Centre Journal

Winter 2002

Inside this issue:

Frequency Response of a Unified Power Flow Controller

FACTS devices, like the Unified Power Flow Controller (UPFC), are likely to find increasing applications in modern power transmission networks. The UPFC, shown in Figure 1, consists of a shunt and series Voltage Sourced Converter (VSC) sharing a common dc busbar. The series converter allows for the injection, within certain limits, of an arbitrary ac voltage in series with the transmission line, thereby allowing precise control of the real and reactive power flows (*p* and *q*) on the line. The shunt converter supplies the necessary

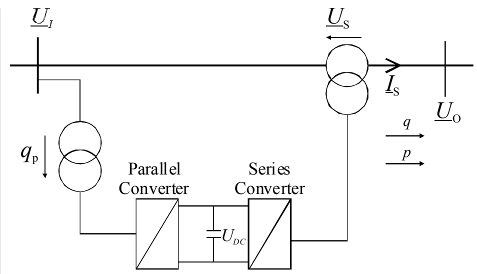


***Figure 1:** UPFC Schematic Diagram*

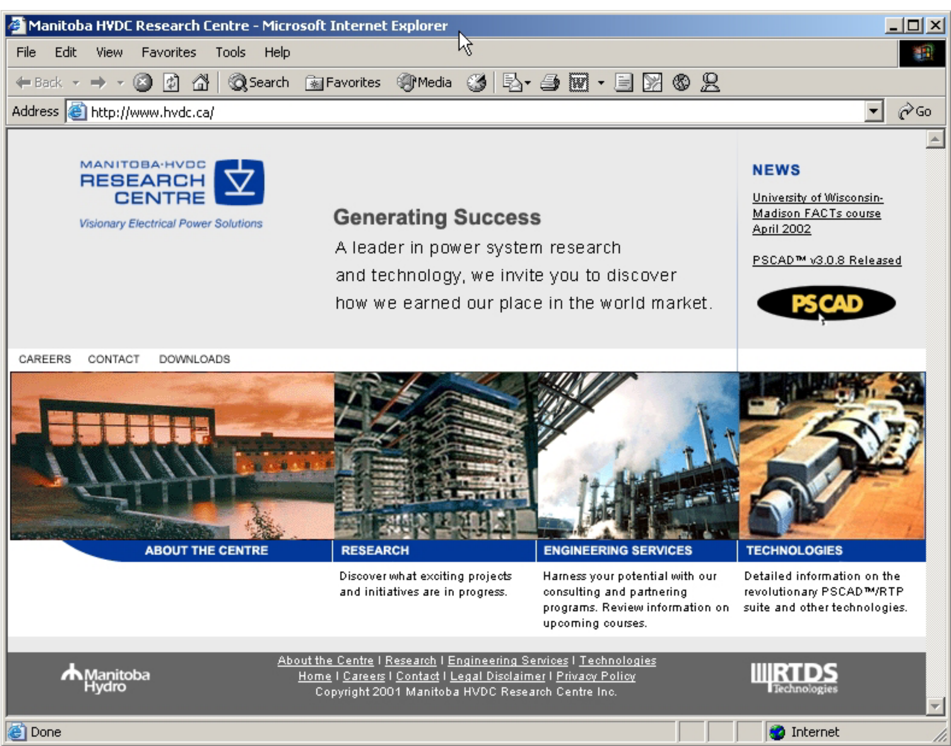
real power to the series converter and is also capable of independently generating reactive power at the ac posed on the balanced three phase ac waveforms. The resulting currents in the UPFC are at frequencies ω, as well as at a frequency ω-$2\omega_o$, ω_o, being the fundamental frequency. The component at frequency ω is of the same phase sequence as the exciting voltage, whereas the ω-$2\omega_o$ component is of opposite phase sequence. Similarly, a harmonic of frequency ω-ω_o is also introduced onto the capacitor dc voltage. An expression of the form $\mathbf{X}_\omega=\mathbf{T}_\omega\mathbf{U}_\omega$, where $\mathbf{X}_\omega$ is a vector containing the various direct and quadrature components of the shunt and series currents at angular frequencies ω, ω-$2\omega_o$; and the capacitor voltage at angular frequency ω-ω_o. The vector $\mathbf{U}_\omega$ consists of the direct and quadrature components of the series and shunt exciting voltages. The mathematical equation for $\mathbf{T}_\omega$ is derived in the reference, and is a function of the UPFC's component values, as well as its operating point. From this equation, the response of any of the entries in $\mathbf{X}_\omega$ to the excitation $\mathbf{U}_\omega$ can be plotted as a function of frequency.

