METHODS OF ATTENUATING WIND TURBINE AC GENERATOR OUTPUT VARIATIONS

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ABSTRACT

Wind speed variation, tower blockage and structural and inertial factors produce unsteady torque in wind turbines. Methods for modifying the turbine torque so that steady torque is delivered to the coupled AC generator are discussed. The method that may evolve will be influenced by the power use that develops and the trade-offs of cost, weight and complexity.

INTRODUCTION

The production of AC power at substantially constant level by a wind turbine driven synchronous generator has not yet been achieved. Improvements in blade angle response and torsional damping appear to be steps that will lead to significantly reduced power distortion from wind velocity variation; but the as yet unexplained and probably characteristic persistance of the 2P tower shadow effect observed on Mod 0 may be more difficult to attenuate. A number of methods of attenuating the tower shadow effect have been tried or have been proposed. A review and discussion of a number of these methods will be given herein. The methods included are listed in Table I.

WIND DISTURBANCE

Direct wind disturbance was analyzed in reference 1, where a damped compliant shaft was found to be effective for attenuating gust disturbances. The effect of a finite capacity network was not evaluated and the shadow effect was not considered.

Some experience with the feed-forward concept has been obtained on Mod 0, where it has been found to be partially effective. The Mod 0 system could very likely be improved by faster pitch operation and wind velocity signal averaging.

TOWER SHADOW/STRUCTURAL DISTURBANCE

The compliant shaft with a combination of mechanical and generator induced damping as the means of attenuating the 2P tower shadow effect is being planned for Mod 1 and Mod 2. There is an uncertainty about the effectiveness of this approach because Mod 0 data show a considerably greater 2P disturbance than is predicted by the present spring-mass models. The feasibility of obtaining adequate damping through generator damping windings and exciter manipulation remains to be demonstrated, and much the same can be said for a satisfactory mechanical-torsional damper.

The slip coupling was used on the Smith-Putnam wind turbine, but definitive data is not available. Operation on Mod 0 has shown that a two percent slip furnishes sufficient damping to completely suppress the first generator-torsion resonant peak. However, the coupling does not suppress the power dip at 2P because the coupling is neither an energy storage or active device. Power loss in steady state is an added disadvantage of the slip coupling.

Two torsion dampers that do not cause a power loss in steady state are shown in Figure 1. The elastomeric shaft is made up of coaxial, tubular segments that are bonded together by an elastomeric compound. A model has been built and is awaiting test on Mod 0. Bench tests of this model show very high compliance and substantial damping.

The second configuration shown in Figure 1 is currently in use on engine mounted aircraft generators. The compliance is provided by the spring steel quill, and the clutch type flanges provide the damping.

If a wind turbine generator that produces substantial power variation is coupled to a large power facility, it looks to the line as a noisy consuming device, but the line impedance may be so low that the effect is not seen. However, oscillatory stresses on the wind turbine structure, which are principally the result of line synchronization, are not attenuated.

A small parallel generator can provide an effectively low parallel impedance, provided the governing of the prime mover is sufficiently responsive. This result was reported in reference 2.

Direct mechanical power insertion or extraction can be accomplished through the planetary differential. A system of this type has been in use on aircraft gas turbine driven generators for over a decade. A schematic drawing of this gearing is shown in Figure 2. In this configuration, the wind turbine drives the planet carrier, the ring gear drives the generator and the sun gear is held or driven by the auxiliary motor. At design conditions the motor speed is zero, and the motor runs in either direction, the direction depending on the existence of either a power excess or deficiency. The power capacity of the motor can therefore be set at the maximum expected wind turbine power variation or about 20 percent of the generator power.

On the aircraft system the motor is hydraulic and is supplied by a variable displacement, engine driven pump. The engine also drives the planet carrier. The motor compensates for a steady state speed variation of approximately $\pm$ 25 percent. In the wind turbine case there is no steady state power requirement. For this reason and because efficiency is less important, the motor could be supplied by a servovalve instead of a variable displacement pump. The aircraft system parallels AC generators through a phase-lock loop. Phase lock could be applied to the wind turbine mechanical power insertion system.

The planetary transmission can also be used to provide a very low compliance and damped shaft. For this function, the sun gear is held from rotating by a lever arm that is restrained by a spring and a dashpot, or by a torsion spring and a rotary dashpot. The spring and dashpot do not rotate and therefore a very wide range of spring constants and damping coefficients can be incorporated.

The system employed on aircraft utilizes the planetary because it provides a system of considerably higher efficiency than a full hydraulic drive system. Efficiency is not as important in the wind turbine case, and therefore a full hydraulic drive can be considered. A full hydrostatic drive system was reviewed by a proposer on Mod 2. It was not proposed mainly because the variable displacement pump of sufficient size was not in production, but its development was considered to be technically feasible.

