第16卷 第6期　　电子科学学刊　　Vol. 16, No. 6
1994年11月　　JOURNAL OF ELECTRONICS　　Nov. 1994

多相开关电容网络Z域不变拓扑系统分析法——状态变量法

刘长林　申石虎　刘淑敏
（东北重型机械学院自控系　齐齐哈尔　161042）

摘要　本文把开关视为固定支路，使开关电容网络变成不变拓扑网络，应用时不变网络的拓扑分析法，导出了多相开关电容网络 Z 域不变拓扑系统分析法——状态变量法.

关键词　开关电容网络，时不变拓扑分析，状态变量法.

1 引言

开关电容网络（SCN）的分析，国内外大多数学者是把 SCN 视为时变拓扑进行分相分析的. 对于大规模 SCN 的分析，急需一种不考虑它的拓扑变化，按通常的不变拓扑一次列出电路方程的系统方法. 文献[1]已给出 SCN 时域不变拓扑分析法，文献[2]给出了两相 SCN Z 域全相分析法. 本文在文献[1, 2]的基础上，给出了多相 SCN Z 域不变拓扑系统分析法——状态变量法.

2 SCN Z域不变拓扑分析法——状态变量法.

2.1 *约定*　(1) SCN 的开关是受N相周期性的、均匀的、非重叠时钟脉冲控制. (2) 把开关视为固定支路，则 SCN 为时不变拓扑. 在 SCN 的拓扑图中，按下列优先顺序选一棵树：(a) 独立电压源支路；(b) 运放输出端支路；(c) 电容支路；(d) 开关支路. (3) SCN 的拓扑图中，支路编号次序为：(a) 独立电压源支路 (U)；(b) 运放输出端支路 (P)；(c) 树支电容支路 (CT)；(d) 树支开关支路 (ST)；(e) 连支开关支路 (SL)；(f) 连支电容支路 (CL)；(g) 运放输入端支路 (I). (4) 各支路电压和支路电荷的参考方向一致.

2.2 SCN *Z域不变拓扑方程*　SCN Z 域不变拓扑方程是由基本割集方程、基本回路方程和支路特性方程组成.

SCN 的基本割集方程为

$$DQ(Z)=0, \tag{1}$$

其中

1993-06-09 收到，1994-01-03 定稿

刘长林　男，1936年生，副教授，现从事电路理论的教学和研究工作，在开关电容网络和神经网络方面亦有研究.
申石虎　男，1932年生，教授，现从事电路理论的教学和研究工作，在网络综合、开关电容网络、网络图论和数字信号处理等方面有很多成果.
刘淑敏　女，1952年生，工程师，现从事模拟电子技术和数字电子技术的研究工作.

$$D=\begin{array}{c} \\ U \\ P \\ CT \\ ST \end{array}\begin{array}{c} \begin{array}{ccccccc} U & P & CT & ST & SL & CL & I \end{array} \\ \begin{bmatrix} 1 & 0 & 0 & 0 & D_{US} & D_{UC} & D_{UI} \\ 0 & 1 & 0 & 0 & D_{PS} & D_{PC} & D_{PI} \\ 0 & 0 & 1 & 0 & D_{CS} & D_{CC} & D_{CI} \\ 0 & 0 & 0 & 1 & D_{SS} & D_{SC} & D_{SI} \end{bmatrix} \end{array}, \tag{2}$$

$$Q(Z)=[Q_U(Z),Q_P(Z),Q_{CT}(Z),Q_{ST}(Z),Q_{SL}(Z),Q_{CL}(Z),Q_I(Z)]^T. \tag{3}$$

$Q(Z)$ 为 SCN 各支路电荷序列 Z 变换(序列形式)组成的列向量.

