Speed-Matching During Synchronization
Steam Turbine Application

1.0 Abstract

This Application Note will discuss two methods of issuing pulses to governor systems that are designed to accept them. The method using proportional control to change the speed of the turbine shall be examined and the benefits of *proportional pulse width* control will be explained.

2.0 Issues

Steam turbines, although usually stable, can be difficult to synchronize. The problem has two roots. Each will be explored individually.

2.1 High Inertia of the Turbine

Steam turbines typically operate at high RPM's (≥ 1,800 RPM). This, coupled with large diameters, produces a high inertial constant that exhibits control lag.

2.2 Lag of the Governor Input to Corrective Control

When a corrective pulse is given to the governor system, steam valves must close via an actuation device. This action is not instantaneous, therefore it constitutes a lag.

3.0 Pulsing Methods

Two types of pulsing methods that exercise proportionality in control are commonly used. Proportionality is exercised as a function of mismatch to the acceptable bandwidth of frequency about the running bus to which the generator is synchronizing. Gain of the control pulses can be defined as Y = KX, where K is the on/off time of the pulse train.

3.1 Pulse Frequency Modulation

Pulse Frequency Modulation attempts to exercise proportionality by varying the <u>rate</u> that a fixed time pulse is generated in direct proportion to mismatch, as shown on the idealized graph in Figure 1.

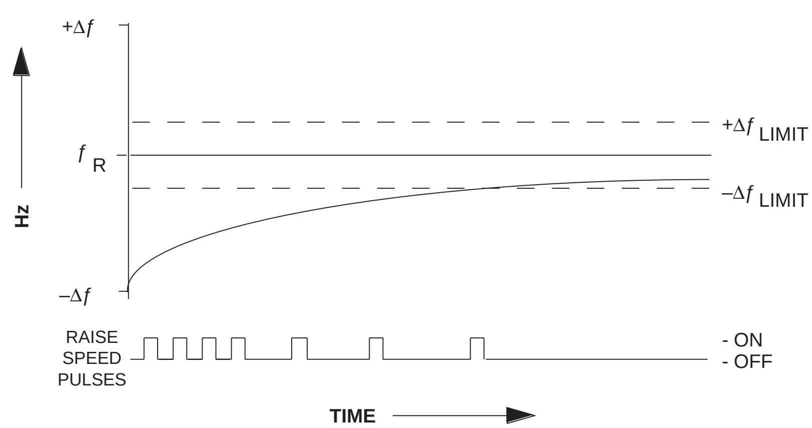

Figure 1 IDEALIZED CONTROL ACTION

3.2 Proportional Pulse Width Modulation

Proportional Pulse Width Modulation exercises proportionality by varying the on time of a corrective pulse in direct proportion to mismatch, while maintaining a fixed off time as shown graphically in Figure 2.

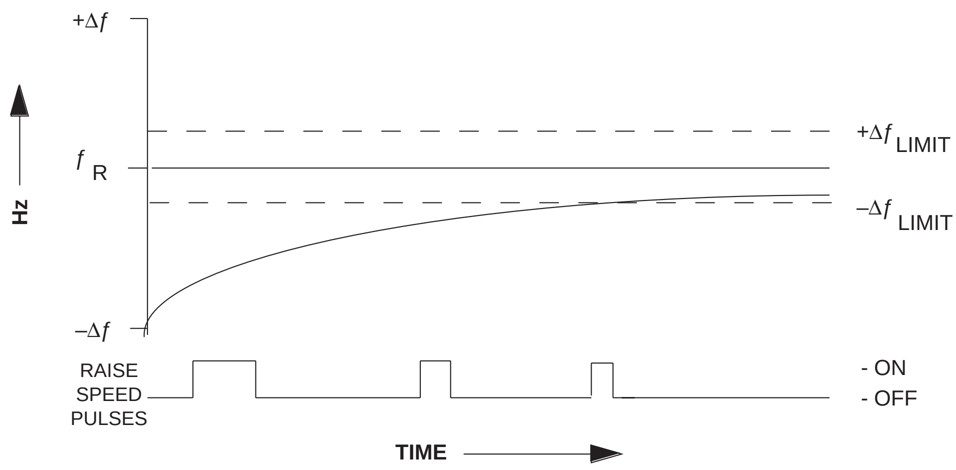

Figure 2 IDEALIZED CONTROL ACTION

4.0 Steam Turbine Reactions to Pulsing Methods

4.1 Pulse Frequency Modulation

In real world situations, where turbines have inertia and governors exhibit lag, the frequency response of turbines reacting to pulse frequency modulation often appears as shown graphically in Figure 3.

