QRB power requirements & simulation

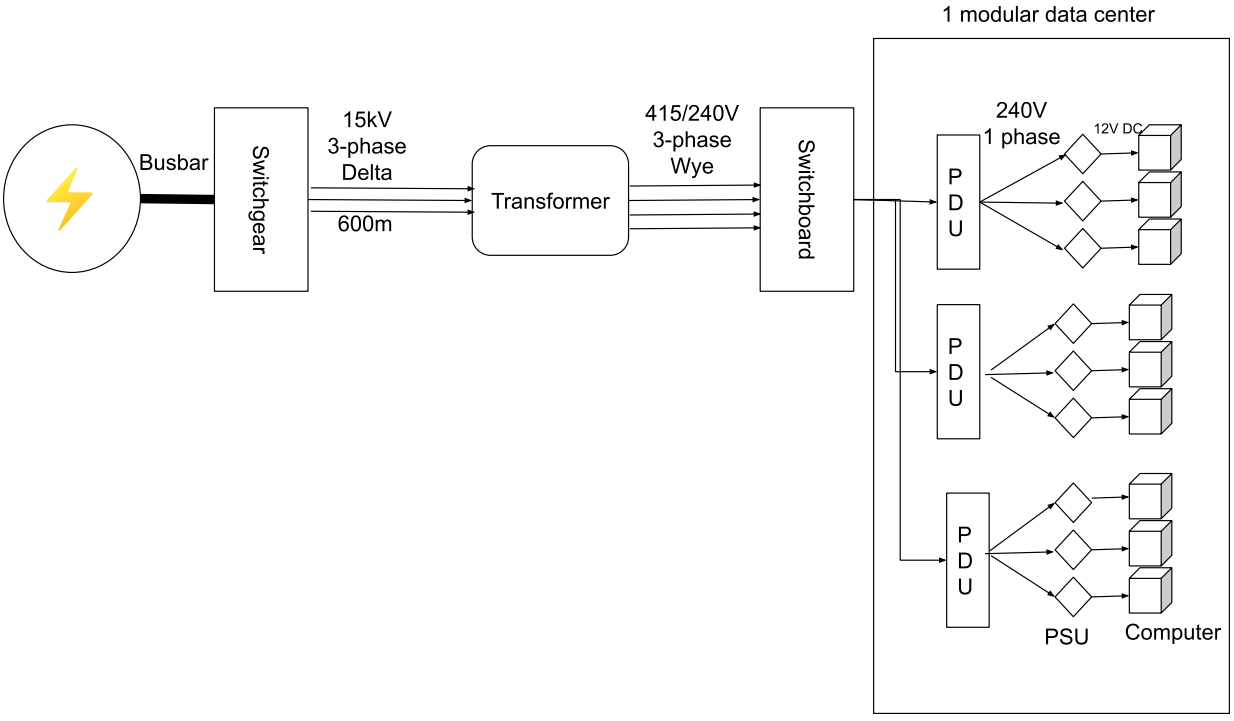
Objective

Specify high-level power system requirements and simulation of modular data centers in an electrical substation.

Background

QRB is deploying modular data centers for energy-intensive computation.

