Modelling of Common shaft Multi-generator Horizontal axis Wind turbine for Stability and Efficiency Enhancement

L V Suresh Kumar
Assistant professor, EEE department
GMR Institute of Technology
Rajam, srikakulam, india
lvenkatasureshkumar@gmail.com

T V S Madav
Business Development Officer,
Raj Group Of Companies, Hydarabad, India
Madhavtripasuril1993@gmail.com

***Abstract*— A novel wind turbine generator system is introduced, and its mathematical model, stability criterion was tested using a prototype and also by using simulation software for the performance prediction are presented. The notable feature of WTGS is that it consists of two generator systems positioned with multi stage gear box mounted on the common low speed shaft. In this paper, this new wind turbine generator system is treated as a constrained multi-body system, and the system equations, transfer function of this novel turbine and generator architecture are obtained by using differential equations and Laplace transforms approach. The results proved it as beneficial over single generator system, extracting higher wind power by maintaining system in stable state and improved power output along with enhancement of overall efficiency and were observed experimentally and through simulations. Here we successfully designed a prototype model of HAWT with a gross mechanical power output of 645.55W and a raw electrical power of 24W using PMDC generators with the gear box ratio as 1:6.444. Finally, Mat-lab simulation software is used to predict and analyze the performance and stability of the Multi gear box multi generator wind turbine system .**

Keywords*— *Common Shaft Multi-Generator, Horizontal Axis Wind Turbine (HAWT), Permanent Magnet Direct Current (PMDC), Multi gear box multi generator wind turbine system.

I. INTRODUCTION (*HEADING 1*)

During the last decade, the wind energy industry has seen a dramatic increase in the installation of wind turbine generator systems (WTGS) all over the world [1], and naturally the research and development activities related to the WTGS have drawn a renewed attention. A typical WTGS consists of rotor, pitch hub, gear boxes and power train, generators, power conditioning device, and software for control and monitoring. Although the theoretical limit of WTGS efficiency is known to be 59% [2], the practical performance of WTGS has been steadily increasing mainly due to the advancements in more aerodynamically efficient blade design, modern control theory, and use of more powerful electrical components [3-8].

On the other hand, a new and different WTGS has been recently introduced, this new WTGS characterized by two sets of rotor systems, is aerodynamically more efficient than the conventional single rotor WTGS [9]. But due to the two rotors namely upwind and downwind, the cost of system increases reduced mechanical stability due to variation in rotor diameters, this strategy leads to additional pitch control and drive motors for downwind rotor which adds cost to the system. Hence in order to increase the efficiency, stability, power output and reduce cost to the system a novel architecture was proposed in this paper.

This paper produces an investigational exploration of the horizontal axis wind turbine. It also describes performance, testing and results of wind turbine model with multi generators on common shaft architecture. This system is especially intended for home lighting system, street lighting with a turbine to lamp ration of 1:10 and for rural people to use easily and economically, which meets all the objectives of ASTRA (Applied science and technology for rural application).

In this paper the multi generator system was designed and tested under different operating conditions, the stability analysis was performed through simulation using MATLAB software. The efficacy of the proposed work was verified using a prototype model of wind turbine using multi generator systems.

II. PROTOTYPE STRUCTURE

The MGMGS-HAWT comprises two PMDC generators mounted on common low speed shaft using multi stage gear boxes shown in fig.1. In the proposed architecture to reduce harmonic torques, gears were arranged as 52:27:9 for consistent operation of the system. The WTGS is a typical multi-body system in that all components such as the rotor, shaft, gear boxes and generators are constrained to rotate as a single body. Yellow colors are gear box and silver colors indicate dc generators and single shaft also shown in below wind energy system.

