Restructuring and Innovating of Power System Analysis and Power Electronics Courses at the University of Northern Iowa

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Abstract

This paper presents; (1) innovating changes to a course, power system analysis (PSA), and (2) development of a new course, industrial applications of power electronics (IAPE) aided with advanced power system simulation studies at the University of Northern Iowa (UNI), Electro-Mechanical Systems (EMS) – Engineering Technology division of Industrial Technology Department. Basic energy and power concepts will be introduced in required major core courses and this change will provide students the core background in power along with additional breadth in digital systems, signal theory, and basics of modern control theory. Students will also be introduced to power quality issues of grid-connected solar and wind powered systems in both classes. Real-time power monitoring studies will be part of the laboratory sessions of the PSA course. The PSA course will be dealing with mostly the complete system and related topics, while the IAPE course will be concentrating on individual devices and drives. Since the EMS program does not have a physical power system simulator yet, a well-known power system simulation program PSCAD/EMTDC developed by Manitoba HVDC Research Center will be used as a digital simulation tool in both courses. Two example cases are simulated, and the results are reported in this study. The first one is a power system fault study, which includes generator, transformers, transmission lines, circuit breakers, and three separate loads including one 500 HP induction motor. The second case study is an AC/DC power system interaction based on a proposed 1000 MW High Voltage Direct Current (HVDC) transmission line between Wyoming and California in order to export Wyoming's rich electrical power resources.

Key Words: Power Systems, Curriculum Development, Digital Simulation, and Stability Analysis.

I. Introduction

Although electrical power engineering education continues to be a great area in the U.S., traditional energy system and electrical machinery courses have been adversely affected by the lack of undergraduate and graduate enrollments at the University of Northern Iowa as well as at some other U.S. colleges. The traditional power and electrical machinery courses are based on an overwhelming amount of analysis starting from the introduction to three-phase and magnetic circuits to machine theory, and systems. Therefore, this may be one reason for declining student interest in power system and machinery courses. However, there are a lot of opportunities for a dynamic professor to attract students to engineering and technology teaching and research in the electrical power area by stimulating interdisciplinary topics using modern control, digital systems, fuzzy logic, neural networks, and signal processing.

There are many promising studies documenting the results in curriculum development in energy and power area. An interconnected power systems laboratory aided with data acquisition and real-time simulation tools has increased the student interest in the power system curriculum of the electrical engineering department at Drexel University [1]. Multimedia tools and well-designed animations describing AC and DC machine operation, and transmission systems transients resulted in a better learning experience at the Virginia Polytechnic Institute and State University [2]. A knowledge-based tutoring system for teaching fault analysis has increased student attention to energy and power engineering [3]. The development of design-based and project-oriented courses has increased the enrollments more than 11 percent at the Nanyang Technological University [4]. Another project-oriented power engineering laboratory, based on Computer Aided Design (CAD) technique, where students analyze, design, simulate, and demonstrate power system related topics has been successful compared with traditional power engineering laboratories [5]. A MATLAB-based power system analysis and design software has been taught in basic principles of power system stability and modeling at Rensselaer Polytechnic Institute [6]. Another advanced computer program, Electric Machine Analysis program (EMAP) was developed to provide easy and fast access to answers for self-checking of student work [7]. EMAP brought many user-defined models and gained student interest to power system studies. Furthermore, new material added to power system course topics such as environmental effects of electromagnetic fields, alternate generating sources and graphical based power system simulation programs increase student attention and the number of enrollments in this area.

Although there are decreasing enrollments in some of the power and energy undergraduate courses, there are also excellent enrollments in courses on new material such as environment, power electronics, and renewable generating sources [8].