Figure 2 shows the frequency response for a negative sequence

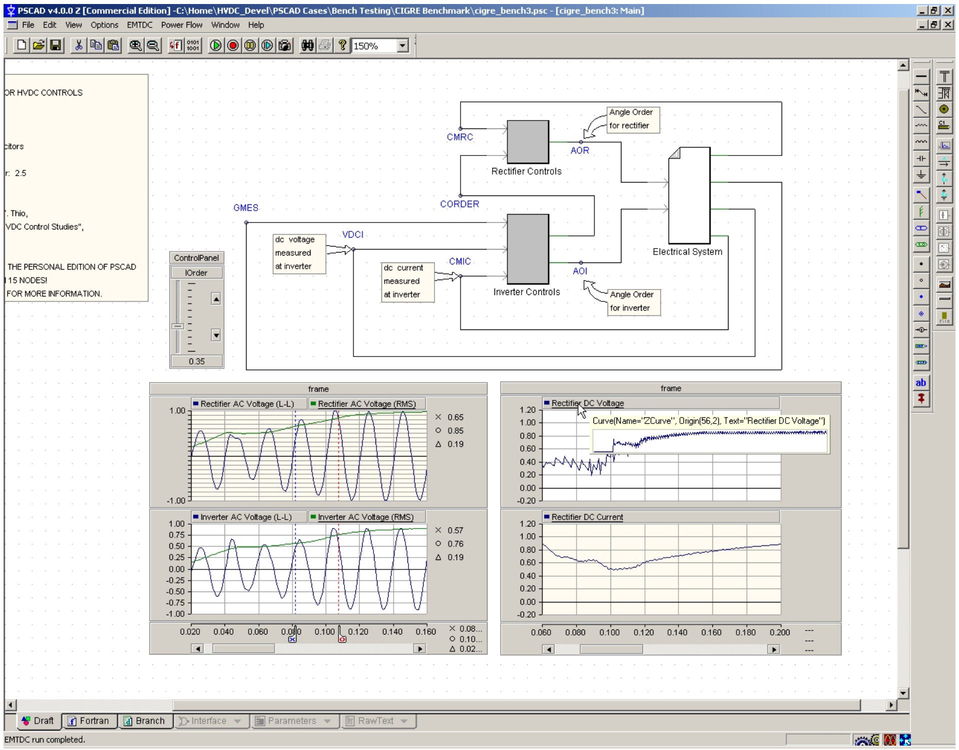
Continued on page 3...

Visit the New HVDC Research Centre Website

We invite you to visit the new Manitoba HVDC Research Centre website at www.hvdc.ca. This site will be an important information link for all of our customers and research partners. Also stay tuned for www.pscad.com, which will be a valuable information source for all PSCAD simulation users.



PSCAD V4 Power System Simulation Suite Development



Significant progress has been made here at the Centre towards the upcoming release of PSCAD V4. PSCAD V4 will be an integrated set of power systems simulation and analysis tools all benefiting from the core PSCAD graphical design environment and advanced plotting technology.

PSCAD V4.0 incorporates a new Microsoft Foundation Class (MFC) based graphical programming architecture, which provides a common look and feel to PSCAD V4 application modules. An intuitive navigation structure, new plotting and controls - including X-Y plots, and additional components and libraries will make Version 4 of interest to both new and experienced users of PSCAD. PSCAD V4.0 will include an optional single-line diagram representation of 3-phase electrical networks and will support multiple control settings for users who need to run a large series of simulations in batch mode.

We are particularly encouraged by our new Power Flow application, which will be the first modular addition to the PSCAD power system simulation family planned for release as V4.1 in November. Initially, the input data format will be the widely used PTI PSS/E data format. PSS/E's load flow data files can be directly accommodated and solved by PSCAD/Power Flow and/or EMTDC. The result will be a very powerful and fully functional load flow application integrated into PSCAD's graphical design environment.

