The University of British Columbia (UBC)
Department of Electrical & Computer Engineering

Past, Present and the Future of Electric Power Systems

from my Perspective

Hermann W. Dommel
hermannd@ece.ubc.ca
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Please ask questions as we go along.

My Background

- I studied Power Engineering at Technical University of Munich in Germany.
- My "Diplomarbeit" was on power flow solution for a simplified network of the Bavarian Transmission System (1959).
- I used this "Friden" electro-mechanical calculator:

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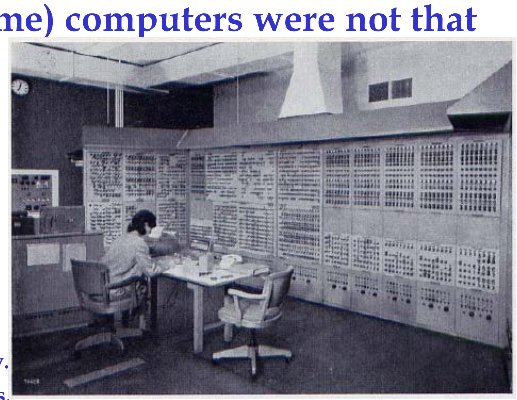
My Background

- For Ph. D. thesis in Munich (1962), I worked on short circuit, normal and optimal power flow solutions for digital computers.
- Digital (mainframe) computers were not that common at that time.
- Here is my first computer PERM (in "Deutsches Museum" in Munich now).
- Built in 1956 at the University.
- Worked with 2500 radio tubes.



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My Background

- **First programs that I wrote were in machine code.**

$y = ax + x^2$ looked like this:

•100	read into register	(x)
•101	store into location 107	
•102	read into register	(a)
•103	add value from 107 to register	(a + x)
•104	multiply with value from 107 in register	$(a + x) \cdot x$
•105	print the value in register	
•106	stop	

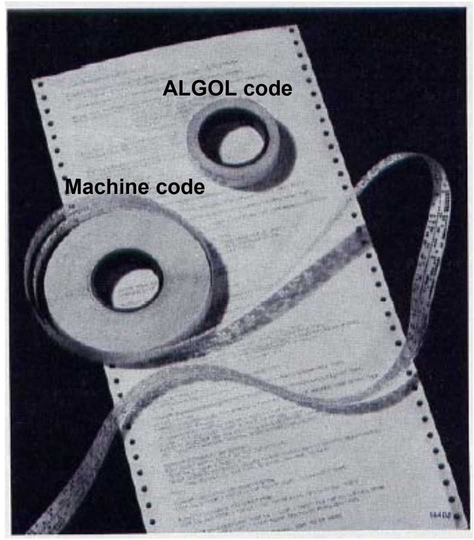
My Background

- **Fortunately, programming language "ALGOL" became available for most of my Ph. D. work.**
- **To solve 2 linear equations, I could simply write:** $\begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} y_1 \\ y_2 \end{bmatrix}$

```
'BEGIN' 'REAL' A11, A12, A21, A22, X1, X2, Y1, Y2, D;
READ (A11, A12, A21, A22, Y1, Y2);
D: = A11*A22-A12*A21;
IF ABS(D)<1.0₁₀-8
     'THEN' WRITE ("DET = 0")
     'ELSE' 'BEGIN'   X1: = (Y1*A22-Y2*A12)/D;
                      X2: = (Y2*A11-y1*A21)/D:
                      PRINT (X1,X2)
            'END'
'END'
```

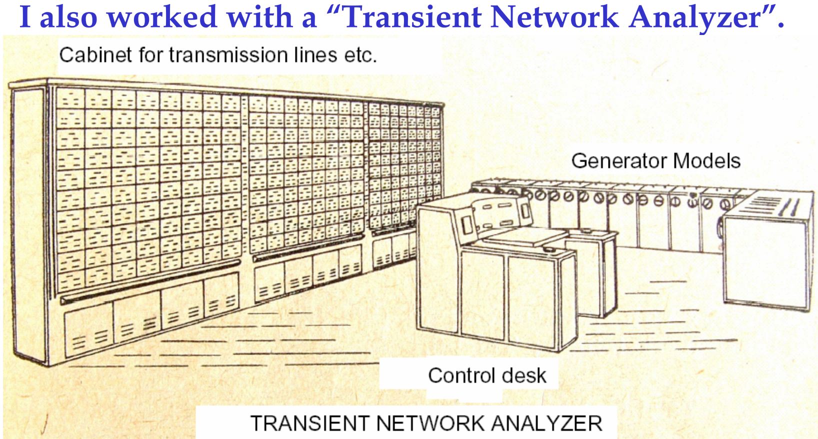
My Background

- Input device was a paper tape on teletype machine.
- Output device was the teletype printer.