This study documents curriculum developments in electrical power and energy courses at the UNI. The UNI - Department of Industrial Technology offers BS degree in the Electro-Mechanical Systems covering two separate options; (1) Engineering Technology, and (2) Industrial Supervision and Management. Students used to take AC/DC circuits knowledge from a three-credit circuit course, which was not enough to include many topics to help the advanced power courses. In the new curriculum, the basic circuits course is increased to four credits to introduce basic energy and power concepts. This change will provide students the core background in power, so that additional breadth in simulation applications of digital systems, signal theory, and basics of modern control theory to power systems will be introduced in the advanced power courses. To include renewable energy developments in the power program, a wind power generator unit has already been installed at the Industrial Technology Center (ITC), and an additional solar power generation unit, which has a power rating of 0.525 kW will be added soon. The total power generated from the hybrid system, a combination of solar and wind generation, will be monitored and analyzed for a better power quality fed to the local power grid.

II. Power System Transient Studies

Analysis of power system transients plays a significant role in power system stability studies. Although due to the curriculum limitations, most of the detailed transient studies are generally involved in graduate level power system courses, some introduction would be very helpful for undergraduate students. Transient stability in which the considered period of time is usually limited to 3 to 5 seconds following disturbance, is the ability of the power system to maintain synchronism when subjected to a severe transient disturbances such as loss of generation, line-switching operations, faults, and sudden load changes [9-10]. A real-time power system simulator interfaced with a digital computer would be significant tool for power system simulation and transient studies. Although considerable linearizations may oversimplify the actual large system model, an appropriate power system model can still be obtained and its transient, steady state, and dynamic stability analysis provides considerable information about the system.

III. Power System Simulation

One of the best methods for obtaining a power system analysis study is through simulation on a digital computer. Electromagnetic transients simulation is a detailed field of study allowing exploration into circuit and system analysis, signals and systems, and control theory. Therefore, compared with the transient network analyzers, the simulation time for the entire power system model is shortened dramatically due to the digital models used in the system modeling. Power system electromagnetic transient studies typically need a complex computer program called the Electromagnetic Transients Program (EMTP) first developed by the Bonneville Power Administration (BPA) in 1969. At present four large-scale power system transients programs are commercially available: EMTP96 (developed by the Electric Power Research Institute) [11], EMTP-BPA-ATP [12], PSCAD/EMTDC (Electromagnetic Transients Program of Manitoba HVDC Research Center) [13], and NETOMAC [14]. These software packages are used to simulate electromagnetic, electromechanical, and control system high-speed power transients on both three-phase and multi-phase electric power systems.

The EMTP was first developed as a digital computer counterpart to the analog Transient Network Analyzer (TNA). Many other capabilities including transient analysis of control systems, HVDC and Static Var Compensator (SVC) controls are added to the EMTP and EMTDC. EMTP and EMTDC have continued to be valuable tools to simulate any newly developed control strategies and devices for power system stability and dynamic performance improvement. The PSCAD/EMTDC is chosen as a simulation tool to be used in new power system and power electronics curriculum at the UNI. The program’s performance has been acceptable and used by many universities, research institutions and power industry. The strength of EMTDC is its ability to model any conceivable power system with almost all the components and control sections. The EMTDC is packaged with a graphical interface, Power System Computer Aided Design, PSCAD, which has friendly features that does not require much time to learn.

The following case studies will be covered in both courses; digital filter applications in ac/dc power systems, power system fault studies, HVDC transmission simulation and HVDC control, ac/dc power system interactions, static var compensation (SVC) control using FACTS devices, optimal reactive power allocation issues, power quality studies using pulse width modulation (PWM) for ac voltage control, harmonic studies due to the nonlinear loads, power industry bundling and restructuring issues, and power quality problems of grid-connected solar and wind powered systems. Digital simulations using PSCAD/EMTDC are accomplished for most of the cases mentioned above. This paper discusses only two of these cases and their corresponding simulations. According to the number of early enrollments, the EMS program will have enough students in both courses for the semesters of spring and summer 1999.

IV. Case Studies

To analyze the transient operations, two example studies, Case 1 and Case 2 to be used in the courses of PSA and IAPE are documented in this study. Switching studies based on single phase-to-ground faults and a three-phase-to-ground fault are simulated and the results are discussed.

