Transient Stability Closed-Loop Emergency Control

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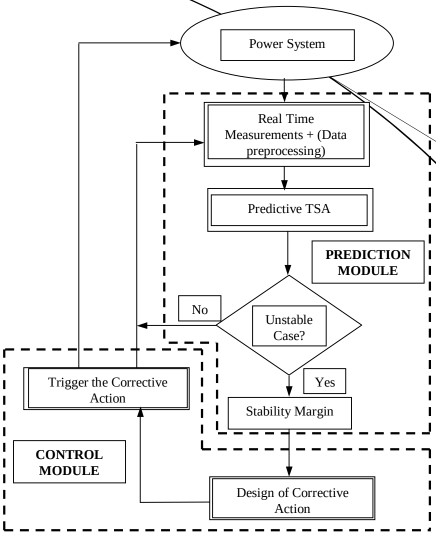
An emergency control cycle

- Data acquisition at power plants and their transmission to the control room,
- Data processing at the control room, ← E-SIME
- Order transmission from the control room to the system,
- The order actual implementation.

E-SIME is responsible for the data processing at the control room and the processing include: (in)stability prediction and assessment and control action design

General framework



Power System

Real Time Measurements + (Data preprocessing)

Predictive TSA

PREDICTION MODULE

Unstable Case?

No

Yes

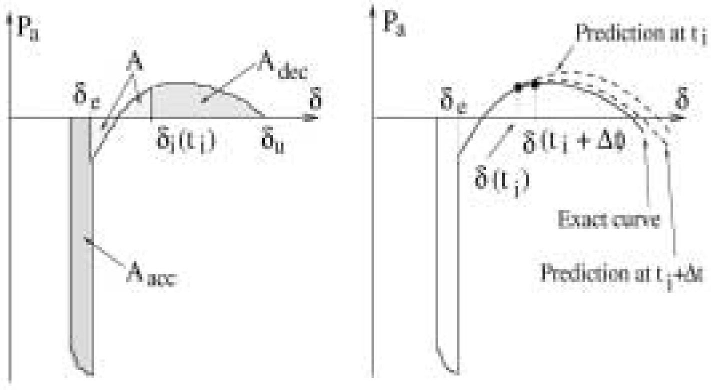
Stability Margin

Trigger the Corrective Action

CONTROL MODULE

Design of Corrective Action

Prediction module – the principle



Prediction module, ctd. -1

- Predicting the OMIB structure
- Predicting the OMIB swing curve (using weighted least-squares estimation)

$$\hat{P}_a(\delta) = a\delta^2 + b\delta + c$$

- Predicting instability by searching whether the above curve reaches SIME instability conditions

$$\hat{P}_a(\delta_u) = 0 \ , \ \dot{\hat{P}}_a(\delta_u) > 0$$

Prediction module,ctd. -2

- Computing of the corresponding margin and time to instability

$$\eta = -\int_{\delta_i}^{\delta_u} \hat{P}_a d\delta - \frac{1}{2} M \omega_i^2$$

$$t_u = t_i + \int_{\delta_i}^{\delta_u} \frac{d\delta}{\sqrt{\frac{2}{M} \int_{\delta_i}^{\delta_u} (-\hat{P}_a d\delta) + \omega_i^2}}$$

Control module
(generation shedding scheme)

- From the predicted swing curves of the individual machines, take the most advanced one(s),
- Compute the margin of the corrected system, if the margin is still unsatisfactory shed another machine(s),

$$\eta = -\int_{\delta_{ct}^{(1)}}^{\delta_u^{(2)}} \hat{P}_a^{(2)} d\delta^{(2)} - \frac{1}{2} M^{(1)} \omega_{ct}^{(1)2}$$

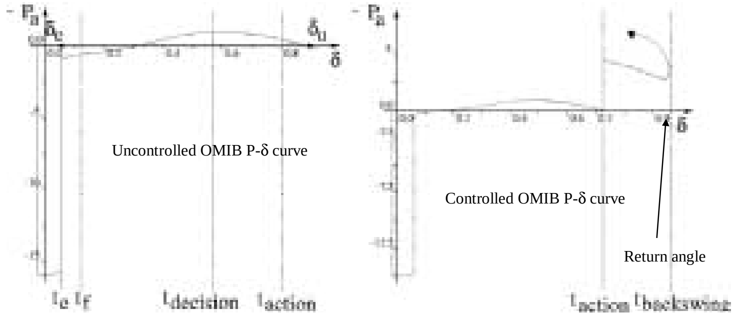
$$\hat{P}_a^{(2)} = a^{(2)}\delta^2 + b^{(2)}\delta + c^{(2)}$$

$$\delta^{(2)} = \delta^{(1)}, \quad \hat{P}_a^{(2)} = \hat{P}_a^{(1)} - M^{(1)} \frac{P_{ej}}{M_C^{(1)}}$$

$$x = \int_{\delta_i^{(1)}}^{\delta_{ct}^{(1)}} \frac{d\delta^{(1)}}{\sqrt{\frac{2}{M^{(1)}} \int_{\delta_i}^{\delta^{(1)}} (-\hat{P}_a^{(1)} d\delta^{(1)} + (\omega_i^{(1)})^2}}$$

Control module, ctd.

