

J. R. Taylor*

Water depression changes generators to condensers

System in newer Ontario Hydro hydraulic stations
smooths change to synchronous condenser operation
for supplying or absorbing reactive power on lines

Water depression systems at several hydraulic generating stations constructed in recent years by Ontario Hydro allow the operation of the generators as synchronous condensers.

These stations, built primarily as peaking plants, will employ their generators as synchronous condensers when they are not needed for power generation. This use will have one or several of the following purposes:

- The stations, particularly those close to load cen-

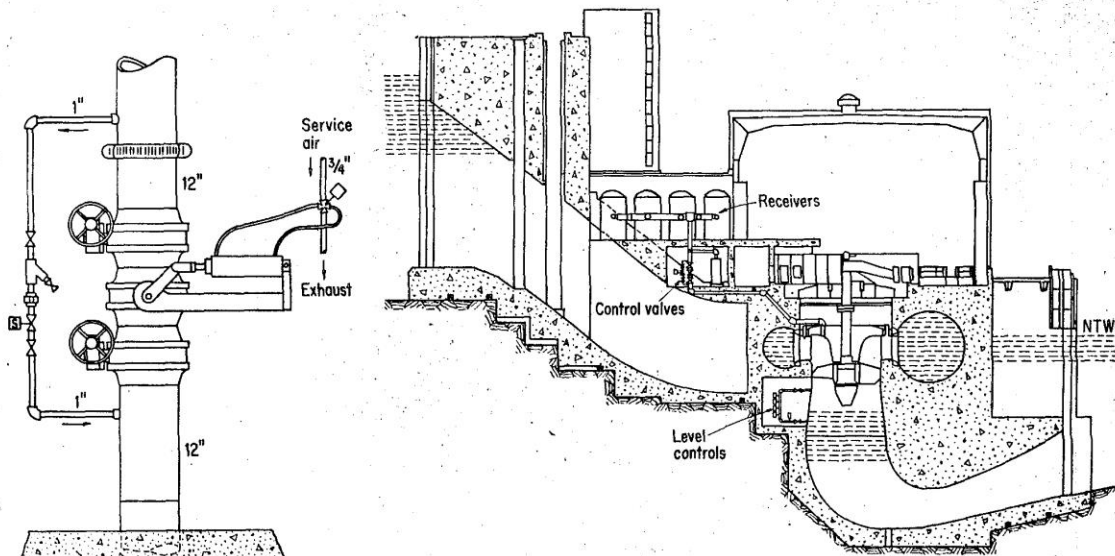
ters, will supply reactive power for supporting system voltage;

- They will absorb reactive power due to the charging effect of long transmission lines;

- They will provide spinning reactive-absorbing capability for safeguarding the system from over-voltages or self-excitation of generator following the opening of breakers at a line's remote end. This applies to generators connected to the system over a long single-circuit line.

Provision for operation of the units as synchronous condensers can be made at low cost when the work

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Valve controls air admitted to the plant's water depression system

Schematic shows the basic arrangement of the draft tube in the water depression system for smoothing changeover of generator to condensing

is done during construction of the plant. The alternative would be installation of a combination of shunt reactors and static capacitors.

Although the relative economics of the alternatives must be calculated for each site, use of the generating units as synchronous condensers is usually economic when reactive capacity is required in a significant amount.

Setting the turbine runners below tailwater level, particularly at low-head stations, is required for minimizing cavitation when the stations are running as conventional hydro units. If the runners remain immersed in water when the generator operates as a synchronous condenser, the power needed from the system would be too high for economic operation. Damage to the units is also likely due to vibrations induced by the runner.

But a water depression system lowers the water level in the draft tube to free the turbine of all load other than windage and friction. A turbine water depression system compresses, stores, and controls a supply of air for displacing the water surrounding the turbine runner. It leaves the runner free to rotate in a pocket of air.

Ontario Hydro first investigated water depression systems in 1943, although the first of them was installed only in 1956 in Manitou Generating Station on the English River. Subsequently they were installed at Whitedog Falls, Silver Falls, Red Rock Falls, Otter Rapids, Little Long and Harmon, all unattended and operated by remote control.

Ontario Hydro uses one of two available methods for changing a generator to operate as a synchronous condenser. The method involves backing off on the load on the generator until the turbine wicket gates are at the no-load synchronous-speed position. The air valves are then opened and, after a short delay, the wicket gates close automatically.

This method, properly applied, gives a fairly smooth transition from generation to condensing. It requires, however, a rapid admission of air to minimize power surges.

The alternative method delays admission of air until wicket gates are fully closed and draws heavy power from the system while fixed-blade wheels are motoring in water.

Air compressors, air receivers, control air valves, and draft-tube water-level controls constitute the water depression system. When a unit is to run condensing, the

receivers are brought up to pressure and the main control valve is opened. When sufficient air has been admitted to depress the water in the draft tube to a predetermined level, the main control valve is closed. A small make-up valve maintains water level while the unit operates as a synchronous condenser.

