Topics for Today:

- URL: http://www.ece.mtu.edu/faculty/bamork/EE5223/index.htm
- Labs - EE4224/5224 - Begins in Week 3 (note this change)
- Term Project - form teams of ~3, begin in week 4 or 5.
  - Single Bus, Single Bus w/tie
  - Main & Transfer
  - Ring Bus
  - Breaker-and-a-half
- How to read a one-line (print out week 1 handout “Sub Schem”)
- Radial Protection (read sections 12.5, 12.6), G&S Ch.10
- Instrument transformers: VTs, CTs, CCVTs, MOCTs, etc.
- CTs - pedestal vs. bushing
- CT saturation & accuracy, ratios, multi-ratio CTs
Figure 5.10  Burdens on CTs for various types of CT connections and faults. The unexcited CT load is neglected.

5.6.1  CT Ratio Selection for Phase-Connected Equipment

Select the ratio such that the maximum short time or continuous current will not exceed the thermal limits of the CT secondary and connected equipment. The conventional practice, over many years, has been that the secondary
current should be just under 5 A for the maximum load. This was because instruments were often in the same circuit, and they had 5-A movements. Following this practice, select the CT ratio of 100/5 ($R_c = 20$). This gives a maximum continuous secondary current, when the load is 90 A, of $I_s = 90/20 = 4.5$ A.

5.6.2 Select the Relay Tap for the Phase-Overcurrent Relays

Overcurrent taps represent the minimum pickup or operating current of an overcurrent relay. Thus, a tap is chosen that is higher than the maximum load, in this example, above 4.5 A. How much higher is based on relay characteristics, experience, and judgment. There is no problem if a time overcurrent relay picks up on a cold load, offset currents, or other, provided these currents subside below the relay pickup before it operates. This may be required when the margin between minimum fault and maximum load is small.

Small tap 5 is selected. The ratio above load $5/4.5 = 1.1$. This provides a small margin more than any potential increase in the continuous load, but a large margin with inverse-type relays for transient overcurrents, such as a cold load. Minimum fault of $350/20 = 17.5$ A, and $17.5/5 = 3.5$ times the minimum relay pickup that is desirable for any possible fault restriction.

If tap 6 were selected, then the margin above load is greater ($6/4.5 = 1.33$), but a smaller margin ($17.5/6 = 2.9$) above the relay pickup.
Either type of transformer provides excellent reproduction of primary voltage, both transient and steady-state, for protection functions. Saturation is not a problem because power systems should not be operated above normal voltage, and faults result in a collapse or reduction in voltage. Both have ample capacity and are highly reliable devices. VTs are normally installed with primary fuses, which are not necessary with CCVTs. Fuses are also used in the secondary. A common practice is to use separate secondary fusing for voltage supply to different groups of relays used in the total protection. Fuses are a hazard. A loss of potential by a fuse may result in unwanted, incorrect relay operations. In some cases, overcurrent fault detectors are used to minimize this possibility.

Some CCVTs may exhibit a subsidence transient when the system voltage is suddenly reduced such that the secondary voltage momentarily is not a replica of the primary. This is caused by the trapped energy ringing in the secondary compensating or turning reactor (L) and the associated circuit. This transient can be at a different frequency from that of the system frequency, or unidirectional. This has not been a problem for electromechanical relays, but it may cause problems for solid-state types. Modern-design CCVTs are available to eliminate this problem.
Other arrangements exist and can be considered as combinations or variations of these.

Fortunately, bus faults are not too common, but are serious, for they can result in considerable loss of service through the circuits that must be opened to isolate the fault. The most common causes of bus faults are equipment failures, small-animal contacts, broken insulators, wind-driven objects, and contamination.

![Diagram of bus system with differential protection zone](image)

**Figure 10.1** Typical four-circuit single breaker-single bus and the bus differential protection zone.

- **NC** = Normally Closed
- **NO** = Normally Open
Differential protection provides sensitive and fast phase and ground-fault protection and is generally recommended for all buses. In the figures the dashed-line box or boxes outline the bus differential protection zone: the primary protection zone. Backup is usually provided by the protection associated with the connecting circuits. A second differential scheme is sometimes used for very important buses.

10.2 SINGLE BREAKER—SINGLE BUS

The single-breaker—bus type (Fig. 10.1) is the most basic, simple, and economical bus design and is used widely, particularly at distribution and lower-transmission voltages. For this type of bus, differential is easy to apply as long as suitable CTs are available, with the protective zone enclosing the entire bus, as shown.

