Global Summit on Electronics and Electrical Engineering

Valencia - Spain

Phase-error Correction by Single-phase Phase-Locked Loops based on Transfer Delay

Main research Project: Distributed Harmonics Compensation for the Power Quality in Smart grids

Supported by the National Research Fund of Luxembourg - FNR
Project ID 8043977

Patrick Kobou Ngani

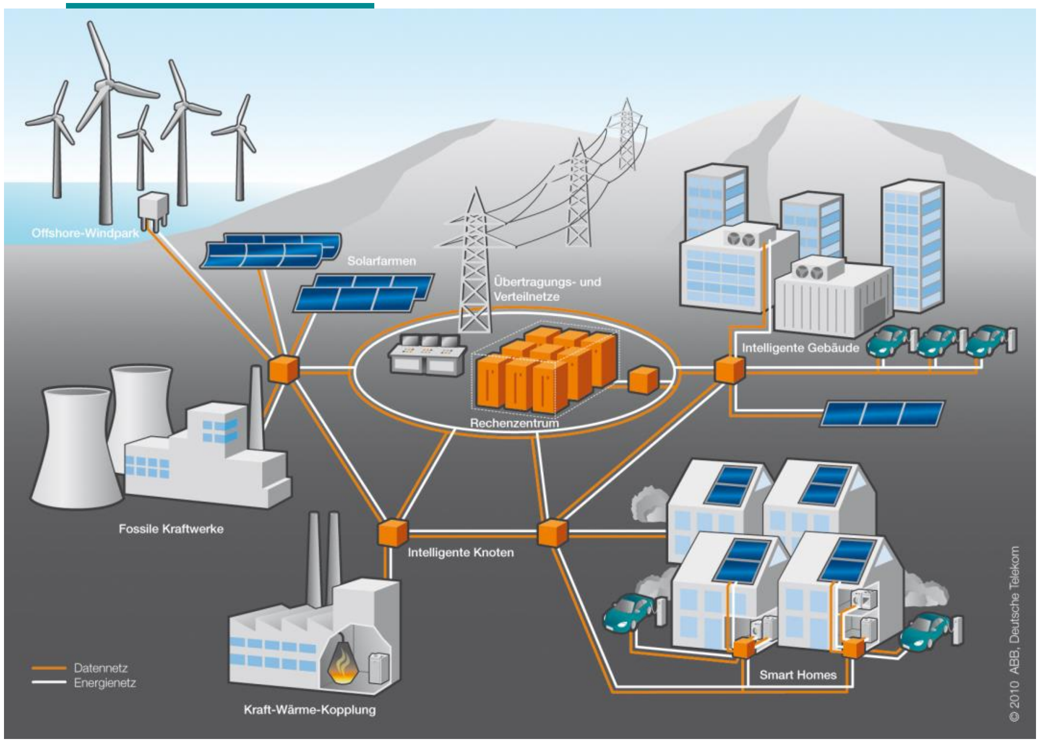
04/11/2015

RUES | RESEARCH UNIT IN ENGINEERING SCIENCES

Fonds National de la Recherche Luxembourg

uni.lu UNIVERSITÉ DU LUXEMBOURG

Context



PLLs are used everywhere in the grid by

- Energy producers for quantification
- Grid manager and energy distributors for reliability and security
- Special energy consumers for power conditioning.

Goal: Harmonics detection in a 3-phase voltage system

Constraint: limited computational resources

Adjustment: How can I reduce the number of calculations? Or maybe buy a faster processor?

Solution: Use a single-phase PLL instead of a 3-phase PLL.

RUES RESEARCH UNIT IN ENGINEERING SCIENCES

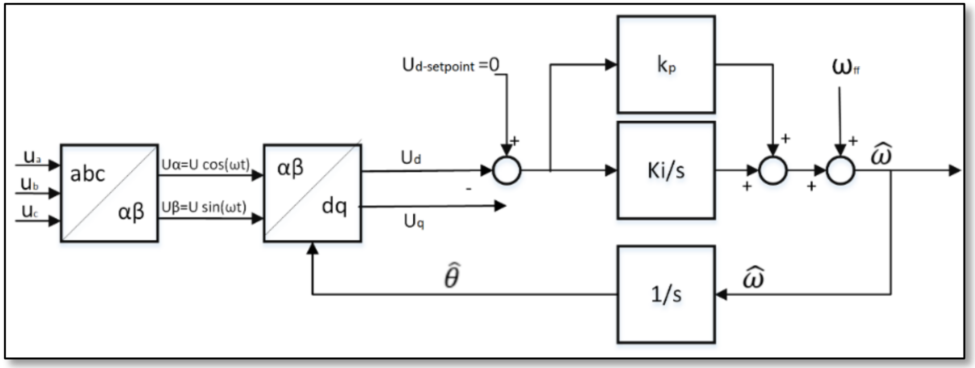
UNIVERSITÉ DU LUXEMBOURG

Summary

- PLLs details
  - 3-phases Synchrone Reference Frame PLL dqPLL
  - Single Phase delay PLL dPLL
- Proposed solutions
- Simulation performances
- Conclusions and perspectives