New Manuals and On-line Help

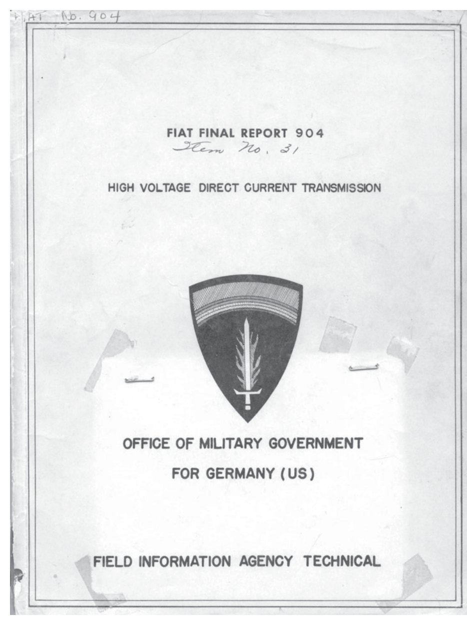
In the V4 development, we are working to provide comprehensive documentation to our end-users. You can look forward to new PSCAD V4 and EMTDC printed manuals, a new on-line Help system, and a new pscad.com website with the latest FAQs and help materials.

The new manuals includes topics on program structure, writing models, and theory for transformers, machines and transmission lines. The PSCAD V4 User's Guide will include "how to" instructions, License Manager information, Component Workshop help, and detailed information on the use of the Master Library components. ☒

By Paul Buchanan, P. Eng.

Centre Receives Gift

The Manitoba HVDC Research Centre would like to thank Professor M.Z. Tarnawecky, distinguished faculty member of the University of Manitoba, for his thoughtful donation of historic HVDC references and books. One particularly interesting document was the Final Report on High Voltage Direct Current Transmission compiled by the Technical Industrial Intelligence Division of the Office of Military Government of the United States in occupied Germany of 1947. The collection contained many other useful books including one of local interest – a report entitled "The Future of the Manitoba Electric Utility Industry," August 1959. This report by the Manitoba Hydro-Electric Board (Manitoba Hydro) discusses emerging energy sources of the day. ☒



Editor's note: it should be noted that Britain and Sweden also contributed to the development of HVDC technology prior to the Second World War. It was the Swedes (ASEA, now ABB) that developed the first mercury arc dc valve, which they licensed to English Electric in the 1960's. Several of these vintage mercury arc dc valves (the largest ever built) are still operational at Manitoba Hydro's Dorsey HVDC Converter Station. (source: "High Voltage Direct Current Transmission," by Adamson and Hingorani, and also from Dennis Woodford, Electranix Corporation).

(UPFC Continued from page 1)

voltage of 50 Hz (base frequency) on the sending end bus U_1. Here, negative frequencies indicate negative sequence. The three curves in each graph correspond to different operating points as in Table 1.

In cases 1 and 2, the transmission line transmits 5.0 pu real power (note: P_{base} equals the UPFC's rating which is much smaller than the transmitted power), with different amounts of reactive powers (+0.9 or -0.9) delivered by the series branch. Case 3 corresponds to a transmittal of 1.0 pu in the line. From Figure 3, it is clear that operating points 2 and 3 have very similar responses, indicating that the frequency response is not significantly affected by the transmission line power. On the other hand, if the reactive power of the shunt branch is changed, the characteristic changes significantly. In our particular case, there is a negative sequence resonance (-50 Hz) for leading reactive power (+0.9 pu). For this operating condition, there will be a large negative sequence component in the series and shunt currents; as well as a complementary current of positive sequence at the frequency