SCN 的基本回路方程为

$$BV(Z)=0, \tag{4}$$

其中

$$B=\begin{array}{c} \\ SL \\ CL \\ I \end{array}\begin{array}{c} \begin{array}{ccccccc} U & P & CT & ST & SL & CL & I \end{array} \\ \begin{bmatrix} -D_{US}^T & -D_{PS}^T & -D_{CS}^T & -D_{SS}^T & 1 & 0 & 0 \\ -D_{UC}^T & -D_{PC}^T & -D_{CC}^T & -D_{SC}^T & 0 & 1 & 0 \\ -D_{UI}^T & -D_{PI}^T & -D_{CI} & -D_{SI}^T & 0 & 0 & 1 \end{bmatrix} \end{array}, \tag{5}$$

$$V(Z)=[V_U(Z),V_P(Z),V_{CT}(Z),V_{ST}(Z),V_{SL}(Z),V_{CL}(Z),V_I(Z)]^T. \tag{6}$$

$V(Z)$ 是 SCN 各支路电压序列 Z 变换(序列形式)组成的列向量.

SCN 的电容支路特性为

$$Q_{CT}(Z)=C_TV_{CT}(Z)-C_TV_{CT}^{[1]}(Z), \tag{7}$$

$$Q_{CL}(Z)=C_LV_{CL}(Z)-C_LV_{CL}^{[1]}(Z). \tag{8}$$

$V_C^{[1]}(Z)$ 是右移一位电容电压序列的 Z 变换(序列形式).

由文献[2]，当把开关视为固定支路时，引入开关变量 $S(Z)$，则开关支路特性为

$$S_T(Z)=V_{ST}(Z)+Q_{ST}(Z), \tag{9}$$

$$S_L(Z)=V_{SL}(Z)+Q_{SL}(Z), \tag{10}$$

$$V_{ST}(Z)=\bar{\phi}_TS_T(Z), \tag{11}$$

$$Q_{ST}(Z)=\phi_TS_T(Z), \tag{12}$$

$$V_{SL}(Z)=\bar{\phi}_LS_L(Z), \tag{13}$$

$$Q_{SL}(Z)=\phi_LS_L(Z). \tag{14}$$

其中 ϕ_T 和 ϕ_L 是树支开关和连支开关控制时钟脉冲序列组成的对角阵，$\bar{\phi}_T$ 和 $\bar{\phi}_L$ 是它们的反码.

对于理想运放，输入端口的电压和电荷恒为零，即

$$V_I(Z)=0, \tag{15}$$

$$Q_I(Z)=0. \tag{16}$$

2.3 SCN Z 域全相解——全相状态方程　展开(1)式和(4)式，把(7)，(8)和(9)-(14)式代入，消去变量 $V_I(Z)$，$Q_I(Z)$，$V_{ST}(Z)$，$Q_{ST}(Z)$，$V_{SL}(Z)$，$Q_{SL}(Z)$，$Q_{CT}(Z)$，$Q_{CL}(Z)$，则得

$$Q_U(Z)+D_{US}\phi_LS_L(Z)+D_{UC}C_LV_{CL}(Z)=D_{UC}C_LV_{CL}^{[1]}(Z), \tag{17}$$

$$Q_P(Z)+D_{PS}\phi_LS_L(Z)+D_{PC}C_LV_{CL}(Z)=D_{PC}C_LV_{CL}^{[1]}(Z), \tag{18}$$

$$C_TV_{CT}(Z)+D_{CS}\phi_LS_L(Z)+D_{CC}C_LV_{CL}(Z)=D_{CC}C_LV_{CL}^{[1]}(Z)+C_TV_{CT}^{[1]}(Z), \tag{19}$$

$$\phi_T S_T(Z) + D_{SS}\phi_L S_L(Z) + D_{SC}C_L V_{CL}(Z) = D_{SC}C_L V_{CL}^{[1]}(Z), \tag{20}$$

$$D_{PS}^T V_P(Z) + D_{CS}^T V_{CT}(Z) + D_{SS}^T \bar{\Phi}_T S_T(Z) - \bar{\Phi}_L S_L(Z) = -D_{US}^T V_U(Z), \tag{21}$$

$$D_{PC}^T V_P(Z) + D_{CC}^T V_{CT}(Z) + D_{SC}^T \bar{\Phi}_T S_T(Z) - V_{CL}(Z) = -D_{UC}^T V_U(Z), \tag{22}$$

$$D_{PI}^T(Z) V_P(Z) + D_{CI}^T V_{CT}(Z) + D_{SI}^T \bar{\Phi}_T S_T(Z) = -D_{UI}^T V_U(Z). \tag{23}$$

