Real-time implementation of the multi-swarm repetitive control algorithm

Piotr Biernat, Bartlomiej Ufnalski and Lech M. Grzesiak

Institute of Control and Industrial Electronics
Warsaw University of Technology, POLAND

FACULDADE DE CIÊNCIAS E TECNOLOGIA UNIVERSIDADE NOVA DE LISBOA
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Outline

Some known techniques and the novelty

- Multi-oscillatory (multi-resonant) controllers — the internal model principle (IEEE Trans. on Ind. Electron. 2015).

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- Repetitive neurocontrollers (the derivative-based approach) — a fairly new concept within the frame of 2D systems (IEEE IECON 2013).
- Direct particle swarm repetitive controller (the derivative-free approach) — a novelty within the frame of 2D systems (Archives of Electrical Engineering 4/2014).

The motivation

The very basic P-type control law

$$u(p,k) = 1.0u(p,k-1) + k_{\mathrm{RC}}e(p,k-1),$$

where u denotes the control signal, e is the control error, k_{RC} is the controller gain, k is the iteration (pass, trial, cycle) index and p is the time index along the pass ($1 \leq p \leq \alpha$, where α is the pass length).

Theoretically perfect tracking could be achieved if only...

The long-term stability issue

... this formula had been stable!

It then has to be modified into

$$u(p,k) = \cancel{1.0}\;\mathbf{Q}\left(z^{-1}\right) u(p,k-1) + \cancel{k_{\mathrm{RC}}}\;k_{\mathrm{RC}}\mathbf{L}\left(z^{-1}\right) e(p,k-1)$$

where **Q** and **L** are usually non-causal low-pass zero-phase-shift filters. This compromises the performance and hence there still is plenty of room for new iterative learning techniques.

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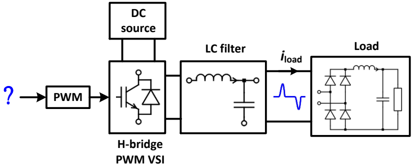
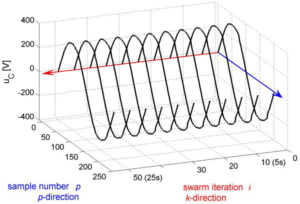
Two-dimensional (2D) behavior of a controller





The objective

Rejection of a repetitive disturbance load current in a constant-amplitude constant-frequency VSI

Let us attack the problem using DOP-capable PSO

✓ The repetitive control task at hand can be formulated as the DOP. It cannot be dealt with as the SOP because of a load current shape that can and will vary with time.
✓ Control tasks encountered in repetitive processes are ideally suited to be tackled with iterative DOP solvers – surprisingly, still not a widely recognized and acknowledged fact. Why?
✗ Online optimization techniques impose significant computational burden on a microcontroller.
✓ PSO related calculations can be effectively distributed in time and consequently implemented using an off-the-shelf industrial DSC – such as TI TMS320F2812.

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The control objective

The cost function for the controller

$$\mathcal{J}(k,n) = \mathcal{J}_0 + \underbrace{\sum_{p=\alpha_{n-1}+1}^{\alpha_n} \left(u_{\mathrm{C}}^{\mathrm{ref}}(p) - u_{\mathrm{C}}^{\mathrm{m}}(p,k)\right)^2}_{\text{penalty for control error}} +$$

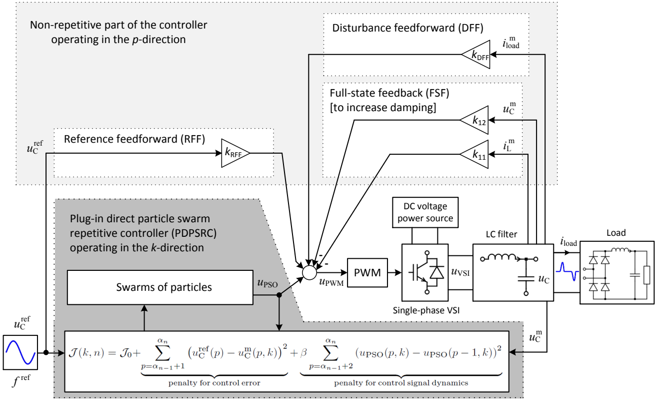
$$+\beta \underbrace{\sum_{p=\alpha_{n-1}+2}^{\alpha_n} \left(u_{\mathrm{PSO}}(p,k) - u_{\mathrm{PSO}}(p-1,k)\right)^2}_{\text{penalty for control signal dynamics}}$$

PSO algorithm

$$\mathbf{v}_{nj}(i+1)[p] = c_1\mathbf{v}_{nj}(i) + c_2 r^{\mathrm{pbest}}[p]\delta_p[p]\left(\mathbf{q}_{nj}^{\mathrm{pbest}}[p] - \mathbf{q}_{nj}(i)[p]\right) + \\ + c_3 r^{\mathrm{gbest}}[p]\delta_p[p]\left(\mathbf{q}_{n}^{\mathrm{gbest}}[p] - \mathbf{q}_{nj}(i)[p]\right)$$