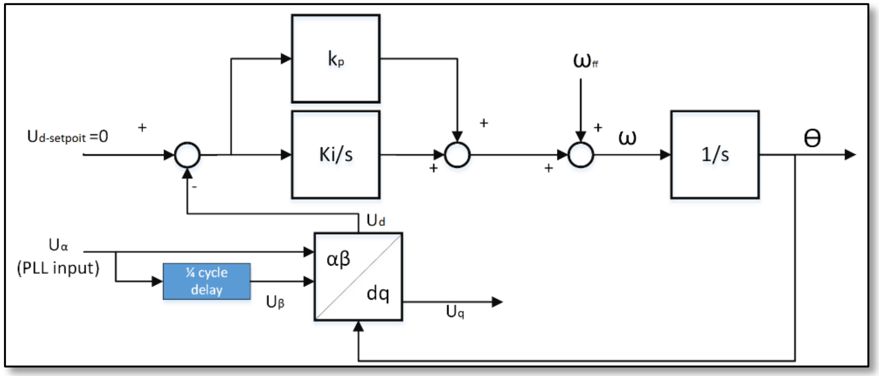
PLLs details

3-Phase SRF PLL - dqPLL



- Stability condition: $k_p > 0$ and $k_i > 0$
- Robustness depends on k_p and k_i
- Stable for all input signal disturbances

Delay PLL - dPLL



- Stability condition: $k_p > 0$ and $k_i > 0$
- As robust as dqPLL
- No phase-error at rated PLL frequency
- Oscillating U_d error when signal ang. Vel. ω deviates from rated ang. Vel. ω_{ff}
  - U_d error freq. nears the double of the input signal freq.
  - U_d error ampl : $U \cdot \frac{\pi}{4} \cdot \epsilon_\omega$; $\epsilon_\omega = \frac{\omega - \omega_{ff}}{\omega_{ff}}$
  - →Oscillating phase angle error + steady offset

Proposed solutions

For the delay PLL
$$\begin{cases} U_\alpha = U\cos(\omega t) \\ U_\beta = U_\alpha\left(t - {}^{1}/_{4}\,T_0\right) = U\sin\left(\omega t - \frac{\pi}{2}\,\varepsilon_\omega\right) \end{cases}$$
with $\varepsilon_\omega = \dfrac{\omega - \omega_0}{\omega_0}$

$$\rightarrow U_d = U(-\Delta\theta + \alpha) + U\alpha\cos(2\theta - \Delta\theta - \alpha)$$

With $\alpha = \frac{\pi}{4} \cdot \epsilon_\omega$ (ϵ_ω as the relative frequency variation)

Non-oscillatory part: $U_{d0} = -U\Delta\theta + U\alpha$, Standardly controlled value

$-U\Delta\theta + U\alpha = 0 \rightarrow \Delta\theta = \alpha$ → Steady phase angle offset

Phase angle error cancellation strategies

- Change the PI controller set-point to $U\alpha$
- Correct the final output phase position by α
- Correct the estimated U_β value obtained after the sample delay

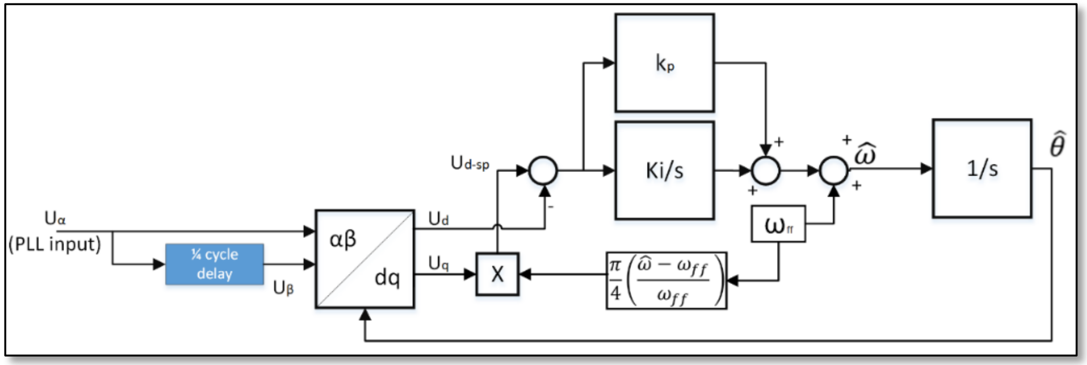
The real relative angular velocity is unknown but is estimated just like the estimated delivered angular velocity

