NPTEL ONLINE CERTIFICATION COURSES

DIGITAL CONTROL IN SMPCs AND FPGA-BASED PROTOTYPING

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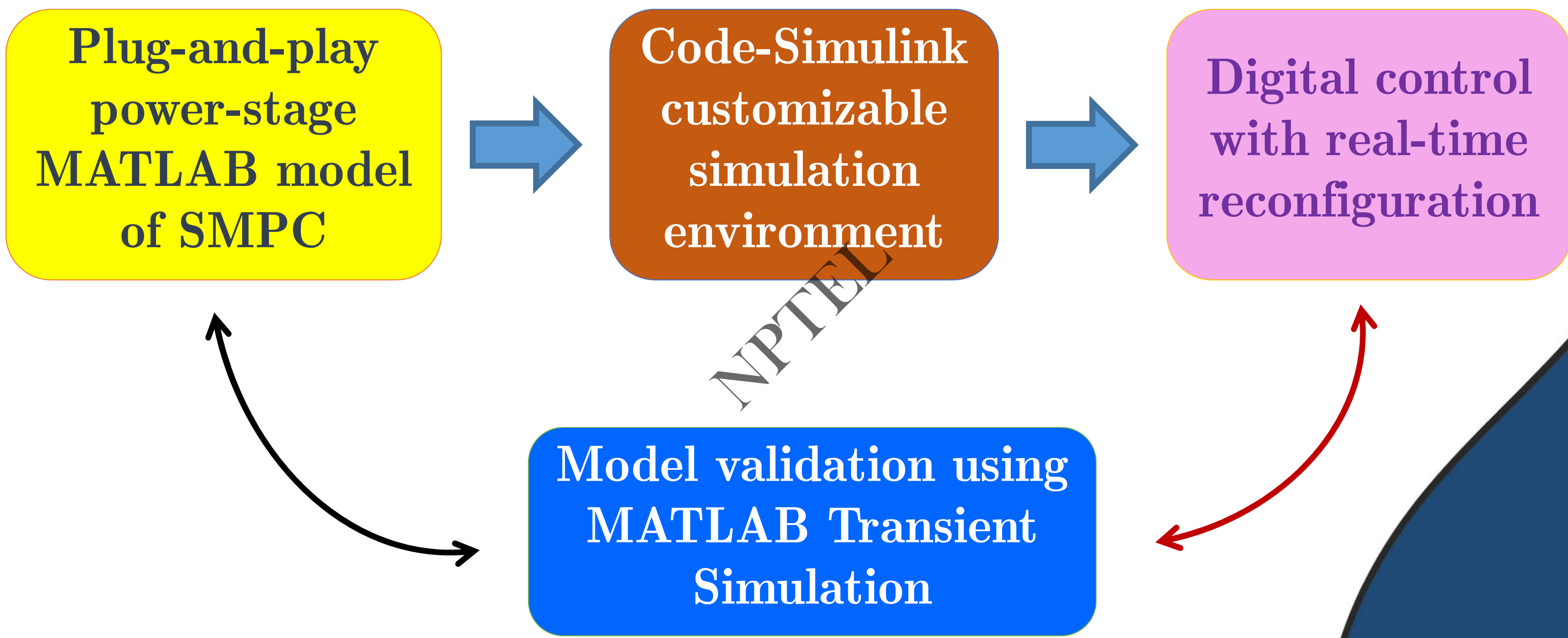
Module 04: Modeling Techniques and Mode Validation using MATLAB

Lecture 36: Validation of Discrete-Time Large-Signal Models using MATLAB – Part II

