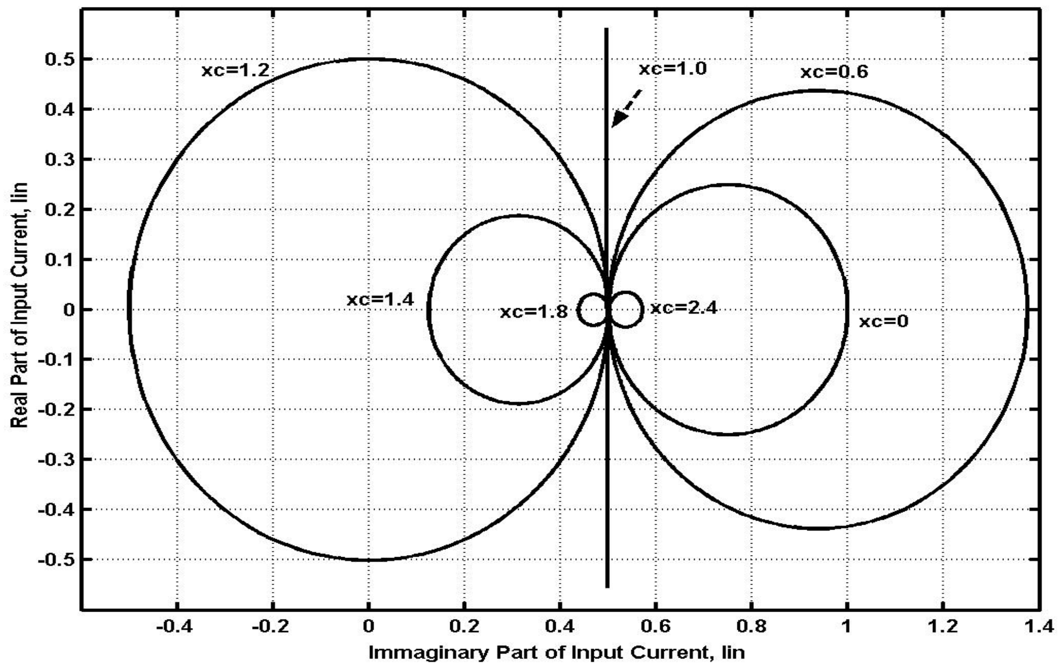

Figure 5: Current loci of the idealized hybrid machine

Figure 5 presents the straight line extending from zero to infinity in the current loci which implies a very high output power corresponding to loci to $X_Q = 0$ as expected. The power factor is given by

$$Cos\phi = \frac{\text{Re}}{\sqrt{\text{Re}^2 + Xe^2}}$$
(26)