$$150Hz = (-[50 - 2 \bullet 50]Hz)$$

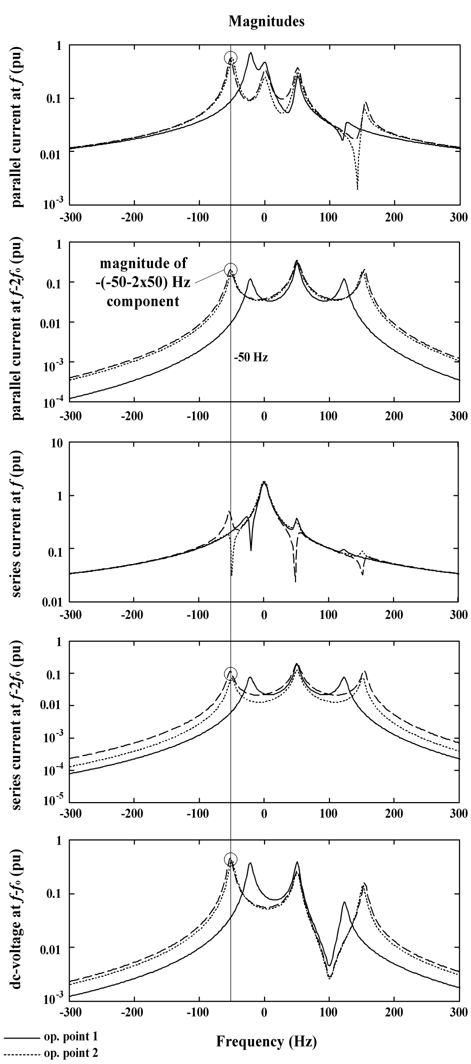


Figure 2: UPFC Frequency Response Characteristic

We carried out a detailed simulation using a quasi 24 – pulse voltage sourced converter based UPFC (Figure 3) to obtain the current waveforms shown in Figure 4. As can be seen, the fundamental frequency negative sequence component and the 3rd harmonic positive sequence component are clearly evident. Their magnitudes were also shown to agree very well with the derived characteristics of Figure 4. The resonance disappears when the shunt reactive power order is changed to -0.9 pu (lagging).

The simulation shown here only verified one point on the characteristic. By using the method discussed in [2] where we inject a suitable "white noise" signal into the PSCAD/EMTDC model and plot the spectrum of the observed response, we also obtained the entire characteristic. This study therefore confirms the validity of the mathematically obtained frequency response, as the PSCAD model is detailed and contains all the inherent non-linearities of the actual UPFC.

by Dr. A. Gole (University of Manitoba, CANADA), and Dr. Igor Papic (University of Ljubljana, SLOVENIA)

References:

[1] I. Papic and A.M. Gole, "Steady State Response of the Unified Power Flow Controller," IEEE PES Winter Meeting, New York, NY, January 27- Feb 1, 2002.

[2] X. Jiang and A.M. Gole, "A Frequency Scanning Method for the Identification of Harmonic Instabilities in HVDC Systems," IEEE Trans. Power Delivery, Vol 10, No. 4., October 1995, pp 1875-1881.

Operating Point	i_{pq}'/ pu	i_{sd}'/ pu	i_{sq}'/ pu	u_{dc}'/ pu
1	-0.9	5.0	0.0	1.57
2	0.9	5.0	0.0	1.57
3	0.9	1.0	0.0	1.57