Fig. 1. Multi generator wind Energy system

III. MATHEMATICAL MODELING

Therefore, a relatively simple approach has been widely adopted to model the system dynamics. If the whole mechanical system is treated as a single body and its dynamics can be represented as

$$T_0 = T_t + T_{GB1} + T_{G1} + T_{GB2} + T_{G2} \qquad (1)$$

T_o= over all torque of the system,
= Torque of gear box 1,
= Torque of gear box 2 ,
T_t= turbine torque,
Torque of Generator 1,
Torque of Generator 2

Neglecting damping, friction coefficient for simplified approach as the paper mainly focuses on power enhancement and steady state stability. In fig.2 single shaft multi gear multi generator block diagram shown and mathematical equations are implemented from above assumptions

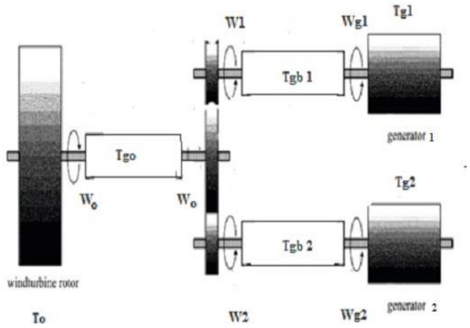

Fig.2 Multi Gear Multi Generator

$$T_{01} = T_t + 2T_{GB} + 2T_G \qquad (2)$$

$$T_{01} = T_t + 2(T_{GB} + T_G) \qquad (3)$$

$$P_0 = T_0 \times \omega_0 \qquad (4)$$

$$P_{01} = T_t + 2(T_{GB} + T_G) \times \omega_{01} \qquad (5)$$

System power, = over all system speed

On applying differentiation and Laplace transforms on both sides we get

$$\frac{P_{01}(s)}{\omega_{01}(S)} == [ST_t(s) + 2ST_{GB}(s) + 2ST_G(s)] \quad (6)$$

$$\frac{V_{out}(S)}{\theta_o(S)} = \frac{K_b}{\frac{Lg}{Cg}S^2 + \frac{Rg}{Cg}S + 1} \qquad (7)$$

$$\frac{V_{out}(s)}{\theta o(S)} = \frac{K_b}{AS^2 + BS + 1} \qquad (8)$$

$$\frac{Vo(S)}{P_m(S)} = \frac{K_b \times K_S}{S(AS^2 + BS + 1)} \qquad (9)$$

Where $K_S = T_T(s) + 2T_{GB}(S) + 2T_G(S$

K_S $= 24.89$, La $= 1.1$mH , R $_g$

K_s= system constant, K_g=generator constant, R= armature resistance, L_a= armature inductance.

For Multi Generator System

$$\frac{Vo(S)}{P_m(S)} = \frac{12 \times 10^{-3} \times 24.89}{1.1 \times 10^{-3}S^3 + 18.2S^2 + S} \qquad (11)$$

For Single Generator System

$$\frac{Vo(S)}{P_m(S)} = \frac{12 \times 10^{-3} \times 12.445}{1.1 \times 10^{-3}S^3 + 18.2S^2 + S} \qquad (12)$$

In this work, we have adopted a more fundamental formulation to obtain the turbine, generator model. Equation (11) & (12) are evaluated using Mat lab simulation. In this way we can consider factors such as variation in power with respect to the configuration of the system adopted. Based on the preliminary analysis, predicted a significant increase in the system power of the Multi gear box multi generator system over the conventional single generator system**.** The basic stability determining tools were used such as bode plot for prediction of both magnitude and stability, root locus for stability.

