Black-startup simulation of a repowered thermoelectric unit

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A typical ENEL repowering project

Introduction

Gas turbine

120 MW gas turbine

Steam power plant

320 MW once through UP boiler
The problem to be studied

- Possibility to use a local repowering TG to perform a black start operation on a UP-steam unit without feeding auxiliaries from the network. This could:

1. Spare precious time if load rejection on SPP fails

2. Avoid SPP auxiliaries feeding from network, complex operation involving personnel on large geographical areas.

3. Allows to the group TG/SPP to feed at last other power stations, helping to restore the network as fast as possible
CESI has developed a real time simulation environment, named ALTERLEGO. Its core consists of:

- **an efficient and reliable implicit solver** of large sets of algebraic-differential equations,
- **CAD-like user-friendly tools** for building and managing models,
- **a large library of mathematical models** in the field of energy production processes.

A run-time executive enables to run together the various parts and the MMI.
Simulator structure

- **Gas turbine**
- **GT load demand**
- **Load scheduler**
- **SPP load demand**
- **GT synchronous generator**
- **SPP synchronous generator**
- **Steam section control system**
- **Steam turbine**
- **UP boiler with start-up circuit**
- **SPP**
- **Electrical auxiliaries system and external network**
• The temperature control is not represented and it is approximated by reducing the maximum fuel limit.

• The fuel valve positioner has two different actuation speeds.

• Valve position 22% $\Rightarrow$ balance between gas turbine and compressor power
GT model validation
GT model validation

The simulator
UP Boiler: main assumptions

• Thermal balance equations are not represented: load connections generate $\Delta T_{\text{max}} = 5-10 \, \text{C}$

• Feedwater flow rate proportional to fuel flow rate at each load

• Steam production proportional to feedwater flow rate; time constant greater at diminishing loads

• Neglected F.T. drainings (but oil was increased by program at low load)

• Mass accumulation has been considered in: SH1, FT, SH2
UP Boiler

The simulator

![Diagram of UP Boiler system]

- From feedwater system
- To deaerator
- Flash Tank
- HP steam valve
- Condenser
UP Boiler

The simulator

Start-up circuit

- **boiler**
- **Superheater 1 (SH1)**
  - Relief valve
  - 200 valve steam flow rate
  - 207 valve position
  - Steam flow rate to flash tank
  - sh1 output pressure
  - \( T_b = 7.5 \text{ s} \) boiler time constant
  - \( T_{sh1} = 7.5 \text{ s} \) superheater 1 time constant
- **Superheater 2 (SH2)**
  - Relief valve
  - 205 noreturn valve
  - 205 valve position
  - HP steam flow rate
  - sh2 pressure losses
  - \( T_{sh2} = 2.8 \text{ s} \) superheater 2 time constant
  - \( T_{ft} = 3 \text{ s} \) flash tank time constant
- **Flash Tank**
  - 270 valve position
  - 240 valve position

Fuel (steam equivalent) to the boiler:
- Main steam pressure
- \( \text{SPP load demand} \)
- \( \frac{1}{1+0.5s} \)
- \( \frac{1}{1+sT_b} \)
- \( \frac{1}{1+sT_{sh1}} \)
- \( \frac{1}{1+sT_{sh2}} \)
- \( \frac{1}{1+sT_{ft}} \)

\( s = \frac{k}{1+ST_d} \) sh1 output pressure

\( k \) sh2 pressure losses

\( Q_{sh1} \) sh1 output pressure

\( Q_{sh2} \) sh2 output pressure

\( Q_{ft} \) flash flow rate

\( T_b \) boiler time constant
\( T_{sh1} = 7.5 \text{ s} \) superheater 1 time constant
\( T_{sh2} = 2.8 \text{ s} \) superheater 2 time constant
\( T_{ft} = 3 \text{ s} \) flash tank time constant
Steam turbine and electrohydraulic control

The simulator

- Impulse stage pressure regulator
- HP control valve positioner
- Main steam pressure
- HP steam chest
- HP control valve positioner
- Interception valve positioner
- RH heater
- Crossover
- React. stages
- Intercept

Parameters:
- \( T_{pr} = 0.1 \text{ s} \) - pressure reg. time const.
- \( T_{cv} = 0.8 \text{ s} \) - control valve time const.
- \( T_{CH} = 0.15 \text{ s} \) - HP chest time const.
- \( T_{RH} = 11 \text{ s} \) - RH time const.
- \( T_{CO} = 0.4 \text{ s} \) - crossover time const.
- \( y \) - constant \((\frac{P_{rh,nom}}{P_{ch,nom}})\)
- \( F_{hp} = 0.4 \) - fraction of total power generated by HP and LP sections

