Controlling the DC output voltage of a Mercury Arc Rectifier


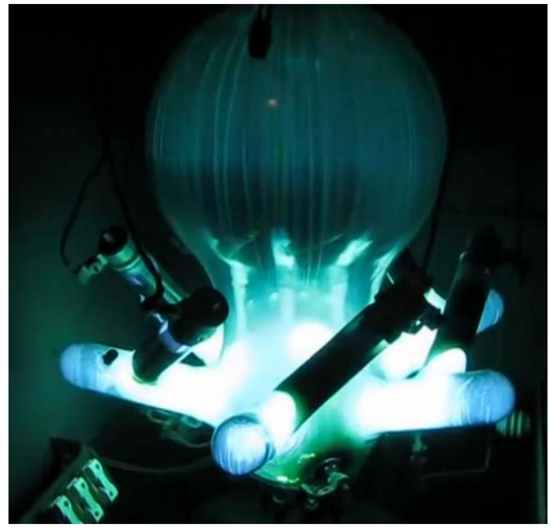

Figure 1: 3-anode and 6-anode Mercury Arc Rectifier

Controlling the DC output voltage of a Mercury Arc Rectifier (MAR) means varying the AC input voltage. Two of the standard methods for this are:

- Grid-controlled MAR, see pp. 175-200 in ref. 1, §6.4 in ref. 2. This requires that the MAR has a control-grid at each anode, and analog phase-shift circuitry to control the firing of the grids. The grid-control method varies the fraction of the time that the anodes are "on", out of each half cycle (180° phase) of the AC power, which varies the DC-output voltage. This is basically the same method a used in household dimmers for incandescent light bulbs. Control can be open-loop (manual) or closed-loop (automatic, based on the speed feedback-signal from a tachometer).The required phase-shift ("firing angle") between anode and control grid can be provided in two basic forms:
  - A grid voltage that is a fixed-amplitude AC voltage, that is delayed (= phase shifted) with phase shift with respect to the anode voltage. Due to the smooth sinusoidal shape of the control voltage, this method is not very precise. The phase shift can be varied , e.g., with a "induction regulator" rotary variable transformer.
  - A grid voltage that is a narrow pulse, the relative position (= phase) of which is varied.
- Free-firing MAR - the MAR has no control-grids, and the firing of the anodes is driven by the AC input voltage.
  - Transformer tappings. The standard way to adjust an AC-voltage for traction motor control has traditionally been to use an auto-transformer with tapped secondary windings (Tapped Auto-Transformer, TAT). The output voltage of the auto-transformer depends on the selected output tap. This basically provides a transformation ratio that can be changed in a number of discrete steps. Having selectable transformer output-taps means that we need a tap-selector. For the control of traction motors, the current should not be interrupted when changing taps. I.e., changing taps should be done with the motor-load connected (via the MAR). This is called "on load". Also, consecutive taps should not be short-circuited when changing taps, as this can damage the tap-selector and the transformer. The standard tap-selector that meets both requirements is a so-called On-Load Tap Changer (OLTC). See Figure 2. OLTCs date back to the 1920s and are still used today.
    - The auto-transformer provides "up" transformation of the input voltage, hence "down" transformation of the current. This reduces the size of the transformer, and makes it easier to add taps, as the secondary winding of the transformer has many turns. The selected output voltage of the auto-transformer is then reduced with a step-down transformer, to a level that is suitable for the DC-motor. Multiple load-sharing motors may be connected in parallel.
    - This has been a long-time standard in trains and streetcars/tramways, where the tap changes are often quite noticeable to the passengers. However, those applications are only powered by single-phase AC line voltage. When using 3-phase AC line voltage, the transformer and the OLTC switching elements have to be triplicated. A 3-phase transformer can be constructed either by

connecting three single-phase transformers, or by using one 3-phase transformer that consists of three pairs of single-phase windings mounted onto one single laminated core.

- "Sliding-contact variable transformer". This regulator is an extreme form of a TAT: the entire secondary winding of the transformer is exposed, and a sliding-contact can be moved along the length of that winding. This is equivalent to a tap at every secondary turn. This mechanism is similar to a rheostat variable wire-wound resistor. This approach is common when the motor is driving a heavy load, and it takes a long time to accelerate to nominal speed.