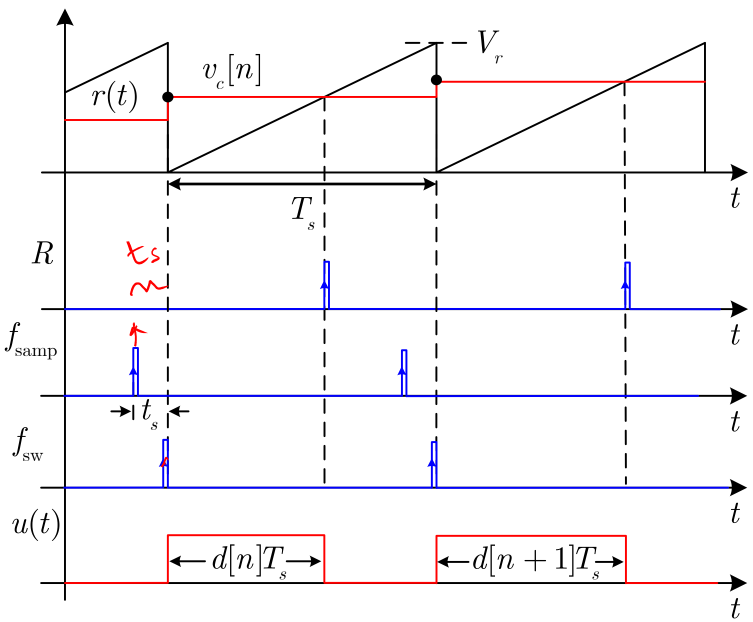
CONCEPTS COVERED

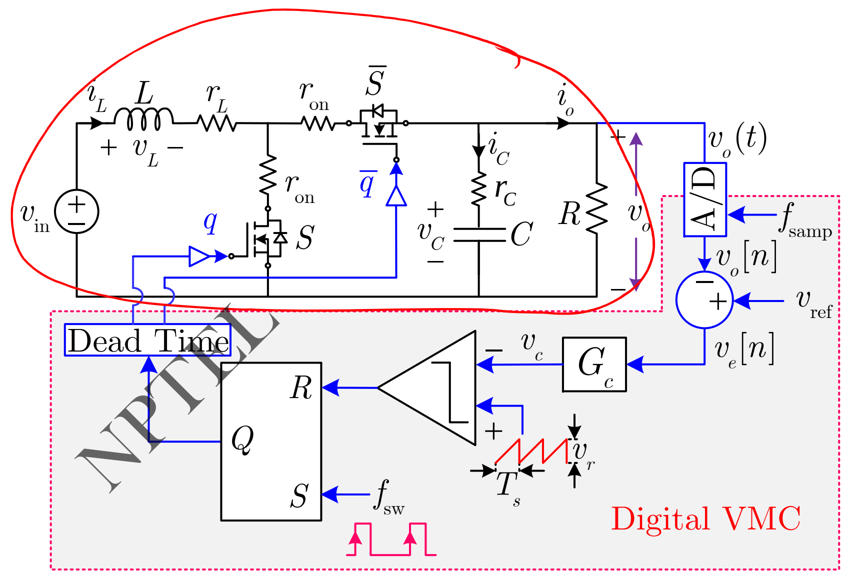
- Recall of digital control architectures and MATLAB models
- Steps for simulation using MATLAB detailed switch models and discrete-time large-signal models
- MATLAB codes and step-by-step methods for model validation
- Validation case studies using a Boost Converter