IV. SIMULATION RESULTS

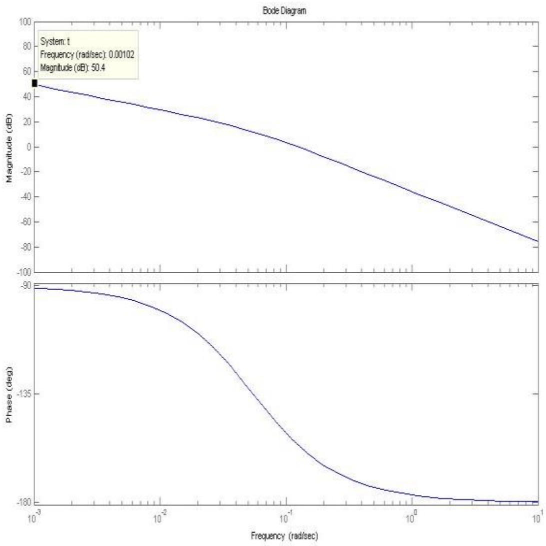

Fig.3 Multi Generator- Bode Plot

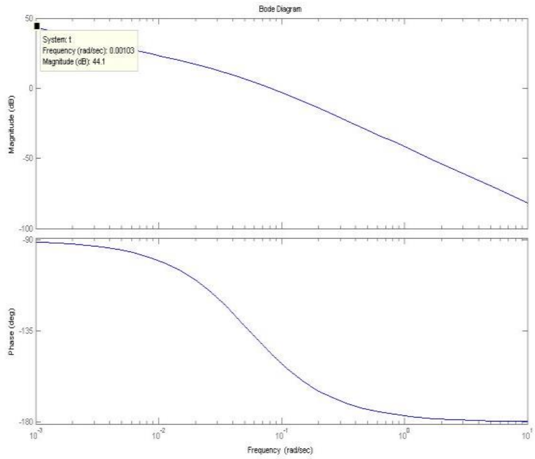

Fig.4 Single Generator- Bode Plot

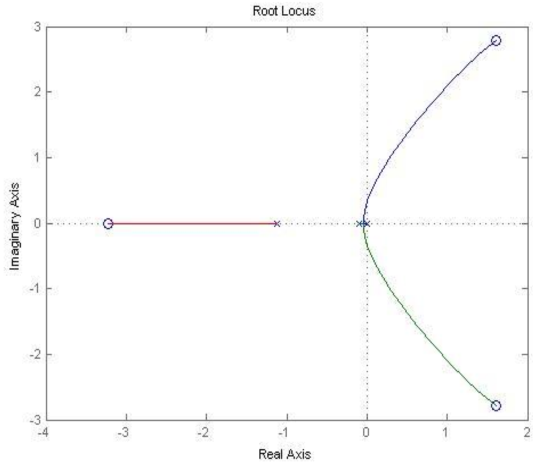

Fig.5 Multi Generator- Root Locus

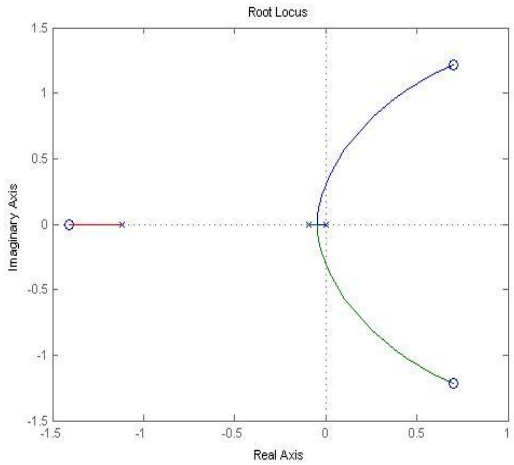

Fig.6 Single Generator- Root Locus

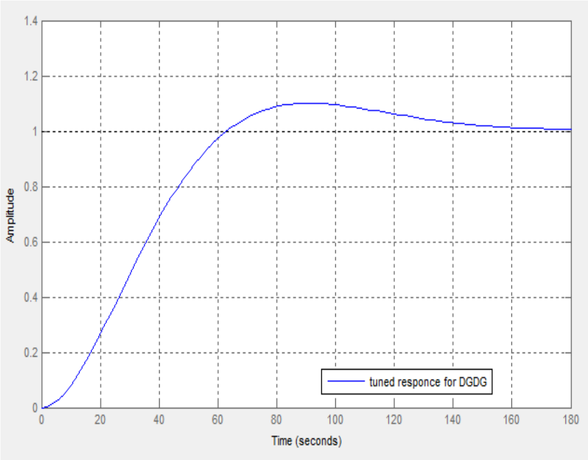

Fig.7 Step Response for Multi Gear Multi Generator

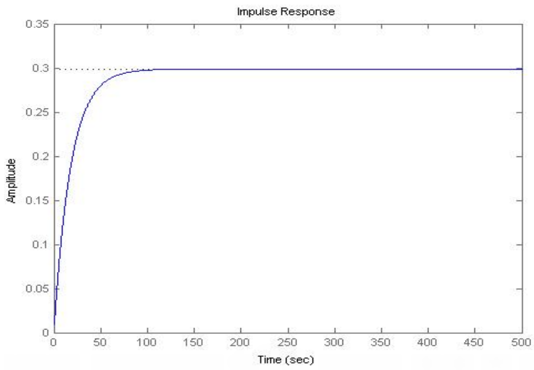

Fig.7 Impulse Response for Multi Gear Multi Generator

TABLE I. RESPONSE FOR DOUBLE GEAR DOUBLE GENERATOR

s.no	*Particulars*	*Subhead*
1	Rise time (seconds)	44.5
2	Settling time(seconds)	156
3	Overshoot (%)	9.07
4	peak	1.09
5	Gain margin(rad/s)	114/30
6	Phase margin (rad/s)	60.6/0.02 967