The diagram below shows a typical OLTC, for an arbitrarily chosen number of taps. There are two concentric contract rings (the blue and red circles in the diagram). Outside each contact ring is a ring of contact notches. The even-numbered transformer taps are connected to one set of notches (here the red ones), whereas the odd-numbered taps are connected to the other set of notches (the blue ones in the diagram). There are two tap selector arms. They are not interconnected electrically. One arm can be rotated to interconnect any blue notch to the blue contact ring. The other can interconnect any red notch to the red contact ring. The two contact rings are connected to two transition switches (*TS1* and *TS3*). A transition resistor bridges *TS3* to a third transition switch (*TS2*). The position of the selector arms and the diverter switches cannot be changed arbitrarily: the arms can never be more than one notch apart. They are actuated by a camshaft mechanism that can be controlled remotely (solenoids, air pressure).

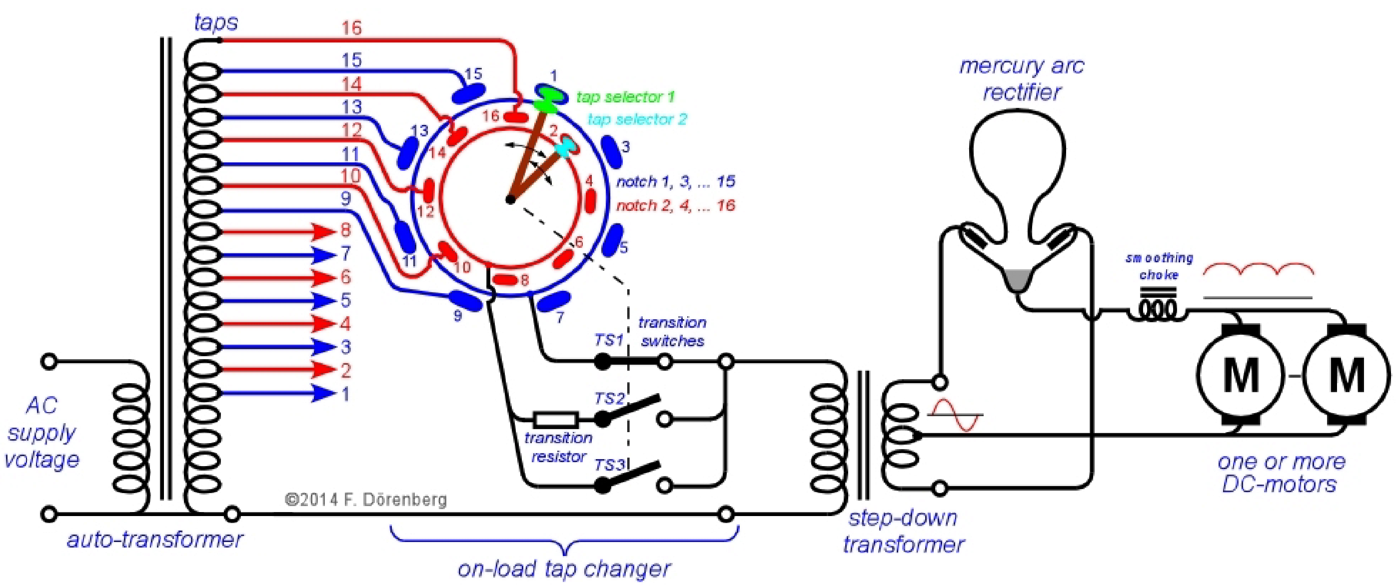

Figure 2: Principle of DC-motor speed control with an On-Load Tap Changer and full-wave Mercury Arc Rectifier
(shown for single-phase AC voltage; rectifier igniter control-circuitry not shown)

In the diagram above, switch *TS1* is closed, and blue notch number 1 is selected with the selector arm. Hence, transformer tap number 1 is selected. Red notch 2 is (pre-)selected on the red contact ring, but switch *TS3* is open (as is *TS2*). To select tap 2, first *TS2* is closed - the resistor limits the short-circuit current between tap 1 and tap 2. Then *TS1* is opened, to disconnect tap 1. This is followed by closing of *TS3*. Finally, *TS2* is opened. Now tap 2 is selected. The blue selector is moved to notch 3, to pre-select tap 3. A similar sequence of "make-before-break" selector arm movements and opening/closing of the three switches is used for all tap changes. It is not possible to skip a notch, e.g., to jump from notch 4 to notch 11.

Ref. 1: "Mercury Arc Rectifier Practice", F.C. Orchard, Pittsburg Instruments Publ. Co., 1936, 255 pp.

Ref. 2: "The characteristics and control of rectifier-motor variable speed drives" [mercury-arc rectifiers], P. Bingley, in "Proc. of the IEE Part II: Power Engineering", Vol. 99, Issue 69, June 1052, pp. 189-202 (Author's reply to discussion: pp. 205-206)