My Background

- From 1962 to 1966, I worked as a Postdoctoral Fellow at Technical University Munich on an electromagnetic transients program, that became "EMTP" later on.
- I also worked with a "Transient Network Analyzer".



My Background

- **From 1966 to 1973, I worked in industry for the utility company "Bonneville Power Administration" in Portland, Oregon, U.S.A. on:**
  - further development of EMTP,
  - optimal and normal power flow,
  - stability with implicit integration.
- **Programming language was FORTRAN.**

- **As a U.S.A. Government Agency, what we did was available for free under the Freedom of Information Act. This helped me in getting my work known.**

My Background

- **My experience from Ph.D. work on power flow solutions was useful.**
- **From nodal equations**

$$[Y][V]=[I] \; with \; I_k = \frac{P_k - jQ_k}{V_k^*} \; ,$$

- **I derived Newton's method for the "current-equation form", with rectangular coordinates Re{V_k} and Im{V_k} as variables.**

$$Re\left\{\sum_{m=1}^{n} Y_{km}V_m - \frac{P_k - jQ_k}{V_k^*}\right\} = 0$$

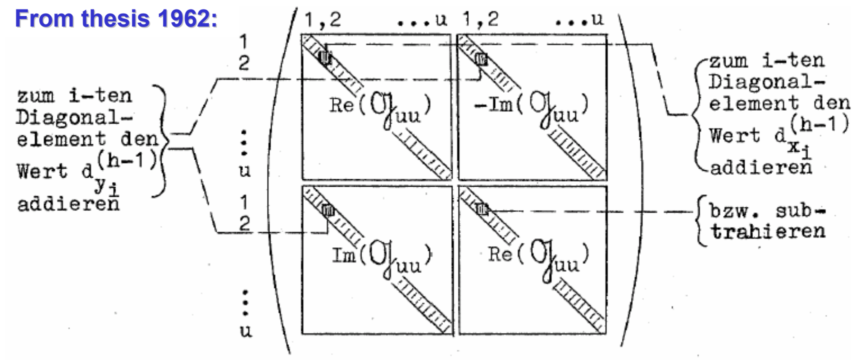
$$Im\left\{\sum_{m=1}^{n} Y_{km}V_m - \frac{P_k - jQ_k}{V_k^*}\right\} = 0$$

My Background

- "Jacobian matrix" for solving equations iteratively is almost the real form of the [Y]-matrix:

$$\begin{bmatrix} [G] & -[B] \\ [B] & [G] \end{bmatrix} \; where [Y] = [G] + j[B]$$

From thesis 1962:



My Background

- The entries into the diagonal elements "ruin" the possibility to write it as complex equations with complex variables.
- Reason: these terms do not fulfill the Cauchy-Riemann conditions that definite analytic functions.
- For $u + jv = f(x + jy)$, the Cauchy-Riemann conditions say that

$$\frac{\partial u}{\partial x} = \frac{\partial v}{\partial y} \; and \; \frac{\partial u}{\partial y} = -\frac{\partial v}{\partial x}$$

- which are not true in the four diagonals because of the terms coming from the complex conjugate voltage in $I_k = \frac{P_k - jQ_k}{V_k^*}$

My Background

- **Bonneville Power Administration used the "power-equation" form, with polar coordinates $|V_k|$ and Θ_k as variables, where $V_k = |V_k e^{j\Theta_k}|$:**

$$Re\left\{V_k^* \sum_{m=1}^{n} Y_{km} V_m\right\} - P_k = 0$$

$$-Im\left\{V_k^* \sum_{m=1}^{n} Y_{km} V_m\right\} - Q_k = 0$$

- **In this form, it is somewhat easier to handle nodes where P_k and $|V_k|$ is specified in this form.**

