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# EMTP Applications

## FOR POWER SYSTEM PROTECTION

The EMTP can supplement conventional fault studies and hand calculations to improve the understanding of power system phenomena and to assist in proper protection applications.

A protection engineer may determine extreme conditions of steady state fundamental frequency unbalances or harmonic distortion that will be faced by a protection system.

### Biographical Sketch

Demetrios Tziouvaras was born in Monahiti, Grevena, Greece. He holds a Masters Degree in Electrical Engineering from Santa Clara University, California, USA. From 1980 to 1998 he worked for Pacific Gas and Electric Co., where he held various positions in the System Protection Department including Principal Protection Engineer responsible for protection design standards, application of new technologies, substation automation, relay settings, and analysis of relay operations and system disturbances. He joined the Research Engineering Department of Schweitzer Engineering Laboratories, Inc. in 1998 where he is involved in digital relay algorithm development and electromagnetic transient simulations.

Mr. Tziouvaras is a senior IEEE member and member of the Power System Relaying Committee. He is a member of CIGRE and the convenor of CIGRE SC B5.15 on "Modern Distance Protection Functions and Applications."

He is the author of more than 35 IEEE and Protective Relay Conference papers, holds three patents in the area of power system protection and has more pending. He has taught seminars in Protective Relaying, Digital Relaying, and EMTP at the University of Illinois at Urbana-Champaign, the California Polytechnic Institute in San Luis Obispo, IEEE PES, and elsewhere. He served as the chairman of an IEEE P5SRC working group that developed an IEEE PES tutorial on "EMTP Applications to Power System Protection"

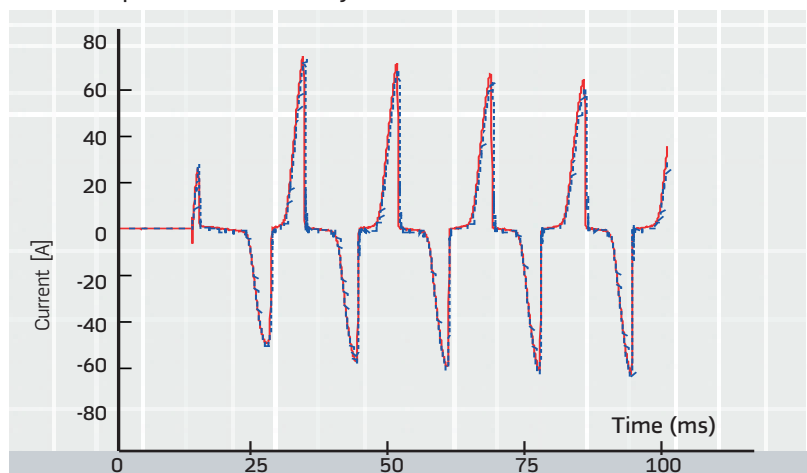
### STEADY-STATE APPLICATIONS

Power system operations can cause unbalanced currents and volages in the network that could impact the operation of protective relays, e.g., during a single-phase trip, unequal gap flashover of series capacitors, or when a three-phase transformer bank consists of different single-phase units. These operating conditions cannot be analyzed using conventional load-flow programs but can be easily studied using steady-state EMTP simulations and demonstrate the benefits of applying EMTP for power system protection applications.

Conventional short-circuit and load-flow programs assume

## 1 Comparison

Comparison of a laboratory and an EMTP simulated CT saturation test



a balanced power system. The assumption of a balanced system is usually adequate under normal operating conditions. In cases where network unbalances exist under normal conditions, conventional programs may not be able to determine the magnitude of normal unbalances. EMTP steady-state solutions are performed in the phase domain, not using sequence components, thereby easily solving networks with nonsymmetrical phase impedances. The EMTP steady-state solution may be used to help quantify the extent of normal unbalances to assist in relay applications.

Open conductors create series unbalances that are not normal conditions, and relays may be expected to protect against them. However, the resulting system unbalances may be significantly less than unbalances resulting from short circuits. In fact, the unbalance currents and voltages are heavily dependent on the magnitude of load currents. EMTP steady-state solutions can readily determine voltages and current measured by relays under such conditions. Cases of interest are: *single-phase tripping*; *1 phase of a disconnect switch open*.

