AC Ward Leonard drive systems

Induction motors, particularly those of the squirrel-cage type, have been the principal workhorse for long time. However, until the beginning of 1970s, they had been operated in the constant-voltage-constant-frequency (CVCF) uncontrolled mode, which is still very common nowadays. VSDs were dominated by DC motors in the Ward Leonard arrangement. Ward Leonard Drive Systems, also known as Ward Leonard Control, were widely used DC motor speed control systems introduced by Harry Ward Leonard in 1891. A Ward Leonard drive system consists of a motor (prime mover) and a generator with shafts coupled together. The motor, which turns at a constant speed, may be AC or DC powered. The generator is a DC generator, with field windings and armature windings. The field windings are supplied with a variable DC source to produce a variable output voltage in the armature windings, which is usually used to power a second DC motor that drives the load.

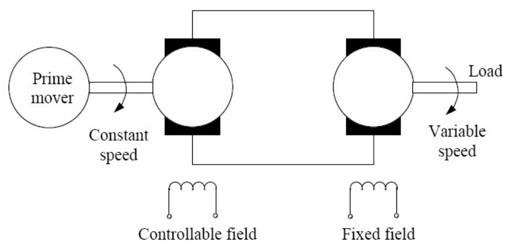


Figure: Conventional (DC) Ward Leonard drive systems

A natural analogy is to replace the DC generator with a synchronous generator and the DC motor with an AC machine (an induction motor or a synchronous motor). This configuration will be called AC Ward Leonard Drive Systems. Surprisingly, after extensive literature search, nothing relevant to this idea has been found. A possible reason is described below. The prime mover in a DC WLDS maintains a constant speed and the flux of the generator is variable; the prime mover in an AC WLDS needs to have a variable speed (so that the frequency of the output can be varied) and the flux of the generator is constant. The output of the generator (voltage) in a DC WLDS is varied via controlling the field voltage and the output of the generator (voltage and frequency) in a AC WLDS is varied via controlling the speed of the prime mover. If the speed of the prime mover could be varied, it could have been used to drive the load straightaway and hence there is no need to have an AC WLDS. In this paper, this idea has been explored. Instead of having a physical synchronous generator that is driven by a variable-speed prime mover, an inverter that captures the main dynamics of the physical system (the synchronous generator, the variable-speed prime-mover and its controller) is used. Ideally, if the motor has the same pole number as the generator and there was no loss, the torque of the generator would be the same as the torque of the motor. Hence, the torque of the motor could be controlled via controlling the torque entering the synchronous generator.

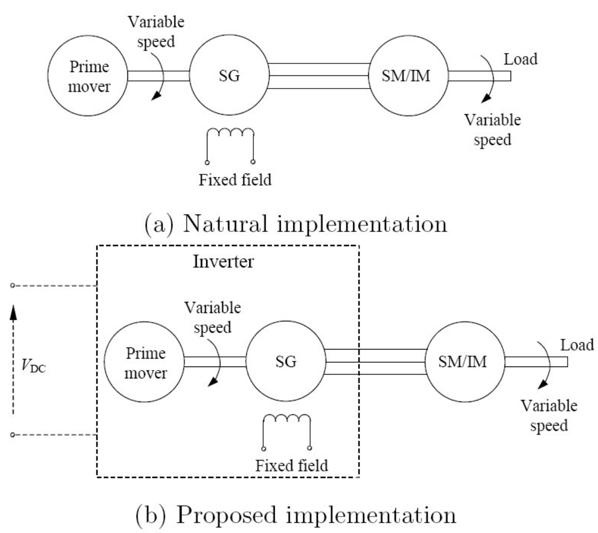


Figure: AC Ward Leonard drive systems

The idea of the proposed AC drive system is to power the AC motor with a synchronous generator, driven by a variable-speed prime mover that is implemented via an inverter. Hence, the focus of the control system is to control the generator instead of the motor. The mechanical torque T_m applied to the generator can be easily generated by a speed controller (governor), e.g. a PI controller, that compares the actual speed $\dot{\theta}_f$ with the reference speed $\dot{\theta}_r$. If the motor is synchronous, then the actual speed can be directly taken from the generator without a speed sensor as the motor runs at the synchronous speed $\dot{\theta}$. This will be discussed elsewhere. If the motor is inductive, then the actual speed (mechanical) can be measured from the motor and it should be converted to the electrical speed via multiplying it with the number of pole pairs p. Usually this involves a low-pass filter to reduce the measurement noise. Another aspect could be easily taken into account is the voltage drop on the stator winding of the motor, particularly, when the speed is low. It can be compensated via a feedforward path containing the stator winding resistance R_s from current i to the generated voltage e. Thus, the resulting complete controller consists of a synchronous generator model, a speed measurement unit, a speed controller and a current feedforward controller. In order to speed up the system response and to minimise the number of tuning parameters, it is advantageous to choose the inertia of the generator to be $J = 0$ (i.e., zero inertia). This also reduces the system order by one, which is very good for system stability.