Plots for the power factor for various values of Xc are shown in Figure 6

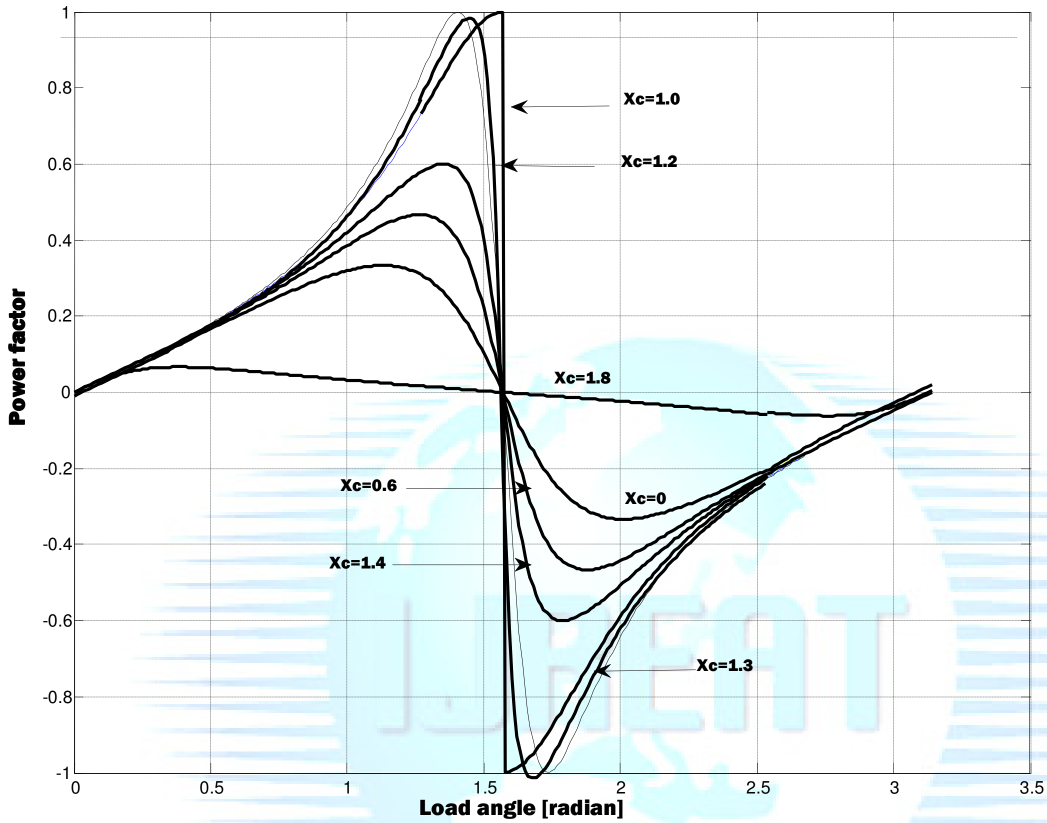

Figure 6: Power Factor - Load Angle plots of the idealized hybrid machine

SHORTCOMINGS ASSOCAITED WITH THE REPORTED SYNCHRONOUS MACHINE

One of the demerits of the hybrid synchronous machine reviewed is that the cylindrical rotor half of the generator does not contribute to the torque production since there is no winding in the rotor. Again, the generator cannot operate as a standalone machine as it must be connected to an existing mains supply for the purpose of deriving its magnetizing current in a manner similar to induction generators.

Obe and Senjyu [5] due to the mentioned demerits, suggested the exploration of the possibility of including some permanent magnets in the cylindrical rotor half of the machine with a view to making it contribute to the output power and therefore reduce the load angle δ for maximum output power of the generator.

This paper is an extension of the machine generator reported in [1-4] to operate in line with the pure synchronous mode by introducing a direct current field winding spanning both sections of the generator and mounting them on the combined rotors.

This method enables the salient pole of the machine to produce excitation and reluctance power while the cylindrical section contributes excitation power only. Therefore, the novel coupled synchronous generator will have superior output power characteristics to the machine reported [1-4] and the conventional direct current field excited synchronous machine generators.

NEW MACHINE UNDER STUDY

The difference between the machine [1-4] and the machine under study is that a direct current excitation field winding is mounted on the combined rotors as shown in Figure 7.

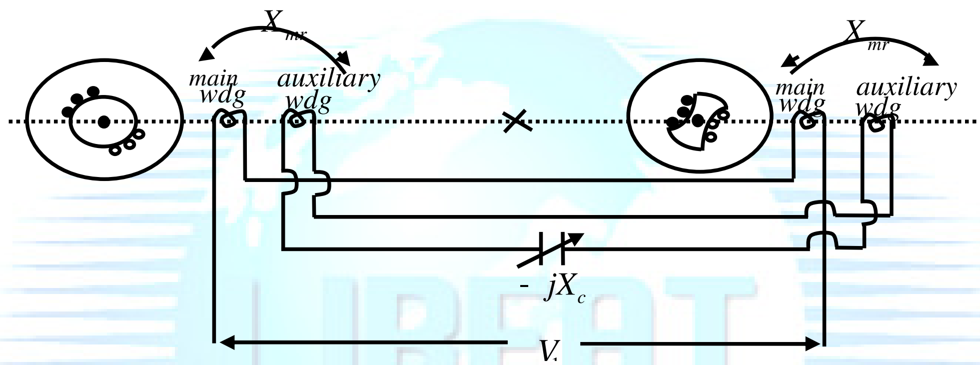

Figure 7: Per - phase schematic diagram of the new hybrid synchronous machine with rotor field winding