IV.1 Case 1

Figure 1 shows a single-line diagram of Case 1, a simple power system with a generator (G_1), a transmission line between a step up (T_1) and a step down (T_2) transformers, and three types of loads including an induction motor with a power rating of 500 HP at the point of common coupling (PCC). For the detailed system model shown in Figure 2, a single-phase (C) to ground fault at the distribution transformer (T_2) terminals is applied at 0.2 s, and cleared at 0.25 s. Another single-phase (C) to ground fault on the G_1 generator terminals is simulated with the fault occurring at 0.4 s and clearing at 0.45 s.

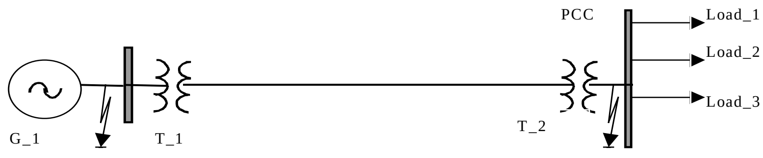

Figure 1. Single-line diagram of Case 1

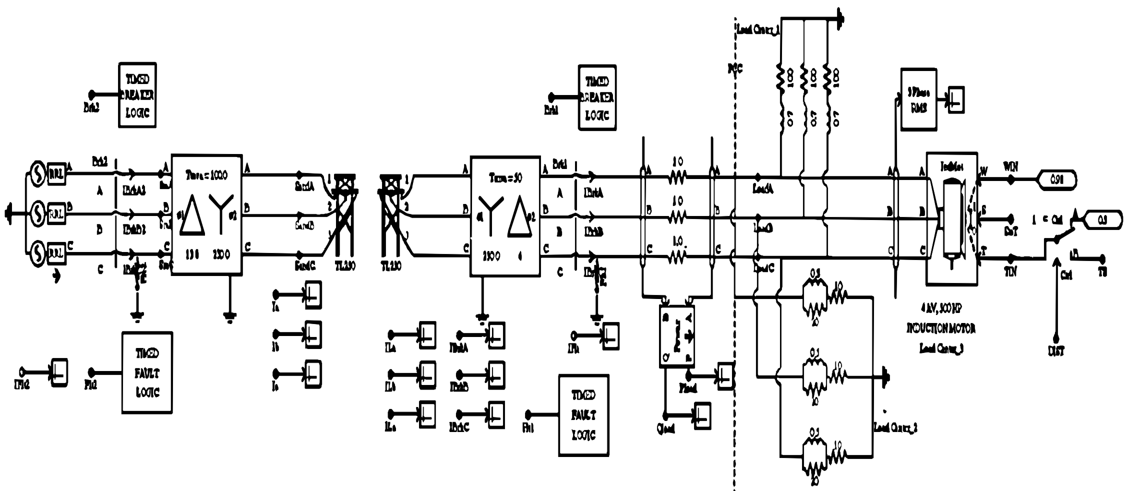

Figure 2. Detailed PSCAD/EMTDC draft of Case 1

Figure 3 (a) shows that the generator voltages for the phases A and C are not affected from the first fault at 0.2 s due to the fast generator exciter control system. The second fault at the generator terminals caused the phase_A voltage to oscillate between the peak values of ±14 kV, while the faulty phase_C stayed zero during the fault. Figure 3 (b) shows that the load voltages are affected considerably due to both faults. The induction motor terminal RMS voltage decreased to a minimum value of 2.1kV during the first fault, and reached its rated value at about 0.1 s, after the fault occurs. The second fault caused oscillations across the induction motor terminals between the RMS values of 4.1 kV and 1.7 kV. As seen in Figure 3 (b), the first fault caused the phase_A voltage to oscillate between the peak values of 5.7

kV and –3.2 kV across the distribution bus. In Figure 3 (c), the ILc shows the current waveform of the load through the distribution transformer (T_2). As seen in Figure 3 (c), phase_A and phase_C currents were around zero during the first fault at the PCC, since the circuit breaker opened the circuit. However, the second fault caused high oscillations in phase_A current waveform. Figure 3 (d) shows real and reactive power transfer waveforms from generator bus to the PCC.

