Power Flow Application in Power Systems

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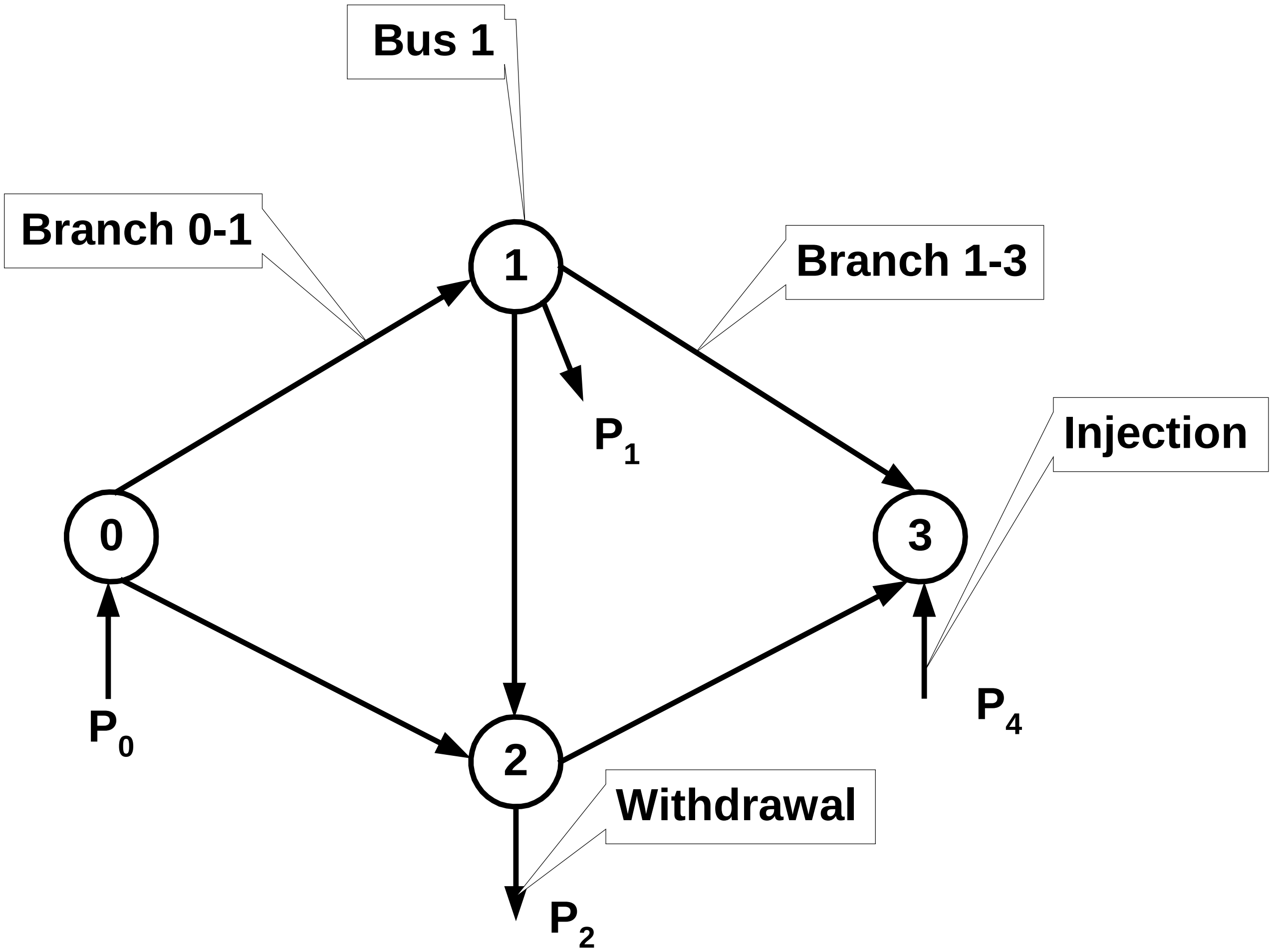
Electrical Network and its Model



Network Model

- Bus – connection point of two or more branches in the network model
- Branch – physical or equivalent line connecting two buses
- Injection – flow of power into the bus – generation
- Withdrawal – flow of power from the bus – load