Overall Plan for MATLAB based Validation

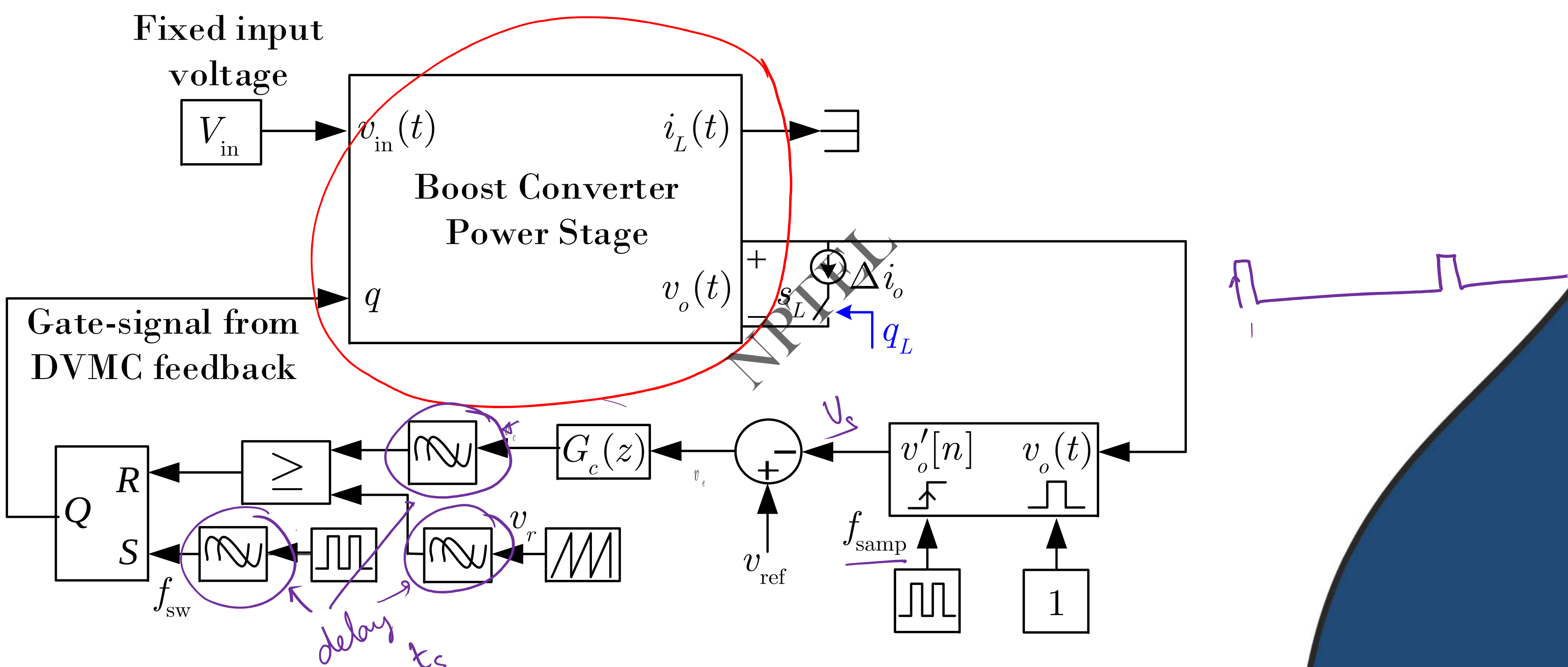


Digital Voltage Mode Control (DVMC) of Boost Converter





Device Under Test (DUT) for Validation of DT Large-Signal Model



Validation of DT Large-Signal Model under Closed Loop

a) Using actual switch simulation

1. Provide initial conditions for $v_C(t)$ and $i_L(t)$
2. Do not turn on S_L for 1 ms and let the converter reach steady-state
3. Apply a load step
4. Capture time domain data and store as v_o and i_L

Validation of DT Large-Signal Model under Closed Loop (contd…)

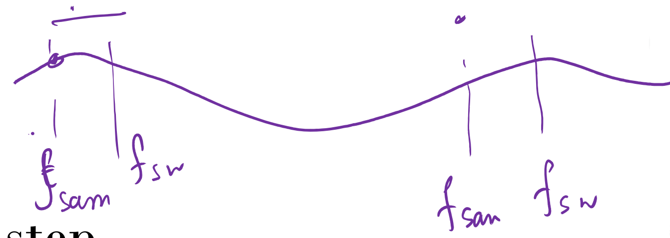
b) Using DT large-signal model

1. Provide initial conditions for $v_C(t)$ and $i_L(t)$ same as the switch simulation

2. Let the DT large-signal model run for 1 ms

3. Capture $v_o(t)$ and $i_L(t)$ for every sampling cycle until 1 ms

Validation of DT Large-Signal Model under Closed Loop (contd…)



b) Using DT large-signal model

4. Change the load resistance at 1 ms to emulate a load step

5. Capture $v_o(t)$ and $i_L(t)$ for every sampling cycle until the end time same as simulation run time

6. Compare the captured data of v_o & i_L for DT large-signal validation

Steps to Verify Large-Signal DT Model using MATLAB

boost_conv_DVMC_simulation.m

```
clear; close all; clc;
%% Setting parameters
boost_parameter;
DCM_En=0;
N_tran=500; T_tran=2*N_tran*T;
t_start=0; t_sim=T_tran;
%% Controller parameters
Kp=8;  Ki=0.7;  Kd=(1*C)/T;
t_s=0.1*T;
V_m=10;  R1=10;  R2=2; R=R1;
I_L_int=0;  V_c_int=4.99;
V_s_int=V_c_int; V_integral=0;
……
```

