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TechTopics No. 77

Residual voltage on load side of an open circuit breaker

Siemens is occasionally asked to comment on the existence of a voltage on the load side of an open circuit breaker. For convenience, this will be called "residual voltage." Most often, this is a result of measurements made during commissioning a project, when there is no load on the switchgear bus and the main circuit breaker is in the connected position and open, with the incoming source (the line side of the main circuit breaker) energized. Any feeder or tie circuit breakers connected to the main bus are open.

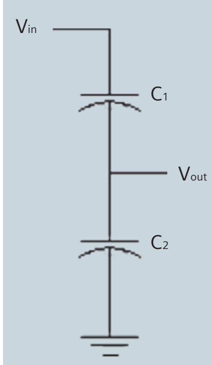
In this situation, the open contacts of the circuit breaker constitute a capacitor in series with the incoming source and the load-side (main) bus. The main bus has capacitance to ground, but in the situation described, has no other load as the feeder and tie circuit breakers are open.

The resulting circuit is a simple capacitive voltage divider, as illustrated in the schematic.

Consider a typical example, a lineup of 13.8 kV switchgear with a main circuit breaker, eight feeder circuit breakers and one tie circuit breaker arranged in a two-high (stacked) configuration.

In this example, the load-side main bus consists of approximately 45 feet (about 14 meters) of copper bus. The capacitance between the open contacts of the vacuum interrupter, C_1, is of the order of 15 picofarads (pf). The capacitance of the main bus is of the order of 10 pf per meter (refer to IEEE C37.015, clause B.2), or 140 pf for this example.

Figure 1: Schematic



Variables:

- V_{in} Incoming source voltage on the line side of an open main circuit breaker
- V_{out} Voltage on main bus (load side of main circuit breaker)
- C_1 Capacitance between the open contacts of the vacuum interrupter
- C_2 Capacitance of the switchgear main bus to ground.

The voltage relationship for a capacitive voltage divider is:

$$V_{out} = V_{in} \frac{C_1}{(C_1 + C_2)}$$

Answers for infrastructure.

In this example, when energized at 13.8 kV phase-phase (8 kV phase-ground), the expected voltage on the load side of the main circuit breaker (in this example, on the main bus) with all feeder and tie circuit breakers open would be:

$$V_{out} = V_{in} (C_1/(C_1 + C_2))$$

$$V_{out} = 8.0 \text{ kV } (15/(15 + 140))$$

$$V_{out} = 8.0 \text{ kV } (15/155)$$

$$V_{out} = 755 \text{ volts.}$$

This is a very simplistic example and ignores several factors, such as the capacitance of the circuit breaker conductors and primary disconnect assemblies in the feeder circuit breaker cubicles. These factors would increase the load-side capacitance, reducing the resulting voltage (V_{out}) calculated. However, this does not alter the basic concept that, in the situation described, the open circuit breaker is essentially a capacitor in series with the capacitance of the load-side conductors to ground, and thus that there will be a voltage on the load side of the circuit breaker.

The capacitance values cited are representative, but will vary from installation to installation. The capacitance between the open contacts of the vacuum interrupter will vary with the diameter of the contacts and the gap between them. The bus bar capacitance is an approximation based on a review of the literature, but is believed to be representative. The figures presented in the example are for purposes of illustration of the physics phenomena rather than an attempt for precision.

What are the ramifications of this residual voltage? Siemens believes this is an academic issue rather than a practical issue. No person should be working on the main bus in this condition, as this would violate numerous documents relating to safety.

The standards for switchgear do not recognize an open circuit breaker as an isolator. In an outdoor distribution circuit breaker situation, air disconnect switches should be located on each side of the circuit breaker to provide the isolation function before maintenance is performed. In a drawout, metal-clad switchgear situation, the circuit breaker should be withdrawn from the connected position to the test or disconnected position, as IEEE C37.20.2 recognizes this as the condition that fulfills the function of an isolator.

The National Electric Code® (NEC)® ANSI/NFPA 70® also recognizes an open circuit breaker does not provide an isolating function. Specifically, article 490.22 says (in part):

> 490.22 Isolating Means. Means shall be provided to completely isolate an item of equipment from all ungrounded conductors. The use of isolating switches shall not be required where there are other ways of de-energizing the equipment for inspection and repairs, such as draw-out-type metal-enclosed switchgear units and removable truck panels.