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My Background

- **Current-equation form with rectangular coordinates has recently been used for <u>three-phase</u> power flow solutions in <u>distribution</u> networks:**

1. Paulo A.N. Garcia, Jose Luiz R. Pereira, Sandoval Carneiro, Vander M. da Costa, Nelson Martins, "Three-phase power flow calculations using the current injection method", IEEE Trans. Power Systems, Vol. 15, pp. 508-514, May 2000.
2. Paulo A.N. Garcia, J.L.R. Pereira, Sandoval Carneiro, Marcio P. Vinagre, Flávio V. Gomes, "Improvements in the representation of PV buses on three-phase distribution power flow", IEEE Trans. Power Delivery, Vol. 19, pp. 894-896, April 2004.

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My Background

- **In 1973, I joined the University of British Columbia (UBC) in Vancouver, Canada, where I am Emeritus now.**
- **Most work with my graduate students at UBC has been on power system transients ("EMTP"-type programs).**
- **Some work with graduate students at UBC, that found its way into many versions:**
  - Laurent Dubé: Transient analysis of control systems (TACS).
  - José Marti: Frequency-dependent line models.
  - Vladimir Brandwajn: Synchronous machine model.
  - K. C. Lee: Untransposed line model.
  - Luis Marti: Cable models.
  - Many other contributions.

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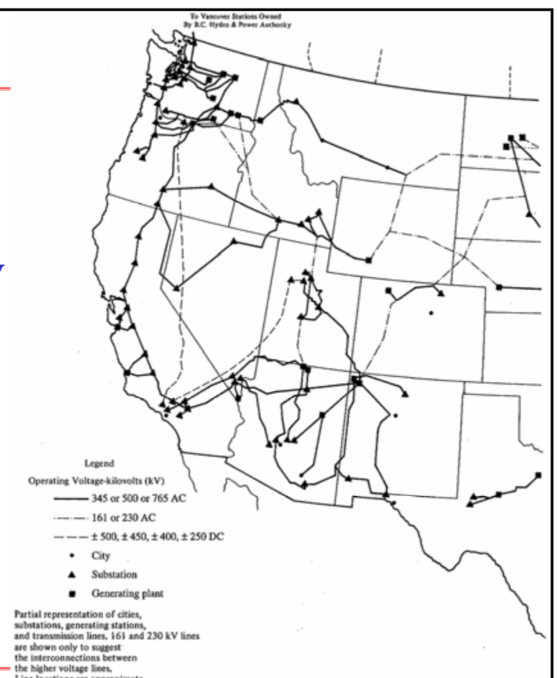
Transmission System

(from A. R. Bergen & V. Vittal, Power System Analysis, 2nd Ed., Prentice Hall, 2000).

Western Electricity Coordinating Council.

British Columbia is part of this interconnected system.



