Cairo University

APPLICATIONS OF MODEL PREDICTIVE CONTROL (MPC) IN ENERGY CONVERSION SYSTEMS

By

Islam Ahmed Ali Sayed

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
Master of Science
in
Electrical Power and Machines Engineering

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Under the Supervision of

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Summary:

The present thesis investigates the model predictive control as a power system stabilizer to damp the frequency oscillations. It discusses the different types of MPC which consider constraints or not. It also discusses some other controllers like Linear Quadratic Regulator and Pole Placement. The controllers are designed in detail and applied to three different power system models; a single machine connected to an infinite bus, a multi-machine power system model, and a multi-machine power system model with a wind power plant. Then, some disturbances are made to test the controllers including a three-phase fault, transmission line outage, and machine's voltage reference sudden change. The design and simulation are done by MATLAB/SIMULINK.

Disclaimer

I hereby declare that this thesis is my own original work and that no part of it has been submitted for a degree qualification at any other university or institute.

I further declare that I have appropriately acknowledged all sources used and have cited them in the references section.

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Nomenclature

AC	Alternating Current
AVR	Automatic Voltage Regulator
cMPC	Constrained Model Predictive Control
CSO	Cuckoo Search Optimization
CSP	Concentrated Solar Power
DC	Direct Current
DE	Differential Evolution
DFIG	Doubly Fed Induction Generator
GA	Genetic Algorithm
HSO	Harmony Search Optimization
LQR	Linear Quadratic Regulator
MMPS	Multi-Machine Power System
MMPS-WPP	Multi-Machine Power System with Wind Power Plant
MPC	Model Predictive Control
N4SID	Subspace State Space System Identification
PI	Proportional Integral Controller
PID	Proportional Integral Derivative Controller

PLL	Phase Locked Loop
PSO	Particle Swarm Optimization
PSS	Power System Stabilizer
PV	Photo Voltaic
SCIG	Squirrel Cage Induction Generator
SFC	State Feedback Control by Pole Placement
SMIB	Single Machine Connected to an Infinite Bus
uMPC	Unconstrained Model Predictive Control
WOA	Whale Optimization Algorithm
WPP	Wind Power Plant

Abstract

Since the first power system was introduced, its stability became on the spot. The researchers have been developing controllers to keep the power system's voltage and frequency around nominal values. The first power system consisted of a generator connected to a load. An automatic voltage regulator (AVR) is used for controlling the excitation voltage and the generated voltage correspondingly. A governor is used to regulate the rotating speed and the frequency consequently. While the power system is increasing, a lot of machines are connected to it every day. This requires a new controller to keep the power system stable. The power system stabilizer (PSS) is introduced. It supplies a damping signal to the excitation system via the AVR. This signal depends on the machine's frequency change. Several control strategies have been being used as PSS. In this thesis, model predictive control (MPC) is investigated to be used as PSS. Besides, a lot of countries spread in using renewable energies particularly wind and solar. This increase certainly affects the power system stability. MPC is investigated in treating these effects as well.

MPC is optimal control and uses numerical optimization algorithms to get an optimal control output concerning the system's constraints. It can handle these constraints with a big degree of stability and robustness. These merits are so considerable as the PSS has some constraints due to the synchronous machine's nature. In this thesis, MPC is explained and designed in detail. Then, it is applied to three power systems; a single machine connected to an infinite bus (SMIB), a multi-machine power system (MMPS), and a multi-machine power system with a wind power plant (MMPS-WPP). Some disturbances are made to test it including a three-phase fault, transmission line outage, and machine's voltage sudden change. Then, its performance is investigated and compared to state feedback control via pole placement (SFC) and linear quadratic regulator (LQR). The design and simulation are done by MATLAB/SIMULINK.

MPC shows efficient performance among the controllers especially in handling the constraints. In the SMIB, the constrained MPC gives the best performance. The unconstrained MPC with an infinite prediction horizon performs similarly to LQR. SFC competes in most cases. In the MMPS, LQR performs efficiently with the constrained MPC as the controllers do not need to exceed the constraints in most of the studied cases. SFC performs well in some cases. In the MMPS-WPP, the controllers succeed in stabilizing the power system as well. The constrained MPC proves its ability in handling the constraints especially in the case of three-phase fault.