The power level presently being considered for low cost, fixed pitch wind turbines is well within the range of available hydraulic pumps and motors. A hydrostatic drive comprising a turbine driven variable displacement pump operating in a constant pressure control mode and driving a fixed displacement generator drive motor has many important technical capabilities for this application. AC power of very constant level could be produced even in the presence of the large torque variations that will accompany fixed pitch, synchronous operation.

There is a multiplicity of possible pump, motor and gear configuration, and therefore the optimum cost, weight, complexity and performance trade-offs will require a detailed study.

Complete decoupling of the power line from the wind turbine can be accomplished through the use of a D.C. generator and a D.C. to AC converter. The conversion could be accomplished through a motor-generator set or through a solid state device. The wind turbine has certain desirable characteristics with this system, but motor-generator set is costly, and the solid state converter is susceptable to noise generation.

CONCLUSIONS

It is currently feasible to consider direct hydrostatic drives, connected to the turbine through a gear box, for power levels up to 200 kw, and hydrostatic-planetary drives up to 1000 kw. AC power of high quality could be produced by wind turbines through the development of these systems. The broad use of wind turbine AC power may depend on the quality of the power. The configuration of direct or augmented drive that evolves will be shaped by the power use that develops and the trade-offs of cost, weight and complexity.

REFERENCES

1. Johnson, Craig C.; and Smith, Richard T.: Dynamics of Wind Generators on Electric Utility Networks. IEEE Trans on Aerospace and Electronic Systems, VOL AES-12 No. 4, July 1976.

2. Hannett, L. N.; and Undrill, J. M.: Wind Turbine-Generator Power and Speed Control. Progress Report No. 2, Power Technologies, Inc. Report No. R-36-77, July 1977.

DISCUSSION

Q. Why the need for damping when in the compliant drive system the effect is to decouple the oscillating rotor loads from the generator, particularly at power conditions below rated?

A. Damping in the compliant shaft attenuates ringing during gusts and provides a stabilizing factor under closed loop power control through pitch variation. The correct amount of damping in the compliant shaft will moderate power oscillation at all power levels.

Q. Would not a tuned passive restraint of the planetary sun gear system be satisfactory?

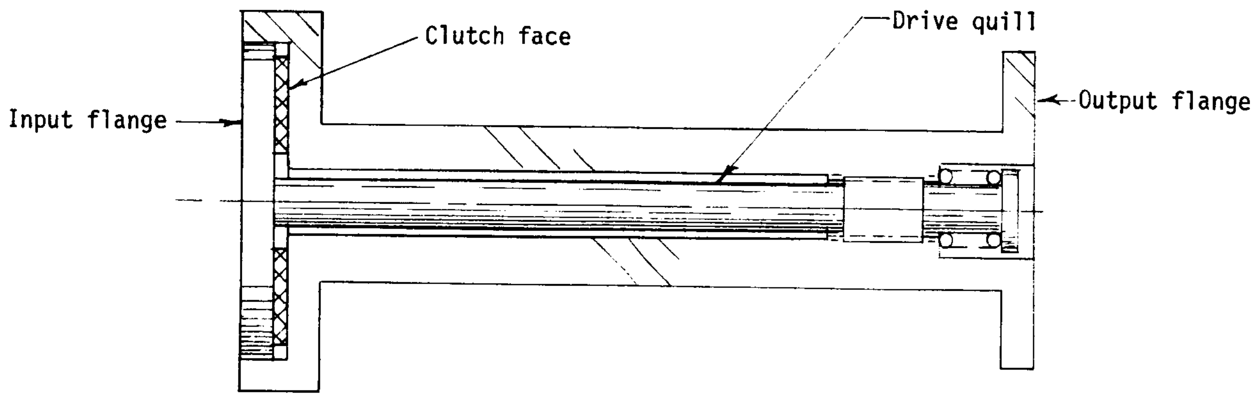
A. The practicality of a tuned passive restraint should be experimentally evaluated. It can be expected to smooth out the 2 P power oscillation; however, the benefits under rapid changing wind speeds would be much less than that of an active restraint.

Q. Is the approximately 10% power loss associated with a direct hydraulic drive an acceptable price to pay for "clean" power?