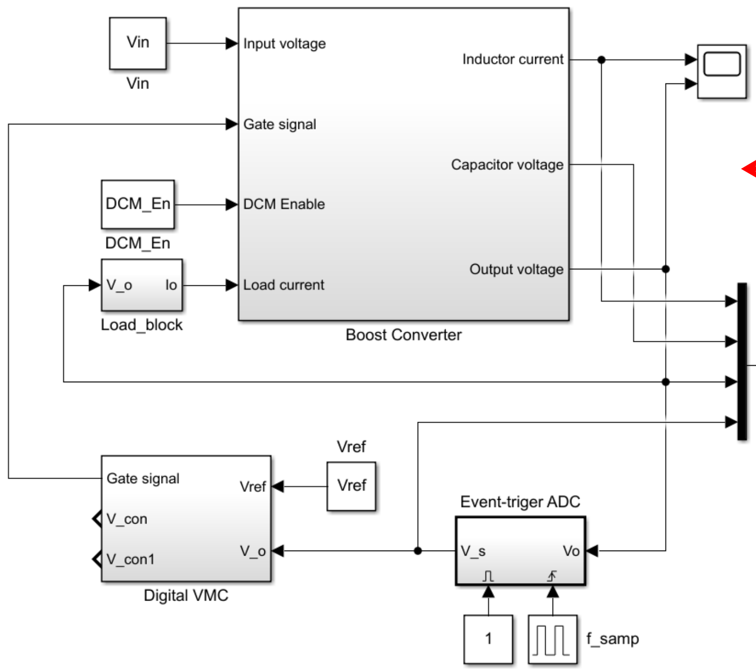
boost_parameter.m

```
L=2e-6;        % inductance
C=100e-6;      % output capacitance
T=2e-6;        % switching time period
r_L=10e-3;     % inductor DCR
v_d=0*0.7;     % diode voltage drop
r_1=5e-3;      % LS MOS on resistance
r_d=5e-3;      % HS MOS on resistance
r_C=5e-3;      % capacitor ESR
Vin=3.3;       % input voltage
Vref=5;        % ref. output voltage
```

$V_{ref} = 5V$

$V_{in} = 3.3V$

Steps to Verify Large-Signal DT Model using MATLAB (contd…)

