PQSoft Case Study

Substation Transformer Switching and Dynamic Overvoltages

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Abstract:

This case study presents the results for a wind plant substation transformer energizing and dynamic overvoltage evaluation. Transformer inrush currents contain harmonic components that may create dynamic overvoltages if a substation transformer is energized with a collector circuit or capacitor bank on the secondary bus. Mitigation alternatives for this problem include energizing a capacitor bank separately from the transformer and energizing the transformer/capacitor bank combination with enough secondary loads to sufficiently damp the transient overvoltages.

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RELATED STANDARDS

IEEE Std. 1159

GLOSSARY AND ACRONYMS

DFT	Discreet Fourier Transform
PCC	Point of Common Coupling
TDD	Total Demand Distortion
TOV	Temporary Overvoltage

INTRODUCTION

A wind plant substation transformer energizing and dynamic overvoltage transient analysis case study was completed for the system shown in Figure 1. The case study investigated transformer energizing transients and the potential for excessive dynamic overvoltages due to resonances created by collector circuit cables or substation capacitor banks. The simulations were completed using the PSCAD® transient program. A transient model was created to simulate a wind plant collector circuit and the resulting transient voltages and currents during transformer switching events.

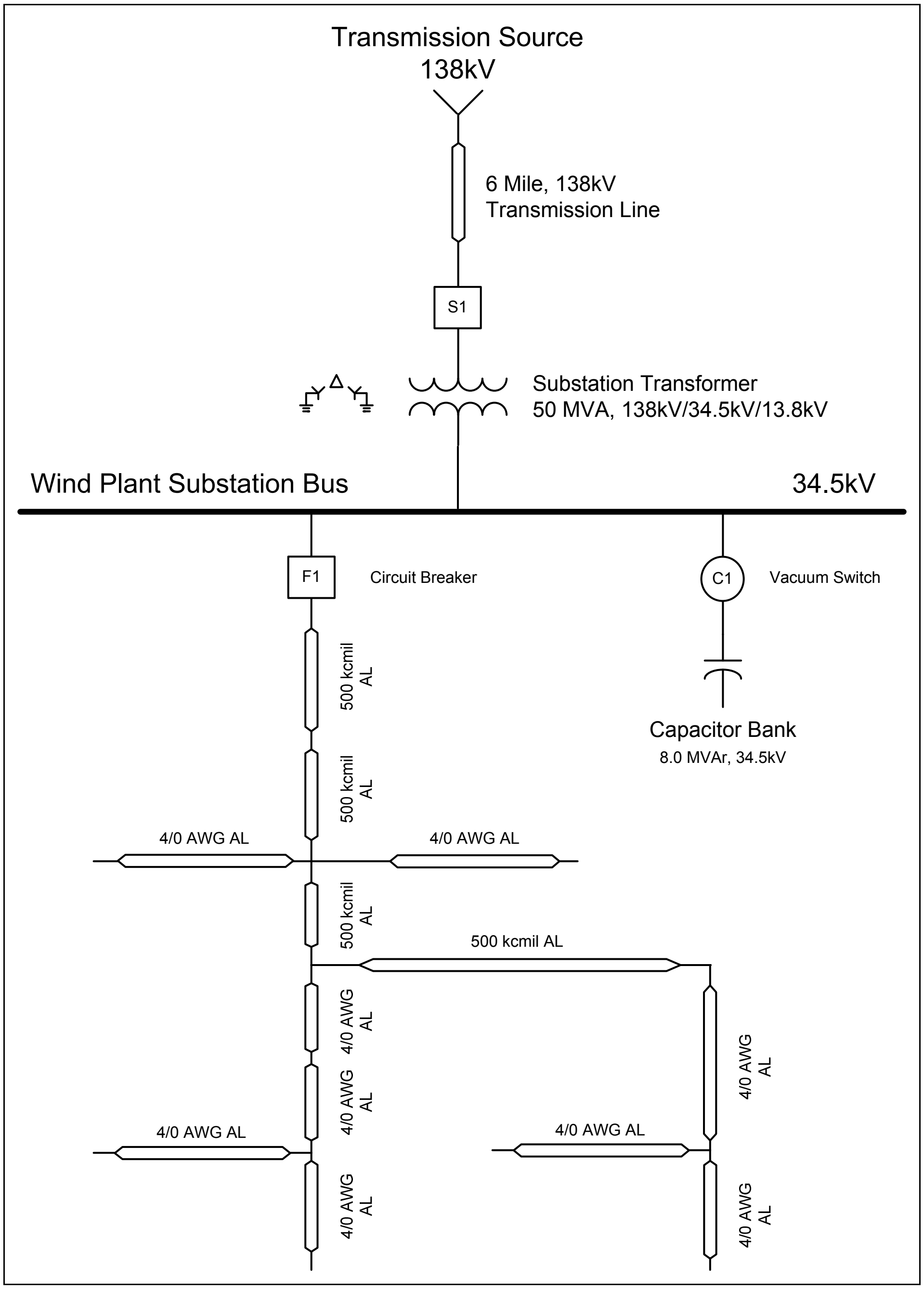

Figure 1 - Illustration of Oneline Diagram for Transformer Switching Analysis

SIMULATION ANALYSIS

The simulation model included a 138kV wind plant substation and a 6-mile transmission line supplying a 50 MVA, 138/34.5/13.8 kV substation transformer. The substation included a 138kV circuit breaker on the transformer high-side bus and an 8 MVAr, 34.5kV capacitor bank on the collector circuit bus. There was one 34.5kV collector circuit included in the model.

The model was designed so transformer energizing transients and the potential for excessive dynamic overvoltages due to resonances created by collector circuit cables or substation capacitor banks could be determined. The accuracy of the simulation model at 60 Hz was determined using simulated fault current magnitudes and other steady-state quantities, such as cable line charging (MVAr) and feeder load flow values (MW & MVAr). The representation of the system short-circuit equivalent at the 138kV source substation, under assumed normal system conditions, included:

Three-phase ($I_{3\varphi}$) fault current: .... 17,500 A @ -85.0° (4183 MVA)
Single-line-to-ground ($I_{\varphi G}$) fault current: .... 20,000 A @ -85.0° (4780 MVA)

These values were converted to ohms for the PSCAD representation, which included a three-phase voltage source with positive and zero sequence impedances. The 6.0 mile, 138kV transmission line was modeled using the following data:

Length: .... 6.0 mi
Positive sequence impedance (Z_1): .... 0.11660 +j0.68140 Ω/mi
Zero sequence impedance (Z_0): .... 0.40245 +j2.72030 Ω/mi
Positive sequence line charging (X_{C1}): .... 0.168142 MΩ-mi
Zero sequence line charging (X_{C0}): .... 0.296228 MΩ-mi

The coupled π-section model was used to model the transmission line. That assured accurate representation of both the series impedances, as well as the line charging characteristics of the transmission line. The coupled π-section is primarily used to represent short overhead transmission lines or underground cables.

The substation transformer was modeled using the classical three-phase, three-winding transformer model. The nameplate impedance data for the substation transformer included:

%Z_1 @ 50 MVA, 138/34.5/13.8kV	% R	% X
Primary - Secondary (H-X)	0.320	8.50
Primary - Tertiary (H-Y)	0.400	10.00
Secondary - Tertiary (X-Y)	0.020	4.00

%Z_0 @ 50 MVA, 138/34.5/13.8kV	% R	% X
Primary - Secondary (H-X)	0.320	8.00
Primary - Tertiary (H-Y)	0.400	9.00
Secondary - Tertiary (X-Y)	0.020	3.50

The 34.5kV collector circuit cable sections were included in the transient model using the following impedance data:

Conductor: .... 500 kcmil AL
Length: .... 2,000 feet
Positive sequence impedance (Z_1): .... 0.0499 +j0.0553 Ω/1000’
Zero sequence impedance (Z_0): .... 0.1508 +j0.0599 Ω/1000’
Line charging (B/2): .... 11.5 μmhos/1000’

Conductor:..4/0 AWG AL
Length: ....1,000 feet
Positive sequence impedance (Z_1): .... 0.1087 +j0.0653 Ω/1000’
Zero sequence impedance (Z_0):............ 0.2567 +j0.0688 Ω/1000’
Line charging (B/2):.. 8.7 μmhos/1000’

It was assumed that positive and zero sequence line charging values were the same. The coupled π-section model was used to model each cable section. That assured accurate representation of both the series impedances, as well as the line charging of the collector system cables.