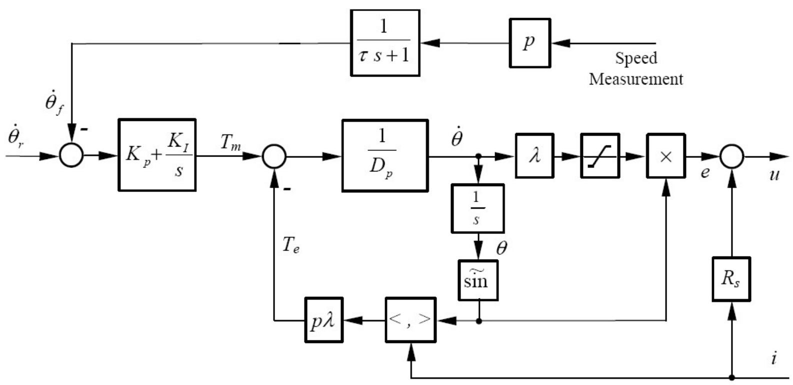


Figure: Control structure for AC WLDS with a speed sensor. $\dot{\theta}_r$, $\dot{\theta}_f$ and $\dot{\theta}$ are all electrical speed.

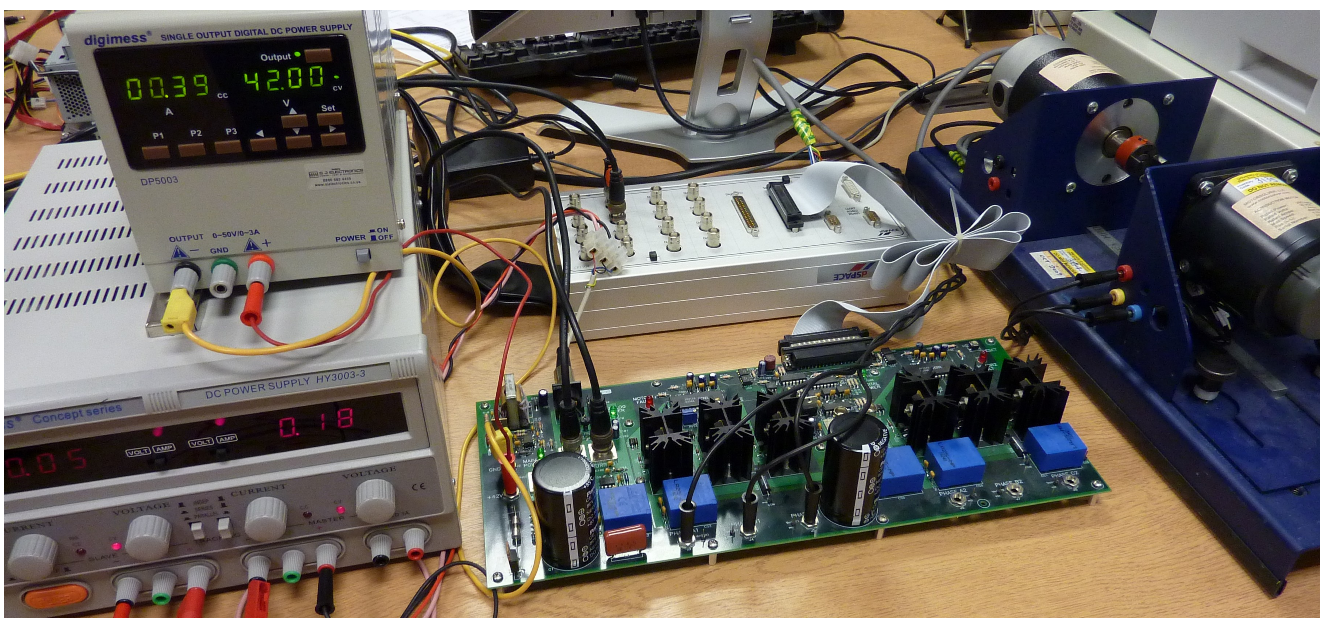
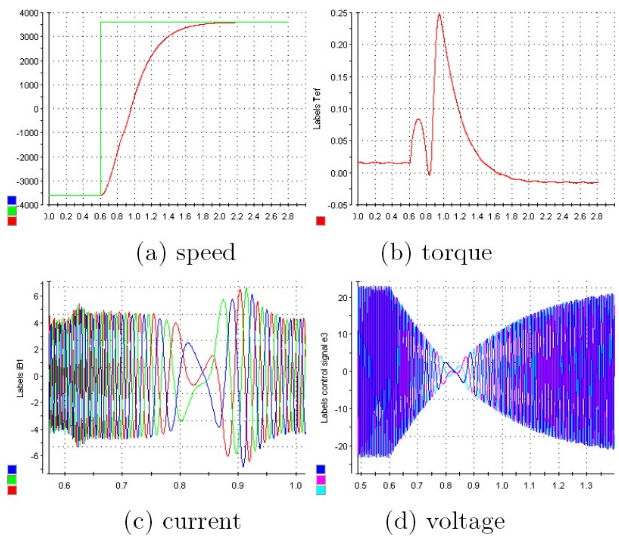