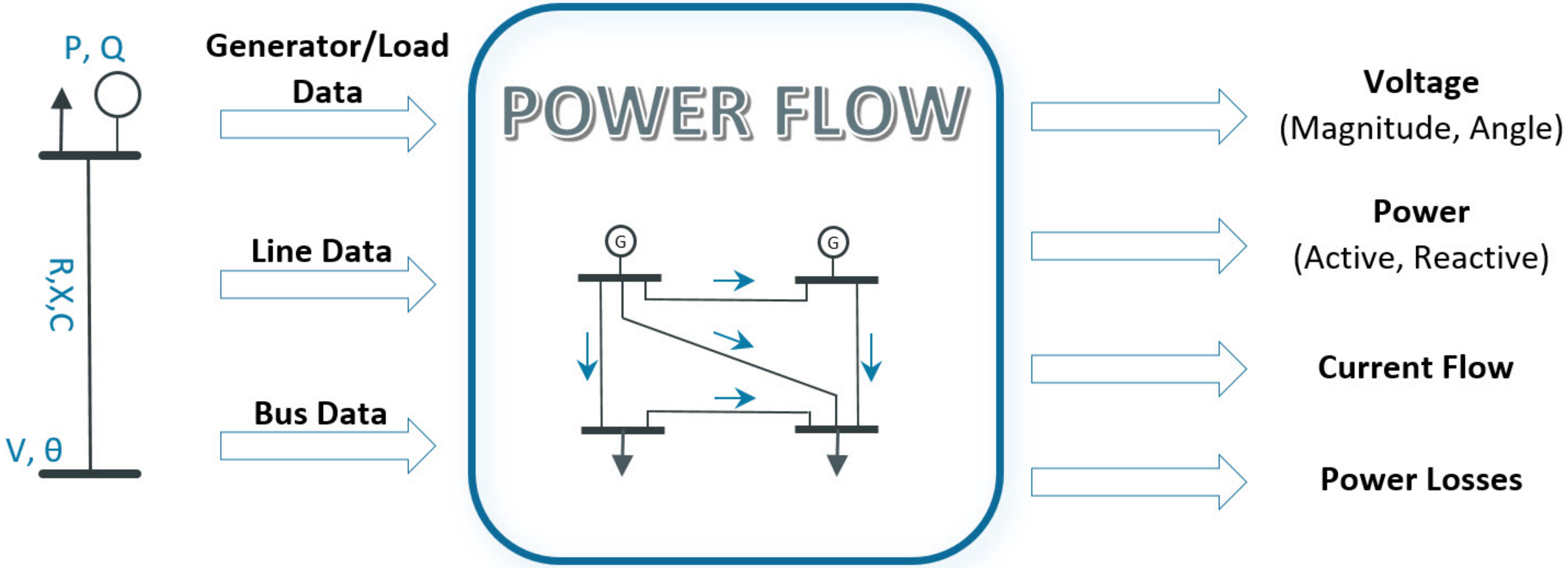
Power Flow

- Power Flow is the most frequently used type of study applied to Power System operation and planning
- It is needed to make sure that the analyzed system state is compliant with the established reliability criteria
- Used to evaluate different scenarios in long- and short-term planning
- Power system state monitored variables are:
  - Voltages at every bus
  - Power Flows at every transmission line and transformer

