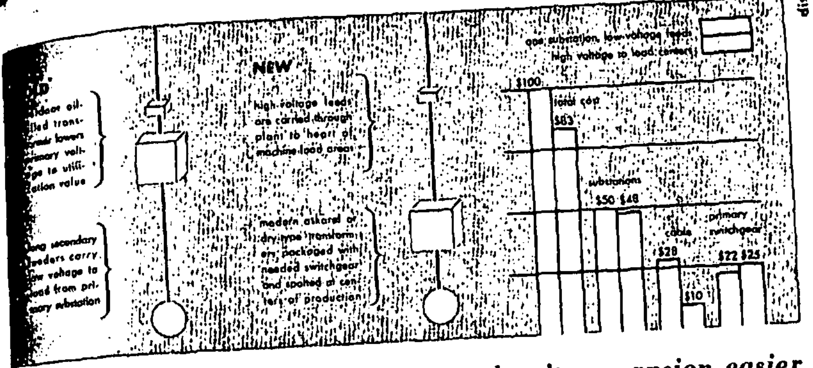
Like leprosy, high voltage was held at a distance in yesterday's plants. Typically, utility feed came into a large primary substation outside the plant proper. The substation housed three large single-phase transformers and a maze of secondary breakers feeding the many loads throughout the plant.

In event of a transformer fault, use of three single-phase units allowed cutting out a faulty one and connecting the two remaining transformers open-delta. In some cases, a spare single-phase unit was kept for just such emergencies.

High voltage has now moved indoors. More dependable equipment, greater degree of safety enclosure, better engineering know-how made this possible.

Main feature of this evolution is the shifting of the point where voltage is lowered to secondary level. Instead of being done at one point outside the plant, it's done at many unit substations near load centers in the plant. There's still a primary substation but, unless utility voltage is over 15 kv, it's now mainly a switching point. Cables from the primary substation still run throughout the plant, but there are fewer of them and they're smaller because they operate at higher voltage.

But there's more to modern distribution than moving high voltage indoors. This was a major step but for top results it must be carried to its logical conclusion by choice of proper circuit arrangement. **Available systems**, some 11 in number, range from simple radial to more complex network hookups. All have their place, but the survey on which this report is based shows that three of these find widest use, by far. So discussion here is limited to simple radial, selective-radial and network systems.



Today's load-center distribution system shows lower cost than . . . . . . low-voltage layout, and flexibility makes its expansion easier

Regardless of the reliability built into production equipment, entire operation of your plant depends on uninterrupted supply of electic power to the many motors, lamps, furnaces, welders, etc. Thus, speaking broadly, function of your electrical distribution system is to receive power at one or more bulk-supply points and deliver it dependably to every electrical device in the plant.

Comparative Costs. Unlike many other advanced methods, carrying high voltage to heart of the plant actually costs less than distributing at low voltage. To drive this point home, let's consider the case illustrated by the relative-cost chart, upper right on facing page. Figures are based on a 250,000-sq-ft single-floor plant. Old method of supply would have a one-line diagram like that at left of illustration. A single large substation would be located outside the building, and long low-voltage feeders would string through the plant to serve the loads. With a 13.2-kv incoming line, this power system, right through to final plug-in bus duct, *would cost about* $100,000 installed.

Load-Center Savings. A modern load-*center system using packaged secondary* unit substations (see diagram, p 89), would cost about $83,000 for the same plant. *This is a saving of $17,000, or 17%.* Secondary substation system has about 3000-kva capacity to allow for diversity, but these substations cost only about as much as a 2500-kva outdoor substation assembled on the job.

Major saving comes in cable cost, as chart shows. This brings out the importance of looking at the over-all system in any economic study. A change in one part may have a significant bearing on cost of another part. Here, high voltage on feeders makes them smaller.

In this case, two primary feeders were selected for the load-center system. This further increases system selectivity compared with old-style layout. Here, by selectivity we mean being able to maintain part of the load in an emergency such as a primary cable or transformer failure. Although sketch doesn't show it, use of two primary feeders requires more circuit-interrupting equipment. In spite of this, switchgear cost runs about the same for either system.

Then, while transformer costs are greater in the load-center system, secondary switchgear cost is materially reduced, since only 15,000-amp interrupting-rating feeder breakers (in cascade) are needed for small 750-kva secondary substations. With old low-voltage distribution scheme, 50,000-amp feeder breakers (in cascade) would be needed for the large 2500-kva substation.

