The utility usually selects protective equipment when it supplies power, except when the customer owns and operates the primary substation. Proper protection of plant generators, particularly against short circuits, is always the power engineer's job.

Today's generators have protective devices that (1) cut down burning of iron and insulation on an internal fault (2) prevent dangerous heating of generator from any prolonged short circuit.

Generator short-circuit devices fall into three classes. *Differential relays compare currents* in opposite ends of generator phase windings, operate when current going in doesn't match that coming out. Essentially independent of load and fault-current magnitude, these relays are quite sensitive.

Overcurrent protectors operate when current exceeds preset amount. These include fuses, direct-acting trip coils and straight overcurrent relays. They must trip fast on shorts but not act on permissible overloads. With fuses, instantaneous trips and relays, current magnitude alone fixes when and how fast device operates. Time-delay relays and trips have mechanically adjustable operating speed.

Voltage-restrained relays measure current and voltage to determine when and how fast to operate. **General agreement** prevails that: (1) Induction overcurrent relays and air breakers with direct-acting trips often fail to give selective short-circuit protection because of decrement of generator short-circuit current. (2) Overcurrent relays with voltage restraint or equivalent can be incorporated to permit coordination with feeder breakers.

Voltage and current relaying both play part in today's generator fault protection

Where neutrals of low-voltage generators (under 600 v) are to be grounded, current-limiting reactors hold line-to-ground faults to size of 3-phase fault currents. General practice on higher-voltage generators (2300 v and above) is to ground the neutral through a resistor. In this case, ground current is limited to a still lower value but not less than rating of largest ct in the circuit, to insure satisfactory relaying. This limitation minimizes damage during short circuit yet maintains advantage of a grounded-neutral system.

Short-Circuit Protection. Even with the above grounding practice, there still remains the problem of getting adequate short-circuit protection *where current magnitude alone* is depended on for operation. The reason: By the time we want the generator breaker to operate, there may not be enough difference between fault current and permissible short-time overload current to insure positive operation without running risk of false operation. And the breaker still must be tripped to break possible arc at the fault point even though current magnitude isn't excessive.

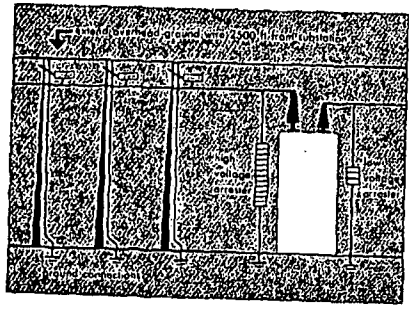
Years back, generators were often operated without protection against external faults other than feeder overcurrent relaying and differential protection around the main bus. Desiring to avoid shutting down generators if at all possible, some utilities still follow this practice (POWER, April 1951, pp 94, 95). Station operators are expected to spot trouble and take steps to clear the fault. This practice was born of the fact that no device was available that could trip the generator breaker on a sustained fault without running the risk of unnecessary shutdowns because of what might be called "normal" surges.

New Practice. This approach is changing since the advent of the overcurrent relay with voltage restraint. This relay can, in effect, size up a given current and decide whether it is a permissible overload or a fault. Sensing ability of the relay comes from taking stock of voltage at the time overcurrent flows. When voltage is normal or close to it, overcurrent is a normal surge. And voltage coil keeps relay from operating. But as voltage goes lower, approaching zero for a solid 3-phase short, the current coil trips the generator breaker.

Some manufacturers recommend such protection for all industrial generators of 2300 v and above. Actually, the scheme is just as desirable on lower voltages but cost often rules it out.

Direct-Acting Trips. Since we're speaking of small machines, why can't direct-acting trip coils of low-voltage breakers be used for short-circuit protection, at least at 600 v and below? They are used. But don't depend on them as sole means of generator protection. They're not in the same league with overcurrent relays since they often can't distinguish between permissible overload and fault current.

Overhead grounding lines help back up lightning arresters in primary substations



If there's overcurrent protection on incoming lines and plant primary feeders, protection of transformer is main item at the primary substation. Transformer windings should be guarded against: (1) surge voltage or lightning (2) overload.

Transformer-winding insulation can be stressed to voltages higher than normal as a result of lightning striking overhead lines or of surges from switching. Practical way to limit such peaks (not new) is with lightning arresters or spark-over gaps between line and ground. Surge current has a low-impedance path to ground when gap breaks down.

But arrester must not break down at normal voltages. And transformer insulation must stand up under voltage surges permitted by the arrester. Today, operating portion of arresters is a ceramic material, able to act as an insulator at one voltage and as a good conductor at a higher voltage.

The arrester has limitations: It often can't handle a direct strike. Hence the overhead ground wire. Grounded overhead line is about the best way to divert any direct strikes.

II

carrying electricity to the job

1 **Which System?** Modern load-center idea is applied many ways. Most widely used system is the simple radial, but others may fit your needs better. Trend is to neutral grounding, higher voltage.

2 **Distribution Components.** Packaged unit substations are economical, flexible. Askarel and dry-type transformers gain ground. Check into new armored high-voltage cables, aluminum conductors.

3 **Circuit Interruption.** In today's plants, interrupting capacity grows ever more important. Air breakers now handle most jobs. New high-rupturing-capacity fuses offer interesting possibilities.