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SPEED REGULATION OF PRIME MOVERS AND PARALLEL OPERATION OF ALTERNATORS.

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Regarding the effect of speed regulation of prime movers on the parallel operation of alternators therefrom, three features have to be considered.

1. The permanent variation of speed, due to a change of load.
2. The temporary change of speed, due to a sudden change of load.
3. The periodic change of speed during each revolution.

1. With a change of load on the alternator, the power supplied to the prime mover must be changed correspondingly. This is done by a regulating mechanism, which is is based either on the speed (speed governor) or the acceleration (inertia governor). The speed of the prime mover is a function of the load, usually decreasing more or less with the increase of load. Since, however, alternators in parallel operation, and thus the prime movers driving them, must run in synchronism with each other, it follows that the division of load between alternators driven by independent prime movers depends on the division of power between the prime movers at (electrical) inequality of speed, but not upon the characteristics of the alternator, thus it cannot be changed by a change of excitation of the alternator, etc.; but only by reacting upon the governor (or by a change of belt tension with alternators belted to the same shaft). Therefore for parallel operation of alternators a certain drop in speed with increase of load is necessary, and with a governing mechanism maintaining absolutely constant speed at all loads, the division of load becomes indefinite and parallel operation ceases to be feasible.

If the drop of speed with increase of load is not uniform, but the speed almost constant for moderate load, alternators may operate satisfactorily in parallel at load, but see-saw at light load.

2. With a sudden change of load, since time is required for the governor to act and for the flow of power to the prime mover to change to the condition corresponding to the changed load, a temporary change of speed occurs, larger than corresponds to the change of load, and to reduce this variation of speed, storage of energy by the momentum of the fly-wheel is necessary. With the steam engine the momentum of the steam, as expansive fluid, is usually negligible in its effect, and the temporary effect of speed depends mainly upon the rapidity of the action of the governor. With water power, frequently the momentum of the moving mass of water predominates as a cause of the speed fluctuation with sudden change of load, and the speed fluctuation thus depends upon the momentum of the total moving mass of water. Stand pipes, relief valves, and deflecting nozzles represent means to reduce or eliminate the effect of the momentum of the moving water column upon the regulation of speed at sudden change of load.

3. Most rotary prime movers, as water-wheel, steam turbine, etc., give a uniform supply of power, and thus uniform speed during the revolution. Others, however, as reciprocating prime movers, steam and gas engines, supply the energy by a number of impulses, and the torque, and therefore speed of the prime mover thus periodically varies during the revolution. The resultant torque of these prime movers consists of the pulsating torque of the energy supply (indicator diagram), the alternating torque of acceleration and retardation of the reciprocating masses, the alternating torque due to the finite length of the connecting rod, with vertical engines, the alternating torque of gravity in the ascent and descent of the reciprocating masses, and in gas engines also the pulsating negative torque of the compressor. The speed variation resulting herefrom can be reduced by such a design of the prime mover, that the different components of torque superimpose upon each other to a more nearly uniform torque, or by the use of a heavy fly-wheel. The most objectionable result of this periodic variation of speed is, however, the hunting of alternators and synchronous apparatus (as motors and converters), and this tendency to hunting seems to be aggravated by the use of heavy fly-wheels on the prime mover.

Electrical motors as a rule are not considered as prime movers, although no reason appears for making a distinction between the supply of power through a hydraulic pipe-line or through an electric transmission line. With electric motors the rate of rotation is uniform and the periodic variation of speed thus absent, and due to the practical absence of a time lag, the temporary variation of speed at a sudden change of load absent also, constancy of the supply voltage assumed. With continuous current shunt motors a cumulative series field may be necessary for parallel operations of alternators to secure the necessary drop of speed with increase of load. With induction motors, while the drop of speed under load may be considerably less than required for good parallel operation of engine-driven alternators, the speed variation with the load is so uniform that no difficulties are met.

In parallel operation of alternators driven by synchronous motors due to the absolute constancy of speed under load, an entirely different set of phenomena occurs, similar in some respects to the parallel operation of rigidly connected alternators, but differing therefrom, due to the flexibility of the synchronous motors in their relative phases, but rigidity in frequency.

Difficulties with parallel operation of alternators driven from separate prime movers may be due to:

1. *Lack of synchronizing power*, due to excessive armature reaction. This is practically unknown with modern alternators, in which the synchronizing power is always far in excess of the requirements of keeping them in step.

2. *Surging or hunting* between the alternators. Regarding this, forced surging and cumulative or resonating surging may be distinguished. With prime movors giving a periodic variation of speed during the revolution, periodically varying cross currents flow between the alternators and between alternators and synchronous motors, in extreme cases even between alternator and induction motor, of an amplitude depending upon the amplitude of the speed variation. Under certain conditions this surging becomes cumulative, gradually increasing in amplitude so that the machines may break out of synchronism. The cause of this cumulative effect may be found in the electrical circuit in certain relations between the momentum of the moving mass and the electric constants of the circuit, or it can be found in the mechanical construction of the prime movers, fore-

most their governors. When due to the former cause it can occur also with turbine-driven prime movers and synchronous motors ; while the mechanical hunting of the governing device which is the more frequent and serious phenomenon, is most frequently found in direct-connected, engine-driven plants.

The cumulative hunting is overcome by eliminating its cause; that is, breaking the resonance condition of the electric circuit by interference, or by changing its constants and damping the governor so as to stop its ability to hunt, or by reducing the amplitude of the hunting by a damping device in the electric circuit, usually in the field of alternators or other synchronous apparatus.