ELECTRONIC LOAD GOVERNOR - APPLICATION OF DERIVATIVE CONTROL ACTION FOR IMPROVING TRANSIENT RESPONSE

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ABSTRACT

The Electronic Load Governor is the accepted means of controlling the speed of micro hydroelectric turbines. A microprocessor based ELG has been developed and is presently undergoing site testing. This testing includes the comparison of alternative control strategies.

Previous work produced an algorithm based on proportional control. This paper describes the most recent work done in developing a model for derivative control action. The paper goes on to compare the results of the proportional and derivative control actions and to suggest how the latter may be implemented in the ELG.

INTRODUCTION

The use of Electronic Load Governors for speed control of micro hydroelectric generating sets is now Universal. The methods of achieving this control generally fall into two categories, phase delay or binary switching. Previous papers [1, 2] have described the development of a microprocessor based, 3-phase balancing, Electronic Load Governor (ELG) based on the latter method. A prototype of this ELG is currently completing site trials at Ashfield Mill [3] under the European Commission's THERMIE programme.

The algorithm used originally was recognised to have limitations in respect of its operation during severe load transients, and so investigation into a proportional control strategy was undertaken [4]. The current site trials of the ELG include comparative testing of both the original and the proportional control based algorithms. During the investigation work the potential for further improvement using derivative control action was noted, and this paper describes the outcome of recent studies into this control strategy.

SOFTWARE DEVELOPMENT

A simplified flowchart of the main load governing program is shown in Figure 1. Once the necessary auto-start and initialisation procedures are executed, the program enters a continuous loop and reads the first variable, as set during commissioning. This is the width of the frequency deadband, necessary due to the stepped nature of the ballast load.

The frequency measurement process is handled by an interrupt routine. On detection of a negative going change in polarity of the terminal voltage waveform, a counter is energised. On the repetition of this event (i.e. after one cycle of the ac. waveform), the counter is stopped and read, then the value stored in memory. This value equates to the *period* of the waveform over that cycle.

The main program compares the most recent reading of the period against values corresponding to the upper and lower limits of the deadband. If the frequency is within the deadband range then no action is taken. If the frequency is outwith the deadband then the ballast load is changed accordingly. An output line is then toggled on or off to enable monitoring of the operation of the ELG. The loop repeats itself indefinitely until the power supply to the unit is removed.

The strategy used to effect the change the load is the key subject of this paper, and the development of the proportional and derivative actions is now described.

BASIS OF DERIVATIVE ACTION

Previous work identified that the response of the set was, to a large extent, governed by the inertial constant associated with the rotating components. It was acknowledged that over or under applying “excess load” would cause the set to decelerate or accelerate more quickly to the required controlled speed. The controlled speed is set by the ballast, or “final load”. To prevent overshoot past the controlled speed it would be necessary to switch out, or in, additional load to the final level at the appropriate time. This time, referred to as the switch-out time, can be estimated from the relationship between the “final load” and the “excess load”.

Consider the transient response of a generating set with inertia τ to disturbances of magnitude A_{ss} p.u. and B_{ss} p.u. respectively.

$$A(t) = A_{ss}(1 - e^{-t/\tau}) \qquad p.u. \ldots\ldots\ldots\ldots(1)$$

and

$$B(t) = B_{ss}(1 - e^{-t/\tau}) \qquad p.u. \ldots\ldots\ldots\ldots(2)$$

From the characteristics of an exponential function, at $t=4.7\tau$, $A(t) \approx 0.99 A_{ss}$ and a corresponding value of B(t) can be calculated:

$$0.99 A_{ss} = B_{ss}(1 - e^{-t/\tau}) \qquad p.u. \ldots\ldots\ldots(3)$$

The time, t_O, at which this condition occurs is estimated from:

$$t_O = -\tau \times \ln\left(1 - \frac{A_{ss}}{B_{ss}}\right) \qquad \sec onds \ldots\ldots.(4)$$

Now if A_{ss} is the measured p.u. disturbance and B_{ss} is the available correcting load, t_O is the switch-out time referred to above. Further simplification can be made if it is assumed that the available correcting load is B_{ss}=1p.u.. The switch-out time can be estimated in terms of the generating set time constant, p.u. ballast load and p.u. measured disturbance as:

$$t_O = -\tau \times \ln(1 - A_{ss}) \qquad \sec onds \ldots\ldots\ldots(5)$$

PERFORMANCE PREDICTION

The effect of corrective action can be modelled using the principle of superposition. Figure 2 shows a disturbance of 0.5 p.u. with a corrective action of -0.5 p.u. switched in one cycle after the disturbance is detected and the resulting composite waveform, “prsigma”. This demonstrates the application of proportional control action.

