Virtual machinery of the cruise ship C32

for dynamic performance studies
Presentation summary

• Context
  – Project organization
  – Project objectives
  – Machinery of the cruise ship C32

• Simulation tool definition:
  – Problems solved
    • Heterogeneous model case
    • Proper model library
    • Parameters getting
    • Integrating models
  – Results

• Simulation tool exploitation:
  – Problems solved
    • Global model exploitation
    • Library management
  – Results: examples / scenarios

• Conclusion
Project context

- Cruise ship C32 built by ALSTOM Marine (Chantiers de l’Atlantique) for P&O
- ALSTOM Marine chose model and simulation as basis of this study
- CAPSIM realized the stability studies of the machinery for ALSTOM Marine
Project objectives

Industrial tool for prediction of the machinery behavior

- Under steady state conditions
- On normal working transients
  - Load increase and rejection
  - Swell impact
  - Crash stop maneuver
- During abnormal conditions
  - Trip of generators
  - Trip of propulsion motors
  - Short circuits

**Essential parameters**
- Frequency
- Currents
- Voltage
- Power factor
- Load sharing

**Analysis of**
- Dynamic performance
- System stability
- Plant flexibility

Operational calculation time on classical PC
Machinery of the cruise ship C32

Characteristics of the plant:

- 2 main diesel generators (17 MW / 11 kV each),
- 1 gas turbine generator (25 MW / 11 kV),
- 2 propulsion electric motors (20 MW each),
- 11 kV / 690V main switchboards,
- Harmonic filters,
- Electric motors for pumps, fans, thrusters or compressors,
- Power and propulsion management systems.
- Hotel load

Specific problems to AES (All Electric Ship):

- Different type of prime movers (turbine, diesels),
- Global power management.
Problem solved: heterogeneous model case

Specificities:

- Multi-domain phenomena
  - Electrical
  - Mechanical
  - Thermo dynamical
  - Regulations

- Large panel of time constants
  - Fast: commutation in converters
  - Slow: load sharing

Solution = use of a proper simulation platform

PSIM software from Powersim Technologies
- Simple using (graphic interface)
- Adapted to power electronics
- Adapted to multi-domain power transfer
- Open (Fortran or C code)
Problem solved: heterogeneous model case

Example: diesel generator model 17 MW

Mechanical power

Regulation

Electrical power

Voltage regulator

Diesel engine

Speed regulator

coupling

Alternator

Syncro-coupling

Power measure
Problem solved: proper model library

**Defining model = managing the trade off**

- CAT application
- Solver software PSIM
- Input data:
  - C32 network
  - Simulation objectives
    - Validation of technical options
    - Interoperability of equipments
    - Regulation design
    - Expertise during sea tests

**Calculation time**

- Stability

**Fidelity**

No generic solutions
Problem solved: proper model library

Example: Diesel engine Wärtsilä 16V46C

Needed fidelity:
- Steady state torque and speed at any load
- Precise speed response for load step and rejection

Important phenomena:
- Fuel actuator / combustion torque transfer
- Turbo charger limitation non linearity
- Engine losses
- Speed regulator with droop

Solution = specific model

40% load step from no load
1. Droop influence
2. Characteristic torque response (turbo charge influence)
Problem solved: parameters getting

C32 machinery data:

- Equipment from various industrial sources
  - Research problem multiplication
  - Different industrial cultures

- Unavailable parameters
  - Equipment in development
  - Confidentiality / industrial property

Solutions:
- Industrial partnerships
- Targeted dialog with ALSTOM
- Default parameters data base
- Models definition adapted with available elements
Problem solved: parameters getting

Example: gas turbine
General Electric LM2500+

- Elements / parameters hold by GE
- Specific engine regulation for C32 application

No reliable generic model

Solutions:
- Confidential agreement ALSTOM/CAPSIM/GE
- Obtaining specific tunings / testing results
- Model adaptation / application

Results:
- Reliable validation of LM2500+ model
- Integration with synchronous alternators
- Precision on network frequency variations results
Problem solved: integrating models