This bus arrangement provides no operating flexibility. All bus faults require opening all circuits connected to the bus. Breaker problems or maintenance require that the circuit be removed from service. However, maintenance may not be too much of a problem if maintenance on the entire circuit and the protection can be scheduled together.

![Diagram of single breaker—single bus differential protection zones]

**Figure 10.2** Typical four-circuit single breaker—double bus with bus tie and the bus differential protection zones.
switching of the protection: both the bus differential and line protection. Two differential zones for the buses are required. In Fig. 10.4, lines 1 and 2 are shown connected to bus 1, with lines 3 and 4 connected to bus 2. For this operation the differential zones are outlined: dashed for bus 1, and dash-dot for bus 2.

As for the previous bus arrangement (see Fig. 10.3), the bus tie protection must be adaptable for the protection of any of the lines when 52T is substituted for any of the line circuit breakers. When a line breaker is bypassed and the bus tie (52T) breaker substituted, using one bus as a transfer bus, the differential protection on that bus must be removed from service.

Faults on either bus or associated circuits require tripping of all circuits connected to the bus at that time. Faults in the bus tie breaker (52T) must trip both buses and all circuits.
With all disconnect switches normally closed (NC), as shown, a fault on either bus does not interrupt service on the lines. All switching is done with breakers, and either bus can be removed for maintenance.

Line-side voltage, either VTs or CCVTs, is necessary if required by the line protection.

### 10.7 RING BUS

The ring bus arrangement (Fig. 10.6) has become quite common, particularly for higher voltages. High flexibility with a minimum of breakers is obtained. Each breaker serves two lines and must be opened for faults on either line. The bus section between the breakers becomes part of the line, so that bus protection is not applicable or required. The interconnection of the CTs for protection of each line is shown dashed in Fig. 10.6, and line faults must trip two breakers. If the ring is open for any reason, a fault on a line may separate the other lines and the bus.

Line protection voltage, if required, is obtained from VTs or, more commonly, at the higher voltages by CCVTs connected to each line.

![Diagram of a typical four-circuit ring bus.](image)

**Figure 10.6** Typical four-circuit ring bus. Differential protection not applicable. Bus sections are protected as part of the lines or connected equipment, as shown dotted.
10.8 BREAKER-AND-A-HALF BUS

This arrangement (Fig. 10.7) provides more operating flexibility, but requires more circuit breakers than the ring bus. It, too, is widely used, especially for larger multicircuit, higher-voltage systems. Two operating buses each

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**Figure 10.7** Typical four-circuit breaker-and-a-half bus and the bus differential protection zones. The mid-bus sections are protected as part of the lines or connected equipment, as shown dotted.
have separate differential protection. Each line section is supplied by both buses through two circuit breakers. The center circuit breaker serves both lines; hence, the half designation.

The CT interconnections are shown for each line section as dashed lines in Fig. 10.7. Voltage for line relays must use line-side CCVTs or VTs. Line faults trip two breakers, but do not cause loss of service to the other lines if all breakers are normally closed as shown.

**10.9 TRANSFORMER–BUS COMBINATION**

This is the single breaker–single bus of Fig. 10.1, with a transformer bank directly connected to the bus as shown in Fig. 10.8. The advantage is the cost saving of the circuit breaker between the transformer and the bus. It is practical for small stations, such as distribution, where there is only one transformer to supply several circuits. Here a fault in either the transformer

![Diagram](image)

**Figure 10.8** Typical four-circuit single breaker bus and transformer with combined bus-transformer differential protection zone.
severely limited and distorted. This is illustrated in Fig. 5.14 for a 20-times-rated fully offset current with resistive burden. This type of burden causes a sharp drop-off of the secondary current during each cycle.

After saturation occurs, the decay of the dc component results in the CT recovering, so that during each subsequent cycle, the secondary current more nearly approaches the primary. As the dc disappears, the secondary is again a reproduction of the primary. This assumes no ac saturation. It is possible, but rarely occurs, that the secondary current may be practically zero for a few cycles in very severe cases.

Inductance in the burden results in a more gradual drop-off, whereas a lower burden reduces the distortion. These several effects are shown in Fig. 5.14. As shown, this saturation does not occur instantly; hence, initially,