A 0.5 p.u. disturbance corrected with derivative action was modelled using corrective action of -0.58 p.u. applied one cycle after the disturbance is detected. The excess load of 0.08 p.u. is removed at t_O seconds, calculated from equation (5), after the initial disturbance. Figure 3 shows the outcome of the composite waveform “dtsigma”, along with “prsigma” for comparison purposes. It can be seen that a significant improvement in settling time is achieved.

The corrective action magnitude does not correspond with the assumption that B_{ss}=1. For the case demonstrated B_{ss}=0.58, equivalent to a gain of around 1.2. This value was found to give a near optimal response, i.e. with no overshoot and shortest return time, across a range of disturbance magnitudes. Switch-out time was always calculated from equation (5). No improvement in the transient response with respect to magnitude is noted - this parameter is dominated by the inertia of the rotating equipment.

To implement this scheme in the ELG will require a straight line approximation of equation (5) as there is no resident mathematics function library. A polynomial representation could present a significant computation overhead and require the development of a complex FORTH algorithm.

CONCLUSIONS

The site testing of the ELG Unit has indicated that there is a requirement to improve on the response of the ELG in the event of transient consumer load conditions. The proportional control based algorithm has shown superior performance during these trials, and so any further benefits to be accrued by adopting a derivative control strategy are likely to result in similar performance improvements.

Work remains to be done to implement the derivative control algorithm in the FORTH software along with further investigation into the gain vs. Switch-out time combinations.

ACKNOWLEDGEMENTS

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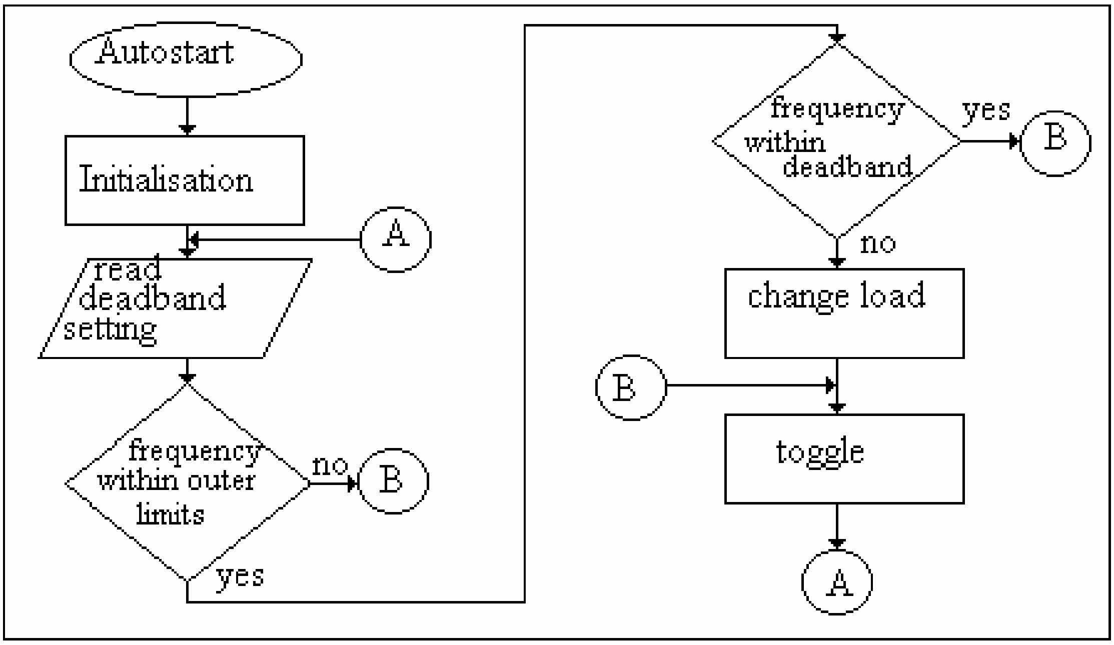