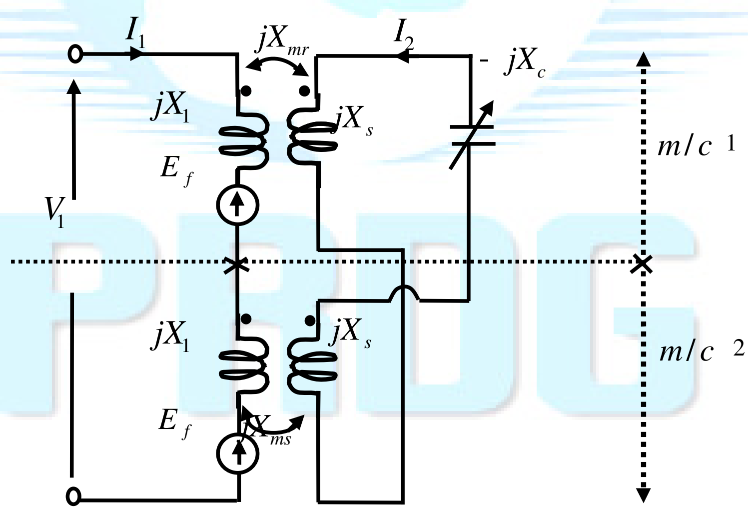

Figure 8: Coupled equivalent circuit of the machine including the effect of induced e.m.f

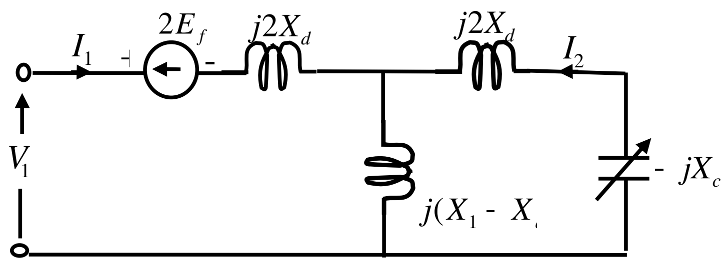

Figure 9: Equivalent Circuit of the new hybrid synchronous machine

Analysis of the coupled synchronous machine

The magnitude of the electromotive force (E_f) induced in both halves of the machine by the field winding is assumed equal (E_f). The total electromotive force induced in the main winding is thus the sum of the emfs (E_f) in both halves of the machine and equal to $2E_f$. Similarly, the emfs induced in both halves of the auxiliary winding are equal and adds up to zero due to the transposition (anti –series connection) of the auxiliary winding. The field winding is omitted from the equivalent circuit since it has no induced voltage components as there is no relative motion between it and the rotating magnetomotive force (mmf) in the air-gap due to the stator winding current, both rotating at the synchronous speed.

Applying the KVL emf equation for the two meshes of Figure 8, it can easily be shown that

$$V_1 = 2E_f + 2X_d I_1 + (X_1 - X_d)(I_1 + I_2) \quad (27)$$

$$0 = 2X_d I_2 + (X_1 - X_d)(I_1 + I_2) - I_2 X_c \quad (28)$$

The impedance of the circuit looking through the terminals of V_1 is given below:

$$Z_{in} = j[2X_d + \frac{(X_1 - X_d)(2X_d - X_c)}{(X_1 - X_d + 2X_d - X_c}] \quad (29)$$

Hence,

$$V_1 = 2E_f + j[2X_d + \frac{(X_1 - X_d)(2X_d - X_c)}{X_1 + X_d - X_c}]I_1 \quad (30)$$

Equation 30 may be represented as shown in Figure for generator operation

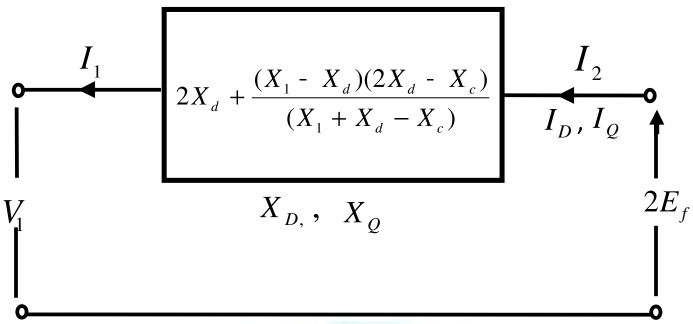

Figure 10: Equivalent circuit of the Hybrid synchronous machine operating as generator

Note: $X_1 = \frac{X_d + X_q}{2} + \frac{X_d - X_q}{2}\cos 2\delta + j\frac{X_d - X_q}{2}\sin 2\delta$