Series capacitor gap flashing during a fault is a special case of a multiple unbalance. Unbalanced gap flashover may occur as a result of a short circuit, or unbalanced bypass may occur as a result of control or bypass equipment problems. EMTP can calculate steady-state unbalance currents and voltages resulting from such unbalanced operation. Knowledge of these quantities can assist in proper protective relay application and settings. Simultaneous or cross-country faults are difficult to analyze with conventional short-circuit programs that use sequence components for analysis but are easily handled by EMTP simulations.

Under some conditions, unbalances are deliberately introduced into a network to address special problems. For example, failure of a large single-phase transformer may necessitate its replacement with another single-phase transformer having different MVA capability and different leakage reactances. EMTP simulations can be used in such a situation to determine the steady-state unbalances resulting from load flowing through the unbalanced transformer impedances. The simulations would reveal the

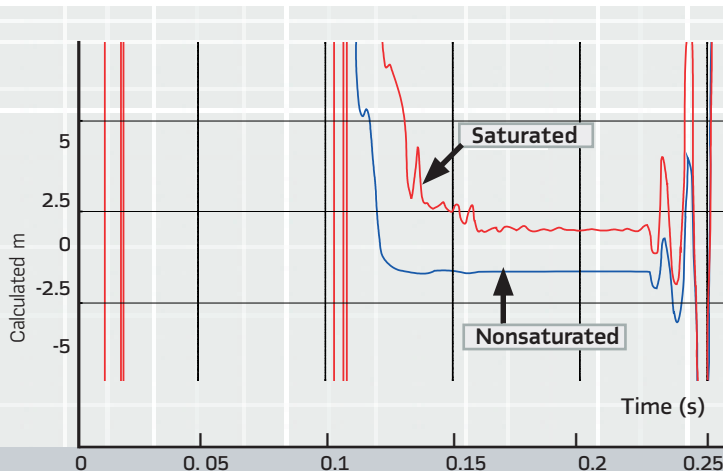
## EMTP is a valuable tool for analyzing the transient and dynamic behavior of power systems.

level of system unbalance and the circulating current in the transformer bank tertiary winding. Relay engineers can use the results of the EMTP steady-state simulations to determine the effect on transmission line protection and the required settings for transformer tertiary overload protection.

In addition to unbalanced analysis, steady-state EMTP solutions help to study the effect of non-fundamental frequencies on relays. For instance, the system response at a variety of frequencies generated by a multifrequency injection may be used to test for the presence of system resonances. Such information will help determine the importance of harmonic rejection in relays in particular applications.

## 2 Calculated distance values

Calculated distance  $m$  values with normal and saturated currents



The calculated distance to the fault  $m$  value corresponding to a normal fault current settles to 0.33 as expected. For a saturated phase current (Fig. 2), the calculated distance  $m$  value crosses the unity line with a half-cycle delay and settles around 0.45 because the current remains in a saturated state.

Effectively using EMTP to model complex power system operating conditions can improve the protection schemes and provide answers to relay operations that otherwise are difficult to obtain.

Power line carrier frequencies propagate in several modes on a multiphase transmission system. Study of these propagation modes is complicated by discontinuities in the transmission circuit, such as transpositions and overhead-to-underground interfaces. At high frequencies, such as those of power line carrier, EMTP steady-state solutions can be used to study the effects of line transpositions and discontinuities on wave propagation.

#### Transient Applications

Several transient applications are discussed here to demonstrate the benefits of EMTP applications in the field of system protection engineering.

EMTP is a very powerful tool in the study of transient conditions. EMTP aids significantly in protective relay applications since protective relays operate during transient conditions. Traditional relay application has considered fault conditions to be temporary steady-state conditions that can be studied by fundamental frequency steady-state fault studies. Conventional short-circuit studies exclude some important phenomena, and some conditions are not even caused by short circuits. Additionally, the duration of a transient EMTP study is variable. The period of signals of interest may vary from microseconds to tens of seconds.