令

$$V_C(Z) = \begin{bmatrix} V_{CT}(Z) \\ V_{CL}(Z) \end{bmatrix}, \quad S(Z) = \begin{bmatrix} S_T(Z) \\ S_L(Z) \end{bmatrix}, \quad V_C^{[1]}(Z) = \begin{bmatrix} V_{CT}^{[1]}(Z) \\ V_{CL}^{[1]}(Z) \end{bmatrix}, \tag{24}$$

由(23)式，合并(19)与(22)式，(20)与(21)式，得

$$V_C(Z) = H_7 S(Z) + H_8 V_P(Z) + H_9 V_C^{[1]}(Z) + H_{10} V_U(Z), \tag{25}$$

$$V_P(Z) = -H_{16} V_C(Z) - H_{17} S(Z) - H_{18} V_U(Z), \tag{26}$$

$$H_{19} V_C(Z) + H_{20} S(Z) + H_{21} V_P(Z) = H_{22} V_C^{[1]}(Z) - H_{23} V_U(Z), \tag{27}$$

其中

$$\left.\begin{aligned}
&H_1 = \begin{bmatrix} 1 & C_T^{-1} D_{CC} C_L \\ -D_{CC}^T & 1 \end{bmatrix}_{(C\times C)}, \quad H_2 = \begin{bmatrix} 0 & -C_T^{-1} D_{CS} \\ D_{SC}^T & 0 \end{bmatrix}_{(C\times S)}, \\
&H_3 = \begin{bmatrix} \bar{\Phi}_T & 0 \\ 0 & \phi_L \end{bmatrix}_{(S\times S)}, \quad H_4 = \begin{bmatrix} 0 \\ D_{PC}^T \end{bmatrix}_{(C\times P)}, \quad H_5 = \begin{bmatrix} 1 & C_T^{-1} D_{CC} C_L \\ 0 & 0 \end{bmatrix}_{(C\times C)}, \\
&H_6 = \begin{bmatrix} 0 \\ D_{UC}^T \end{bmatrix}_{(C\times U)}, \quad H_7 = H_1^{-1} H_2 H_3, \quad H_8 = H_1^{-1} H_4, \quad H_9 = H_1^{-1} H_5, \\
&H_{10} = H_1^{-1} H_6, \quad H_{11} = [D_{CI}^T \ \ 0]_{(P\times C)}, \quad H_{12} = [D_{SI}^T \ \ 0]_{(P\times S)}, \quad H_{13} = H_{12} H_3, \\
&H_{14} = D_{UI}^T, \quad H_{15} = D_{PI}^T, \quad H_{16} = H_{15}^{-1} H_{11}, \quad H_{17} = H_{15}^{-1} H_{13}, \quad H_{18} = H_{15}^{-1} H_{14}, \\
&H_{19} = \begin{bmatrix} D_{CS}^T & 0 \\ 0 & D_{SC} C_L \end{bmatrix}_{(S\times C)}, \quad H_{20} = \begin{bmatrix} D_{SS}^T \bar{\Phi}_T & -\bar{\Phi}_L \\ \phi_T & D_{SS}\phi_L \end{bmatrix}_{(S\times S)}, \\
&H_{21} = \begin{bmatrix} D_{PS}^T \\ 0 \end{bmatrix}_{(S\times P)}, \quad H_{22} = \begin{bmatrix} 0 & 0 \\ 0 & D_{SC} C_L \end{bmatrix}_{(S\times C)}, \quad H_{23} = \begin{bmatrix} D_{US}^T \\ 0 \end{bmatrix}_{(S\times U)}.
\end{aligned}\right\} \tag{28}$$