- Continue until the margin becomes satisfactory.
- Once the shedding order is sent, continue monitoring the system.



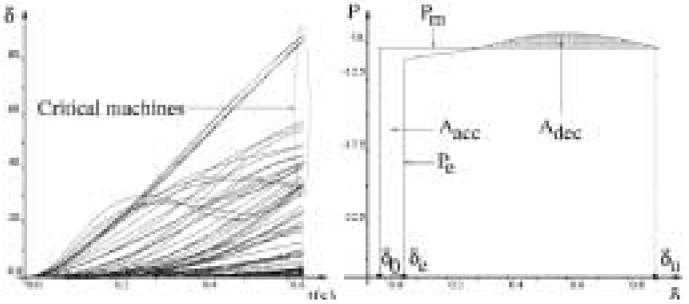
Uncontrolled OMIB P-δ curve

Controlled OMIB P-δ curve

Return angle

The principle of emergency control

Simulations – EPRI 88-machine test system



Uncontrolled system

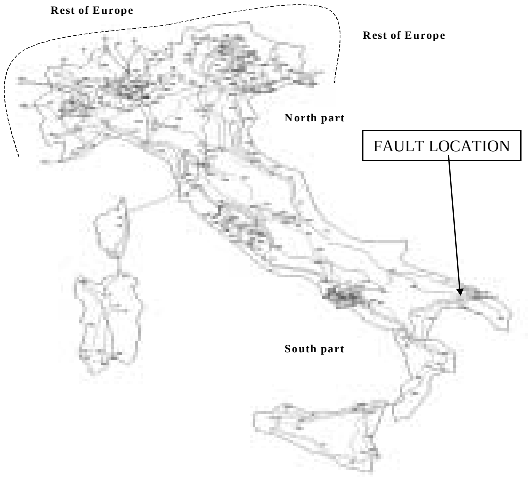
NOTE: Real-time measurements are “artificially” created, on the basis of T-D simulation using ETMSP program. Base case: 350,749 MW.

Controlled system - summary

Preventive SIME:
- Time to instability 635 ms
-Normalized margin –1.044 (rad/s)**2

1	2	3	4	5
t_i (ms)	δ_i (rad.)	t_u (ms)	η/M (rad/sec)^2	η/M after shed.
375	1.094	788	-0.60	
395	0.922	676	-0.81	
Corrective decision is taken (3 units shed, 2,463 MW)				
415	0.850	631	-0.88	0.271
435	0.822	614	-0.91	0.115
455	0.813	610	-0.91	0.092
475	0.820	617	-0.91	0.113
495	0.826	622	-0.90	0.151
515	0.836	631	-0.90	0.234
535	0.850	642	-0.89	0.347
555	0.858	649	-0.89	0.376
Corrective action is applied				
575	0.861	652	-0.89	0.352
595	0.860	652	-0.89	0.361
615	0.859	651	-0.89	0.373
635	0.861	652	-0.89	0.384

Simulations - Italian Power System



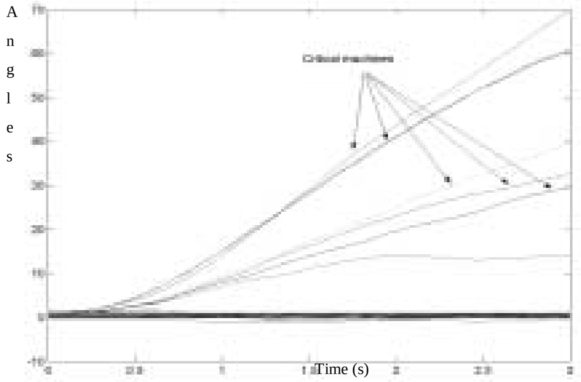
An unstable scenario in Italian Power System

- No preliminary network weakening,
- Sequence of events:
  - permanent 3-phase short circuit on the 380 kV line Andria-Brindisi, at 10% distance from Brindisi
  - opening of the line at both ends after 0.3 s from short

NOTE 1: Scenario simulates a protection malfunctioning or improper setting–typical value for the clearing time 100 ms