Series capacitors in transmission lines often present challenges to protection systems. Depending on the size and location of the capacitor bank and the overvoltage protective equipment such as spark gaps or metal oxide varistors (MOVs), the operating and polarizing signals presented to transmission line protection can be very unusual. Conventional short-circuit programs often have difficulty in calculating fault quantities because of the non-linear performance of the series capacitor overvoltage protection gaps or MOVs. Further,

the interaction of the series capacitors and power system introduce off-nominal frequencies that can affect protective relays. When the capacitor is switched into or out of the transmission line, system oscillations arise that should be considered for line protection application and setting.

Relay response to evolving faults is sometimes uncertain. This is especially applicable to protection systems, which must determine the type of fault before measuring the faulted loop impedance (such as switched distance protection schemes). The uncertainty arises because of the wide variety of rapidly changing conditions that may potentially confuse a protection system, which is trying to determine the type of fault. EMTP provides a convenient way to generate test signals to physically test a relay's response to such faults.

Traveling wave high-speed transmission line protection systems do not use the fundamental frequency components. They use higher frequency signals to determine the direction or type of fault. EMTP-generated signals are essential for application studies, testing and settings of such relays.

Some power system effects simply cannot be investigated by any other means than a transient analysis program. Single-phase switching is one area where EMTP has been widely applied. An important problem in such cases is extinction of the secondary arc after the faulted phase is opened at the line terminals. This secondary arc may be maintained by capacitive and inductive coupling with adjacent energized phases. Special four-reactor bank applications have been designed and widely applied to minimize the duration of secondary arc. The presence of these reactors and the secondary arc can have significant effects on transmission line relaying. EMTP has been used to study the secondary arc extinction characteristics and protective relay

response to such transients. To perform single-phase tripping, transmission line protection relays are required to determine the faulted phase. Numerous faulted phase selection schemes have been designed. The effect of heavy load and possible high fault resistance during single line-to-ground faults remain challenging applications. EMTP has been widely used to test relay response to such challenges.

High-speed automatic reclosing is frequently applied to maintain the integrity of a transmission system after a short circuit. Voltage detectors are sometimes used to supervise such reclosing to ensure the remote line terminal has opened before reclosing occurs. The oscillatory decay of the trapped charge remaining on the line may cause problems to voltage detectors used for such supervision. EMTP offers a convenient way to test voltage detector's response to such oscillatory decay. The dynamic response of the power system to faults and automatic reclosing has an important effect on relay performance. This is particularly important on protection systems designed to trip or block on OOS conditions or to respond to rate of change of certain parameters. EMTP may be used to simulate such conditions to determine protection performance.

The time varying response of rotating machines to changes in system conditions has always caused difficulties in protection application. Induction motors can contribute current to short circuits for a brief time, but such contributions are normally neglected in protection applications. Synchronous motors and generators contribute a varying amount of current to short circuits, depending on the type of

Effectively using EMTP can provide answers to relay operations.

Protection engineers are encouraged to apply the various capabilities of EMTP to help them design more robust and dependable power systems.

excitation system and the duration of the period of study. Protection of synchronous motors is normally applied considering response within a cycle or two of the fault initiation, or after a considerable period of time when steady-state fault conditions exist. This type of study leaves a gap in simulation that is readily covered by EMTP simulations of the generator and its excitation system. Synchronous machines could lose synchronism (OOS) with the power system, requiring prompt protective relay action. These OOS conditions are readily simulated by EMTP. The results of such simulations aid in the application of power swing blocking, OOS tripping, or field failure protection applications.

EMTP simulations are not limited to electromagnetic transients. EMTP can be used to study electromechanical transients. For instance, large thermal turbine-generators have been damaged or destroyed by electromechanical subsynchronous oscillations caused by series

## 4a CVT Transients - wave

CVT transients reduce the fundamental voltage magnitude

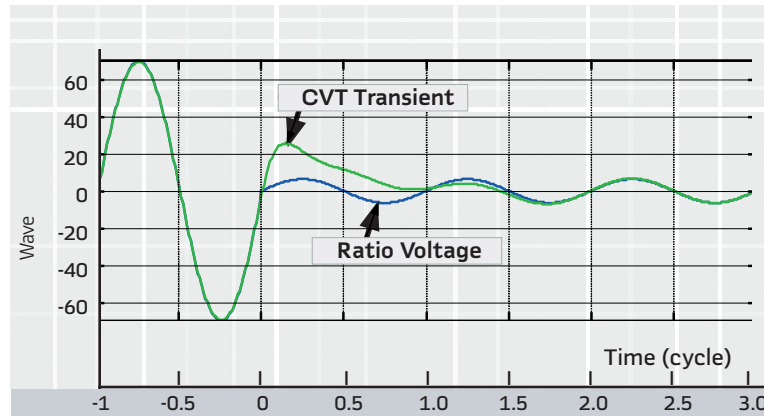


Figure 4 a/b: shows a CVT transient response during a line-to-ground fault.

