Pulse Testing of Representative Power Substation Equipment

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The dependability of our electric power infrastructure requires the reliable operation of the vast number of power substations. These have control equipment, using low level signals, with many connected wire lines of various lengths. These lines may couple to transient electromagnetic field, introducing pulses on the line, which may disrupt or damage the connected equipment, and jeopardize the power system. The types of lines include: phone or network (connected to central stations, for monitoring and control), intersite control lines of various types, and device power lines. For such equipment, it is virtually impossible to predict what pulse levels would have an effect, whether temporary upset or permanent damage. In this talk, we will discuss a series of pulse injection tests performed to determine such susceptibility levels for samples of substation type equipment.

Standard 50 Ω test pulsers were used in these tests: EFT (5 ns rise, 50 ns width, up to 8 kV) and CWG (1.2 μs rise, 50 μs wide, up to 4.3 kV), using both differential and common mode configurations. Emphasis was common mode, being careful to try to be realistic in the hookup configuration, especially the grounding. As much as possible, the equipment was operating during the tests, and we watched for upsets (abnormal operation) during each shot, and checked for permanent damage afterwards. For a given test, pulse levels were gradually increased, and pulse voltage polarity alternated, to look for the lowest damage level. We tried to test all the various ports on the equipment. The tests used about 3660 shots over a two month period.

The device devices included:

- Electromechanical protective relays, from General Electric (GE): senses problems in the high voltage phase wires, and sends appropriate control signals.
- Electronic protective relays, from Schweitzer Engineering Laboratories, Inc. (SEL): newer forms of the electromechanical relays.
- PLC (programmable logic controllers), from Allen-Bradley and Fisher: plant control computers.
- SCADA (Supervision Control And Data Acquisition) RTU and MTU (Remote and Master Terminal Units) – equipment from SEL, a standard network switch, and a Compaq PC: connects unmanned substations to manned control stations.

In general, there was some very weak equipment, and some that was very hardy.

Up to the highest pulse levels, we did not notice any damage to the electromechanical relays (although we could not thoroughly test for damage). The electronic relays, and the SEL SCADA units, appear to have been very carefully designed for protection against pulses – for the fast pulse we only found one port that upset, and for the wider pulse, a few that had damage. For the PLC (computers, with various I/O ports for controlling other equipment), there was much more upset and damage. The PC and network switch also had upsets and damage.

Some interesting results were found. Often there was air-gap arcing – if close to the entry point of the device, it might be protective, diverting the pulse from the rest of the circuit; if deeper down, it could be destructive. Sometimes effects appeared elsewhere within the system from the port that was pulsed. For upset this might not be unexpected. On an Allen-Bradley PLC, pulsing a Discrete Input port caused the Analog Output signal to momentarily glitch, and pulsing a specific SEL serial port caused widespread abnormalities in the relay (noteworthy in that this occurred at 5.5 kV, while every other port in the unit was good to 8 kV). Some interesting damage results were that pulsing a Fisher PLC serial port caused permanent damage to its Analog Input card. For this plastic-enclosed unit, the pulse has to find some way, through the system, between the port and the AC ground.