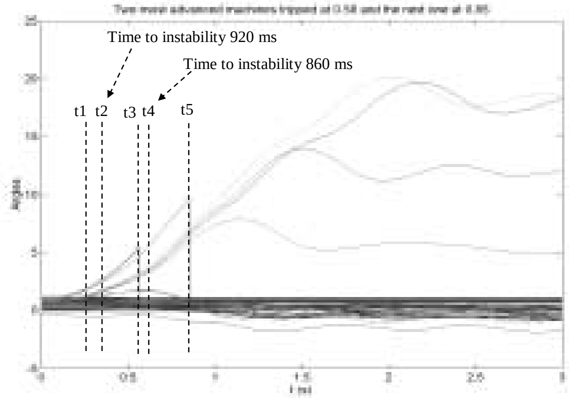
NOTE 2: Real-time measurements are “artificially” created, on the basis of time-domain simulation using SICRE-ENEL simulator.

Simulation results-1



Uncontrolled system

Simulation results-2



Controlled system

Controlled system - summary

1	2
Time (ms)	Description
t1=260	The first negative margin, tu=920 ms
t2=360	Margin converged to a constant value
Corrective decision is taken (2 units shed 968 MW)	
t3=560	
Corrective action is applied	
t4=640	Negative margin appeared again, tu=860 ms
Corrective decision is taken (1 unit shed 42 MW)	
t5=850	
Corrective action is applied	

Ongoing and future research

- Data preprocessing (estimating rotor angles from PMU measurements),
- Appraise of other controls (dynamic breaking, fast valving, etc…),
- SIME-based adaptive emergency control (combining OLEC and CLEC),
- Adaptive emergency control by combining E-SIME and Reinforcement Learning,
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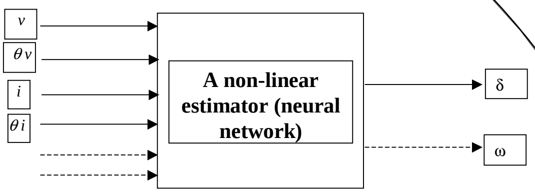
Data preprocessing (Why to estimate rotor angles?)

- Rotor angle of the synchronous generator is the most important quantity in power system transient stability control
- PMU measured quantities are electrical variables and experience fast changes, unlike rotor angles (mechanical variable)
- Wrong or noisy rotor angles may result in wrong E-SIME OMIB structure (prediction module) and wrong determination of control actions (control module)

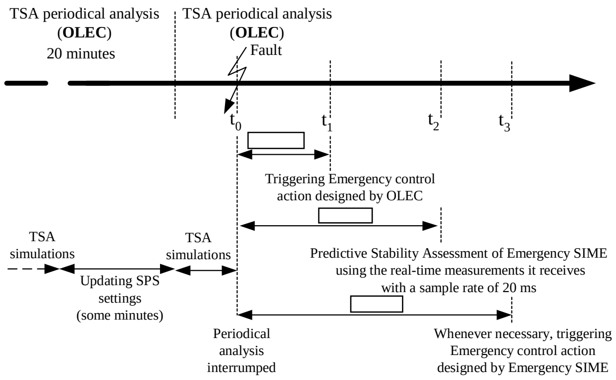
Data preprocessing, ctd.

$$f:\{u_t\}\in R^n \Rightarrow \{\delta_t\}\in R^{1(2)}$$



$$\{u_t\}=\left[v_t, v_{t-1}, \theta_{v_t}, \theta_{v_{t-1}}, i_t, i_{t-1}, \theta_{i_t}, \theta_{i_{t-1}}\right]^T$$

Combining OLEC and CLEC



TSA periodical analysis (**OLEC**) 20 minutes

TSA periodical analysis (**OLEC**)

Fault

t_0 t_1 t_2 t_3

Triggering Emergency control action designed by OLEC

TSA simulations

TSA simulations

Updating SPS settings (some minutes)

Predictive Stability Assessment of Emergency SIME using the real-time measurements it receives with a sample rate of 20 ms

Periodical analysis interrupmed

Whenever necessary, triggering Emergency control action designed by Emergency SIME

Conclusions

- E-SIME is free from system modeling and parameter uncertainties, location and clearing scenario of the contingency. High computational efficiency,
- The total time required for the whole cycle “prediction-assessment-design and triggering of the action” is expected not to exceed 500-600 ms,
- The applications on the EPRI 88-machines test system and Italian Power System were shown to provide effective control,
- The generation shedding scheme has shown to effectively apply to three other real-world Power Systems (the Hydro-Quebec system(Churchill Falls corridor), the Brazilian Power System (Itaipu site)), and WSCC,
- E-SIME and OLEC have more or less complementary features and assets. Combination of these controls comes quite naturally.