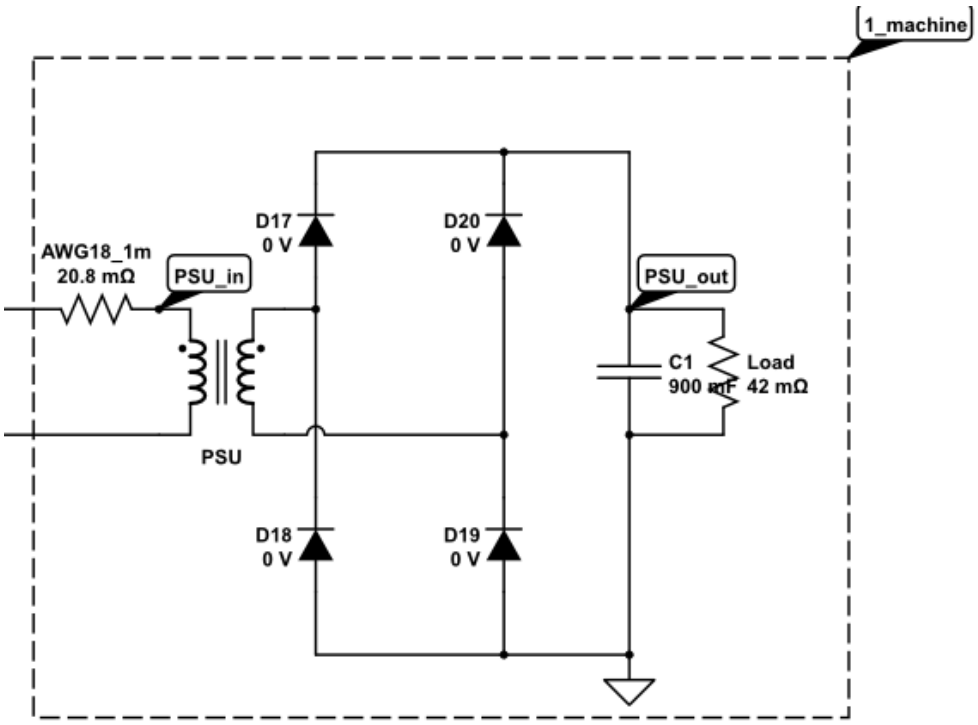
- Each module is a shipping container, loaded with 100-300 high power computers.
- The computers run on direct current 12V DC, drawing 3-4kW. They come with power supply units (PSUs) drawing 10-20A at 240V.
- Datacenter modules are deployed in electrical network substation compounds.
- Power supplied is AC 3-phase Δ configuration (3-wire) at 15kV, 50Hz.
- Transformer steps down to AC 240V Y config (4-wire): three 240V circuits plus neutral.
- Via switchboard, each circuit feeds 1/3 of the machines in the datacenter
- Inside the data center, each rack is supplied via one power distribution unit (PDU)



Single machine circuit model

A single machine (computer+PSU) can be modeled by the following circuit.

- PSU input :
  - 240V AC single phase
  - Coming over a AWG18 gauge wire with resistance 20.8 Ohms/km;
- Load:
  - 12V DC
  - Expect 3400W power consumption
  - Model the load as a pure resistance 12*12/3400 = 0.042 Ohms.
- PSU simulation parameters:
  - N=21 turns
  - Primary resistance R1=0.7 Ohms
  - Inductance L=10H.