The peak magnitude and duration of the transformer inrush current is dependent on a number of factors, including, the point on the voltage waveform when the switch contact is closed, the impedance of the circuit supplying the transformer, the value of the residual flux in the core, and the nonlinear magnetic saturation characteristic of the transformer core. Typical transient inrush current magnitudes for energizing unloaded transformers are 5-10 times the rated transformer current. However, these values may be somewhat lower when energizing a transformer from a relatively weak source.

The substation transformer was modeled using the three-phase, three-winding classical transformer model. The nonlinear portion (saturation) of the transformer characteristic was included by specifying three parameters of the core saturation characteristic. The air core reactance of the transformer was 0.2 per-unit, the knee voltage was 1.2 per-unit, and the magnetizing current was 0.1%. The calculated full load current (high-side) for the transformer is 210 amps.

The three circuit breaker closing times were selected to be three successive phase voltage zero values so the worst-case inrush currents, without residual flux, would be simulated. The equivalent source voltage for the transformer inrush case was adjusted so that the pre-switching voltage magnitude at the transformer high-side would be 1.05 per-unit (105%).

Case 1 involved energizing the substation transformer with no collector circuits or capacitor banks in-service (unloaded). This was the initial basecase to determine the transformer energizing transient inrush current magnitude. Figure 2 shows the simulated three-phase transformer primary inrush current for Case 1, while Figure 3highlights the Phase A current. The peak transient current magnitude was 818.9 amps.

Figure 4 shows the three-phase 34.5kV transformer secondary voltages for Case 1. The peak voltage is 1.05 per-unit. There were no dynamic overvoltages during the energizing event without any capacitance connected to the transformer secondary winding.

