Model based predictive control for flying-capacitor inverters

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1 Introduction

Power-electronic inverters controllably and efficiently transform DC power into AC power. Multilevel inverters recently became important as a higher voltage handling, compared to normal two-level inverters, is possible and these topologies also allow intermediate voltage levels to be applied. Especially the flying-capacitor (FC) topology is very promising, it however needs a regulation of the capacitor voltages. In this case many quantities (all capacitor voltages v_c and the output current i) are regulated simultaneously with a limited set of inputs for the control variable (inverter switch state). Finite set model based predictive control offers a way to control a discrete, multiple input - multiple output (MIMO) system and thus is very suitable to control FC inverters, [1, 2].

2 Multilevel inverter topology and MBPC principles

The topology of the three-level FC converter (figure 1) uses 2 pairs of complementary controlled switches, S_{1x} and S_{2x}, per phase. Depending on the switch state the load (RL series) is connected to the DC-bus or in series with the flying capacitor, C_{1x}. In the latter case an intermediate output voltage is produced and the capacitor voltage changes as the load current flows through the capacitor. The two main control objectives are the tracking of the reference current i_r and the reference FC voltage $v_{c,r}$. In the algorithm, at time instant k, the values of the controlled variables are calculated at the end of the update period ($k+1$, estimation) and one time step into the future ($k+2$, prediction), for all possible switch states of the converter (a finite set). The switch state with the minimal cost $g(k)$ is asserted. The relative importance of an error in the FC voltage is expressed by the weight factor W_{v_c}.

$$g(k) = [i_r(k+2) - i(k+2)]^2 + W_{v_c}\,[v_{c,r}(k+2) - v_c(k+2)]^2$$

3 Results obtained with MBPC

Figure 2 shows simulation results for MBPC of a three-level inverter with a well-chosen weight factor W_{v_c}. Satisfactory control can be obtained with other values, but the objective judgement of the control quality and weight factor selection is difficult based on the waveforms. The mean square error (MSE) of both the current and FC voltages, as well as the total error are good objective measures to compare results for different W_{v_c}, allowing a direct selection of a good range.

3.1 Neglecting the neutral point voltage

Each inverter phase has 4 possible output states which interact due to the neutral point o, resulting in $4^3 = 64$ possible output states of the converter. Thus 3 equations need to be solved 64 times, a total of 192. When neglecting the influence of the neutral point, the switching decisions in the 3 phases are uncoupled and only 12 (3×4) equations are needed. The reduction in computational burden is clear, but the model is less correct and the control is degraded.

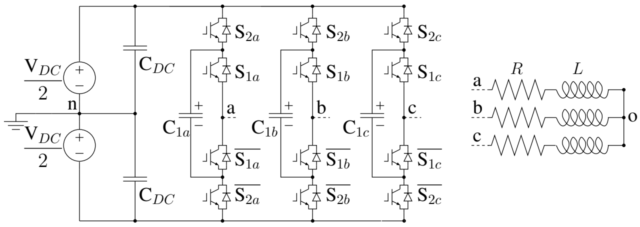

Figure 1: Three-level flying capacitor converter circuit topology.

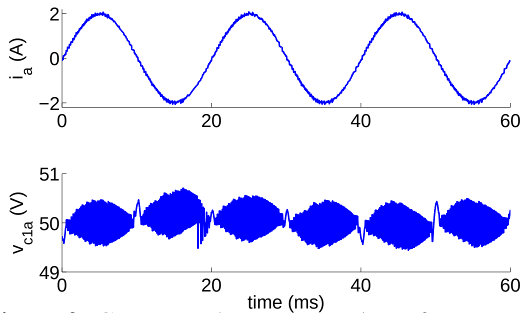

Figure 2: Current and capacitor voltage for $W_{v_c} = 2.15$

3.2 Increasing the prediction horizon

Increasing the prediction horizon to 2 or 3 time steps results in a very high increase in computational requirements (4096 and 262144 combinations respectively). Without other objectives in the cost function this however does not result is an improved control and thus is not advisable.

4 Conclusions

For MBPC of FC inverters a broad range of suitable values for W_{v_c} for all current amplitudes exists. In this study the suitability of the MSE of the controlled variables to quantify the control quality and acceptable values of W_{v_c} is demonstrated. Neglecting the neutral point voltage degrades the control quality and reduces this range. Expanding the prediction horizon is not worth the effort when no additional terms are added to the cost function. Experimental results confirm the validity of the conclusions and show the feasibility to implement MBPC on an FPGA platform.

References

[1] P. Lezana, R. Aguilera, and D. Quevedo "Model predictive control of an asymmetric flying capacitor converter," IEEE Trans. on Ind. Electr., vol.56, no.6, June 2009.

[2] T. Vyncke, S. Thielemans, M. Jacxsens, J. Melkebeek, "Analysis of some design choices in model based predictive control of flying-capacitor inverters," COMPEL.