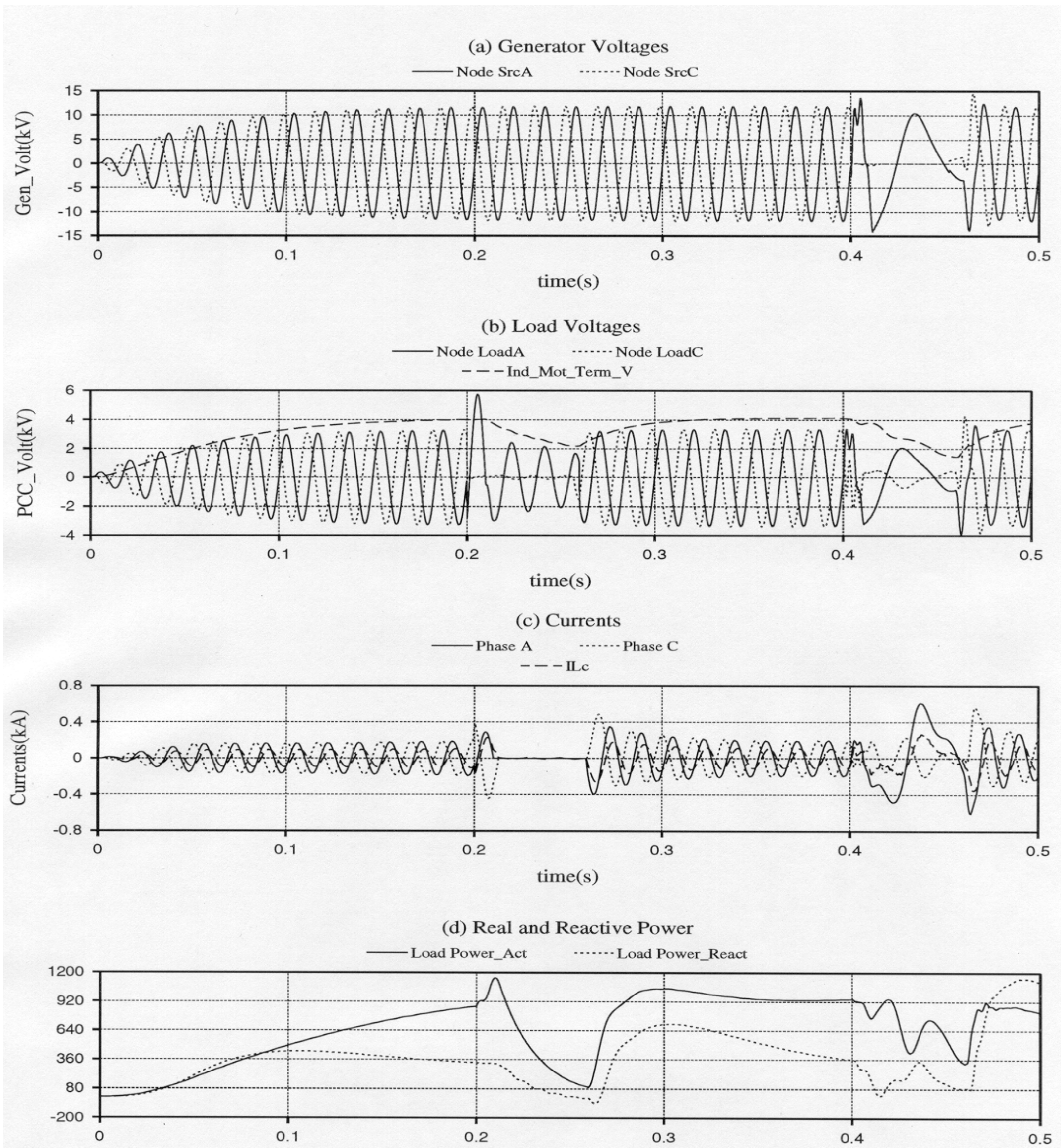

Figure 3. Simulation results for Case 1

IV.2 Case 2

This case study is based on investigation of ac/dc power system interactions including ac/dc and dc/ac converter operations for a proposed HVDC transmission line from Wyoming to