Additional Savings. Average load-center system shows lower losses than older low-voltage distribution. As plant grows, *extra savings result from load-center system's greater flexibility* in handling new loads in existing buildings, or expansion.

We can illustrate this by supposing that the plant we've been talking about is extended so as to need about 1200 *kva more. If we add this transformer* capacity to the old-style low-voltage system, short-circuit currents on all previously installed *feeder breakers are increased.* Possible short-circuit duty would be increased so much that breakers would be inadequate, and there'd be an immediate expansion bottleneck.

Easy Expansion. Contrast foregoing with expansion of a load-center system. Here we merely extend the two high-voltage feeders and add two new unit substations. Short-circuit values aren't increased at any existing unit substations.

But suppose we had put extra transformer capacity in the old-style low-voltage system, in anticipation of load growth. Load-center system still proves less costly to expand, because its capacity can be built up in small units as load grows. Thus power-system and plant growth are closely coordinated. With the older system, a large capital investment must be made initially in a big single substation. Secondary feeders are added as needed until limit of substation capacity is reached. Then another substation is built at great expense. If load doesn't grow, investment is wasted.

In applying load-center methods, however, initial investment can be lower because you need only install capacity for present loads plus a small reserve.

Handling Large Loads. In the following four pages we'll talk about circuit arrangements now in use and some of the thinking behind plant decisions on adoption of one or another system. But before *we get to that, there are some general* thoughts which apply regardless of the specific system used, in particular the *question of handling large loads.*

Typical would be large motors, say above 200 hp. Such units can often be served *more economically at voltages* above 600. Thus they're out of range of secondary side of regular secondary unit substations. *If primary voltage is suitable, they may be served directly.*

Direct from Primary. For example, motors above 200 hp may feed directly from a 2400-v primary system. Likewise, motors above, say, 250 hp, can be served from 4160-v systems and those over 1000 hp from 6900-v. Motors above 2000 hp may be supplied at 11.0 to 13.8 kv.

But you'll still run into cases where there are loads that can't be fed properly from either primary or secondary. *There are two possible answers. If, say,* you have one or two motors too large for secondary voltage (480-v systems) and too small for primary voltage, best bet is to feed such motors from primary through separate transformers.

***Transformers* at Load.** Let's look at an example—an 800-hp motor in a plant with 13.8-kv primary. Most economical answer would probably be to serve the *motor from the 13.8-kv system* through a stepdown transformer with a secondary voltage of the order of 2300 v.

On the other hand, let's say you have concentrated groups of large motors and an electric furnace. You'd normally feed them *direct at primary voltage* but you can't because it's too high—let's say 13.8, 34.5, or even 69 kv if it's a very large plant. With exception of 13.8, these voltages would be too high to apply to any motors, and 13.8 is too high for most.

Medium-Voltage Substation. The answer *in this case lies in an adaptation* of the load-center idea. Supply big loads or groups of large motors from a separate unit substation *having a secondary voltage* in the range between 2.4 and 13.8 kv. A typical case is found in paper mills, where primary voltage is *often* 13.8 kv. Here large motors are generally supplied at 2.4 kv through a 13.8/2.4-kv substation. Smaller motors *operate at* 480 v.

Here are the basic elements of a modern load-center system

switchgear Today, switchgear is often the major equipment item in the primary substation where incoming feeder voltage is less than 15 kv. Circuit breakers are the usual interrupting means, operated through induction relays and ct's. But load-interrupter switches and high-voltage power *fuses* may be used. Either way, packaging is the theme, rather than field assembly of the separate components.

feeders For connecting primary and secondary substations, cable in conduit is meeting tough competition since advent of armored cable. This new version of low-voltage armored cable licks cost of conduit installation and cable pulling. It offers increased mechanical protection. Simple mechanical methods of splicing and terminating have been developed to eliminate the need *for* costly lead wiping of joints.

substations Heart of modern system is the secondary unit substation. It has three parts: incoming ac-line section, transformer, secondary switching section. Incoming line may have breakers, junction boxes, interrupter switches. Transformer may be oil, askarel, ventilated or sealed dry type. Secondary section *may* have drawout air circuit breakers, molded-case breakers or some *form* of motor control incorporated.