联立求解(25)，(26)，(27)三式，则得

$$S(Z) = H_{37} V_C^{[1]}(Z) + H_{38} V_U(Z), \tag{29}$$

$$V_P(Z) = -H_{39} V_C^{[1]}(Z) - H_{40} V_U(Z), \tag{30}$$

$$V_C(Z) = H_{41} V_C^{[1]}(Z) + H_{42} V_U(Z), \tag{31}$$

其中

$$\left.\begin{aligned}
&H_{24} = 1 + H_{16} H_8, \quad H_{25} = H_{17} + H_{16} H_7, \quad H_{26} = H_{16} H_9, \\
&H_{27} = H_{18} + H_{16} H_{10}, \quad H_{28} = H_{24}^{-1} H_{25}, \quad H_{29} = H_{24}^{-1} H_{26}, \\
&H_{30} = H_{24}^{-1} H_{27}, \quad H_{31} = H_7 - H_8 H_{28}, \quad H_{32} = H_9 - H_8 H_{29}, \\
&H_{33} = H_{10} - H_8 H_{30}, \quad H_{34} = H_{20} + H_{19} H_{31} - H_{21} H_{28}, \\
&H_{35} = H_{22} + H_{21} H_{29} - H_{19} H_{32}, \quad H_{36} = H_{21} H_{30} - H_{19} H_{33} - H_{23}, \\
&H_{37} = H_{34}^{-1} H_{35}, \quad H_{38} = H_{34}^{-1} H_{36}, \quad H_{39} = H_{29} + H_{28} H_{37}, \\
&H_{40} = H_{30} + H_{28} H_{38}, \quad H_{41} = H_{32} + H_{31} H_{37}, \quad H_{42} = H_{33} + H_{31} H_{38}.
\end{aligned}\right\} \tag{32}$$

(29)，(30)，(31)式是 SCN 的 Z 域全相解．$V_C(Z)$ 称作状态变量，(31)式称作全相状态方程．

2.4　SCN Z域的分相解——分相状态方程　SCN Z域分相解可由其全相中分出。为此须把全相解中的序列形式的Z变换改成通常形式的Z变换。对N相的SCN，有

$$\left.\begin{aligned}V_C(Z)&=\phi_1V_C^{(1)}(Z)+\phi_2V_C^{(2)}(Z)+\cdots+\phi_NV_C^{(N)}(Z),\\S(Z)&=\phi_1S^{(1)}(Z)+\phi_2S^{(2)}(Z)+\cdots+\phi_NS^{(N)}(Z),\\V_P(Z)&=\phi_1V_P^{(1)}(Z)+\phi_2V_P^{(2)}(Z)+\cdots+\phi_NV_P^{(N)}(Z),\\V_U(Z)&=\phi_1V_U^{(1)}(Z)+\phi_2V_U^{(2)}(Z)+\cdots+\phi_NV_U^{(N)}(Z);\end{aligned}\right\}\quad(33)$$

$$\begin{aligned}V_C^{[1]}(Z)&=\phi_1(V_C^{[1]}(Z))^{(1)}+\phi_2(V_C^{[1]}(Z))^{(2)}+\cdots+\phi_N(V_C^{[1]}(Z))^{(N)}\\&=\phi_1Z^{-1}V_C^{(N)}(Z)+\phi_2Z^{-1}V_C^{(1)}(Z)+\cdots+\phi_NZ^{-1}V_C^{(N-1)}(Z).\end{aligned}\quad(34)$$

令 $\phi_i=1$，$\phi_1=\phi_2=\cdots=\phi_{i-1}=\phi_{i+1}=\cdots=\phi_N=0$，由(29)，(30)，(31)式得

$$S^{(i)}(Z)=H_{37}^{(i)}Z^{-1}V_C^{(i-1)}(Z)+H_{38}^{(i)}V_U^{(i)}(Z),\quad(35)$$

$$V_P^{(i)}(Z)=-H_{39}^{(i)}Z^{-1}V_C^{(i-1)}(Z)-H_{40}^{(i)}V_U^{(i)}(Z),\quad(36)$$

$$V_C^{(i)}(Z)=H_{41}^{(i)}Z^{-1}V_C^{(i-1)}(Z)+H_{42}^{(i)}V_U^{(i)}(Z),\quad i=1,2,\cdots\cdots N.\quad(37)$$