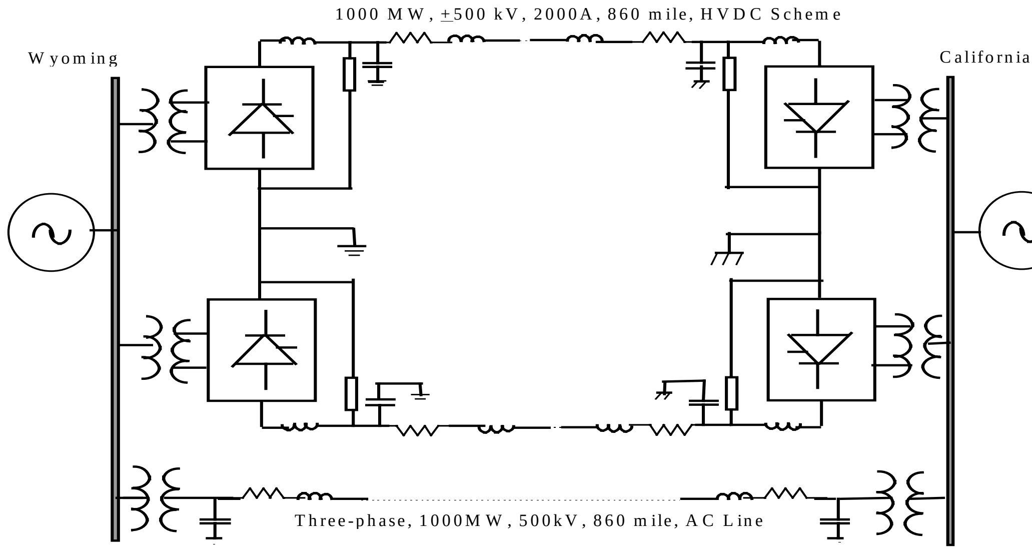

Figure 4. Single-line diagram of Case 2

California as shown in Figure 4 [15-16]. There are three types of faults that affect any ac/dc system: (i) faults on the dc line; (ii) faults on the ac system including ac lines; and (iii) faults