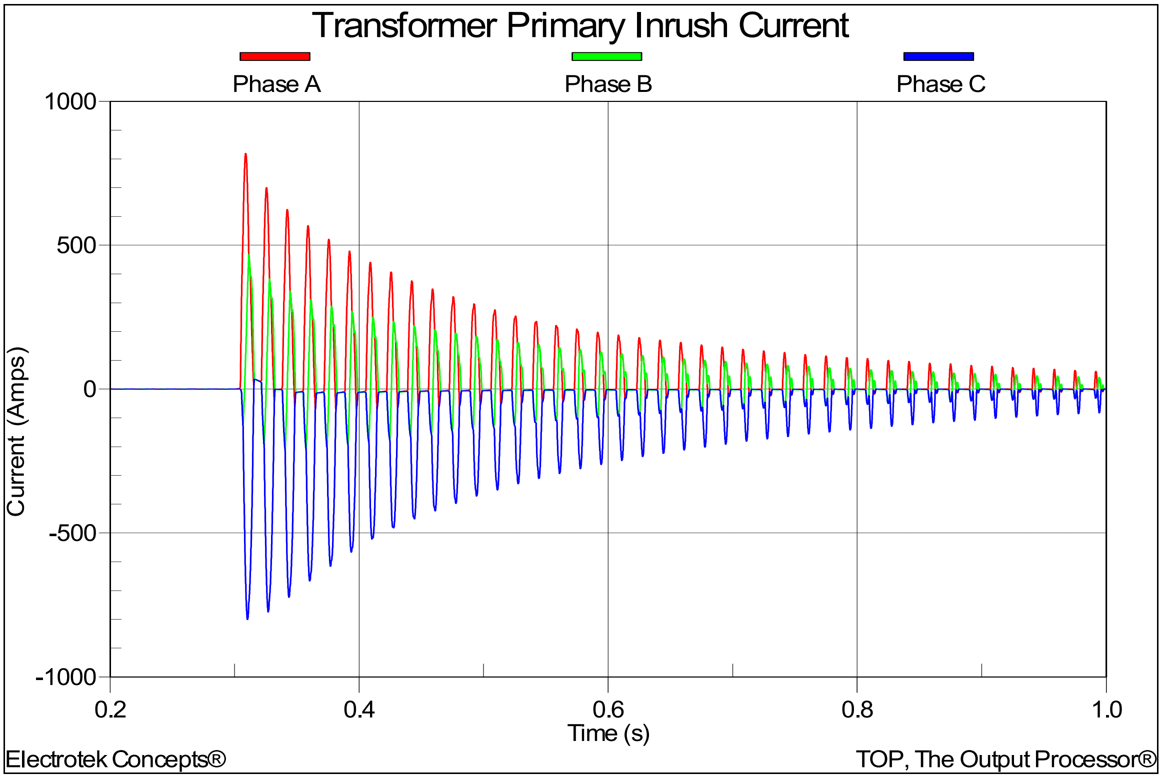

Figure 2 - Simulated Three-Phase Transformer Energizing Current for Case 1

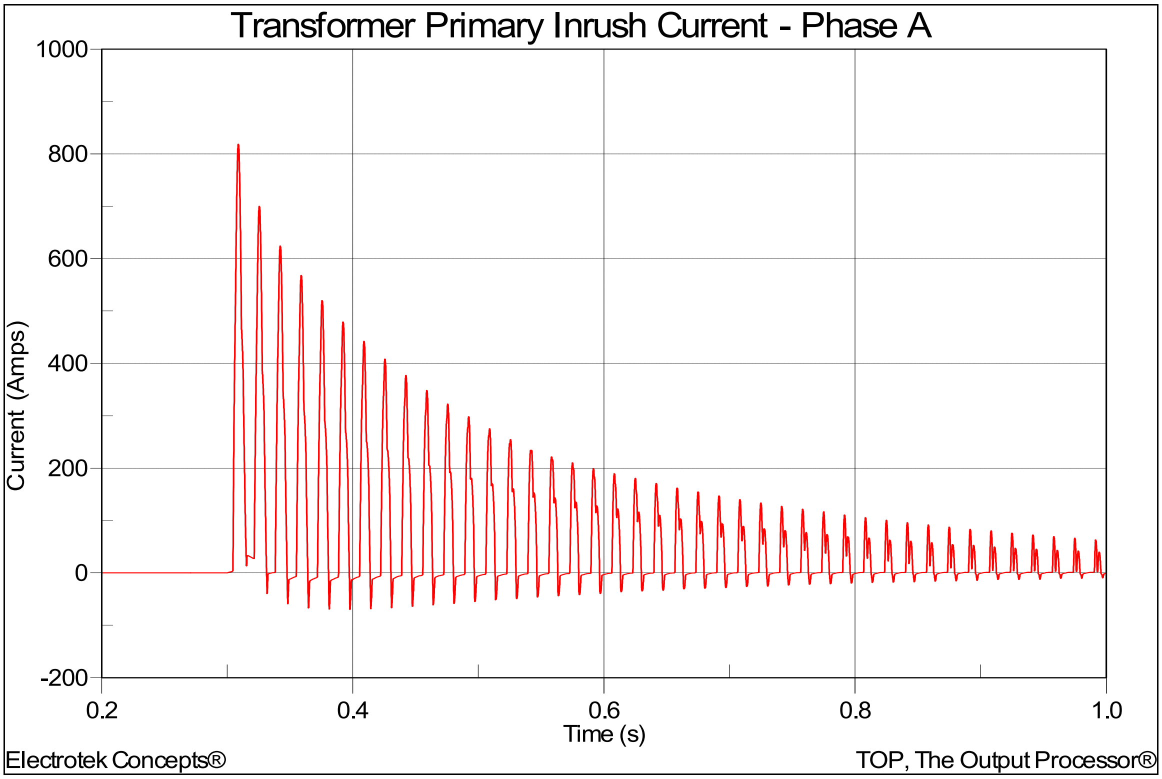

Figure 3 - Simulated Transformer Energizing Current (Phase A) for Case 1

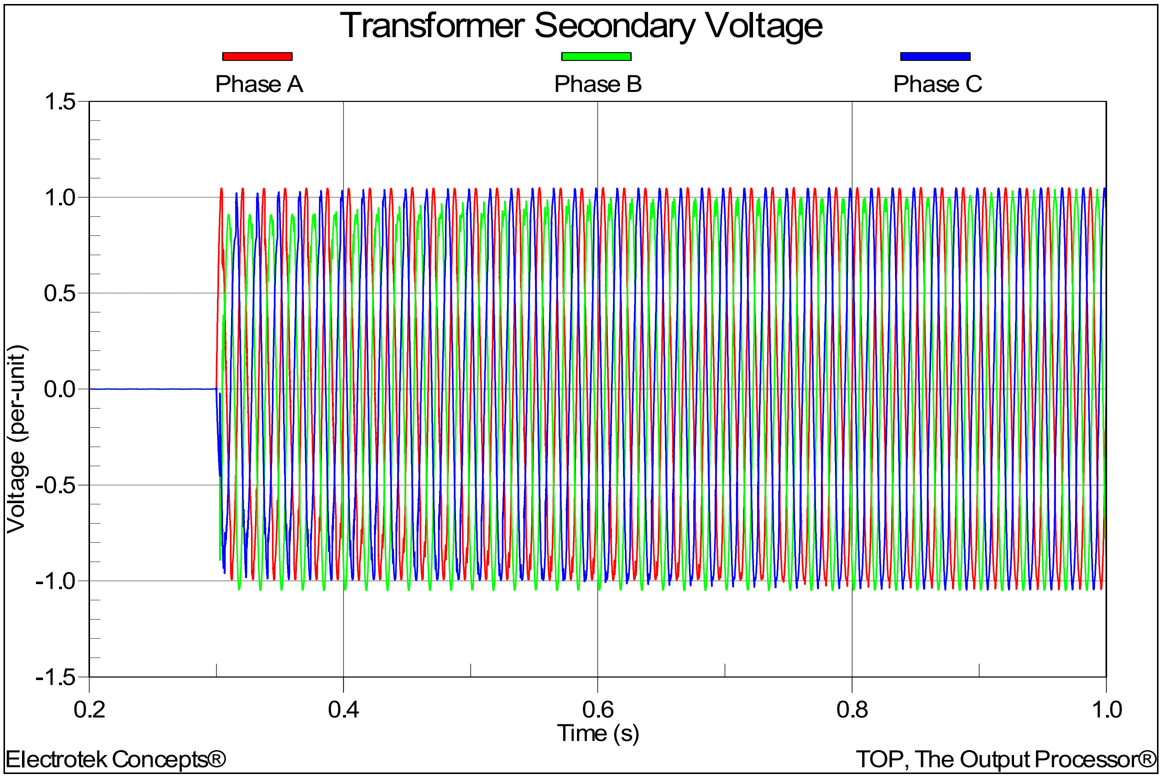

Figure 4 - Simulated Substation Transformer Secondary Voltage for Case 1

Case 2 involved energizing the substation transformer with the 34.5kV collector circuit in-service. The peak transient current magnitude was 822.8 amps. Figure 5 shows the resulting three-phase 34.5kV transformer secondary voltages for Case 2.

The peak transient voltage on the transformer secondary bus increased to 1.33 per-unit with the collector circuit in-service for Case 2. This value is below the assumed protective levels of most typical surge arresters (e.g., MSSPL ~ 1.90 per-unit), so it is anticipated that the arresters would not operate for this condition.

Case 3 involved energizing the substation transformer with both the 34.5kV collector circuit and an 8 MVAr, 34.5kV capacitor bank in-service. The peak transient current magnitude was 968.6 amps. Figure 6 shows the resulting three-phase 34.5kV transformer secondary voltages for Case 3.

The maximum transient voltage on the transformer secondary bus increased to 1.45 per-unit with the substation capacitor bank and collector circuit in-service for Case 3. This value is below the assumed protective levels of most typical surge arresters (e.g., MSSPL ~ 1.90 per-unit), so it is anticipated that the arresters would not operate for this condition.