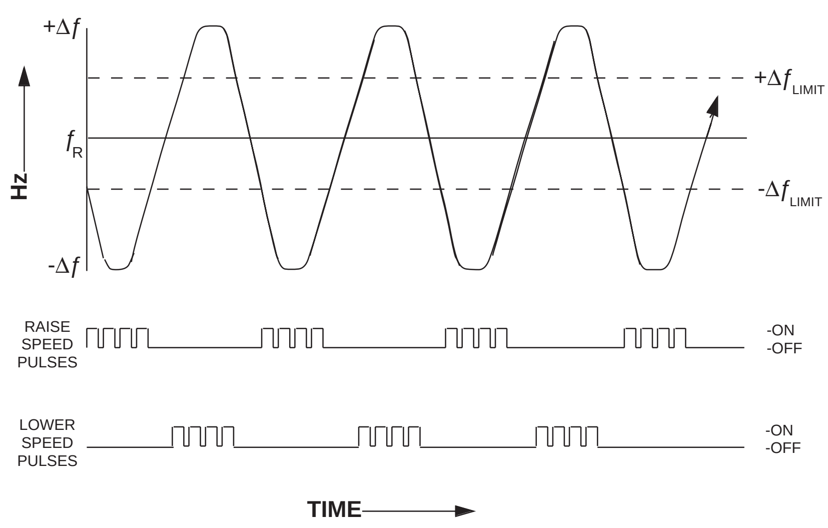

Figure 3 ACTUAL CONTROL ACTION

This situation shown in Figure 3 would be labeled as “Hunting.” The reason hunting exists is that frequency pulse modulation does not adequately address the inertia/lag issue. The pulse train is too condensed when the frequency is outside of the desired slip bandwidth. Possible methods of dealing with this overshoot/hunting is to detune the loop (decrease pulse frequency) or increase the maximum slip frequency acceptance limit.

4.2 Proportional Pulse Width Modulation

Proportional Pulse Width Modulation takes into account inertia and governor lag by providing a pulse off time to match those characteristics for the particular governor / turbine generator set. This is shown graphically in Figure 4.

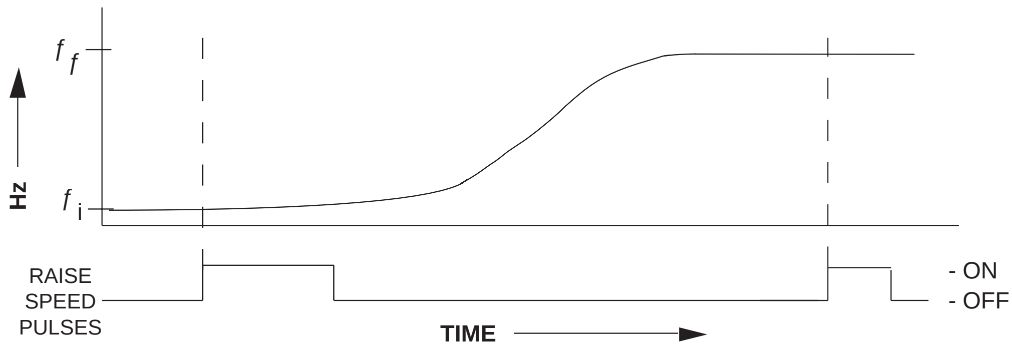

Figure 4 ACTUAL CONTROL ACTION

It should be noted that the increase in turbine speed is gradual, that it begins after the pulse is issued, and the speed change continues for some finite time after the pulse ceases.

The amount of frequency change (f_i to f_f) will be altered due to the pulse time, or width. The reaction time will be the same, only being corrupted by ratio of on time that dynamically varies to the fixed off time.

A typical turbine response is shown graphically in Figure 5.

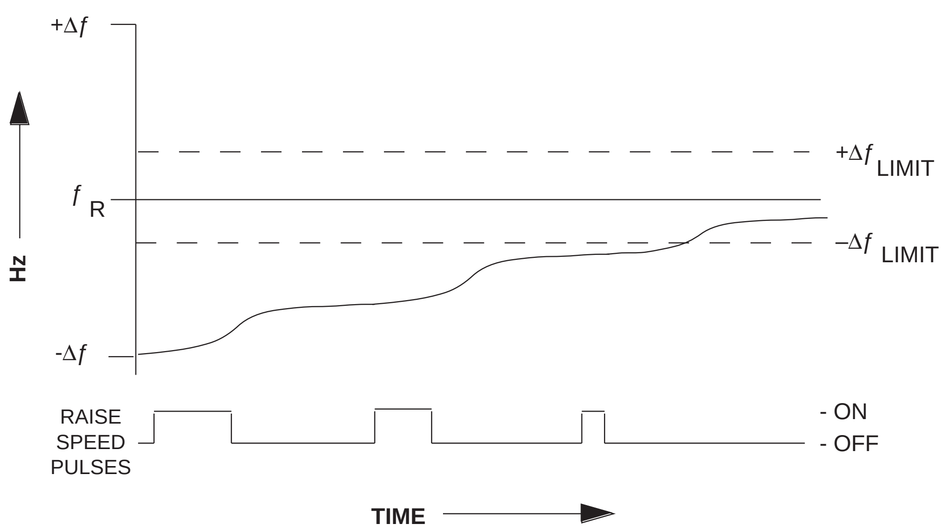

Figure 5 ACTUAL CONTROL ACTION

Notice that the amount of change in frequency decreases as the frequency approaches the bandwidth.

5.0 Conclusions

5.1 Advantages of *Proportional Pulse Width* Modulation Over Pulse Frequency Modulation

1. Compensation for inertia and lag.

2. Higher gain while minimizing or eliminating hunting and overshoot.

3. Tighter slip frequency constraints are possible due to the control gain decreasing as tighter slip bandwidths are approached.

5.2 Benefits to the User

1. Faster synchronization times.

2. Preservation of capital equipment.

3. Confidence in automation.

6.0 Appendix

6.1 Abbreviations

f_i	Initial frequency
f_f	Final frequency
f_R	Running Bus frequency
Δf	Slip frequency
Δf_{LIMIT}	Slip frequency limit on auto synchronizing relay
Hz	Hertz

6.2 Definitions

Slip Frequency - The difference, expressed in Hertz, of the generator compared to the running bus.

Hunting - Oscillating of the process variable about the setpoint. This can be due to too high a gain setting. For this discussion, generator frequency is the process variable and the running bus is the set point.

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