Substituting the expression for X_1 into equation (2.3), it can be shown that for δ = 0, the d-axis reactance (X_D) of the machine is given by

$$X_D = j[2X_d + \frac{(\frac{X_d + X_q}{2} + \frac{X_d - X_q}{2}\cos 2\delta + \frac{X_d - X_q}{2}\sin 2\delta - X_d)(2X_d - X_c)}{\frac{X_d + X_q}{2} + \frac{X_d - X_q}{2}\cos 2\delta + \frac{X_d - X_q}{2}\sin 2\delta - X_d + 2X_d - X_c}] \quad (31)$$

$$X_D = j[2X_d + \frac{(\frac{X_d + X_q}{2} + \frac{X_d - X_q}{2} - X_d)(2X_d - X_c)}{\frac{X_d + X_q}{2} + \frac{X_d - X_q}{2} - X_d + 2X_d - X_c}] \quad (32)$$

$$X_D = j[2X_d + \frac{(X_d + X_q + X_d - X_q - 2X_d)(4X_d - 2X_c)}{X_d + X_q + X_d - X_q - 2X_d + 4X_d - 2X_c}] \quad (33)$$

$$X_D = j2X_d \quad (34)$$

When the salient pole rotor is in q- axis, $\delta = \pi/2$, the quadrature- axis X_Q is given by

$$X_Q = j[2X_d + \frac{(\frac{X_d - X_q}{2} - \frac{X_d - X_q}{2}\cos 2\delta - X_d)(2X_d - X_c)}{\frac{X_d + X_q}{2} - \frac{X_d + X_q}{2}\cos 2\delta - X_d + 2X_d - X_c}] \quad (35)$$

$$X_Q = j\frac{(4X_d - X_c) - kX_c}{k+1-k\dfrac{X_c}{X_d}} \tag{36}$$

Figure 10 using V_1 as the reference phasor and neglecting resistance is given by

$$2E_f = V_1 + jI_D X_D + jI_Q X_Q \tag{37}$$

The phasor diagram corresponding to equation (37) is shown in Figure 11

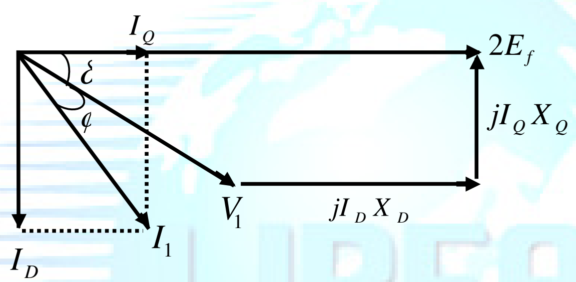

Figure 11: The phasor diagram of the generator mode of the new machine

OUTPOWER POWER OF THE NEW MACHINE GENERATOR

In calculation, the output power per phase of the machine is given by

$$S = V_1 I_1^* \tag{38}$$

Where S is the complex power and I_1^* is the conjugate of the stator current.

$$S = |V_1|\angle -\delta(|I_Q| + j|I_D|)^* \tag{39}$$

From the phasor diagram in figure (3.5)

$$|I_D| = \frac{|2E_f| - |V_1|\cos\delta}{X_D} \tag{40}$$

$$|I_Q| = \frac{|V_1|\sin\delta}{X_Q} \tag{41}$$

Substituting equations (4.4) and (4.3) into equation (4.2) gives

$$S = \frac{|V_1|^2}{X_Q}\sin\delta\angle-\delta + \frac{|V_1||2E_f|}{X_D}\angle(90-\delta) - \frac{|V_1|^2}{X_D}\cos\delta\angle(90-\delta) \quad (42)$$

$$= P + jQ \quad (43)$$

The resultant power P, for the 3-phase synchronous machine is given by

$$P = \frac{3|V_1||2E_f|}{X_D}\sin\delta + \frac{3|V_1|^2(X_D - X_Q)}{2X_D X_Q}\sin 2\delta \quad (44)$$

$$P = \frac{3|V_1||2E_f|}{X_D}\sin\delta + \frac{3|V_1|^2(\frac{X_D}{X_Q}-1)}{2X_D}\sin 2\delta \quad (45)$$

$$= P_f + P_r \quad (46)$$

(Where P_f is the Excitation Power and P_r is the Reluctance Power).