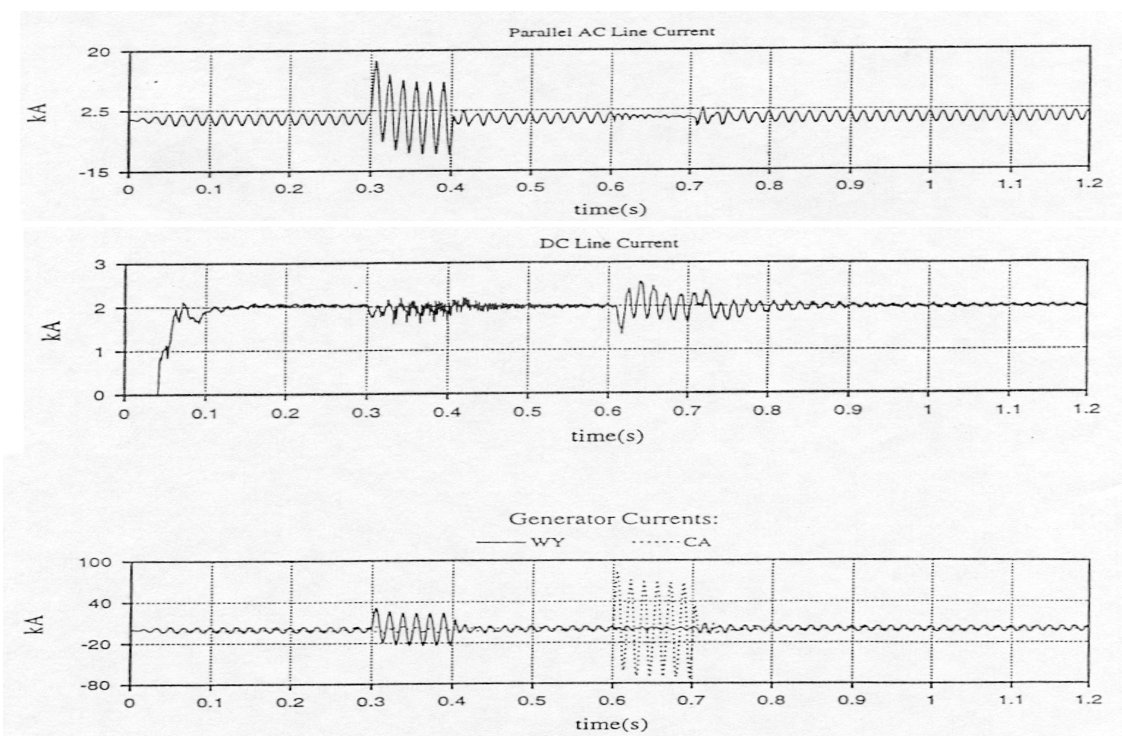

Figure 5. Current waveforms for Case 2

at the converter stations. The converter controls play a significant role for the transient period of the faults in the dc systems, while circuit breakers equipped with measurement and protection relays detect and try to remove the faults in the ac systems. In addition to these fault clearing actions, tap changers of converter transformers also help the steady-state stability to be preserved in a longer time period following a disturbance [15-17].

For the system model shown in Figure 4, three-phase to ground faults, one occurring on the parallel ac line at the Wyoming end and the other occurring at the California end, are simulated with the faults occurring at 0.3 s and at 0.6 s, respectively, with both of the faults clearing in 0.1 s. The corresponding results with a control scheme using a Proportional-Integral (PI) controller available in PSCAD/EMTDC is documented in Figure 5-6.

Figure 5 shows that the generator current at the Wyoming end changes from a peak value of 4.64 kA before the first fault, to a peak value of 32.92 kA after the fault. After the first fault cleared, it attained the pre-fault value in about 0.11 s. The California end generator current slightly decreased and oscillated until the fault cleared.

As seen in Figure 5, the pre-fault dc line current of 2 kA from the Wyoming end started to decrease to a minimum peak of 1.73 kA during the first fault duration. After the clearing of the fault, the dc line current increased to 2.26 kA and reached the rated value of 2 kA in about 0.04 s. Similarly, the dc line current oscillated between 2.7 kA and 1.37 kA due to the second fault. After this second fault clears out, the dc line current reached the rated value of 2 kA in about 0.22 s. Figure 5 also shows that the parallel ac line current at the Wyoming end oscillated between 16.85 kA and -10.28 kA and reached the rated value of $\pm$1.68 kA in about 0.16 s, after the first fault cleared.

As seen in Figure 6, an ac fault at 0.3 s caused the generator voltage at the Wyoming end to drop to about 0.95 pu, and at the California end to oscillate very slightly. Similarly, the second fault, also caused the voltage to drop to about 0.95 pu at the California end and

