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
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.
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. $\omega$ deviates from rated ang. Vel. $\omega_{ff}$
  - $U_d$ 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

\[
\begin{aligned}
U_\alpha &= U \cos(\omega t) \\
U_\beta &= U_\alpha \left(t - \frac{1}{4} T_0\right) = U \sin\left(\omega t - \frac{\pi}{2} \varepsilon_\omega\right)
\end{aligned}
\]

with \( \varepsilon_\omega = \frac{\omega - \omega_0}{\omega_0} \)

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

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

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

\[-U \Delta \theta + U \alpha = 0 \rightarrow \Delta \theta = \alpha \rightarrow \text{Steady phase angle offset}\]

Phase angle error cancellation strategies

- Change the PI controller set-point to \( U \alpha \)
- Correct the final output phase position by \( \alpha \)
- Correct the estimated \( U_\beta \) value obtained after the sample delay

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

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

Solution 2: Correct the final output phase position by $\alpha : dPLL$-$Ca$
Solution 3: Corrected voltage $\beta$-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 $\beta$-component:

\[ U_{\beta c} = \frac{U_\beta + U_\alpha \sin \left( \frac{\pi}{2} \varepsilon_\omega \right)}{\cos \left( \frac{\pi}{2} \varepsilon_\omega \right)} \]
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\textsuperscript{th} harmonic amplitude

Filtered PLLs Peak phase error in function of 5\textsuperscript{th} harmonic amplitude
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
Thanks