Equations:
- \( \frac{1}{1+y} \)
- \( \frac{1}{1+y} \)
- \( \frac{1}{1+y} \)
- \( \frac{1}{1+y} \)
- \( \frac{1}{1+y} \)
- \( \frac{1}{1+y} \)
Start-up control mode

SPP load demand → fuel adjustment → fuel programme

- kg/s 8.06
- kg/s 2.36

80 MW → 110 MW

Fuel (steam equivalent)

synchronisation adjustment

active power output

0.1(1+1/10s) → EHC load reference

bias

-Δf → 1/droop
SPP model validation

The simulator
Additional control system during restoration

TG: greater time constant between fuel and power
The power is immediately available

SPP smaller time constant between 0amm and power
Great “inertia” between fuel and steam production

Using TG to take load rapidly and bring to zero the frequency error (FLI)
When frequency and boiler pressure are correct, unload TG in favor of SPP so that TG preserves enough margin for subsequent load connections
Additional control system during restoration
Auxiliaries’ electrical system

The simulator

- 380 kV
- 250 MVA
- 400 kV / 150 kV
- 150 kV network
- 150 kV
- 20 MVA
- 150 kV / 6 kV
- 6 kV
- 0.63 MVA
- 6 / 0.4 kV
- GT
  - 15 kV
  - 140 MVA
  - 15 kV / 6.3 kV
  - 6 MVA
- GT-MT
  - 400 kV / 15 kV
  - 130 MVA
- SSP-MT
  - 400 kV / 20 kV
  - 370 MVA
- GCB
- AT
  - 20 kV / 6.3 kV
  - 16 MVA
- ST
  - 20 MVA
  - 150 kV / 6 kV
- SPP
  - 150 kV
  - 370 MVA
  - 20 kV
  - AT1
    - 16 MVA
    - 20 kV / 6.3 kV
  - AT2
    - 20 kV / 6.3 kV
    - 16 MVA
  - FWP1, CWP1, AF1, GR1, CWP1
  - M
  - CP2, CWP2, AF2, GR2
  - M
  - 0.63 MVA
  - 6 / 0.4 kV
  - 0.63 MVA
  - 6 / 0.4 kV
  - 0.63 MVA
  - 6 / 0.4 kV
  - 0.63 MVA
  - 6 / 0.4 kV
  - 0.63 MVA
  - 6 / 0.4 kV
  - 0.63 MVA
  - 6 / 0.4 kV
Models of the auxiliaries

Motors: 3 order model
LV auxiliaries: static model

a) Start-up of 2 FW pumps
b) Residual voltage bus transfer
380/220 kV network near the power plant

Montecorvino 380 kV

Tusciiano

220 kV

Rotonda

Rossano Calabro power station

150 kV network

The simulator
150 kV network near the power plant

The simulator

Rossano
Calabro
power station

15 MW
Nova Siri

60 km
60 km

15 MW

Scanzano

5 MW

10 MW
30 MW

Acri

30 km
45 km

Cosenza

10 km

Cosenza

50 km

Feroleto

15 MW

40 km

Cirò

50 km

15 MW

Crotone

5 MW
Ballast load

The simulator

- 48 MW
- 13 MW
- 5 s
- 300 s
- 1,7 s
OLTC model

Discrete
Inverse-time delay

The simulator

a) OLTC of the start-up transformer (±16; 0.625%)

b) OLTC of Rotonda transformer (±8; 1.9%)
Model of the excitation limiters

The simulator

- Generators and power plant auxiliary system **protections**
  abnormal voltages and frequencies
  loss of excitation
  inadvertent energisation
Pick-up of a 30 MW load

SPP alone
Pick-up of a 18 MW load

SPP alone
Pick-up of a 30 MW load  
(after other four loads)

SPP alone

Frequency and SPP outputs

Control valve position and FT pressure

Simulations
Pick-up of a 30 MW load
(after other four loads)

SPP alone

Frequency and SPP outputs

Control valve position and FT pressure
Pick-up of a 30 MW load

SPP and GT synchronized
Power plant ramping

SPP and GT synchronized
Frequency and SPP outputs

GT outputs

Control valve position and FT pressure
Conclusions

The study carried out has shown that

- The GT section can effectively help the SPP section under the start-up and ramping phases
- A load scheduler control system is crucial to coordinate the load requests to the GT and the SPP generators during the manoeuvre
- The repowered thermoelectric power unit can therefore assume the role of "early-restoration plant".