C32 machinery model:
- Integration of sub-models with:
  - many loops (mixed regulations)
  - many non-linearities
  - many state variables
- Difficult cases for calculation (e.g., inductive circuit opening)
- Difficult initialization phase

Solutions:
- Analysis of penalizing elements
- Development of fast and robust models for network integration
  - Work on initialization phases
  - Partnership with solver designer
Problem solved : integrating models

Example : Propulsion converter model

• Platforms library converter models
  – Component commutation description
  – Heavy calculation time

• Stability study objectives
  – Propulsion load impact on network
  – Slow transient representation (> minute ) on frequency and voltage

Solution :
Development of converter models without commutation / representing :
• Active and reactive power transfer with reversibility,
• Pass band and limitations.

Results :
Complete Crash stop simulation on the C32 machinery with calculation time reduction (factor 1/20)
**Results : C32 simulation tool**

**Virtual machinery**
- > 700 blocks and elements
- > 40 macro models
- > 100 state variables

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**Exploitation of the tool :**
1. Various scenarios defined with ALSTOM
2. Simulation phase
3. Result analysis
Problem solved: global model exploitation

Complex definition of initial conditions and network configuration for stresses

Global C32 network:
- Many piece of equipment, non linearities and mixed regulation loops
- Many state variables
- PMS and PLS = sequential control

Solutions:
- Parameter definitions in user format
- Grouping of initial conditions
- User interface for scenarios definition
Problem solved: global model exploitation

Example: design of PMS

Needs for:
- Initialization of the complete network in coherence with PMS
- Representing complex scenarios (unshared load cases)

Solution: easy user interface
1. Global load / sharing mode selection on PMS
2. Only “initial p.u. load” of generators to define
3. Automatic calculation of all initial conditions:
   - Mechanical torques, alternators currents, coupling device..
   - Internal PMS states (orders, set points).

Results: evaluation of PMS strategies using:
- Non-reduced models for equipments
- Complete network model to close the loop
Problem solved: library management

Model and simulation risks:

- Models multiplication
- Data multiplication
- Results multiplication

Study process is no longer controlled

Principle: results must be reproducible

Solutions:

- Structure of the C32 library
  - Component models: generic, reusable
  - System models: specific, characterized
- Version management (models and results)
- Simulation platform management
  - Bugs
  - Evolutions
Example 1: motors start

Conditions

1 gas turbine generator + sudden and simultaneous start of a thruster motor and air conditioning motor

Start

HOTEL LOAD 1
P = 10(MW)
\[\cos\phi = 0.85\]
Example 1: motors start
Example 2: generator trip

Conditions
1 diesel generator + gas turbine generator loaded at 95% of their nominal load. Trip of a GTG

\[ P = 10 \text{MW} \]
\[ \cos \phi = 0.85 \]
Example 2: generator trip

- GTG trip
- DG1 power (MW)
- GTG power (MW)
- Propulsion active power (MW)
- PLS reduction
- Propulsion reactive power (MVar)
- Network Voltage (pu)
- Voltage overshoot: harmonic filter reactive power re-injection = 11 MVar
- Filter and PLS design and tuning
Example 3: crash stop

Conditions
2 diesel generators + gas turbine generator loaded at 85% of their nominal load. Crash stop

P = 1.0 [MW]
\[\text{cos } \phi = 0.05\]

Propulsion power crash stop impact
Example 3: crash stop

- Propulsion active power (MW)
- Reverse mode
- PLS limitation controls re-injection
- GTG power (MW)
- DG1 and DG2 power (MW)

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Example 3: crash stop

- Network frequency (Hz)
- Network Voltage (pu)
- Frequency and voltage stay within acceptable bands
- Speed set points from PMS

PLS / PMS tuning
Conclusion

Virtual machinery = a great contribution to the C32 project:

• Validation of C32 turbine/diesel dynamic association
• Frequency / voltage variations evaluations on extreme cases
• Generators trip simulations pointed out needs for modification of harmonic filters or PLS strategies

Capabilities of virtual machinery:

• Link with ship dynamics models for global propulsion studies
• Complete IAMCS definition and validation
• Short-circuit and protection system studies