Designers of the water depression system first determined air receiver requirements on the basis that the air expanded isothermally, and included a large allowance for air losses. But it is now known that air remaining in the receiver expands very nearly adiabatically and that little of it is lost during a condensing operation.

The total receiver capacity required is a function of the water volume to be displaced in the turbine, the difference in elevation between maximum tailwater level and final depressed water level in the turbine, the initial and residual receiver pressures, and an allowance for air losses.

The final depressed water level is kept at least 5 ft below the bottom edge of the runner blades to prevent them from inducing waves which could interfere with the level controls.

As the water depression compressors are used also as an emergency backup for the plant service air system, the initial receiver pressure, before blowdown, is maintained between 100 and 110 psig. The residual receiver pressure is designed to be the same on completion of a blowdown as the air pressure in the draft tube after the depression is completed.

For design purposes, 10% of the air required for depression is allowed for losses. Field tests have shown, however, that the air unaccounted for after a condensing operation is less than 5%.

Newer receivers outdoors

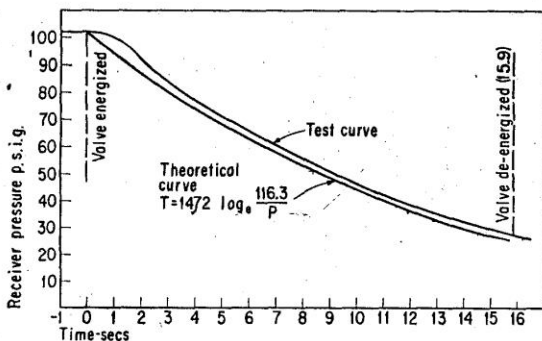
Powerhouse space usually fixes the size and number of receivers for containing a determined volume of air. These receivers—sometimes four or more—are interconnected, without shut-off valves, in such a way as to represent a single, large receiver. Standard practice has been to place the receivers indoors, but in more recent stations they are outdoors.

Compressor capacity is determined by the quantity of air used for one depression, the volume of air for holding a unit on the line as a condenser, and the minimum time between placing any two units in similar service. At a hydro station containing two or more generators, 30 to 45 min are required between placing of any two units on the line as condensers. Air for holding a unit on "condense" has been found to vary from 40 to 100 cfm.

The air's solubility in water is believed to be the major reason for air loss. Water leaking through the closed wicket gate is sprayed into a chamber of compressed air and readily aerated. In most plants, water entering the turbines is admitted many feet below the surface of the forebay where, particularly in winter, it is relatively free of dissolved gases.

Air loss is mainly dependent on the amount of gate leakage and water temperature and is proportional to the air pressure in the turbine passages.

Air control valves for each unit are one main and one small make-up valve. The main valve is used during the initial water depression and serves also as a backup



Test data are compared with theoretical curve for receiver pressure decay. The former curve is shown to lag slightly

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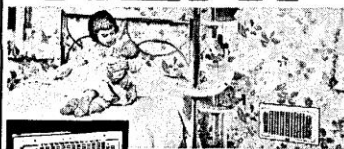
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Water depression systems

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main purpose was to determine the shape of the receiver pressure "decay" curve and to measure transient power conditions during a condenser operation.

A two-channel recorder traced the receiver pressure-decay curve and the transient power conditions. The latter were recorded for different intervals between the time the air valves opened and the wicket gates began closing. The effect of a slower air admission rate on power conditions was obtained by throttling the air valves.

A resistance bridge-type pressure transducer was installed on the air receiver and connected to the recorder by shielded cable. The typical receiver-pressure decay curve was found to lag behind the theoretical curve, as the latter does not allow for the opening time of the main valve.

Transient power conditions were sensed by a transducer connected to instrument transformers on the generator's ac metering system. The device produced a dc output proportional to power in the ac system.

The effect of different time-delay settings on transient power conditions was investigated, and it was found that the longer delay causes the unit to generate momentarily up to 8 Mw.

The tests also showed that time delay, as well as throttling, have no significant effect on the amount of air for depressing the water level or on the amount of air lost or unaccounted for.

The test to prove adiabatic expansion of air in the receiver showed that after 50 min the receiver pressure increased from 29.3 to 42.1 psig as the remaining air warmed up to ambient temperature.

From the general law $PV^N = \text{a constant}$, the exponent N was calculated from test data to be 1.35. This value compares with an exponent of 1.4 for the true adiabatic. Estimated air temperature in the receivers after blowdown was -57°F based on adiabatic expansion.

Southern Peru

[continued from page 58]

The initial phase of industrial expansion will mean an additional load of 1,500 kw, and 10,000 new homes for the growing labor force will require another 7,000 kw.

Present indications are that these operations will reach an annual consumption of 70,000 kwhr within three years and close to 100,000 kwhr by 1975.

to the make-up valve. The make-up valve maintains water level below the runner for the duration of the condense period.

