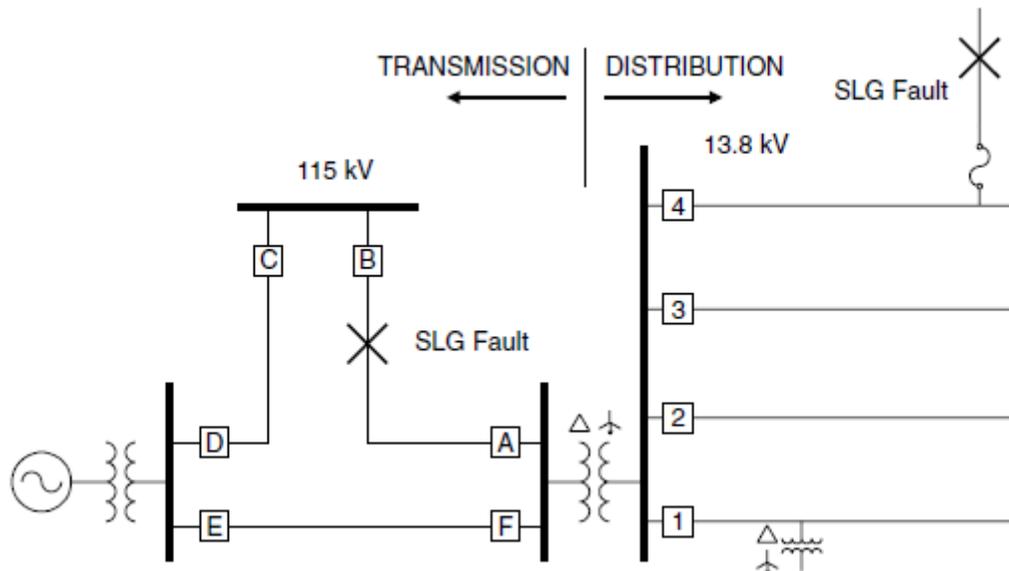


## Sources of sags

Voltage sags and interruptions are generally caused by faults (short circuits) on the utility system.



**Figure 2.3** Fault locations on the utility power system

Consider a customer that is supplied from the feeder supplied by circuit breaker 1 on the diagram shown in Fig. 2.3. If there is a fault on the same feeder, the customer will experience a voltage sag during the fault followed by an interruption when the breaker opens to clear the fault. If the fault is temporary in nature, a reclosing operation on the breaker should be successful and the interruption will only be temporary. It will usually require about 5 or 6 cycles for the breaker to operate, during which time a voltage sag occurs. The breaker will remain open for typically a minimum of 12 cycles up to 5s depending on utility reclosing practices. Sensitive equipment will almost surely trip during this interruption.

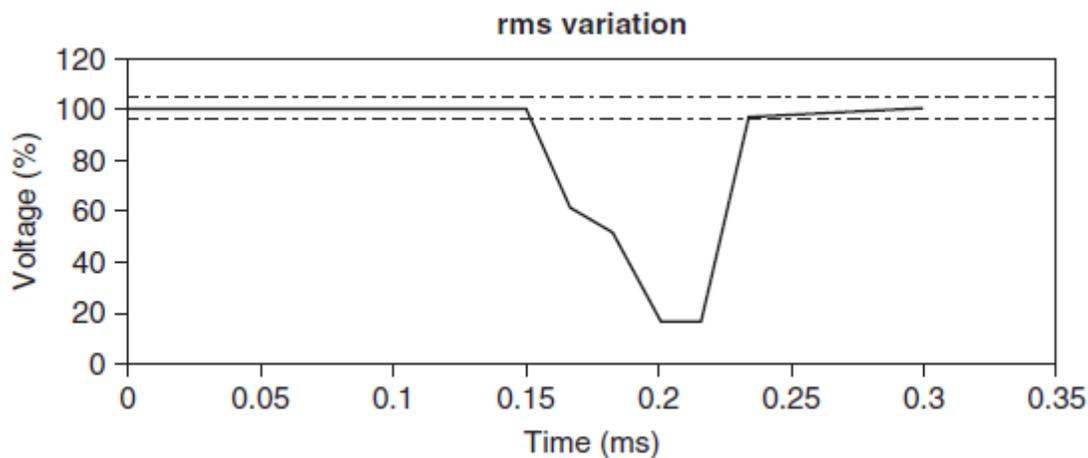
A much more common event would be a fault on one of the other feeders from the substation, i.e., a fault on a parallel feeder, or a fault somewhere on the transmission system (see

