Literature Review on Adaptive Control for Power Electronics

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Contents of the Presentation

Introduction to the problem

- System under consideration : grid connected inverters with LCL filter.
- Problems:
  - LCL filter resonance $[\omega_{res} = \sqrt{\frac{L_1+L_2+L_g}{L_1 C_f (L_2+L_g)}}]$
  - Low-order harmonics due to grid distortion
- Conventional control is designed for stiff grid condition.
- In the case of a changing grid impedance, conventional control fails to give desired result
- A possible solution can be robust control
  - Robust control ensures acceptable performance in a predefined range of disturbance.
- Proposed solution

Adaptive Control

Adaptive Control

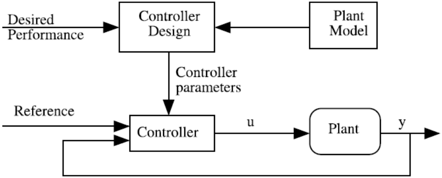


Figure: Control Design Principle (Landau et al., 2011)

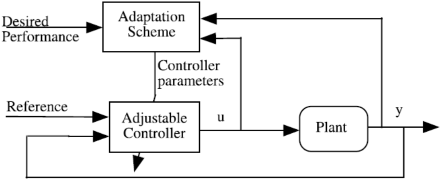
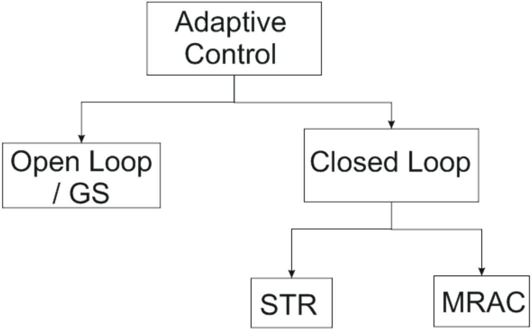


Figure: Adaptive Control Principle (Landau et al., 2011)

- In a conventional control, control parameters are fed to the system only once.
- Adaptive control takes into account the plant input and output and then adapts the parameters of the adjustable controller.

Adaptive Control

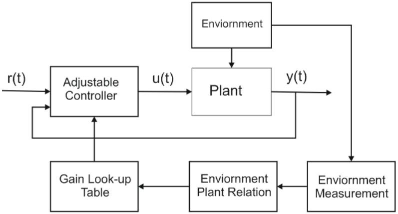


GS: Gain Scheduling

STR: Self Tuning Regulator

MRAC: Model Reference Adaptive Control

Gain Scheduling



- Nonlinear control technique.
- Deploys a linear controller.
- Parameters of the linear controller are changed w.r.t. changes in the environment.

● For a Grid connected inverter with LCL filter,
Plant : LCL Filter
Environment : Grid / Grid impedance
Environment Measurement: Measure of change in grid impedance
$r(t)$: reference input
$y(t)$: output (grid current or voltage at point of common coupling)
$u(t)$: pulsed output voltage of inverter

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Example from reference (Cespedes and Sun, 2014)

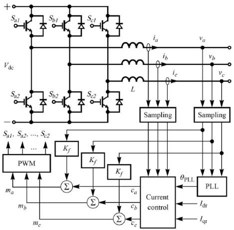

Figure: Grid connected inverter with L filter (Cespedes and Sun, 2014)

- Stability of the system depends on the parameters of PLL and the current controller (PI).
- Grid impedance is estimated by measuring the grid impulse response.
- A look-up-table for control parameters is precalculated using Routh-Hurwitz criteria.

Results

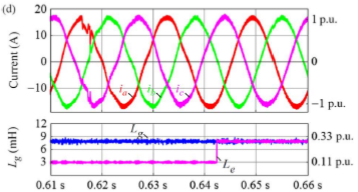

Figure: Phase currents and grid impedance

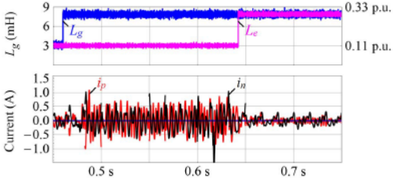

Figure: Sequencs currents

- Grid impedance is changed from 0.11 pu (3.1mH) to 0.33 pu (7.9mH) at 0.46 secs
- The change in impedance is not detected until the next identification pulse 200ms later.
- During the time grid impedance is not estimated phase currents suffer from resonance.

i_p = positive sequence current
i_n = negative sequence current

The positive sequence at fundamental frequency is removed from figure 2 to focus on the harmonics.

Self Tuning Regulator

- Most intuitive type of adaptive control
- Can be direct or indirect
- Direct STR: redesign of control parameters w.r.t. change in the output.
- Indirect STR: Plant parameters are estimated and then the controller is redesigned.

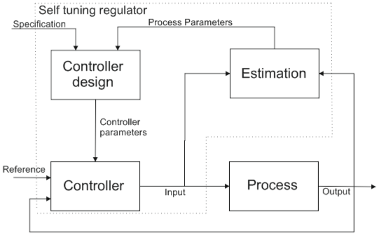

Figure: Control block diagram for self tuning regulators

- For the system under consideration, plant can be considered linear around the operating point and direct self tuning regulators can be applied.