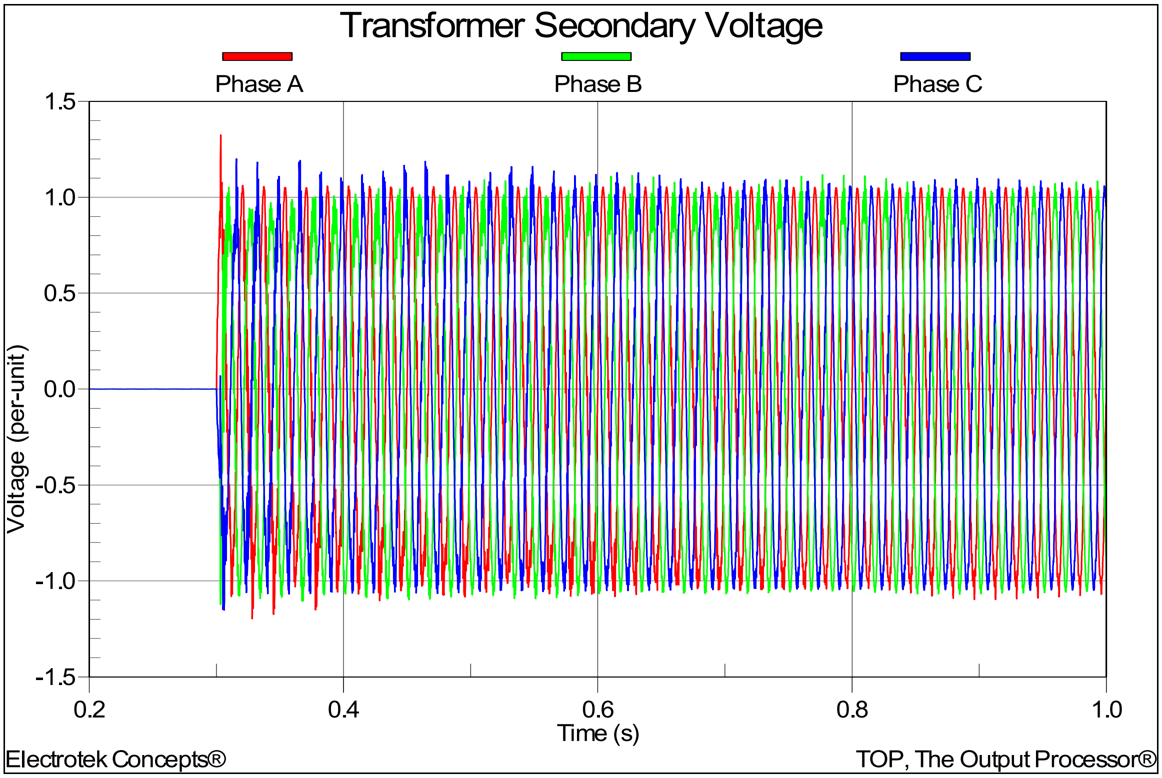

Figure 5 - Simulated Substation Transformer Secondary Voltage for Case 2

Figure 6 - Simulated Substation Transformer Secondary Voltage for Case 3

SUMMARY

This case study presented a wind plant substation transformer energizing and dynamic overvoltage evaluation. Transformer inrush currents contain harmonic components that may create dynamic overvoltages if a substation transformer is energized with a collector circuit or capacitor bank on the secondary bus.

Mitigation alternatives for this problem include energizing a capacitor bank separately from the transformer and energizing the transformer/capacitor bank combination with enough secondary loads to sufficiently damp the transient overvoltages. The concern for dynamic overvoltages is typically limited to cases of energizing large substation transformers with large power factor correction capacitor banks.

The simulation results highlight a concern for dynamic overvoltages when the substation transformer is energized from the primary side with the 34.5kV collector circuit or 8 MVAr capacitor bank in-service. The peak transient voltage on the transformer secondary 34.5kV bus was 1.33 per-unit with the collector circuit in-service and 1.45 per-unit with both the collector circuit and capacitor bank in-service. The transient voltages were below typical surge arrester protective levels (e.g., MSSPL ~ 1.9 per-unit), so it is anticipated that MOV surge arresters would not operate during substation transformer energizing with the simulated circuit conditions.

REFERENCES

1. IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems, IEEE Std. 142 (IEEE Green Book), IEEE, November 2007, ISBN: 0738156392.
2. IEEE Recommended Practice for Monitoring Electric Power Quality," IEEE Std. 1159-1995, IEEE, October 1995, ISBN: 1-55937-549-3.
3. IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems, IEEE Std. 519-1992, IEEE, ISBN: 1-5593-7239-7.