the fault locations shown in Fig. 3.1). In either of these cases, the customer will experience a voltage sag during the period that the fault is actually on the system. As soon as breakers open to clear the fault, normal voltage will be restored at the customer.

Note that to clear the fault shown on the transmission system, both breakers A and B must operate. Transmission breakers will typically clear a fault in 5 or 6 cycles. In this case there are two lines supplying the distribution substation and only one has a fault. Therefore, customers supplied from the substation should expect to see only a sag and not an interruption. The distribution fault on feeder 4 may be cleared either by the lateral fuse or the breaker, depending on the utility's fuse saving practice.

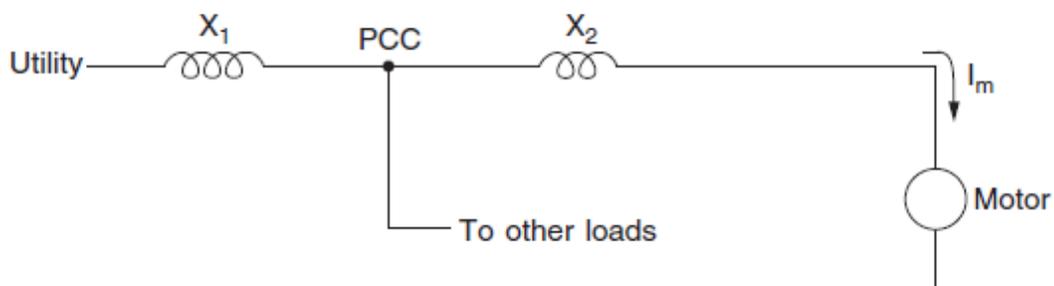
### Sources of sags

A *voltage sag* is an event where the line rms voltage decreases from the nominal line-voltage for a short period of time.



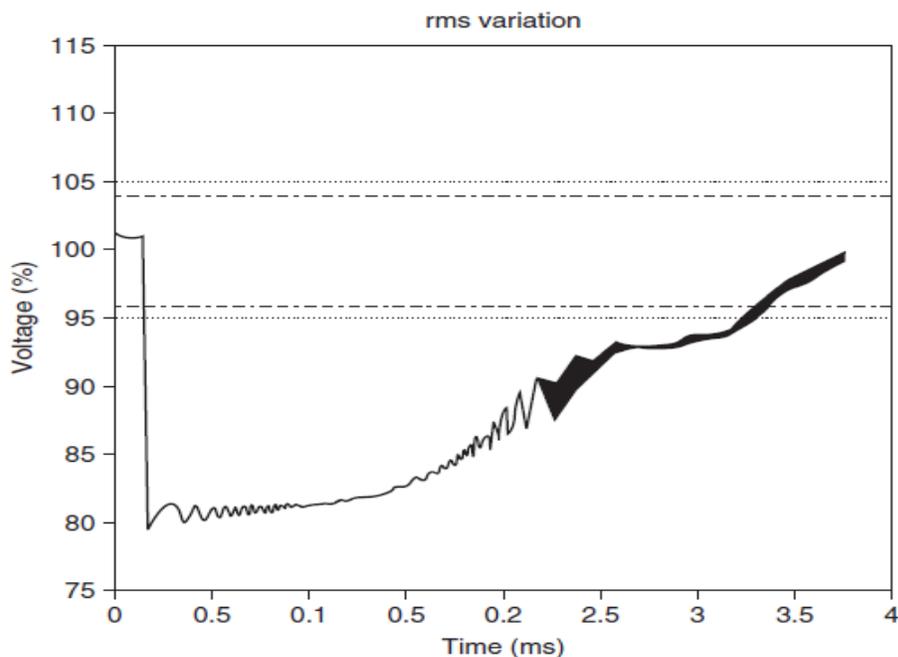
**Figure 2.4 (a)** Voltage sag due to a single line-to-ground fault

The above figure 2.4 (a) shows an 80 percent sag with a duration of a few 60-Hz cycles. This type of variation can occur if a large load on the line experiences a line-to-ground fault, such as a short in a three-phase motor or a fault in a utility or plant feeder.