Example from reference (Andresen et al., 2015)

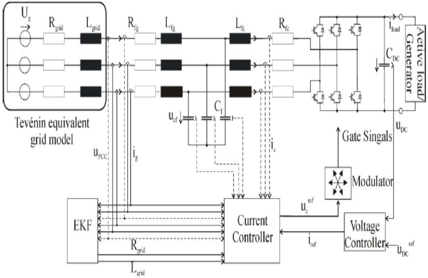

Figure: STR for grid connected inverter with LCL filter (Andresen et al., 2015)

EKF : extended Kalman filter for grid impedance estimation. (Hoffmann and Fuchs, 2014)

- Current Controller: PI controller
- Overall characteristic polynomial is a function of system parameters and the controller feedback vector.
- Desired system performance is specified in terms of pole locations.
- By solving the Diophantine equation control parameters are expressed in terms of the plant parameters and the grid impedance.

Result

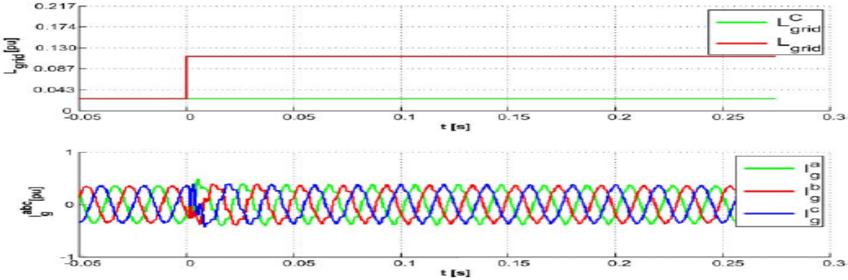

Figure: Without controller adaptation

- Experiment in (Andresen et al., 2015) is carried out on a 30kVA laboratory setup.
- Grid impedance: $0.025pu \rightarrow 0.112pu$
- Without the adaptation of controller parameters harmonics are still visible in the spectrum after more than 10 cycles.

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Result

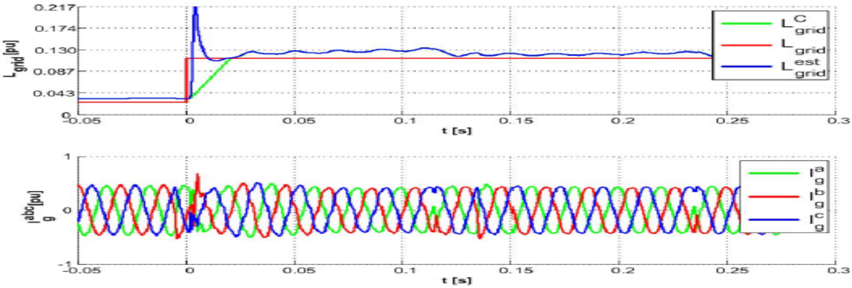

Figure: With controller adaptation

- EKF correctly estimates grid impedance after half a fundamental cycle.
- Visible harmonics in the output spectrum are rejected after 5 fundamental periods.

Model Reference Adaptive Control (MRAC)

- Desired system performance is specified through the reference model.
- Adaptation of the control parameters is influenced by : $\delta e(t)/\delta\theta(t)$.
- The goal of MRAC is to drive the error $e(t)$ to zero.
- Does not ensure that the overall system parameters meet the reference model.
- MRAC can be direct or indirect

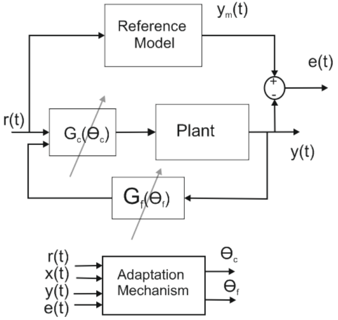

Figure: General block biagram for model reference adaptive Control (Landau et al., 2011)

$r(t)$: reference input $y(t)$: plant output
θ_c: feedforward control parameters
θ_f : feedback control parameters
$y_m(t)$: reference model output
$e(t) = y_m(t) - y(t)$

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Example from reference (Massing et al., 2012)

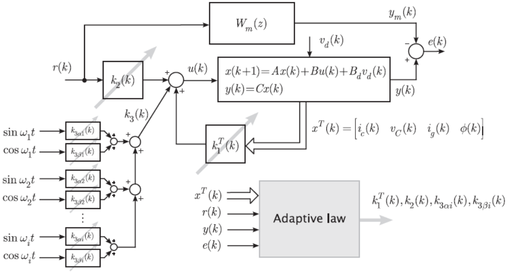

Figure: MRAC control scheme (Massing et al., 2012)

- $W_m(z)$ is the reference model transfer function.
- State space control is used in (Massing et al., 2012)
- Adaptation law can be gradient descent (Massing et al., 2009) or recursive least square (Massing et al., 2012).

Result

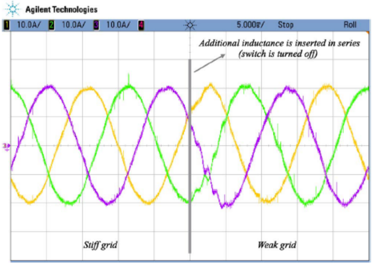

Figure: Effect of change in grid impedance with MRAC (Massing et al., 2012)

- Within the interval of $t = 25$ and $t = 33.33$ seconds, the gird impedance is changed 4 times.
- Additional grid impedance : $1mH$
- Grid current is found stable and well damped even under large parametric variations.

References

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Thank You

Questions?