把(35)，(36)，(37)式写成矩阵形式：

$$\begin{bmatrix}S^{(1)}(Z)\\S^{(2)}(Z)\\\vdots\\S^{(N)}(Z)\end{bmatrix}=\begin{bmatrix}0&0&\cdots&0&Z^{-1}H_{37}^{(1)}\\Z^{-1}H_{37}^{(2)}&0&\cdots&0&0\\\vdots&\vdots&&\vdots&\vdots\\0&0&\cdots&Z^{-1}H_{37}^{(N)}&0\end{bmatrix}\begin{bmatrix}V_C^{(1)}(Z)\\V_C^{(2)}(Z)\\\vdots\\V_C^{(N)}(Z)\end{bmatrix}+\begin{bmatrix}H_{38}^{(1)}&&&\\&H_{38}^{(2)}&&\\&&\ddots&\\&&&H_{38}^{(N)}\end{bmatrix}\begin{bmatrix}V_U^{(1)}(Z)\\V_U^{(2)}(Z)\\\vdots\\V_U^{(N)}(Z)\end{bmatrix},\quad(38)$$

$$\begin{bmatrix}V_P^{(1)}(Z)\\V_P^{(2)}(Z)\\\vdots\\V_P^{(N)}(Z)\end{bmatrix}=-\begin{bmatrix}0&0&\cdots&0&Z^{-1}H_{39}^{(1)}\\Z^{-1}H_{39}^{(2)}&0&\cdots&0&0\\\vdots&\vdots&&\vdots&\vdots\\0&0&\cdots&Z^{-1}H_{39}^{(N)}&0\end{bmatrix}\begin{bmatrix}V_C^{(1)}(Z)\\V_C^{(2)}(Z)\\\vdots\\V_C^{(N)}(Z)\end{bmatrix}-\begin{bmatrix}H_{40}^{(1)}&&&\\&H_{40}^{(2)}&&\\&&\ddots&\\&&&H_{40}^{(N)}\end{bmatrix}\begin{bmatrix}V_U^{(1)}(Z)\\V_U^{(2)}(Z)\\\vdots\\V_U^{(N)}(Z)\end{bmatrix},\quad(39)$$

$$\begin{bmatrix} 1 & 0 & \cdots\cdots & 0 & -Z^{-1}H_{41}^{(1)} \\ -Z^{-1}H_{41}^{(2)} & 1 & \cdots\cdots & 0 & 0 \\ \vdots & \vdots & & \vdots & \vdots \\ 0 & 0 & \cdots\cdots & -Z^{-1}H_{41}^{(N)} & 1 \end{bmatrix} \begin{bmatrix} V_C^{(1)}(Z) \\ V_C^{(2)}(Z) \\ \vdots \\ V_C^{(N)}(Z) \end{bmatrix} = \begin{bmatrix} H_{42}^{(1)} & & & \\ & H_{42}^{(2)} & & \\ & & \ddots & \\ & & & H_{42}^{(N)} \end{bmatrix} \begin{bmatrix} V_U^{(1)}(Z) \\ V_U^{(2)}(Z) \\ \vdots \\ V_U^{(N)}(Z) \end{bmatrix}. \tag{40}$$

(38),(39),(40)式是 SCN Z 域分相解;(40)式是 SCN 的分相状态方程. 从分相状态方程(40)式解出状态向量 $[V_C^{(1)}(Z),V_C^{(2)}(Z),\cdots,V_C^{(N)}(Z)]^T$, 代入(38)或(39)式, 便可解出向量 $[S^{(1)}(Z),S^{(2)}(Z),\cdots,S^{(N)}(Z)]^T$ 或 $[V_P^{(1)}(Z),V_P^{(2)}(Z),\cdots\cdots,V_P^{(N)}(Z)]^T$.

3 示例

图 1 为一三相有源 SCN, 求其电压传递函数.