The diaphragm-operated control valves used initially as main valves have been replaced by pneumatic cylinder-operated butterfly valves with rubber seats. The cylinder operators give rapid opening, and the butterfly type the advantage of a low-pressure drop. The pneumatic cylinder is operated by a four-way solenoid valve connected to the station's service-air system. For ease of maintenance, the main valve is between manual isolating valves of the gear-operated butterfly type. The isolating valves remain open except during maintenance.

The make-up valve is a direct-operated solenoid valve installed in a by-pass around the main valve.

Interlocks ensure that the circuit breaker for the unit is closed, the turbine wicket gates are at no-load synchronous-speed position, and the air pressure in the receivers is adequate before the unit can be operated as a synchronous condenser. For condense operation, the unit is brought to the no-load synchronous-speed position, and the condense control switch moved to the "ON" position.

Immediately the air control valves open, and the time-delay relay is energized simultaneously. After 1 or 2 sec, the unit shutdown solenoid is energized to close the wicket gates. Air is admitted to the draft tube until stopped by the draft-tube water-level control. The latter consists of electrodes in a water column which operate inductive-type level control relays.

Transient inputs acceptable

Rate of the receivers' air discharge has been found to have a definite effect on the power requirements of the generator when air is being admitted to the draft tube. A high rate gives a smooth transition from generation to condensing.

The air discharge rate has been selected to depress the water level below the runner blades in 10 sec or less. The resulting transient power inputs are considered acceptable, and the diameter of piping required is within practical limits.

As depression is very rapid, the air flow is adiabatic. The following formula from Crane Co's Technical Paper No. 410 is used for sizing the piping:

$$w = 0.525 Y d^2 \sqrt{\frac{\Delta P}{K V_1}} \quad (1)$$

Where w = air flow, lb per sec

Y = net expansion factor

d = internal pipe diameter, in.

P = pressure drop, psi

V_1 = specific volume, cu ft per lb

K = resistance coefficient of piping

$= 12 fL/d$

f = friction factor

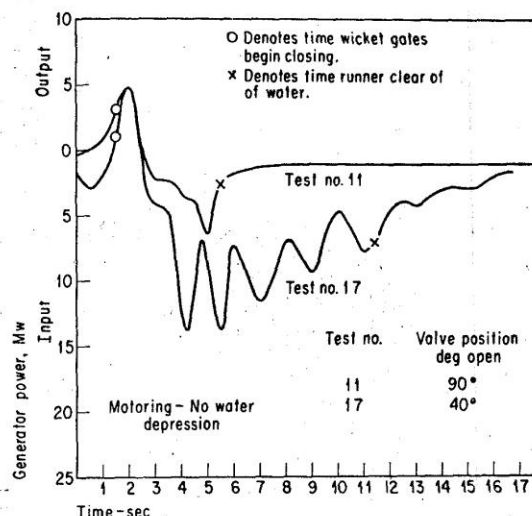
L = equivalent feet of piping

The flow formula is rearranged as follows:

$$w = 0.863 Y d^2 \sqrt{\frac{(\Delta P)}{(P)}} \times \frac{P^2}{12 f L T} \quad (3)$$

Where T = receiver absolute temperature, $F+460$.

As the receiver pressure diminishes during blow-down, checking the time for clearing the runner blades



Curves show the effect of throttling the air supply on Little Long Station's transient power conditions

can be simplified. In formula (1), Y and $\Delta P/P$ are considered to be constant for any value of K . The values used are those for which sonic velocity occurs at the discharge end of the pipe. Temperature T is also considered a constant. The effect of the increasing draft-tube pressure on the flow rate is small enough to be excluded from the calculations.

For the assumed piping diameter, then, the flow formula is reduced to:

$$w = C_1 P \quad (4)$$

Air supplied from the receivers is calculated from:

$$W = \frac{144 P_1 V_1}{RT_1} \left[1 - \left(\frac{P_2}{P_1} \right)^{0.717} \right] \quad (5)$$

Where W = lb of air

P_1 = initial receiver pressure

P_2 = final receiver pressure

R = gas constant (53.3 for air)

T_1 = initial receiver temperature ($F + 460$)

Equation (5) was used to plot an adiabatic curve based on initial receiver pressure and temperature conditions of 100 psig and 70F and for a receiver volume of 1,000 cu ft. From this curve, it is evident that the weight of air available can be represented closely by:

$$W = C_2 d P \quad (6)$$

Combining equations (4) and (6)

$$C_1 P d t = C_2 d P \quad (7)$$

Rearranging and integrating between initial and final receiver pressures

$$t = \frac{C_2}{C_1} \log \frac{P_1}{P_2} \quad (8)$$

Where t = time in sec.

Equation (8) has given values close to those obtained in field tests.

Tests were conducted at Little Long Generating Station, when it was placed in service in 1963. The [continued on page 106]