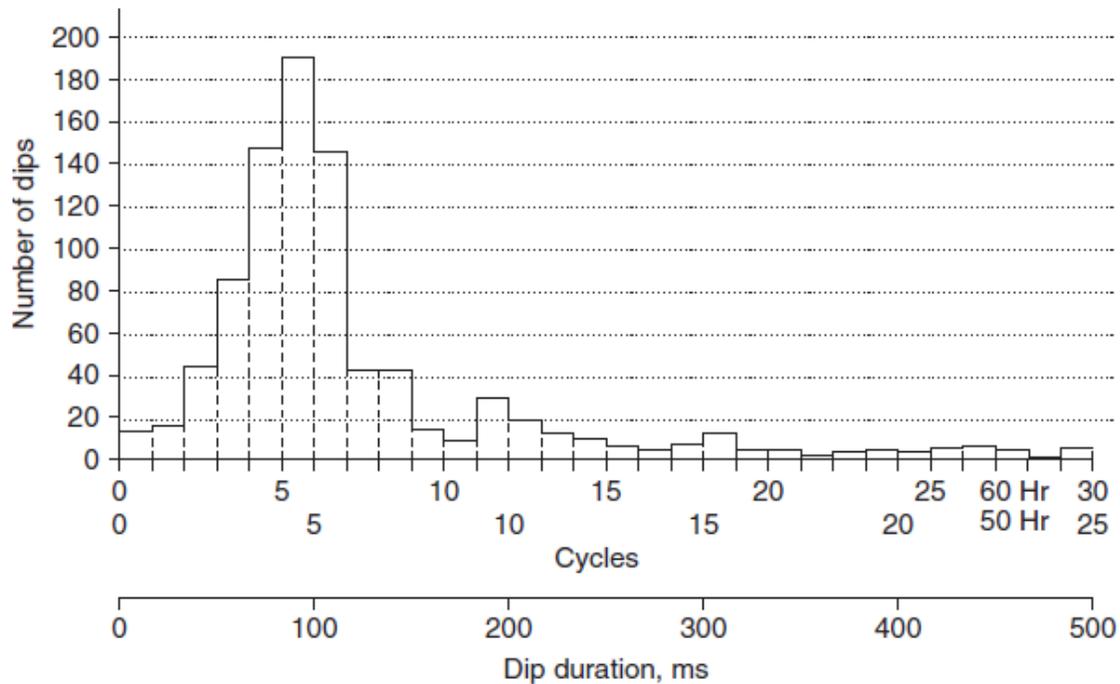
**Figure 2.4 (b)** Circuit that can exhibit voltage sag due to motor starting

In Figure 2.4 (b) we see a circuit with a line supplying an electric motor. Note that the line impedances cause a voltage drop when currents are drawn from the line. When the motor is energized, the motor current  $I_m$  causes a voltage drop to other loads in the system at the point of common coupling (PCC). Figure 2.4 (c) displays a voltage sag due to a large motor starting, such as a pump or air-conditioner motor. Note that when an induction motor starts, it can draw very high currents until the rotor comes up to its normal speed. This high current causes a significant voltage drop due to the impedance of the line.



**Figure 2.4 (c)** Voltage sag caused by motor starting

EPRI study results 2.4(d) shows that the average sag duration in U.S. systems is a few cycles long. This average dip clearing time of roughly 6 cycles (100 milliseconds) is attributable to the circuit breaker switching time for clearing a fault.



**Figure 2.4(d)** Histogram of voltage sag duration from EPRI study on voltage dips in U.S. Systems

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