## 4b CVT Transients - magnitude

CVT transients reduce the fundamental voltage magnitude

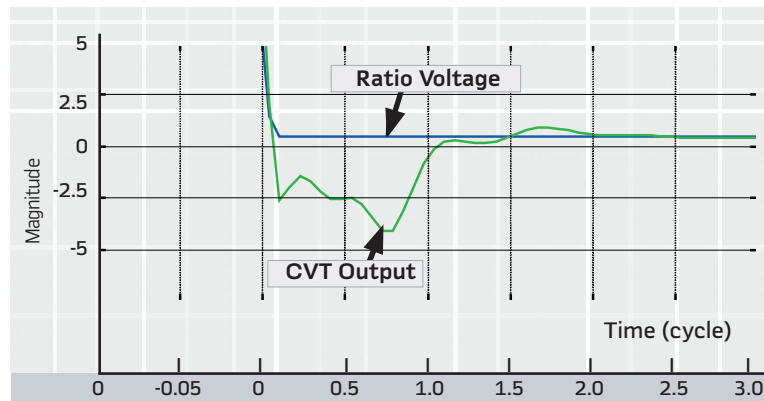


Figure 4 a/b: also shows the fundamental frequency magnitude of a CVT secondary voltage as compared with the ideal ratio voltage.

## 3 Saturated and normal phase currents

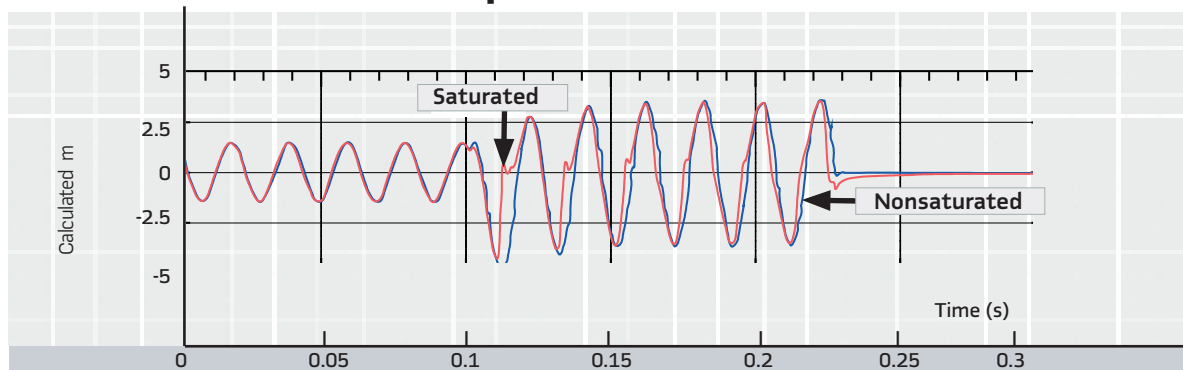
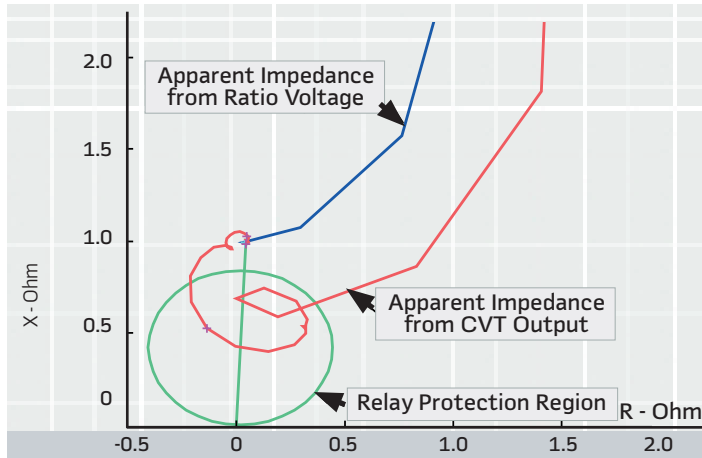


Figure 3: shows the unsaturated and saturated current waveforms from an EMTP simulation of a CT model for a line fault at a distance of 33 percent from the relay location.