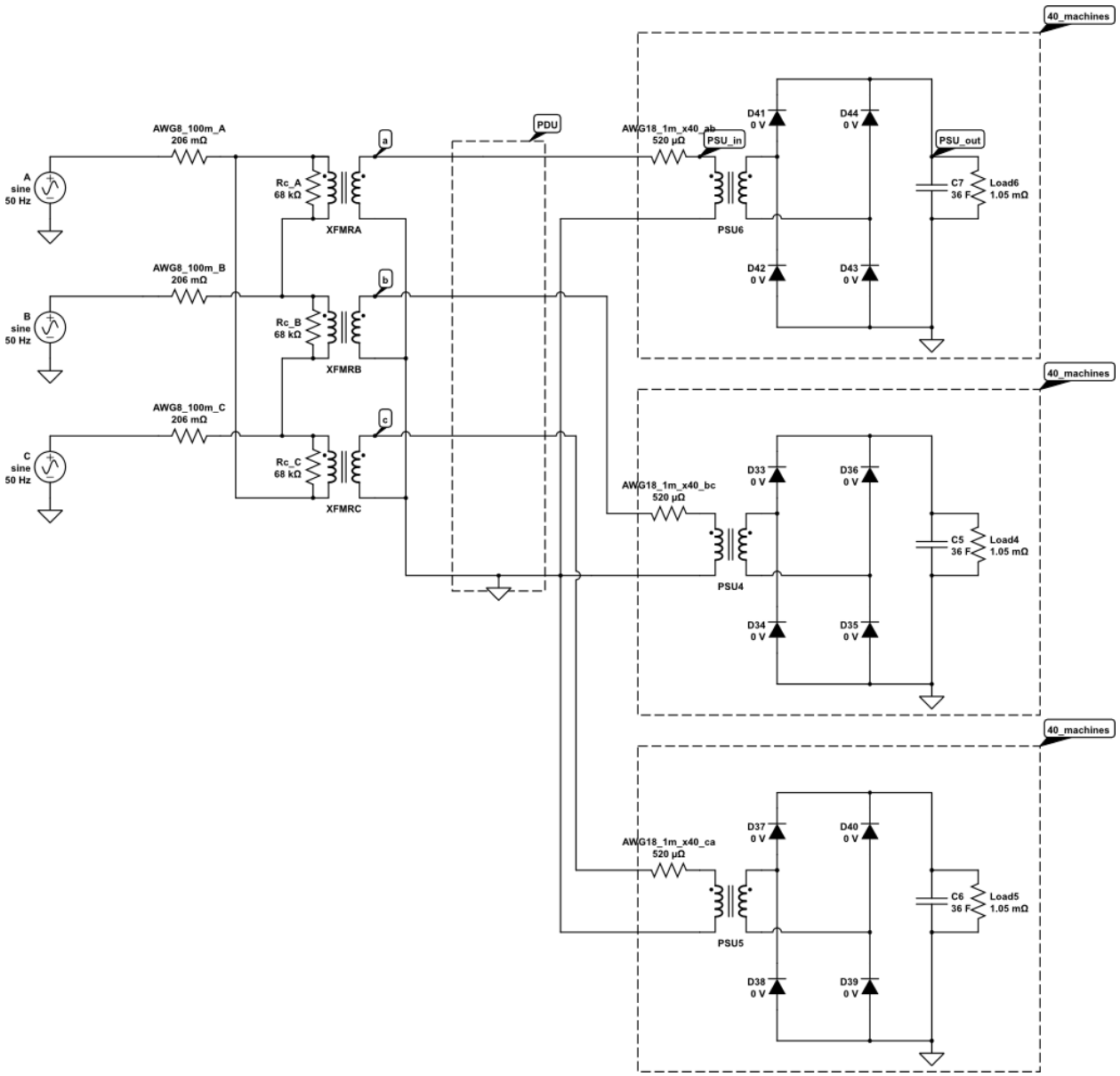
Single data center 3-phase power system (Δ-Y)

- Supply: 50Hz, 3-phase 15kV
- Delta primary: input amplitude is 15000√2 = 21,213V (line to line)
- Load: 240V single phase, 120 machines, 40 on each phase
- Transformer: delta-wye configuration step down transformer
- Output: 40 machines x 3.4kW each = 136kW per phase.
- Rating: Assuming power ratio = 0.8 => rating 136/0.8 = 170kVA per phase (510kVA total)
- Phase current Delta-Wye
    - Primary: 170/15 = 11A (rms) = 16A amplitude
    - Secondary: 170kVA/240V = 708A (rms) = 1kA amplitude