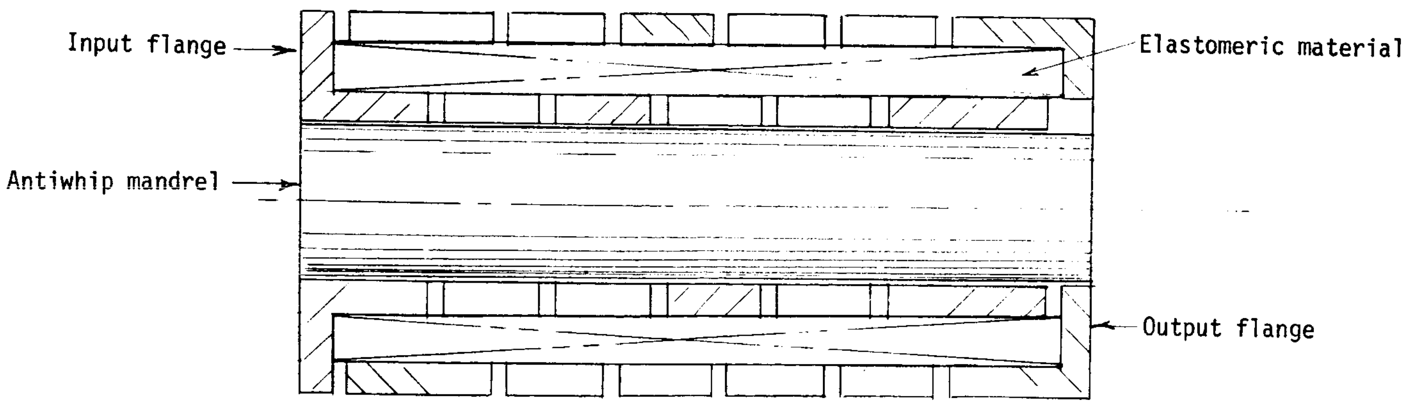
A. In combination with a planetary drive, the maximum hydrostatic transmission load will be less than 20% of the generator power, and the average load will be approximately 5%, giving a power loss of approximately 1/2%.

TABLE I. - ATTENUATION METHODS

I	Wind Disturbance	
	Damped compliant shaft	
	Wind feed forward	
II	Tower shadow/structural disturbance	
	Compliant shaft +	Mechanical damping
		Generator damping
	Slip coupling	
	Auxiliary power insertion	Low impedance line
		Constant speed - parallel generator
		Differential gearing
	Hydraulic power generation + AC drive	
	D C generation + AC conversion	Rotary
		Solid state



Aircraft-generator-type torsion damper



Elastomeric shaft

Figure 1. - Dynamic torsion dampers.

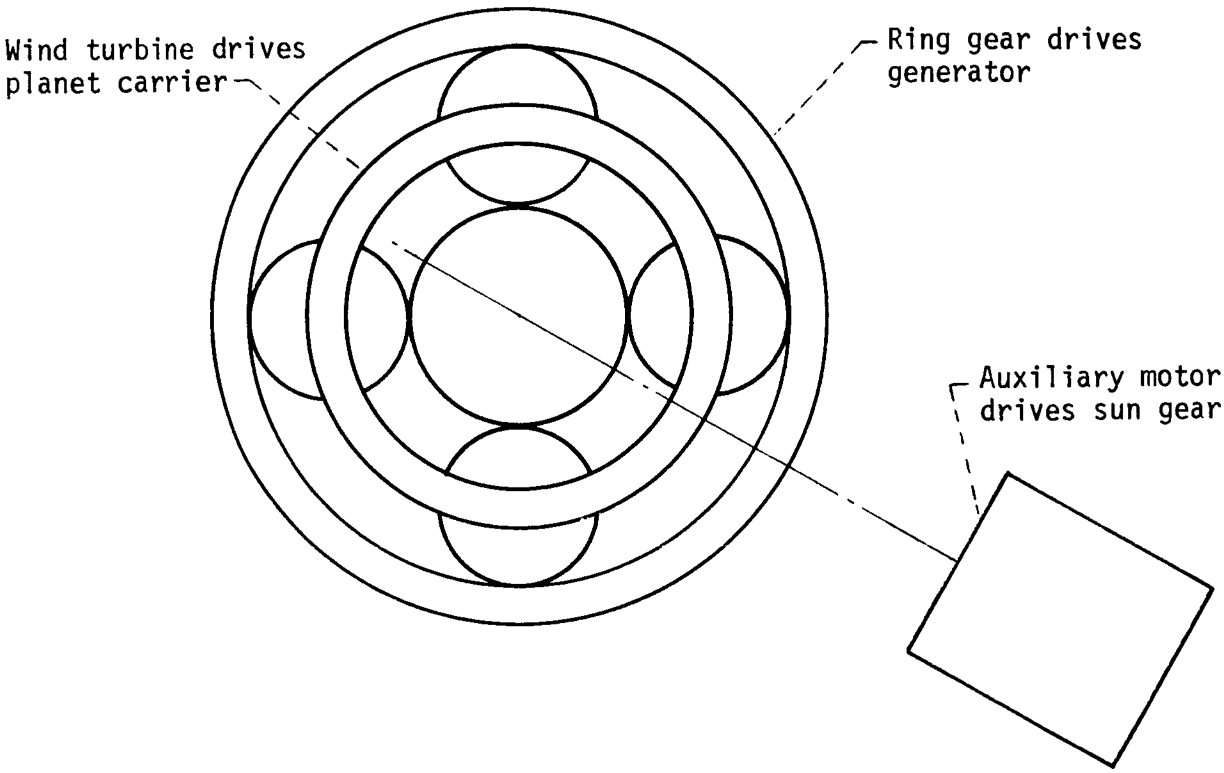


Figure 2. - Power insertion through planetary differential gearing.