## 5 Overreach due to CVT transients

Two apparent impedance loci of an end-of-line fault, calculated from the ideal ratio voltage and the CVT secondary voltage



capacitors on nearby transmission lines. Subsynchronous electrical oscillations can excite mechanical resonances on large thermal turbine generators with sometimes catastrophic results. EMTP simulations have been used to apply protection systems to prevent unit damage by subsynchronous oscillations.

### Examples:

#### ■ Simulation of Instrument Transformer Transients

Current and voltage transducers provide instrument-level signals to protective relays. Protective relay accuracy and performance is directly related to the steady-state and transient performance of the

instrument transformers. Protective relays are designed to operate in a shorter time period than that of the transient disturbance during a system fault. Large instrument transformer transient errors may delay or prevent relay operation. EMTP simulation of instrument transformer transients can be used to study their effect on the performance of relay elements.

#### ■ Simulation of Current Transformer Transients:

CTs can saturate due to large symmetrical fault currents or the prolonged presence of a DC component in the primary fault current. The fidelity of the CT transformation is reasonably good until saturation takes place. Upon

saturation, the CT current delivered to the relays and other instruments deviates in both magnitude and phase angle from the current flowing in the power system. Current transformer transient performance can be easily modeled by EMTP. Transient saturation, steady-state saturation and poor performance, due to low-frequency effects, (including geomagnetic induced currents) can all be simulated.

Figure 1 shows a comparison of recorded laboratory secondary CT waveforms and EMTP simulated secondary CT waveforms. The simulation results are nearly identical to the laboratory tests.

Figure 3 shows the current waveforms from an EMTP simulation of a CT model for a line fault at a distance of 33 % from the relay location. Figure 2 shows the response of a numerical distance relay to the unsaturated and saturated waveforms shown in Figure 3. The calculated distance to the fault *m* value corresponding to a normal fault current, settles to 0.33 as expected. For a saturated phase current (Fig. 3), the calculated distance *m* value crosses the unity line with a half-cycle delay and settles around 0.45 because the current remains in a saturated state.

#### ■ Capacitive Voltage Transformer (CVT) Transients:

Similar to poor CT performance, CVTs can also cause unexpected protection system performance.

## 6 EMTP simulation of out of step phenomena

the OOS condition resembles that of a two-machine system

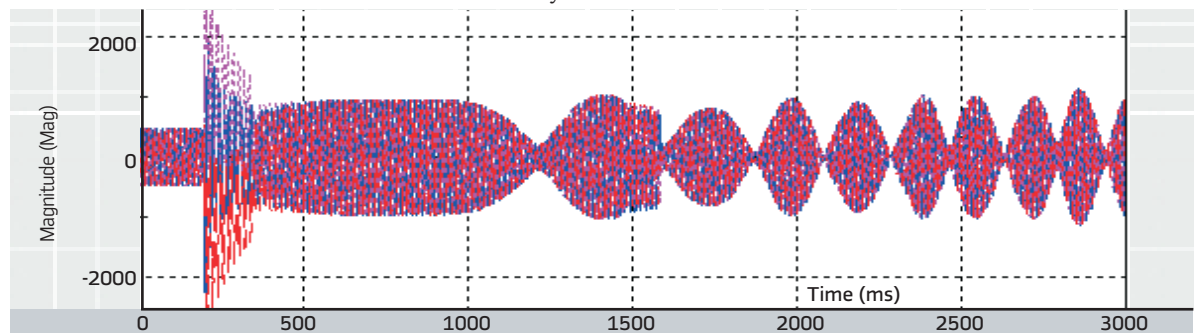


Figure 6, 7: The waveforms shown in those figures are from a simulated multi-machine network.

