



Rahul Kanchan (Autor)  
Ralph Kennel (Autor)  
Arne Linder (Autor)  
Peter Stolze (Autor)

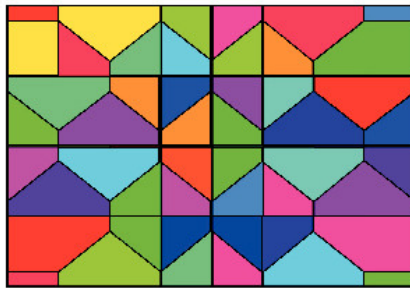
## **Model-Based Predictive Control of Electric Drives**

---

### Model-Based Predictive Control of Electric Drives

---

Arne Linder  
Rahul Kanchan  
Ralph Kennel  
Peter Stolze



 Cuvillier Verlag Göttingen

<https://cuvillier.de/de/shop/publications/717>

Copyright:  
Cuvillier Verlag, Inhaberin Annette Jentzsch-Cuvillier, Nonnenstieg 8, 37075 Göttingen,  
Germany  
Telefon: +49 (0)551 54724-0, E-Mail: [info@cuvillier.de](mailto:info@cuvillier.de), Website: <https://cuvillier.de>

# Contents

<b>Preface</b>	<b>1</b>
<b>1 Introduction</b>	<b>3</b>
<b>2 Field-oriented control</b>	<b>7</b>
<b>3 Cascade control with PI controllers</b>	<b>13</b>
3.1 Current control . . . . .	13
3.2 Speed control . . . . .	15
3.3 Flux control . . . . .	16
3.4 Experimental results . . . . .	16
<b>4 Predictive control</b>	<b>17</b>
4.1 Classification based on operational principle . . . . .	19
4.2 Classification based on prediction horizon and control principle	23
<b>5 Model-based predictive control</b>	<b>27</b>
5.1 Functional principle . . . . .	28
5.2 Models . . . . .	30
5.2.1 State space model . . . . .	31
5.2.2 Linear transfer function-based models . . . . .	32
5.2.3 Nonlinear models . . . . .	35
<b>6 Generalized Predictive Control</b>	<b>39</b>
6.1 “Classical GPC” . . . . .	39
6.1.1 Mathematical derivation . . . . .	39
6.1.2 Experimental results . . . . .	48
6.2 GPC with filter . . . . .	48
6.2.1 Mathematical derivation . . . . .	50
6.2.2 Simulations . . . . .	55
6.3 Cascade control with GPC controllers . . . . .	56
6.3.1 Current control . . . . .	58

6.3.2	Speed control . . . . .	59
6.3.3	Experimental results . . . . .	60
6.3.4	Computation times . . . . .	66
<b>7</b>	<b>Discrete-time machine model for current control</b>	<b>69</b>
7.1	Derivation . . . . .	69
7.1.1	MATLAB . . . . .	71
7.1.2	Difference quotient . . . . .	71
7.1.3	Laplace transformation . . . . .	72
7.1.4	Power series . . . . .	74
7.2	Experimental results . . . . .	76
7.3	Modified machine model for GPC . . . . .	77
<b>8</b>	<b>Multivariable GPC control</b>	<b>83</b>
8.1	“Classical” MIMO-GPC . . . . .	83
8.1.1	Determination of the transfer function . . . . .	83
8.1.2	Calculation of the system matrices . . . . .	85
8.1.3	Mathematical derivation . . . . .	86
8.1.4	Consideration of the control horizon . . . . .	93
8.2	Consideration of disturbance inputs with GPC . . . . .	95
8.2.1	Determination of the transfer function . . . . .	96
8.2.2	Calculation of the system matrices . . . . .	96
8.2.3	Mathematical derivation . . . . .	97
8.2.4	Consideration of the control horizon . . . . .	103
8.3	MIMO-GPC with filter . . . . .	104
8.3.1	Determination of the transfer function . . . . .	105
8.3.2	Calculation of the system matrices . . . . .	105
8.3.3	Mathematical derivation . . . . .	105
8.3.4	Consideration of the control horizon . . . . .	114
8.4	Experimental results . . . . .	115
8.4.1	Current control . . . . .	115
8.4.2	Computation times . . . . .	116
8.5	Comparative summary . . . . .	118
<b>9</b>	<b>Direct model-based predictive control</b>	<b>121</b>
9.1	Published techniques . . . . .	124
9.2	Inverter operation with DMPC . . . . .	125
9.2.1	Consideration of the Bootstrap circuit . . . . .	127
9.3	Model formulation . . . . .	128

9.3.1	Simple machine model . . . . .	131
9.4	Implicit solution . . . . .	132
9.4.1	Solving algorithms . . . . .	134
9.4.2	Mathematical derivation . . . . .	138
9.4.3	Experimental results . . . . .	138
9.4.4	Computation times . . . . .	141
9.5	Explicit solution . . . . .	143
9.5.1	Standard algorithm . . . . .	152
9.5.2	Minimum-Time Controller . . . . .	152
9.5.3	Binary search tree . . . . .	154
9.5.4	Optimal complexity reduction . . . . .	158
9.5.5	Experimental results . . . . .	162
<b>10</b>	<b>Related control structures</b>	<b>171</b>
10.1	Internal Model Control . . . . .	171
10.2	Linear Quadratic Control . . . . .	173
10.2.1	Functional principle of LQR . . . . .	174
10.2.2	GPC and LQR . . . . .	176
<b>11</b>	<b>Summary and future prospects</b>	<b>179</b>
	<b>Bibliography</b>	<b>183</b>
<b>A</b>	<b>Glossary polynomial matrices</b>	<b>195</b>
<b>B</b>	<b>Nomenclature</b>	<b>203</b>
<b>C</b>	<b>Normalization values</b>	<b>215</b>
<b>D</b>	<b>Physical machine constants</b>	<b>217</b>
<b>E</b>	<b>Polynomials and matrices for GPC</b>	<b>219</b>
E.1	SISO system . . . . .	219
E.2	MIMO system . . . . .	221
E.2.1	Definitions . . . . .	221
E.2.2	Dimensions . . . . .	230
<b>F</b>	<b>Methods for matrix inversion</b>	<b>231</b>
F.1	Gauss algorithm . . . . .	231
F.2	Gauss-Jordan algorithm . . . . .	231

*Contents*

---

F.3	Exchange algorithm . . . . .	232
F.4	LR decomposition . . . . .	232
F.5	Algorithm of Cholesky . . . . .	232
F.6	Computation times . . . . .	232
<b>G</b>	<b>Alternative method for matrix decomposition</b>	<b>235</b>
	<b>Index</b>	<b>237</b>