Transformer model parameters

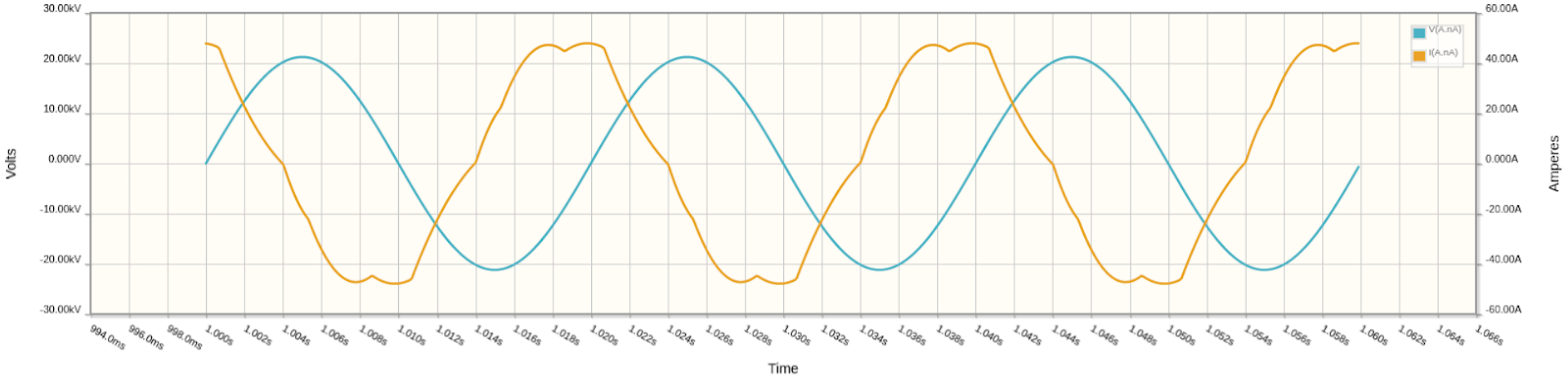
- Windings ratio: N = 15000√3/240= 108
- Transformer Inductance:
    - Delta-Wye: L= (V/I)/2πf = (21213/16)/(2π*50) = 4.2H
- Transformer load-loss/Impedance: Assuming 5% loss
    - Simulate with 5% primary voltage (1060 V amplitude) and short circuit on secondary. Rated current in primary (16A amplitude) achieved when $R_{primary}$ = 32 Ohms and $R_{secondary} = R_{primary}/N^2$ = 0.008 Ohms
    - Load-loss simulation circuit
- Transformer No-load loss: Assuming 2%
    - Simulate with 240V on secondary and open circuit on primary. Exciting current of 2% of rated = 708*0.02 = 14.16A (rms) = 20A amplitude achieved when R_c = 17Ω on secondary, or equivalently, $R_c = 17*63^2$ = 68kΩ on primary.
    - No-load loss simulation circuit