The Reactive Power Q, for a 3-phase system is given by

$$Q = \frac{3|V_1||E_f|}{X_D}\cos\delta - 3|V_1|^2\left|\frac{\sin^2\delta}{X_Q} + \frac{\cos^2\delta}{X_D}\right| \quad (47)$$

A plot of the power output of the machine for typical values of $V_1 = 1 p.u$, $E_f = 1.2 p.u$ and $\delta = 0$ to π for X_c =0.4p.u is as shown in figure (12).

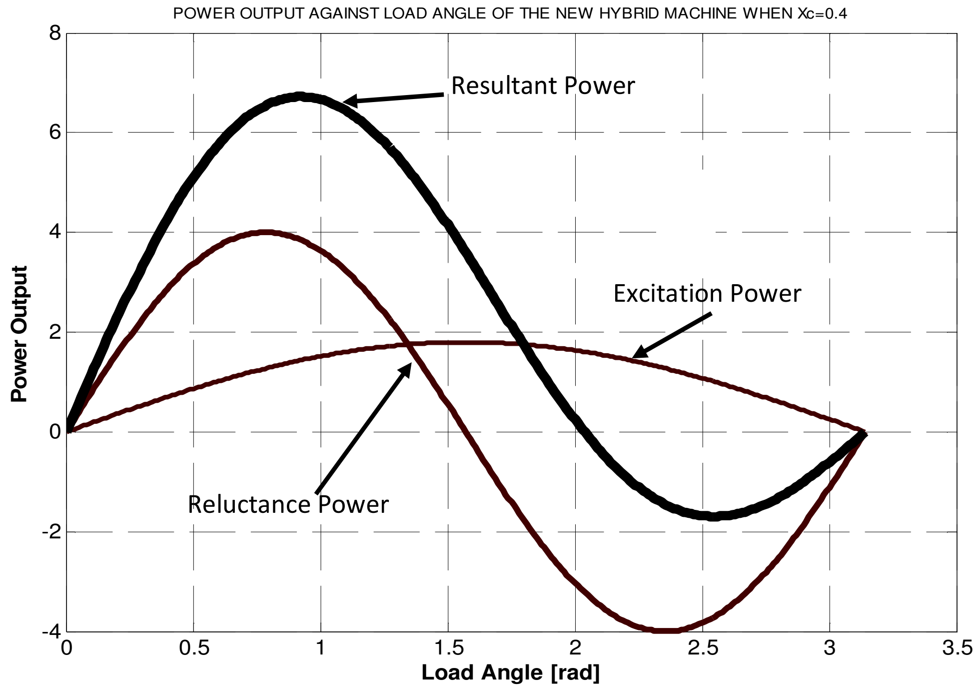

Figure 12: Output Power of the New Hybrid Machine for δ from zero to π At X_c=0.4