When a load is connected to the main bus, the residual voltage largely disappears. To illustrate this, consider the previous example, with one of the feeder circuit breakers closed, and with a cable circuit of 20 meters (66 feet) length connected to the feeder circuit breaker, but with the switch or circuit breaker at the remote end open. Therefore, closing the feeder circuit breaker only picks up the capacitance of the feeder circuit cable. For the example, the cables must be shielded (in accordance with NEC), for which typical cable capacitance is 200 pf/m to 400 pf/m (refer to IEEE C37.015, clause B.2).

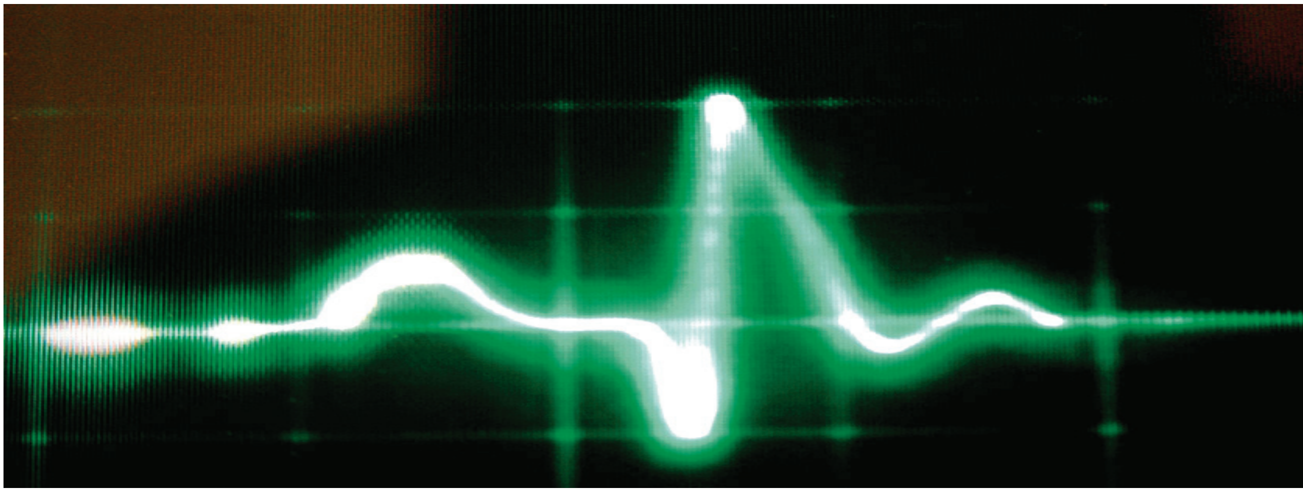
For this situation, the residual voltage (V_{out}) becomes:

$$V_{out} = V_{in} (C_1/(C_1 + C_2))$$

$$V_{out} = 8.0 \text{ kV } (15/(4{,}000 + 15 + 140))$$

$$V_{out} = 8.0 \text{ kV } (15/4{,}155)$$

$$V_{out} = 28 \text{ volts.}$$



Occupational Safety and Health Administration (OSHA) regulations and NFPA 70E® (Electrical Safety in the Workplace) require that any circuit over 50 V be treated as energized until it is isolated and safety grounds are installed. The description of an Electrically Safe Work Condition in NFPA 70E is:

> A state in which an electrical conductor or circuit part or near has been disconnected from energized parts, locked/tagged in accordance with established standards, tested to ensure the absence of voltage, and grounded if determined necessary.

Siemens considers it mandatory that safety grounds be applied before any work is performed on equipment over 50 V. In metal-clad switchgear, isolation requires withdrawal of the drawout circuit breaker to the test or disconnected position. Tests for the presence of voltage are required before any work can be performed on the conductors. After it has been verified that the conductors are de-energized, safety grounds are to be applied.

Therefore, the processes required by OSHA and NFPA 70E will place the equipment in an electrically safe work condition, and eliminate any residual voltage.

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