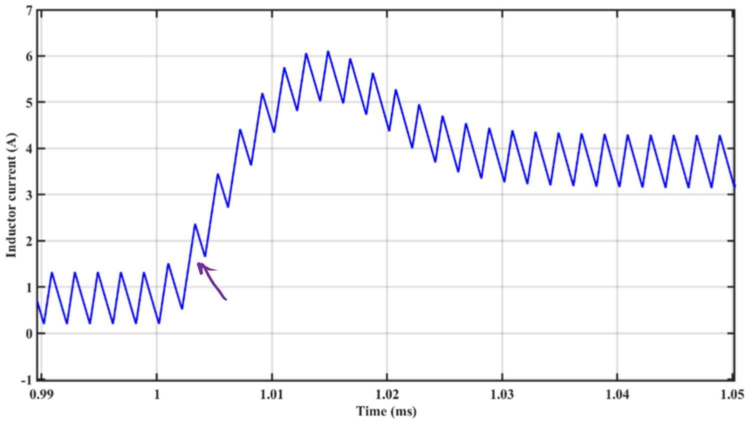


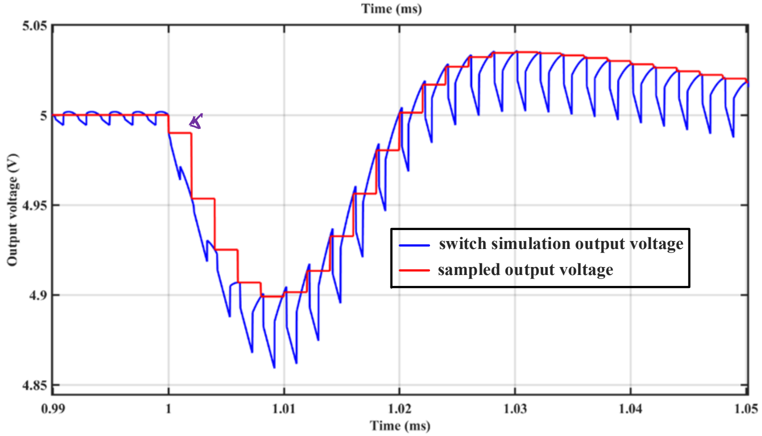
boost_conv_DVMC_simulation.m

```
……
sim('boost_converter_DVMC.slx');

t=boost_result.time; t_scale=t*1e3;
x=boost_result.data;  i_L=x(:,1);
V_cap=x(:,2);
V_o=x(:,3); V_s=x(:,4);
%% Plot subroutine
plot_boost_simulation;
```

Steps to Verify Large-Signal DT Model using MATLAB (contd…)





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%% Plot subroutine
plot_boost_simulation;
```

Steps to Verify Large-Signal DT Model using MATLAB (contd…)

boost_DT_LSM_TE.m

```
clc
boost_parameter;

Kp=8;   Ki=0.7;  Kd=(1*C)/T;
t_s=0.1*T;  V_m=10;   R1=10;
R2=2; R=R1; N_tran=500;

boost_DT_model_matrices;

……
```

Comment

$R_L = R1$

boost_DT_model_matrices.m

```
alpha=R/(R+r_C);  r_e=(r_l+r_L);
T_s=t_s;  I_den=[1 0; 0 1];

%% Define system, input and output matrices
A_on=[-r_e/L 0; 0 -alpha/(R*C)];
A_off=[-(r_e+(alpha*r_C))/L       -alpha/L;
                    alpha/C            -alpha/(R*C)];
B=[1/L; 0];
C_on=[0 alpha];
C_off=[r_C*alpha alpha];
```

A_{on}

A_{off}

B

C_{on}

C_{off}

$C_{off} = [\alpha r_c \quad \alpha]$

$C_{on} = [0 \quad \alpha]$

Steps to Verify Large-Signal DT Model using MATLAB (contd…)

boost_DT_LSM_TE.m

```
……
i_L_n=I_L_int; v_cap_n=V_c_int;
x_n=[i_L_n; v_cap_n];
V_o_s=C_off*x_n;  Vsam=v_cap_n;
V_intg_int=0;  Ve_int=0;
t1=0; t1_scale=t1*1e3;

figure(1)
plot(t1_scale,x_n(1),'o','Linewidth', 2); hold on; grid on;

figure(2)
plot(t1_scale,Vsam,'o','Linewidth', 2);  hold on; grid on;
……
```

Steps to Verify Large-Signal DT Model using MATLAB (contd…)

boost_DT_dynamics.m

N_{tran}

0 to $N_{tran}-1$

```
for n=0:N_tran-1
  figure(2)
  plot(t1_scale,Vsam,'o','Linewidth', 2);  hold on; grid on;
  Ve=(Vref-Vsam);
  V_intg=V_intg_int+(Ki*Ve);  V_intg_int=V_intg;
  V_der=Kd*(Ve-Ve_int);   Ve_int=Ve;
  Vcon=(Kp*Ve)+V_intg+V_der;   D_temp=Vcon/V_m;

    if D_temp<0
       D=0;
    elseif D_temp>1
       D=1;
……
```

$u_I[n] = u_I[n-1] + K_i V_e[n]$

$u_D[n] = K_d \left(V_e[n] - V_e[n-1]\right)$

$u_P[n] = K_p V_e[n]$

$u[n] = u_P[n] + u_I[n] + u_D[n]$

boost_DT_LSM_TE.m