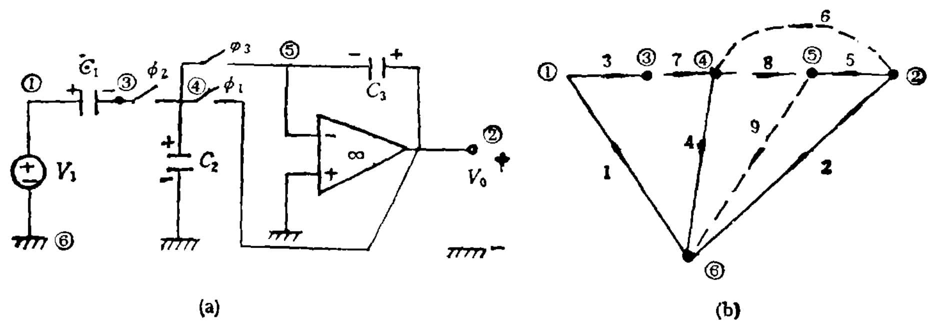

图 1 三相有源 SCN 及其拓扑图

解

$$D = \begin{array}{cc} & \begin{array}{cccccccccc} U & P & & CT & & & SL & & I \end{array} \\ \begin{array}{cc} U & 1 \\ P & 2 \\ & 3 \\ CT & 4 \\ & 5 \end{array} & \left[\begin{array}{c|c|ccc|ccc|c} 1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ \hline 0 & 1 & 0 & 0 & 0 & 1 & 0 & -1 & 1 \\ \hline 0 & 0 & 1 & 0 & 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & -1 & -1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & -1 \end{array}\right] \end{array}$$

$D_{US} = [0\ 1\ 0]$, $D_{UI} = [0]$, $D_{PS} = [1\ 0\ -1]$, $D_{PI} = [1]$,

$$D_{CS} = \begin{bmatrix} 0 & -1 & 0 \\ -1 & -1 & 1 \\ 0 & 0 & 1 \end{bmatrix}, \quad D_{CI} = \begin{bmatrix} 0 \\ 0 \\ -1 \end{bmatrix}, \quad C_T = \begin{bmatrix} C_1 & & \\ & C_2 & \\ & & C_3 \end{bmatrix}, \quad \phi_L = \begin{bmatrix} \phi_1 & & \\ & \phi_2 & \\ & & \phi_3 \end{bmatrix}$$

通过 H_1—H_{42} 矩阵的填写或计算,则得

$$H_{41}=\begin{bmatrix} \frac{C_1}{C_1+C_2\phi_2} & -\frac{C_2\phi_2}{C_1+C_2\phi_2} & 0 \\ -\frac{C_1\phi_2}{C_1+C_2\phi_2} & \frac{C_2\phi_2}{C_1+C_2\phi_2} & \frac{C_1\phi_1}{C_1+C_2\phi_2} \\ 0 & -\frac{C_1C_2\phi_3}{C_3(C_1+C_2\phi_2)} & 1 \end{bmatrix},\quad H_{42}=\begin{bmatrix} \frac{C_2\phi_2}{C_1+C_2\phi_2} \\ \frac{C_1\phi_2}{C_1+C_2\phi_2} \\ 0 \end{bmatrix}$$

全相状态方程为

$$\begin{bmatrix} V_{C_1}(Z) \\ V_{C_2}(Z) \\ V_{C_3}(Z) \end{bmatrix}=\begin{bmatrix} \frac{C_1}{C_1+C_2\phi_2} & -\frac{C_2\phi_2}{C_1+C_2\phi_2} & 0 \\ -\frac{C_1\phi_2}{C_1+C_2\phi_2} & \frac{C_2\phi_2}{C_1+C_2\phi_2} & \frac{C_1\phi_1}{C_1+C_2\phi_2} \\ 0 & -\frac{C_1C_2\phi_3}{C_3(C_1+C_2\phi_2)} & 1 \end{bmatrix}\begin{bmatrix} V_{C_1}^{(1)}(Z) \\ V_{C_2}^{(1)}(Z) \\ V_{C_3}^{(1)}(Z) \end{bmatrix}$$

$$+\begin{bmatrix} \frac{C_2\phi_2}{C_1+C_2\phi_2} \\ \frac{C_1\phi_2}{C_1+C_2\phi_2} \\ 0 \end{bmatrix}V_U(Z).$$