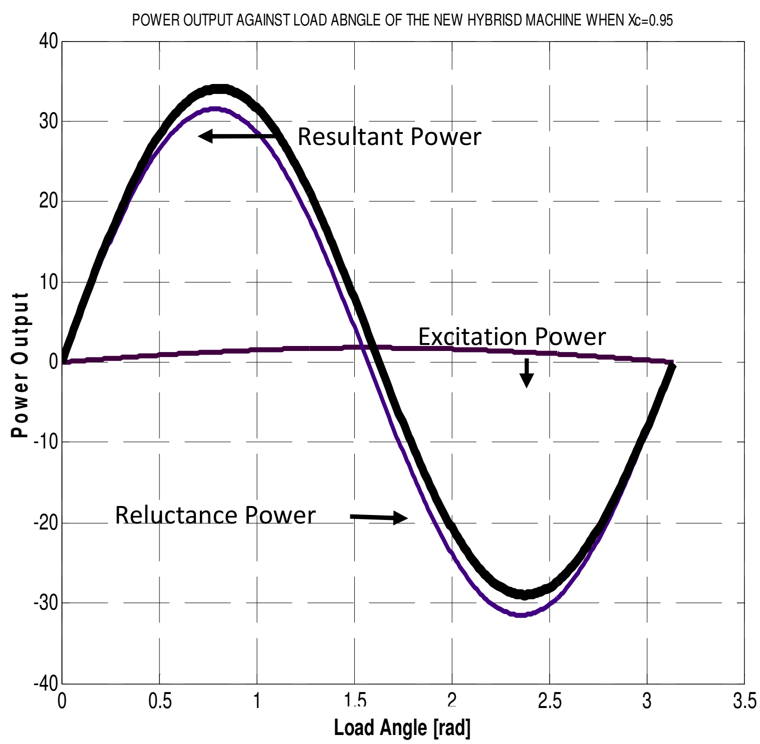

Figure 13: Output Power of the Hybrid Machine for δ from zero to π At X_c =0.95

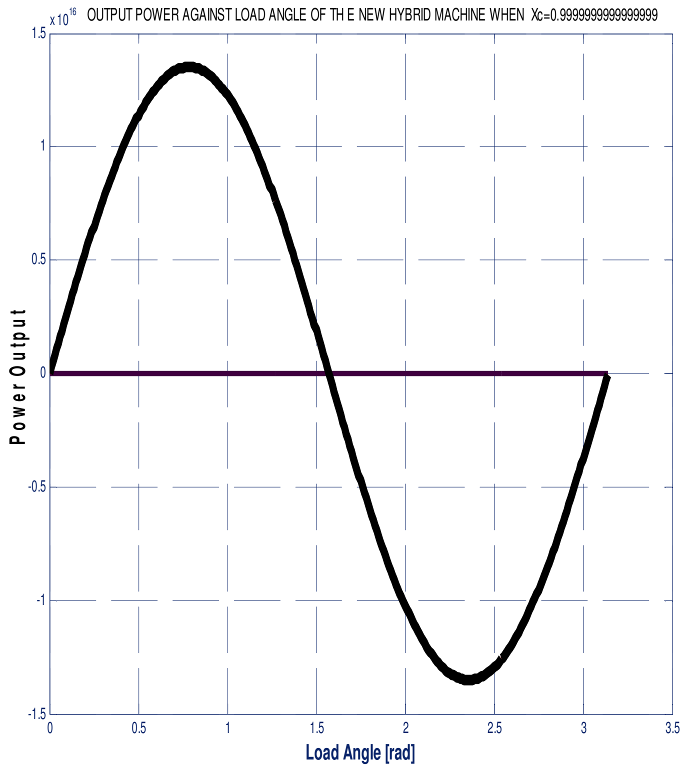

Figure 14: Output Power of the new hybrid machine for δ from zero to π at X_c = 0.999999

For a typical value of $\delta = 30^{\circ} = \frac{\pi}{6} rad$, whereas the excitation power P_f is constant at 0.6pu, the reluctance power P_r for some values of X_c is shown in table two below:

Capacitive Reactance X_c (p.u)	**Value of Capacitor in** *Farad*	**Operational X_D / X_Q Ratio for $k = 3$**	**Excitation Power P_f (p.u)**	**Reluctance Power $\lvert P_r \rvert$ (p.u)**	**Total Output Power $\lvert P \rvert$ (p.u)**	% P_f	% P_r
∞ (infinity)	0.00	1.50	1.80	1.29	3.09	58.25	41.75
0.00	∞(infinity)	2.00	1.80	2.61	4.41	40.82	59.18
0.60	0.0053	2.75	1.80	4.56	6.36	28.30	77.70
0.95	0.0034	11.50	1.80	27.27	29.07	6.19	93.81
0.99	0.0032	51.50	1.80	131.19	132.99	1.35	98.65

1.00	0.0032	∞ (infinity)	1.80	∞ (infinity)	∞ (infinity)	≈ 0.00	≈ 100.00
1.20	0.0027	-1.00	1.80	5.19	6.99	25.75	74.25
1.40	0.0023	0.25	1.80	1.95	3.75	48.00	52.00
1.80	0.0018	0.88	1.80	0.33	2.13	84.51	15.49
2.00	0.0016	1.00	1.80	0.00	1.80	100.00	0.00

Table 1: Three phase output power components of the new hybrid machine for various values of X_c at operational value of $\delta = 30^{\circ}$ and the percentage contributions of Pr and Pf to the total output power P

Glancing at Table 1, it shows that when the auxiliary winding is on open circuit ($X_c = \infty$) that the operational X_D / X_Q ratio is low and consequently the output power. When the auxiliary winding is short circuited ($X_c = 0$), there is a small decrement of the operational q-axis reactance (X_q) and a consequent increase in X_d / X_q as (X_d) is always constant and hence an increased output power. When a variable capacitance load is introduced into the auxiliary winding, there is a marked decrement of the q-axis reactance (X_q) and a corresponding increase in the output power due to the neutralization of the inductive reactance of the machine by the capacitive load. At $X_c = 1.0 p.u$, the inductive quadrature reactance (X_q) of the machine is completely neutralized by the capacitive reactance leading to infinite X_d / X_q ratio and a corresponding infinite output power. If, however, the capacitive reactance exceeds the inductive reactance, the machine operates at leading power factor.