```
……
%% DT Large-Signal Model
boost_DT_dynamics;
R=R2;  N_tran=500;
boost_DT_model_matrices;
V_o_s=C_off*x_n;  Vsam=
V_o_s;
boost_DT_dynamics;
```

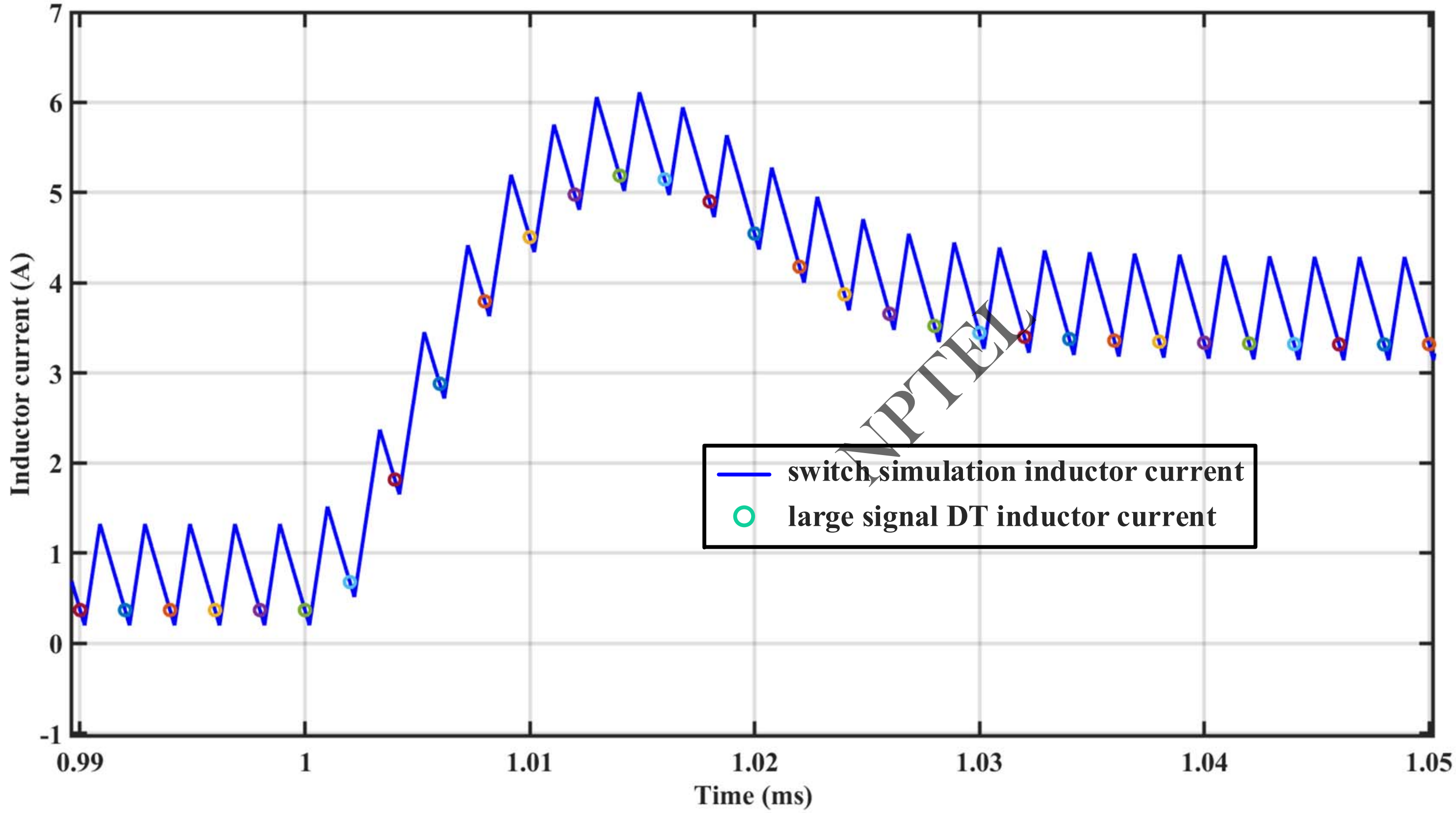
Steps to Verify Large-Signal DT Model using MATLAB (contd…)

