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Approximated discreet-time linear switched model of thyristor converter.

A discreet-time linear switched model is developed for the dynamical system which consists of a linear continuous subsystem and a thyristor converter. Thyristors converters are power electronics circuits which provide controlled conversation alternating current to direct current. Usually the design of control law for such systems is based on linear continuous models (see [1], for example). The main objective of this work is to derive a more accurate model, which can be used to improve performance of the closed-loop system.

The continuous switched model of dynamical system with a thyristor converter is presented in [2].

$$\dot{x} = Ax + Bu, \quad u(t) = U_0 \cos\Big(\frac{3\pi}{T}t - \frac{\pi}{6} - \frac{\pi q_k}{3}\Big), \quad t \in [\tau_{k-1}, \tau_k).$$

The first equation represents continuous subsystem. x is the state vector, $u(t)$ is the thyristor converter output, $q_k \in \{0, 1, \ldots, 5\}$ is the discreet state of the converter on time interval $[\tau_{k-1}, \tau_k)$, $U_0 > 0$, $T = \frac{\pi}{3\omega}$, ω is voltage frequency. Switching instants τ_k are externally forced and plays a role of control input.

The discreet-time switched model [3] has the form

$$x[(k+1)T] = e^{AT}\left(x[kT] + \mathrm{Re}\Big\{\sum_{p=0}^{r_k}(\Psi(\gamma_k^{p+1}) - \Psi(\gamma_k^p))e^{j[\frac{\pi}{3}(k-q_k^p)-\frac{\pi}{6}]}\Big\}\right), \tag{1}$$

where q_k^p is discreet state of the converter on time interval $[(k+\gamma_k^p)T, (k+\gamma_k^{p+1})T)$, $q_k^0 = q_{k-1}^{r_{k-1}+1}$, $\Psi(\gamma)$ depends only on matrices A, B and parameters U_0 and T.

Approximation theory methods (Remez algorithm) are used to simplify right-hand side of (1).

$$\begin{aligned} x[(k+1)T] &= e^{AT}x[kT] + D_{k,q_k^{r^k}} + \sum_{p=1}^{r_k}\left(B_{k,q_k^{p-1},q_k^p}\gamma_k^p + b_{k,q_k^{p-1},q_k^p}\right), \\ \overline{x}_{k+1} &= \frac{1}{T}\Phi x[kT] + \overline{D}_{k,q_k^{r^k}} + \sum_{p=1}^{r_k}\left(\overline{B}_{k,q_k^{p-1},q_k^p}\gamma_k^p + \overline{b}_{k,q_k^{p-1},q_k^p}\right), \end{aligned} \tag{2}$$

where $D_{k,q}$, $B_{k,q,r}$, $b_{k,q,r}$, Φ are known column vectors and matrix, $\overline{x}_k$ is averaged over discretization period $[(k-1)T, kT]$ value of continuous state $x(t)$. This model can be generalized to the case of thyristor converter with commutation delays.

Although the equation (2) defines the linear switched model the standard methods of designing linear control laws are not directly applicable due to presence of discreet state q.

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