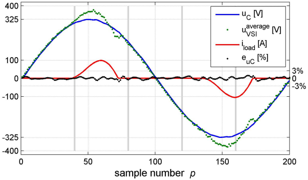
where: j is the particle identification number, n is the subswarm identification number and i denotes the swarm iteration number, $\mathbf{v}_{nj}$ and $\mathbf{q}_{nj}$ are speed and position of the j-th particle within the n-th subswarm, $\mathbf{q}_{nj}^{\mathrm{pbest}}$ stores the best solution proposed so far by the j-th particle (*pbest*), $\mathbf{q}_{n}^{\mathrm{gbest}}$ denotes the best solution found so far by the swarm (*gbest*), δ_p is the attraction/repulsion variable for diversity control, r^{pbest} and r^{gbest} are random numbers uniformly distributed in the unit interval.

Plug-in direct particle swarm repetitive (k-direction) controller with an accompanying non-repetitive (p-direction) controller



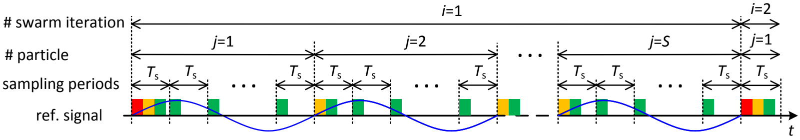
$$\mathcal{J}(k,n) = \mathcal{J}_0 + \sum_{p=\alpha_{n-1}+1}^{\alpha_n} \left(u_C^{ref}(p) - u_C^{m}(p,k)\right)^2 + \beta \sum_{p=\alpha_{n-1}+2}^{\alpha_n} \left(u_{PSO}(p,k) - u_{PSO}(p-1,k)\right)^2$$

[movie] Evolution of output voltage under variable load conditions

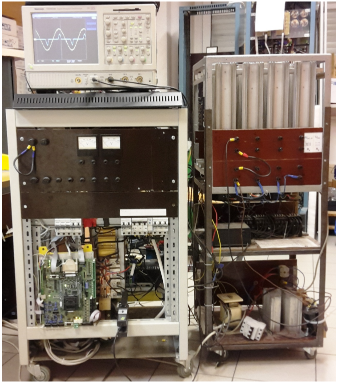


Click on the pictures to play the movie.

Time-distributed swarm calculations



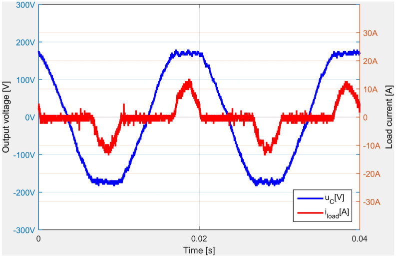
Hardware: TMS320F2812 eZdsp Starter Kit (socketed version)

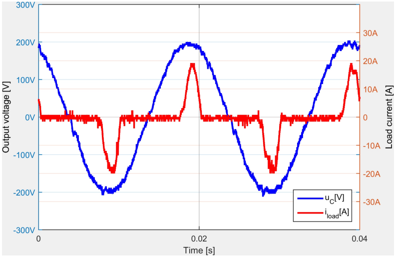


- ✓ 150 MHz clock speed available
- ✗ 18 K on chip RAM
- ✓ 128 K on chip FLASH ROM
- ✓ 64 K words on board RAM
- ✗ on board RAM access time

The first bottleneck (✗) is resolved by using an on-board (external) RAM. The second bottleneck (✗) is circumvented by rewriting variables from the on-board RAM to the on-chip RAM for their manipulation.

Experimental verification





Conclusions

- The novel swarm based repetitive control algorithm has been implemented in the off-the-shelf DSC @10kHz sampling time and @50Hz reference signal (200 samples per pass).

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- It has been demonstrated that the PSO technique can be used in online (real-time) mode to directly shape the control signal for the repetitive process.

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- The novel swarm based repetitive control algorithm has been implemented in the off-the-shelf DSC @10kHz sampling time and @50Hz reference signal (200 samples per pass).
- It has been demonstrated that the PSO technique can be used in online (real-time) mode to directly shape the control signal for the repetitive process.
- It is then feasible to interpret repetitive control tasks as dynamic optimization problems and solve them in real time using the particle swarm optimization technique – the technique almost exclusively associated in power electronics (up to now) with static offline optimization problems.

Questions?

Thank you for your kind attention!

And please do not hesitate to contact us at

✉ ***bartlomiej.ufnalski@ee.pw.edu.pl*** .

This presentation is already available at

www.ufnalski.edu.pl

along with the relevant models/codes published at

www.mathworks.com/matlabcentral/profile/authors/2128309-bartlomiej-ufnalski .

Please cite the accompanying paper using the following BIBTEX entry

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@INPROCEEDINGS{PDPSRC_Ufnalski_IS_2014, author={Biernat, P. and Ufnalski, B. and
     Grzesiak, L. M.},
booktitle={Proc. of the 9th IEEE International Conference on Compatibility and Power
     Electronics (CPE)}, title={Real-time implementation of the multi-swarm
     repetitive control algorithm}, month={June}, year={2015}, address={Lisbon}} .
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