Table 1: Different UPFC Operating Points

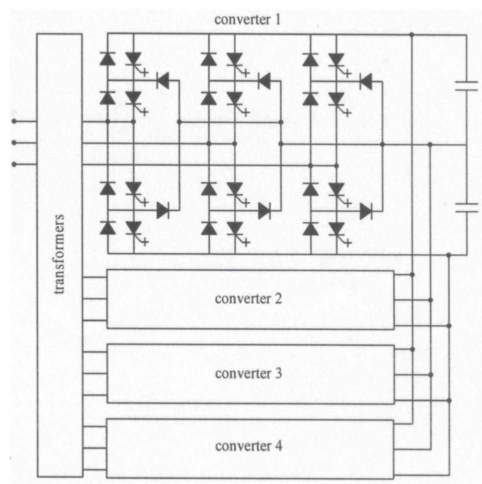


Figure 3: Quasi 24-pulse VSC building block of UPFC

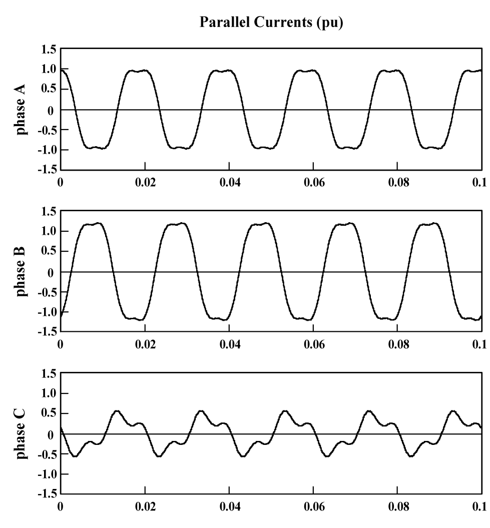
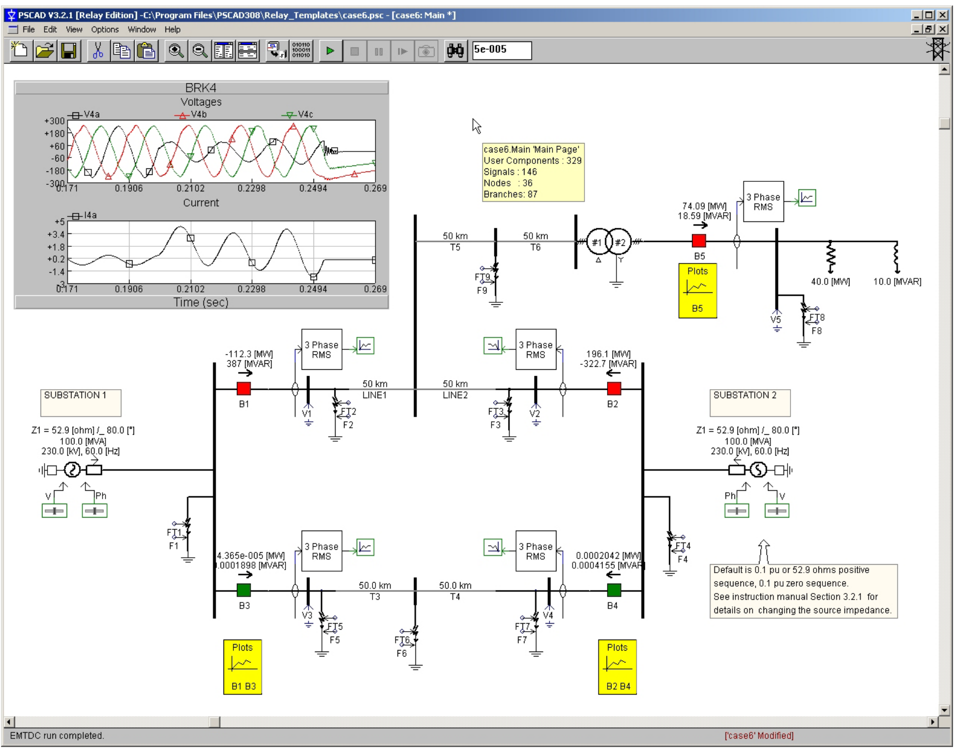


Figure 4: Shunt Converter currents with 0.02 pu negative sequence on U_I

PSCAD/Relay Released!

PSCAD/Relay is a power system simulation program ideally suited for protection engineers and technologists. PSCAD/Relay is used to create accurate full time domain transient (COMTRADE) test waveforms. The transient waveforms are then played into the relay system under test, thus verifying the operation of the protection system under conditions matching real system faults. Transient testing of protection greatly increases the confidence that the protection system will perform as designed.

PSCAD/Relay provides a tool that is fast and easy to use and yet simulates complex features, such as reverse current, point of fault switching, mutual coupling, effects of breaker operation, sequence of fault events, multiple fault resistances, all of which are unavailable with traditional phasor based testing methods. End-to-end GPS based testing is also supported, since both ends of the transmission line are recorded. In short, PSCAD/Relay, with dynamic transient testing, allows the performance of the relay to be tested and validated at the point in the system where it is installed. As a testament to the validity of the PSCAD/Relay technology, we are extremely pleased to announce that **Doble Engineering Company** of Massachusetts, USA has recently signed an agreement with the Manitoba HVDC Research Centre to promote and distribute PSCAD/Relay to the Protection Engineering community. Doble Engineering Company (www.doble.com) manufactures and distributes relay test equipment and other power apparatus test instruments worldwide. Please contact us or Doble Engineering to find out more about this new product. ☒



PSCAD/Relay Protection for transient testing. Highlights the new single line diagram interface.

By Randy Wachal, P. Eng.
Paul Buchanan, P. Eng.

The Manitoba HVDC Research Centre will be participating in the following technical conferences:

- IEEE Advanced Power Electronics Conference, March 10 – 14, Dallas, Texas, Booth 301
- T&D World Conference, May 7 – 10, Indianapolis, Indiana, Booth 707
- WindPower 2002, June 14 – 16, Portland, Oregon
- Electimacs 2002, Official Sponsor, August 10 – 14, 2002, Montreal, Canada
- IEEE-PES International Conference on Power System Technology, October 13-17, 2002, Kuming, China

We look forward to seeing you!

Download PSCAD 3.0.8 at http://www.pscad.com

The Centre Journal is distributed free of charge and is posted electronically at http://www.hvdc.ca.

If you would like to receive email notification of a new Journal in the future and not receive a copy in the mail, please send us your request by email to journal@hvdc.ca