Figure: An experimental AC drive

The figures below show the reversal of speed from -3600 rpm to 3600 rpm at around $t = 0.6$ second. The motor quickly reversed and settled down in about 1.2 seconds. There was a very short period of over-current around 70%; the voltage dropped and then built up.

Figure: Reversal at high speeds without a load



When the speed sensor was not used for feedback (instead, $\dot{\theta}$ was used), the system became slightly slower, as can be seen from the responses shown in Figure [*] (due to the page limit, only the speed and the current are shown hereafter). This led to a smaller over-current, which is only about 30%. The static error in the speed was very small.

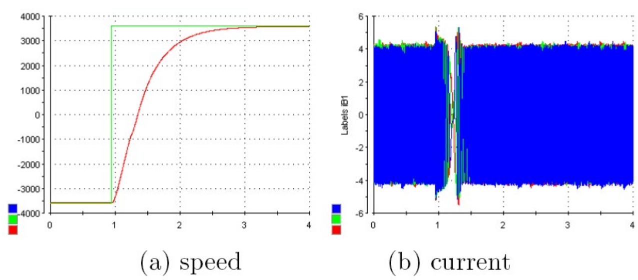


Figure: Reversal at high speeds without a load (no speed sensor)

The figures below show the responses when the reference speed was changed from -1800 rpm to 1800 rpm at around $t=1$ second when the motor was loaded. The motor quickly reversed from -1800 rpm to 1800 rpm in about 1.5 seconds, which is slightly longer than the case without a load. There was about 11% overshoot in the speed and the over current increased to about 150%.

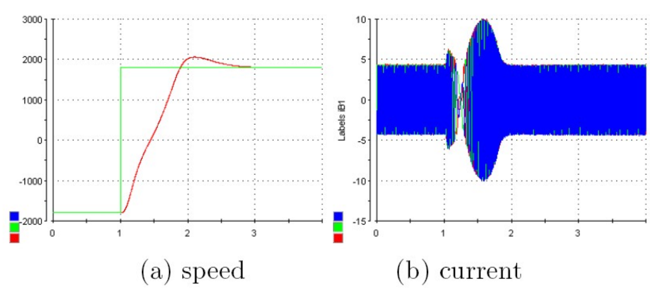
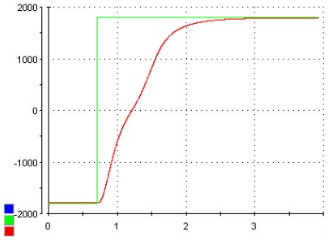


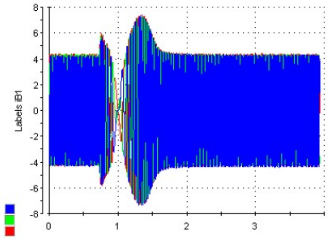
Figure: Reversal at high speeds with a load

When the speed sensor was not used for feedback (instead, $\dot{\theta}$ was used), the performance was better. The response speed was similar but the overshoot in the speed disappeared, which led to a much smaller over-current.

Figure: Reversal at high speeds with a load (no speed sensor)



(a) speed



(b) current

- About this document ...

---

n prev
Next: About this document ...
zhongqc 2010-02-20