The total system transfer function control analysis observed in mat lab that results discussion and practical systems results discussion given below The magnitude plot of bode plot shows clearly in single generator system from fig.3 the magnitude from the plot is 44.1, and from fig.4 the magnitude n the multi generator system is 50.4, hence from this we can analyze that there is an boost of magnitude quantity. The root locus provides us the stability analysis from fig.5 in single

TABLE II PROTOTYPE RESULTS & ANALYSIS

generator system the poles are away from origin and situated at 0 & 0.2 and the system remains in stable state, from fig.7 in

S.NO	R (Mts)	V (Mts/sec)	P_m (Practical) (watts)	P_e (watts) (MGS)	P_e (watts) (SGS)	%n (SGS)	%n (MGS)
1	0.5	1.83	1.774	1.25	0.78	43.96	70.45
2	0.5	2.35	3.773	2.65	1.69	44.79	70.21
3	0.5	2.87	6.883	4.89	3.56	51.72	71.036
4	0.5	3.40	11.371	5.12	4.21	37.02	45.045
5	0.5	3.92	17.474	6.84	4.98	28.49	39.142
6	0.5	4.45	25.425	8	6.53	26.73	31.464

multi generator system the poles shifted towards the origin and were located at 0 & 0.05 but the system remains still in stable state. Hence addition of one more generator drives the system into unstable state. Hence dual gear box and dual generators were employed in this system. Due to its inherent characteristics the system will not facilitates to add more generators as if added the system will be unstable.

As from the table.2, when wind speed is 1.83m/s the system efficiency corresponding to MGS has significant enhancement when compared with SGS, from the stability analysis techniques the MGS is proved to be in stable state. In SGS the stability of the system is high but the power output is satisfactory, but by the implementation of MGS even though there is a gradual decline in stability, but the system is still in stable state with enhanced power output .similarly the system impulse and step response stable at particular point shown in fig.6 and fig.7.MGS system rise time, overshoot. Peek, and phase margin specifications given in table 1.

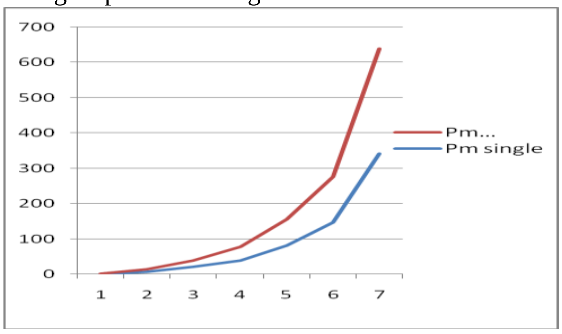

Fig : Power generation characteristics

V. CONCLUSION

In this paper we have designed a highly resourceful and low cost wind energy systems based on a special technique i.e., multi gear box & multi generator system (MGMGS), Which consists of two gear boxes and two generators which were placed on the low speed shaft. Hence both are connected electrically parallel which aids current and hence enhancement in the overall power generated by the system. More over parallel operation of generators enhances reliability of the system. The proposed work had tested under different operating conditions successfully. Considering the results from both practical as well as from simulations the system performance is enhanced by maintaining the system in a stable state.

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APPENDIX

Turbine Type	3 Bladed (HAWT)
Turbine Material	Foam Sheet Plastic
Area Of Swept	0.78539m^2
Radius Of Turbine	0.5m
Generator Type	PMDC, Radial Magnetic Field
Voltage Rating	12V
Current Rating	1A
Rated Speed	1500RPM
Maximum Electrical Power	12W
Hub Diameter	0.096m
Tower Length	1.5m
Pitch Control	Enabled
Yaw Control	Enabled
Cut-in wind speed	3m/s
Rated wind speed	8m/s
Cut-out wind speed	20m/s
System Nominal Power (MGMG)	24W