In comparison, the excitation power component is negligibly small (in the operational range $X_c \approx 1.0$) compared to the reluctance power component and hence the overall output power of the machine which is the sum of P_f and P_r is P_r dominant. At $X_c = 1.0$ the reluctance power P_r (and by implication the total output power, P) will tend to infinity. The steady state limit of the hybrid machine is about 45° unlike the salient pole synchronous machine.

CONCLUSION

In the new hybrid synchronous generator machine, it is shown that when a cylindrical rotor machine is mechanically coupled to a salient pole machine, and spanning excitation field winding mounted on both combined rotors, with the synchronous reactance X_s of the round rotor machine made equal to the direct axis reactance X_d of the salient pole section ($X_s = X_d$); on the d-axis, the overall d-axis reactance of the machine is $X_D = 2X_d$ and the overall q-axis reactance is $X_Q = X_D + X_Q$, giving a ratio $K = \frac{X_D}{X_Q} = \frac{2X_d}{X_d + X_q} = \frac{2k}{k+1}$ $k = \frac{X_D}{X_Q}$ where $k = \frac{X_d}{X_q}$.

For a fixed machine geometry ($k = \frac{X_d}{X_q}$), the effective saliency factor, K, can be raised if a second set of stator (auxiliary) windings whose coil sides are displaced 180º electrical (transposed) between the two sections of the machine are installed and feed a balanced variable capacitance load. By varying the capacitance loading, X_q will vary from zero to infinity while X_D remains unaffected and a variable $\frac{X_D}{X_Q}$ ratio which is directly proportional to the reluctance power component is achieved at good power factors and normal currents.

The new hybrid synchronous machine has a higher output power to size ratio compared to hybrid reluctance synchronous machine, because the excitation power has a factor of 2 which compensates for coupling two machines. Furthermore, the reluctance component is very large and far exceeds the excitation component that even tends to zero.

In construction, the stator of the new hybrid synchronous machine has deeper slots in order to accommodate the two sets of windings (main and auxiliary). The output voltage of the auxiliary winding used in the control of the mechanical governing or adjustment of the field excitation when there is need to improve stability of operation.

The machine has a relatively better asynchronous run-up characteristic than a coupled synchronous reluctance machine because the capacitance of the auxiliary winding can be tuned such that the difference between the effective rotor D-axis reactance X_D and the effective quadrature axis reactance X_Q will not be so pronounced. The pull-in torque, as a ratio of the pull-out torque will therefore be greater. The stability of the machine on load is raised by increasing the auxiliary winding capacitance load after the machine has been brought to synchronism. The New hybrid synchronous machine is thus a synchronous generator for bulk power supply in view of its ultra-high power output potential.

REFERENCES

1. **Agu L. A. and Anih L. U. 1997, A Variable X_q Synchronous Reluctance Machine' *Proceeding of the Electric Power Engineering Conference* (*EPEC)* Nsukka Nigeria 46-53**

2. **Agu L. A. and Anih L. U. 2002 'Enhancement of the Output Synchronous Reluctance Machines by Injection Technique'. Technical Transaction of the Nigerian Society of Engineers 37 (2) 70-80**

3. **Agu L. A. and Anih L. U. 2002 'Polyphase Reluctance Machines Without Rotating Winding' Technical Transaction of the Nigerian Society of Engineers 37 (4) 46-52**

4. **Anih L. U. 1999,'The Performance Characteristics of Coupled Round Rotor and Salient Pole Synchronous Machine, Unpublished Ph. D Theses of the University of Nigeria Nsukka**

5. **Obe E.S. and Sejyu 2006 'Analysis of Polyphase Synchronous Reluctance Motor with Two Identical Stator Windings' Electric Power System Research 76: 515-52**

6. **Lawrenson P. U. and Agu L. A. 1964. Theory and Performance of Polyphase Reluctance Machines', Proceedings of Institute of Electrical Engineers 3 (8) 1435-1445**