RUES | RESEARCH UNIT IN ENGINEERING SCIENCES

UNIVERSITÉ DU LUXEMBOURG

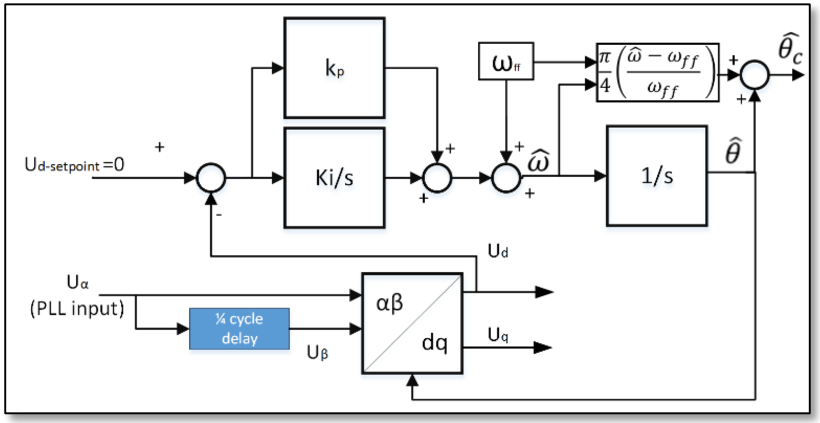
Proposed solutions

Solution 1: Change the PI controller set-point to $U\alpha$: dPLL-Csp



U is approximated to Uq

Solution 2: Correct the final output phase position by α : dPLL-Ca



RUES | RESEARCH UNIT IN ENGINEERING SCIENCES

UNIVERSITÉ DU LUXEMBOURG

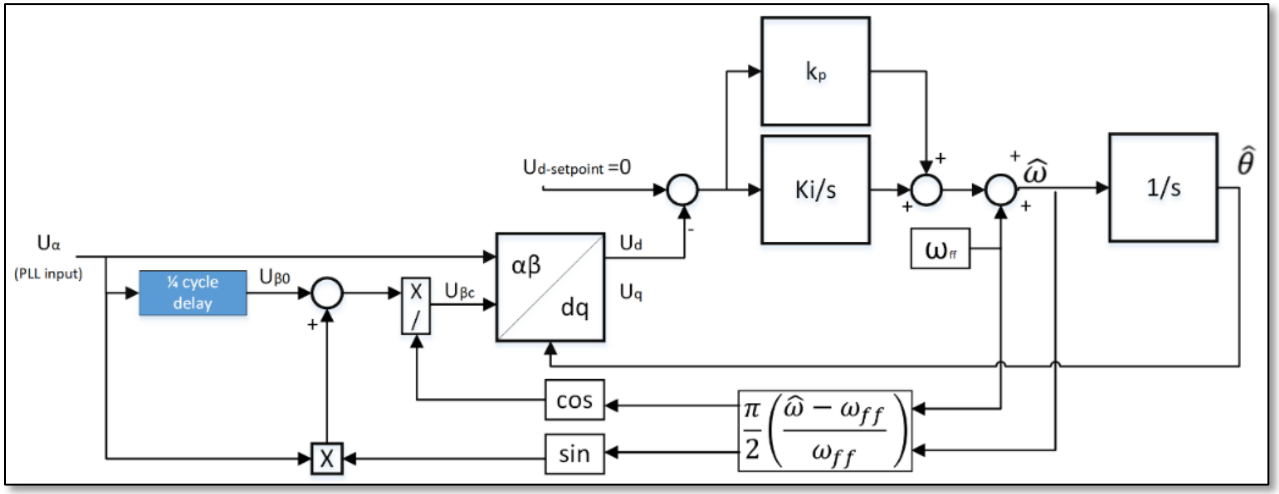
Proposed solution

Solution 3: Corrected voltage β-component : dPLL-CUb

$$U_\beta = U\sin\left(\omega t - \frac{\pi}{2}\,\varepsilon_\omega\right) = U\sin(\omega t)\cos\left(\frac{\pi}{2}\,\varepsilon_\omega\right) - U_\alpha \sin\left(\frac{\pi}{2}\,\varepsilon_\omega\right)$$