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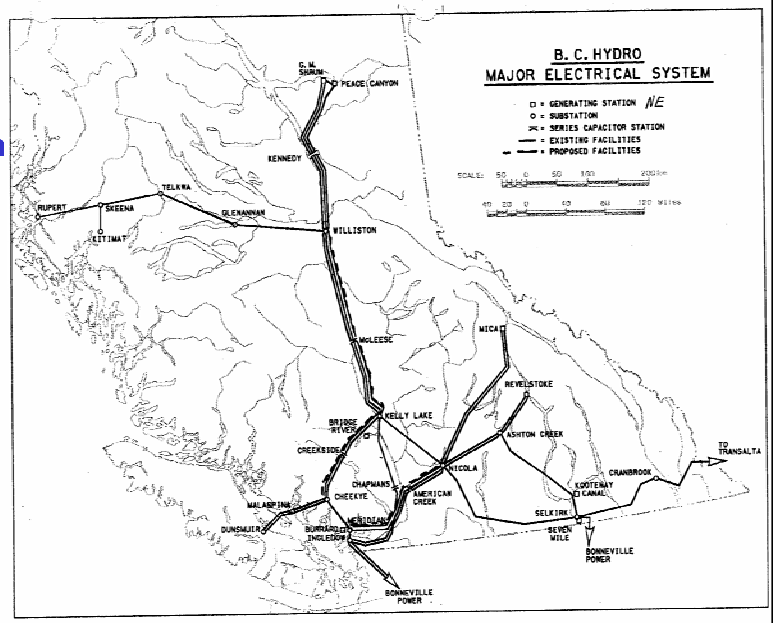
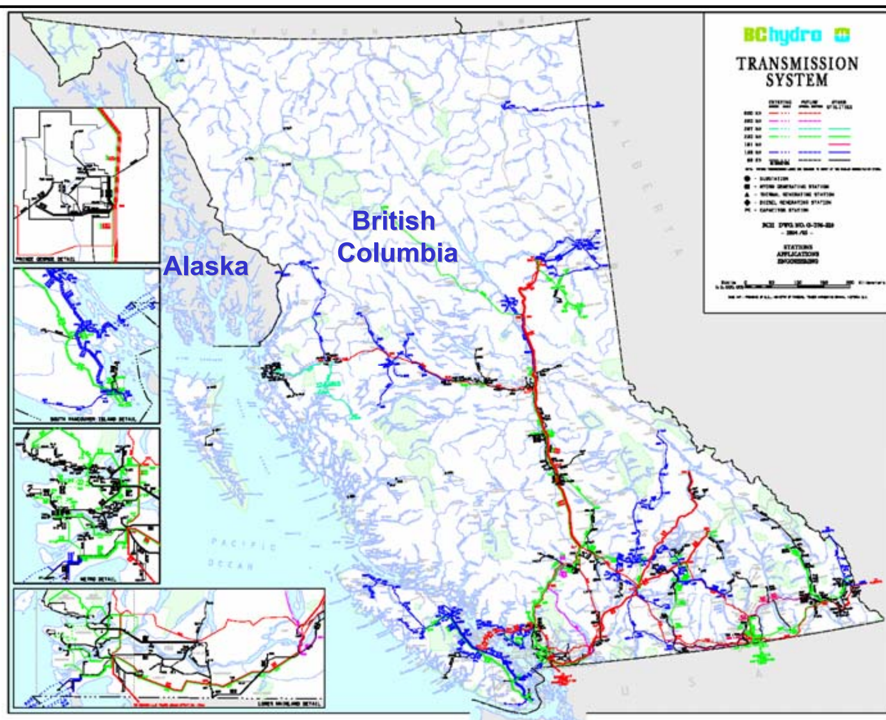
Transmission System in British Columbia

Long distances from generation to loads (1200 km).

More than 90 % is hydro-electric power plants.





Electric Power System in British Columbia

- **Three parts:**
  - generation,
  - transmission,
  - distribution.
- **In the past, all three were "vertically" integrated.**
- **With de-regulation coming now, there is separation to allow competition.**
- **B.C. Hydro & Power Authority split off transmission part to B.C. Transmission Corporation.**

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Electric Power System in British Columbia

- **Before de-regulation, there was fairly free exchange of data among utility companies.**
- **This made planning of generation and transmission easy on an integrated basis.**
- **With de-regulation, there is only limited sharing of data.**
- **There is more uncertainty who will supply power.**
- **Government wants local distributed generation resources, including micro-turbines, fuel cells, solar, and wind generators.**
- **Integrating these small "independent power producers" causes new engineering problems.**
- **Distribution systems may become meshed.**

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Engineering at UBC

- **Main campus is in Vancouver, British Columbia, Canada.**
- **We also have a branch campus in Kelowna (approx. 350 km east of Vancouver).**
- **Faculty of Applied Science (Engineering, Architecture, Nursing) is in both places.**
  - Department of Electrical & Computer Engineering,
  - Civil Engineering,
  - etc.

Electrical & Computer Engineering

- **Undergraduate program either in Electrical Engineering or in Computer Engineering.**
- **Student choices:**
  - Cooperative Education Program places students in industry for short time; very popular.
  - Project Integrated Program teaches more with projects than traditional courses.

Electrical & Computer Engineering

- **Options in undergraduate program:**
  - Software Engineering.
  - Biomedical Engineering (starting Sept. 2006).
  - Electric Power Systems (starting Sept. 2007).