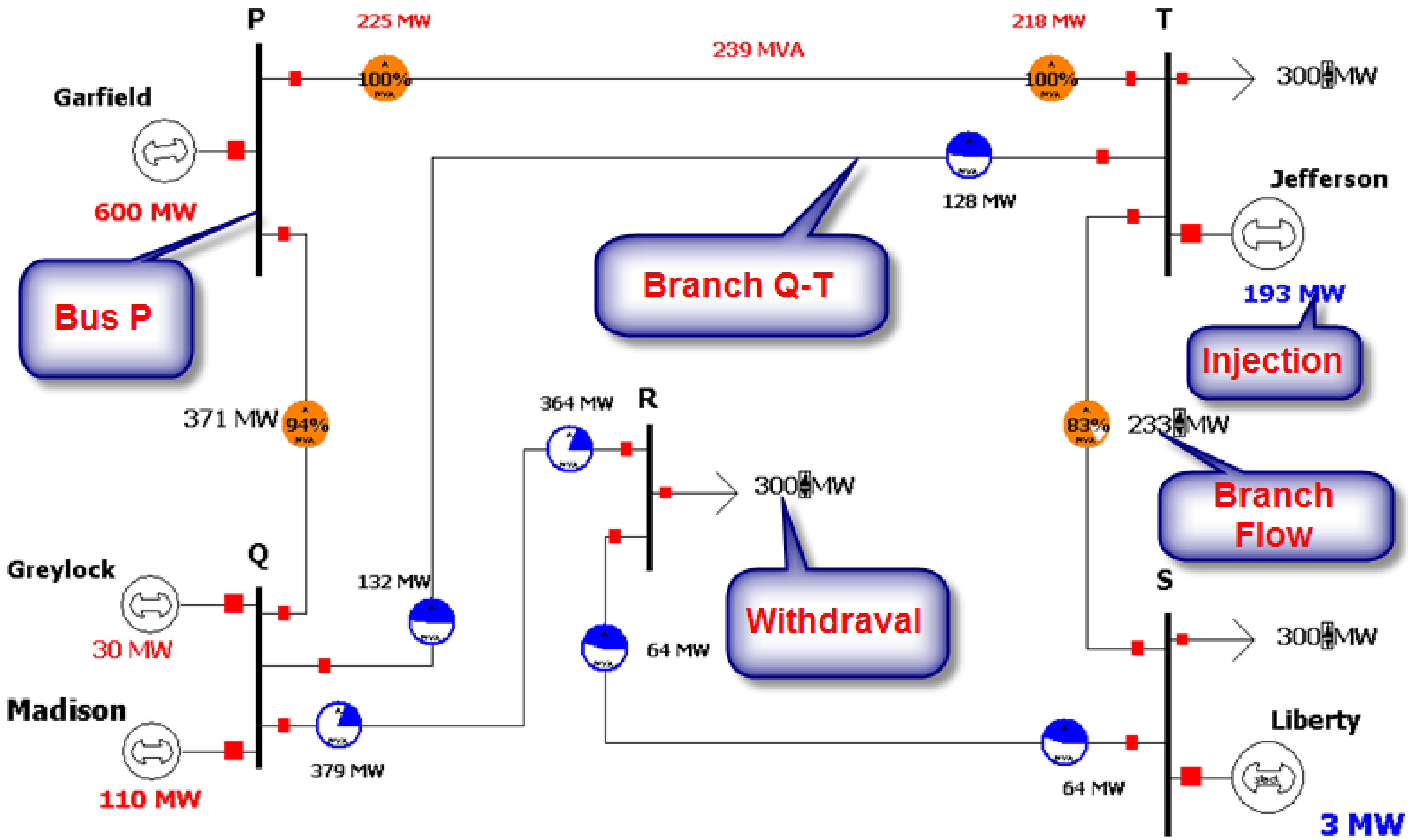
Power Flow Calculation

- Given: injections and withdrawals at every bus, branch parameters, network topology
- Find: power flows and currents in each branch and voltage at each bus
- High voltage electrical networks are three-phase alternate current circuits.
- The theory of power systems provides ways to perform calculations with one-line models for symmetric conditions.
- Complex numbers are used to represent an alternate current circuit variables
- Power Flow calculation implements a numerical solution of the model describing the steady state of the system
- The result is a **feasible** solution – making sure there are no violated reliability constraints