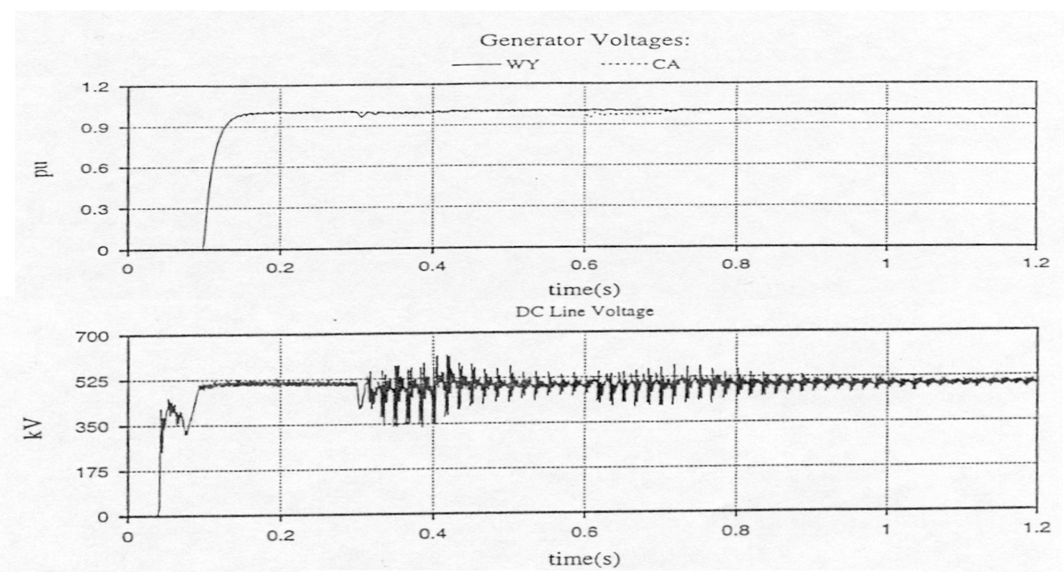

Figure 6. Voltage waveforms for Case 2

resulted in slight oscillations at the other end. Similarly, the dc line voltage oscillated between 590 kV and 337 kV and reached the pre-fault value in about 0.62 s after the first fault cleared.

Figure 7 shows the dc tie power transfer from the Wyoming end to the California end. The power transfer decreased to 0.85 pu during the fault, but the rated dc power transfer

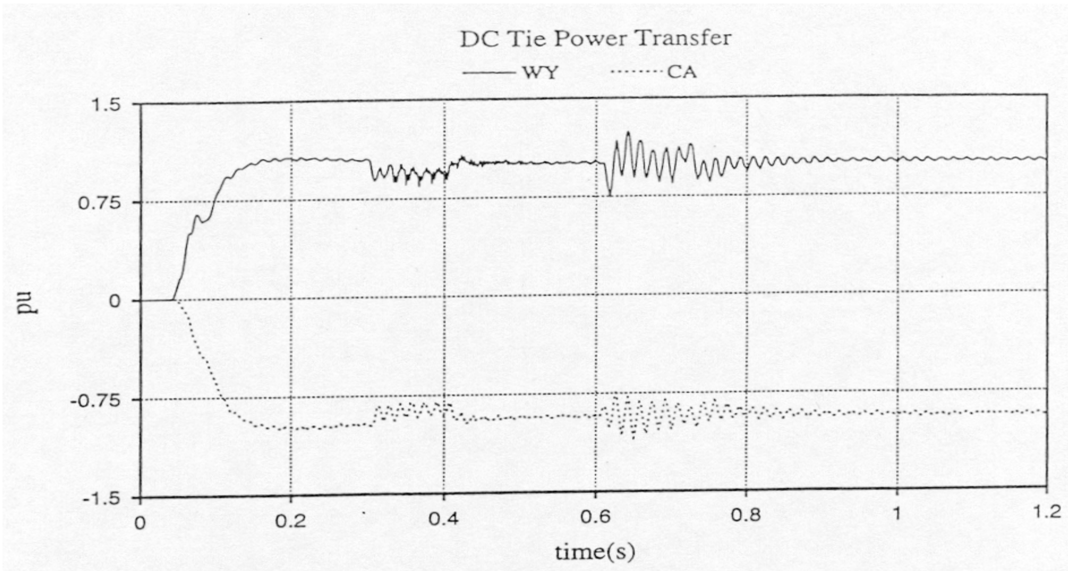

Figure 7. Power transfer waveforms for Case 2

recovered in about 0.07 s after the first fault cleared. Due to the second fault, the sending power started to oscillate between 1.26 pu and 0.76 pu. After the second fault clearing, the rated dc power transmission is reached in 0.22 s. The receiving power at the California end had similar effects.

V. Conclusions

Novel computer classroom aides with digital simulation tools, real-time simulation programs, state-of-the-art laboratories, interdisciplinary collaborations such as applications of digital control, signals and systems, neural networks, and fuzzy logic into power systems have great impact to development of electrical power, machinery and energy programs around the world. It is the recommendation of the author that investigators performing any future work in this topic try to apply more interdisciplinary collaborations into power systems and power electronics studies. In another study, the author has shown that the Kalman filtering, a digital filtering method in discrete-time, applied to the HVDC converter control system discussed in Case 2 of this paper has improved the overall AC/DC power system performance by reducing the voltage and current transients [15-16]. The case studies discussed in this paper have shown that PSCAD/EMTDC will have a great impact to new power technology curriculum at the University of Northern Iowa.

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