Simulation circuit

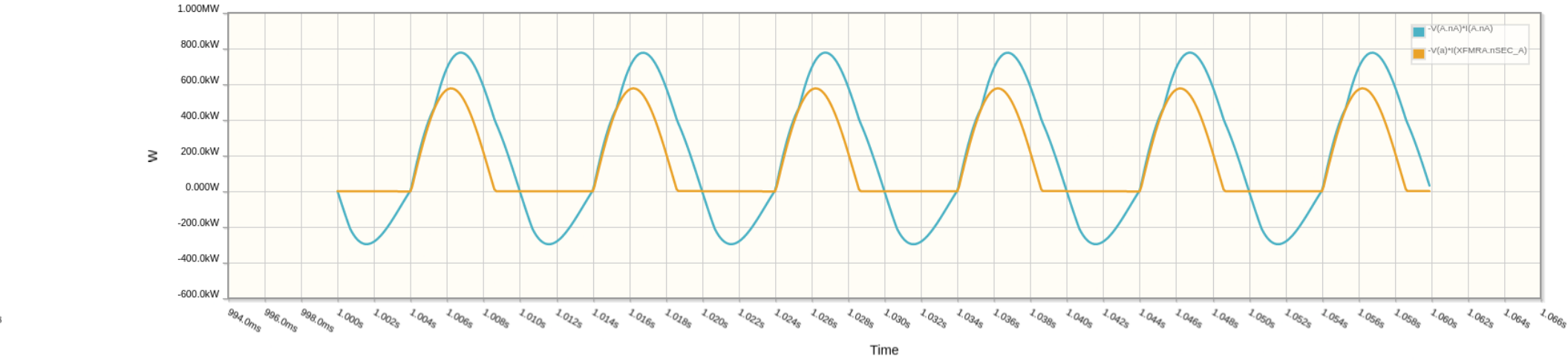


Simulation graphs

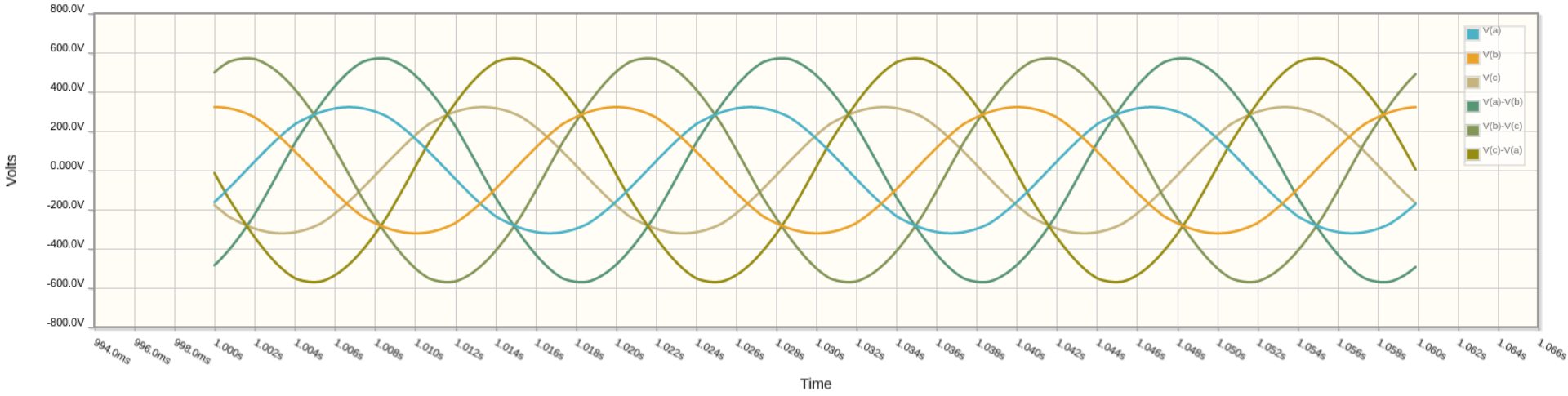
Input line voltage and current



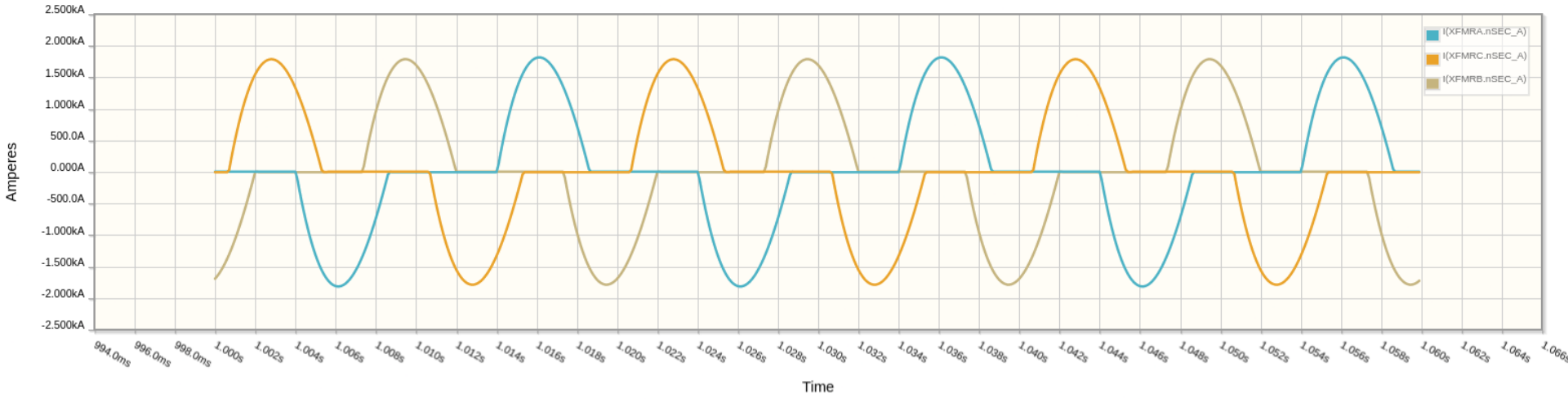
Transformer input and output power (per phase)



Transformer output voltage per phase



Transformer output current per phase



40 machine load voltage, current and power