Electric Power Systems

- **We have a website that describes what we do: www.ece.ubc.ca/power/**
- **Professors:**
  - José R. Martí
  - William G. Dunford
  - Juri Jatskevitch
  - Luis Linares
- **Retired professors (professor emeritus):**
  - Hermann Dommel
  - K. D. Srivastava
  - L. M. Wedepohl

Electric Power Systems

- **We also ask experts from industry to help in teaching:**
  - Until 2006: Prabha Kundur, Adjunct Professor (moved to Toronto)
  - Charles Henville, consultant (was with B. C. Hydro working in protection)
  - Mukesh Nagpal, B. C. Hydro (protection)

José Martí

- **Current Research Projects**
  - Real-Time Power Systems Simulator (OVNI)
    - Network Partitioning Techniques for Large System Solutions (MATE)
    - PC-Cluster Architectures
    - Multi-Rate and Hybrid Solutions

José Martí

- Signal Processing Techniques for Intelligent Diagnostic Systems
  - A current project involves the signature characterization of power transformers from their high-frequency response. This signature is then used for the detection of incipient faults and aging defects while the transformer is in service.
- Frequency Dependent Transmission Line Modelling
- High-Frequency Transformer Modelling

José Martí

- Coordination and Control of Small-Size Distributed Generation Systems
  - An important area of current interest in his group is the simulation of distributed energy systems. Together with other members of the Power Systems Group and the Power Electronics Group, they are studying the coordinated operation and control of local distributed generation resources (LDR's), including microturbines, fuel cells, solar, and wind generators, sharing resources with each other and with the existing power grid.

William G. Dunford

- **Current Research Projects**
  - Power electronics applied to photovoltaic applications and alternative energy systems. Pump and traction drives, high power converters. Micro-controllers and DSP controllers. Distributed Energy Systems. Low power converters. Some examples:
    - CANADIAN CABLE LABS - A Battery Charge Equalizing Circuit.
    - BC HYDRO - A Photovoltaic Powered Water Circulator.
    - Canadian Space Agency - Battery Management System.
    - Design and construction of a 250 kVA IGBT based inverter system.

Juri Jatskevitch

- **Current Research Projects**
  - Fast and computationally efficient models of electrical machines for EMTP-Type programs. The so-called voltage-behind-reactance model (developed at Purdue University) is used that achieves a simultaneous EMTP solution of the machine equations with the external network. A three-phase synchronous machine model requires only 250 flops per time step, which executes under four microseconds on an average PC.

Juri Jatskevitch

- Continuous and computationally efficient dynamic average-value models of power and power-electronic systems/components containing converters, inverters, rectifiers, and rotating electrical machines. The goal is to automatically generate models wherein the effects of fast switching is neglected or "averaged" with respect to a prototypical switching interval and the respective state variables are constant in the steady-state. Method is very accurate in both the time- and frequency-domains, and fast.
- Chairs IEEE PES Task Force on Dynamic Average Modeling.

Juri Jatskevitch

- Modeling and control of distributed energy resources. Proposed an innovative supervisory control scheme for wind farm applications that allows to use distributed wind turbines to regulate the voltage at required remote location(s), while taking into consideration dynamics and the real-time power limits of each individual wind turbine.

Luis Linares

- **Current Research Projects**
  - Computer simulation of engineering systems. Real-time simulation of engineering systems. Modelling of electric machines in real time. Real-time operating systems for embedded applications.

Retired Professors

- **H. W. Dommel**
  - Some work on EMTP issues.
  - Has been teaching one course "Computer Applications in Power", to help out with staff shortage.
- **K. D. Srivastava**
  - Helps with a new university in Trinidad-Tobago.
- **L. M. Wedepohl**
  - Helps with new campus in Kelowna.
  - Plans to write a book about solution of transients with frequency-domain methods.

Some of my Recent Work

- **Technical adviser to EMTP Development Coordination Group.**
- **Using dynamic phasors for slow transients.**
- **Consulting work with a former Ph. D. student in Argentina:**
  - Switching of shunt reactors.
  - Useful input from experiments done here: Ivo Uglešić, Sandra Hutter, Miroslav Krepela, Božidar Filipović-Grčić, and Franc Jakl, "Transients due to switching of 400 kV shunt reactor", International Power Systems Transients Conference IPST 2001, Rio de Janeiro, Brazil, June 24-28, 2001.

Thank you for your invitation!

Any questions?