Corrected β-component:

$$U_{\beta c} = \frac{U_\beta + U_\alpha \sin\left(\frac{\pi}{2}\,\widehat{\varepsilon_\omega}\right)}{\cos\left(\frac{\pi}{2}\,\widehat{\varepsilon_\omega}\right)}$$



RUES RESEARCH UNIT IN ENGINEERING SCIENCES

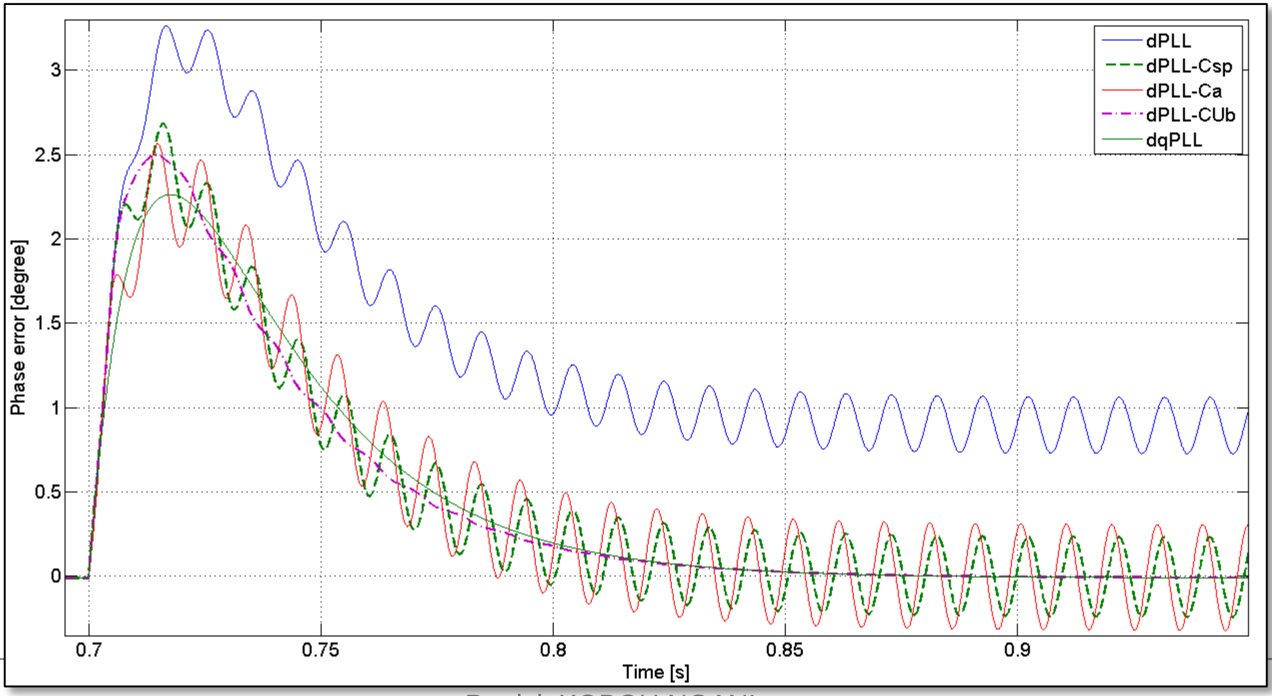
UNIVERSITÉ DU LUXEMBOURG

Performances

Simulation configuration

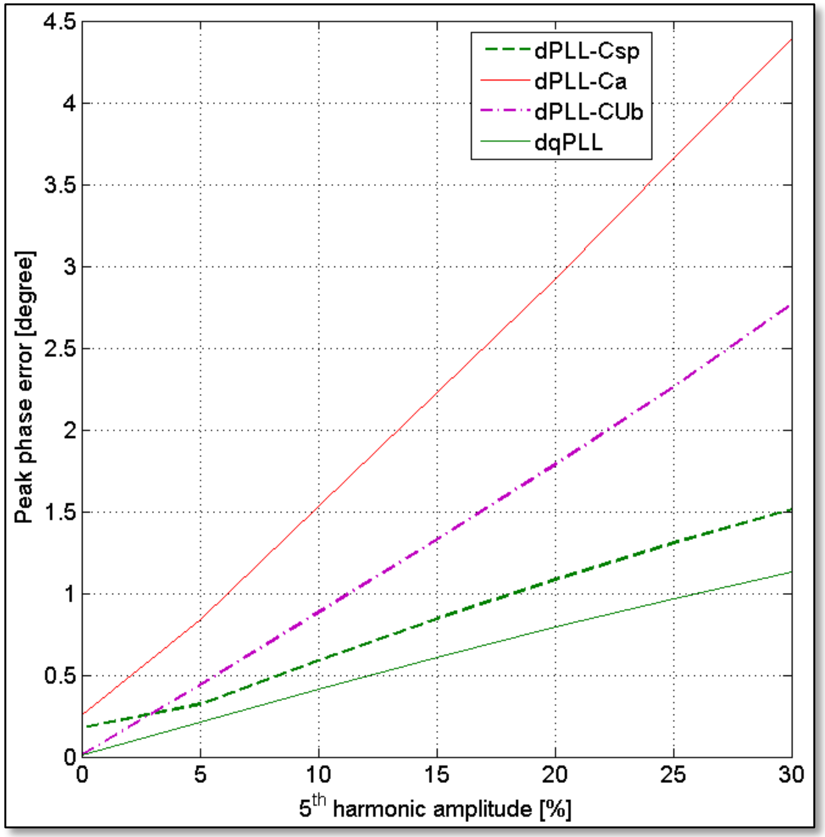
- Matlab Simulink
- 20 kHz sample frequency
- 50 Hz input signal with an amplitude of 100
- Input signal disturbances: 20% amplitude increase at 0.3 sec, 15° phase angle jump at 0.4 sec and a 2% frequency increase at 0.7 sec

Phase-error after frequency change

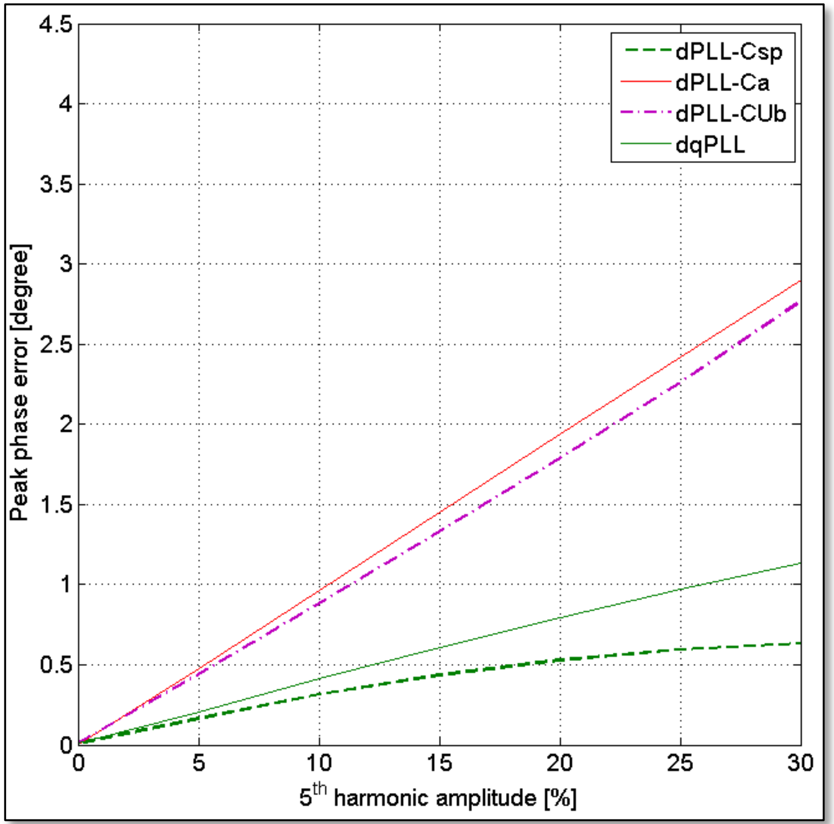


Performances

PLLs Peak phase error in function of 5^{th} harmonic amplitude



Filtered PLLs Peak phase error in function of 5^{th} harmonic amplitude



RUES RESEARCH UNIT IN ENGINEERING SCIENCES

UNIVERSITÉ DU LUXEMBOURG

Conclusion

- For single-phase PLL, the output phase-angle value oscillates with a constant offset error when the input signal frequency deviates from the PLL's rated frequency.
  - Frequency: very close to the double of that of the input frequency.
  - Constant offset value: proportional to the relative frequency variation
  - Amplitude: proportional to the input signal amplitude and the relative frequency variation.
- The three improvement approaches have good performances
  - The curative methods: cancel constant offset error
  - The preventive method: cancels offset + oscillations
- The proposed structures remain stable in harmonics presence
- Bandstop filters can be used

  since the oscillations frequency is known

RUES | RESEARCH UNIT IN ENGINEERING SCIENCES

UNIVERSITÉ DU LUXEMBOURG

Thanks