Power Flow Problem



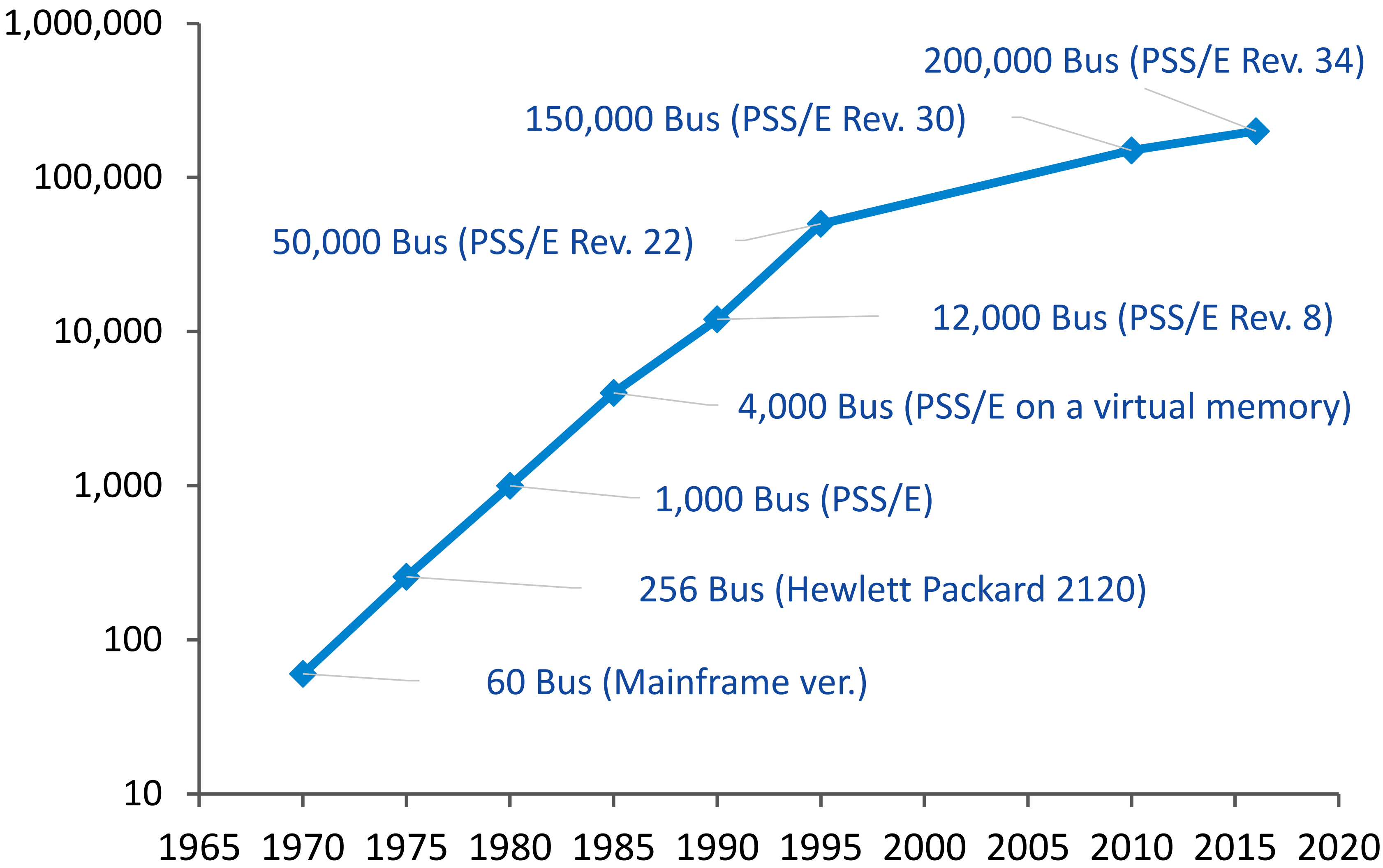
Power Flow Solution



Solving the Power Flow Problem

- Power Flow is described by the system of nonlinear algebraic equations with complex variables and therefore cannot be solved analytically
- Each equation is representing a power balance at each bus. Ohm’s and Kirchhoff’s laws are used to formulate the problem
- Power Engineers operate with power (voltage*current) rather than currents while specifying generation and loads, therefore the nonlinear system
- Different numerical methods are used to solving these equations
- As any numerical solution of the non-linear system, it may not converge, so special measures are needed to make it more robust
- The most popular method is Newton-Raphson
- The size of the problem is quite large and requires using sparse matrix technique

PF Software Evolution (System Size)



Optimal Power Flow (OPF)

- Finding a feasible solution that simultaneously satisfies certain objective function:
  - Minimize losses
  - Maximize transfer capability
  - Maximize social welfare or minimize the cost of production
- For almost all practical purposes, OPF should be used instead of traditional Power Flow. Application was limited by the lack of computational power
- This requires some cultural change for power system engineers who are used to run multiple PF solutions instead of one OPF formulating their task as an optimization problem

Application of Power Flow

- Long-term and short-term planning studies of different scenarios
- Contingency analysis – n-1 criterion
- Cascading analysis
- Real time monitoring of the system
- Economic Dispatch
- Stability analysis – numerical simulation of the transient process solving power flow at each step of the numerical integration
- Governor Power Flow – to analyze quasi steady state frequency response
- Continuation methods for Voltage Stability analysis
- Unbalanced 3-phase PF for distribution grids

Computing Needs in Power Flow Analysis

- Challenges of the system model
  - Nonlinear, non-convex functions
  - Discrete and integer variables
  - Ill-behaved characteristics
  - Hundreds of Thousands of differential and algebraic equations
- Complexity of the power grid today and in the nearest future:
  - Distributed resources
  - Renewable resources
  - High volatility
  - Microgrids
  - Power electronics

Future Directions

- Using High Performance Computing
- Phasor Measurement Units – linear solution
- Cloud computing
- Using Node/Breaker models without a need for topology processing
- Need for robust methods of solution – minimize convergence problems
- Ability to distinguish between numerical and physical instability of the solution. Holomorphic embedding.
- Transmission/Distribution co-simulation