Figure 1. Flowchart of the Main Load Governing Program

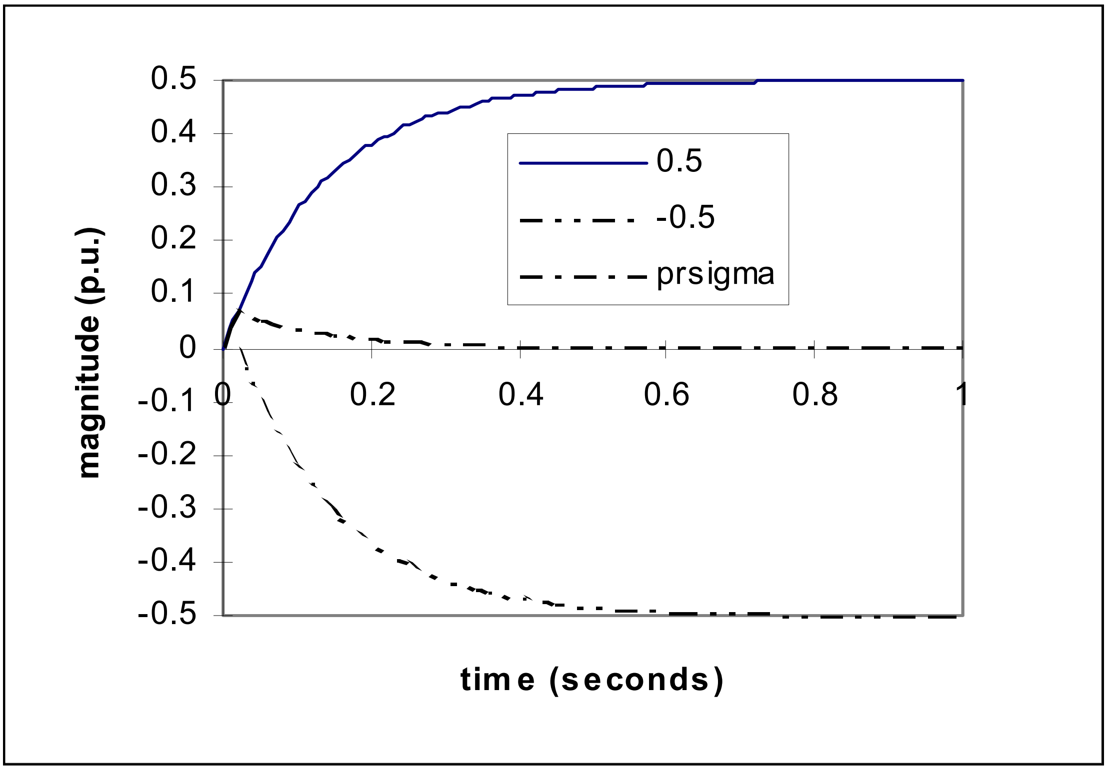

Figure 2. Superposition Model

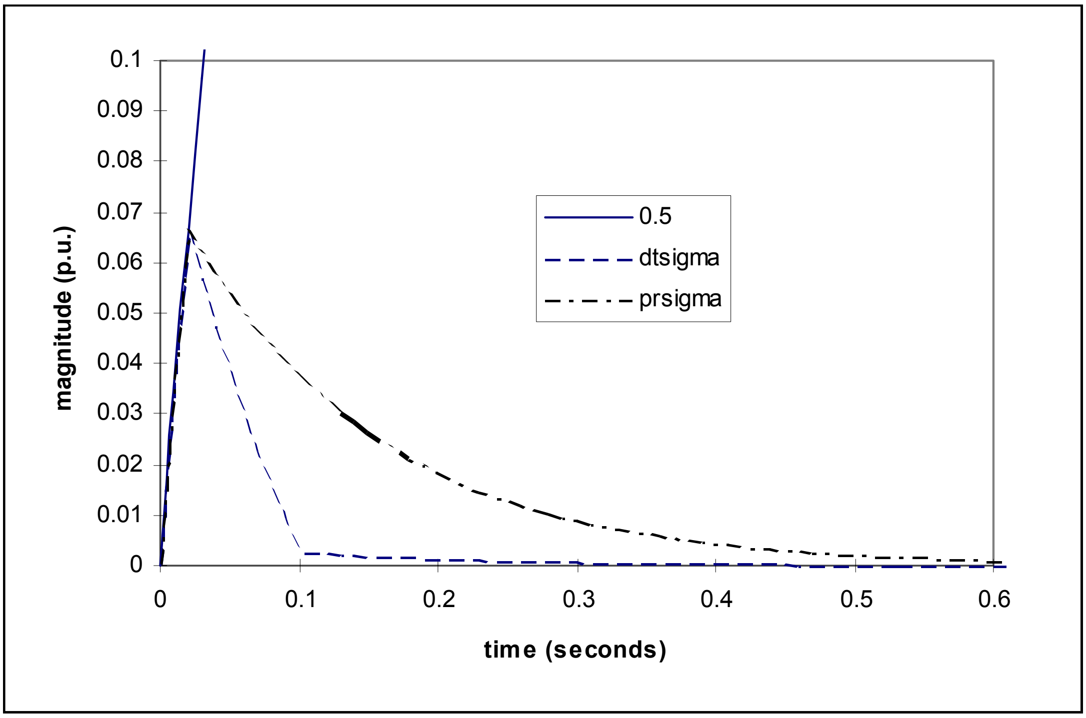

Figure 3. Comparison of Control Actions