分相状态方程

$$\begin{bmatrix} 1 & 0 & -Z^{-1}H_{41}^{(1)} \\ -Z^{-1}H_{41}^{(2)} & 1 & 0 \\ 0 & -Z^{-1}H_{41}^{(3)} & 1 \end{bmatrix}\begin{bmatrix} V_C^{(1)}(Z) \\ V_C^{(2)}(Z) \\ V_C^{(3)}(Z) \end{bmatrix}=\begin{bmatrix} H_{42}^{(1)} & & \\ & H_{42}^{(2)} & \\ & & H_{42}^{(3)} \end{bmatrix}\begin{bmatrix} N_U^{(1)}(Z) \\ V_U^{(2)}(Z) \\ V_U^{(3)}(Z) \end{bmatrix},$$

其中

$$H_{41}^{(1)}=\begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 1 \end{bmatrix},\quad H_{42}^{(1)}=\begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix},\quad H_{41}^{(2)}=\begin{bmatrix} \frac{C_1}{C_1+C_2} & -\frac{C_2}{C_1+C_2} & 0 \\ -\frac{C_1}{C_1+C_2} & \frac{C_1}{C_1+C_2} & 0 \\ 0 & 0 & 1 \end{bmatrix},$$

$$H_{42}^{(2)}=\begin{bmatrix} \frac{C_2}{C_1+C_2} \\ \frac{C_1}{C_1+C_2} \\ 0 \end{bmatrix},\quad H_{41}^{(3)}=\begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & -\frac{C_2}{C_3} & 1 \end{bmatrix},\quad H_{42}^{(3)}=\begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix};$$

$$V_C^{(i)}(Z)=[V_{C_1}^{(i)}(Z),V_{C_2}^{(i)}(Z),V_{C_3}^{(i)}(Z)]^T,\quad i=1,2,3;$$

$$V_U^{(1)}(Z)=0,\ V_U^{(2)}(2)=V_I^{(2)}(Z),\ V_U^{(3)}(Z)=0.$$

用高斯消去法,从分相状态方程中解得 $V_{C_3}^{(1)}(Z)$, $V_{C_3}^{(2)}(Z)$, $V_{C_3}^{(3)}(Z)$, 求得电压传递函数为

$$H^{(12)} = V_{C_3}^{(1)}(Z)/V_I^{(2)}(Z) = \frac{C_1C_2Z^{-2}(Z^{-3}-1)}{C_3(C_1+C_2)-(2C_1C_3+C_2C_3-C_2^2)Z^{-3}+C_1C_3Z^{-6}},$$

$$H^{(22)} = V_{C_3}^{(2)}(Z)/V_I^{(2)}(Z) = \frac{C_1C_2Z^{-3}(Z^{-3}-1)}{C_3(C_1+C_2)-(2C_1C_2+C_2C_3-C_2^2)Z^{-3}+C_1C_3Z^{-6}},$$

$$H^{(32)} = V_{C_3}^{(3)}(Z)/V_I^{(2)}(Z) = \frac{C_1C_2Z^{-1}(Z^{-3}-1)}{C_3(C_1+C_2)-(2C_1C_2+C_2C_3-C_2^2)+C_1C_3Z^{-6}}.$$

参 考 文 献

[1] Shen Shihu. Analysis of SCN's Using Time-Invariant Topologies, Proc. of IEEE ISCAS, May 5—7, 1986, 377—379.

[2] 申石虎. 电路与系统学报(试刊),1991,3(1): 14—20.

A SYSTEMATIC TIME-INVARIANT TOPOLOGY ANALYSIS METHOD OF MULTIPHASE SCN IN *Z*-DOMAIN ——A STATE VARIABLE APPROACH

Liu Changlin Shen Shihu Liu Shumin

(*Northeast Institute of Heavy Machinery, Qiqihar* 161042)

Abstract In this paper, switches are considered as fixed branches, thereby the topology of a SCN becomes time-invariant. The technique for analysis of time-invariant networks is applied to SCN's. A systematic time-invariant topology analysis method of multiphase SCN's in Z-domain——a state variable approach is derived.

Key words Switched-capacitor networks, Time-invariant topology analysis, State variable approach