boost_DT_dynamics.m

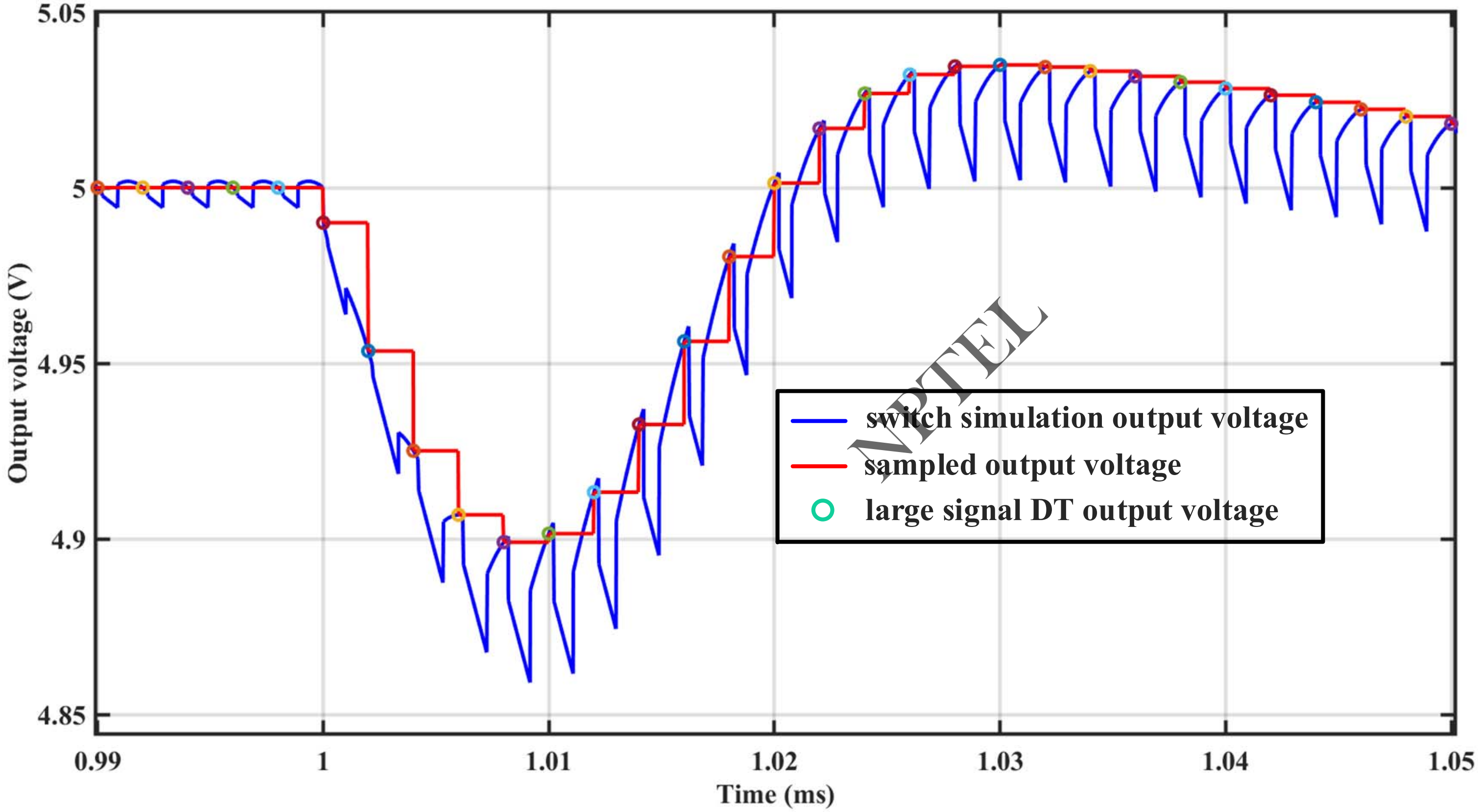
$x_{n+1} = A_{eq} x_n + B_{eq} V_{in}$

```
……
    else
        D=D_temp;
    end
  A_LS=(expm(A_off*(T-(D*T)-T_s)))*(expm(A_on*D*T))*(expm(A_off*T_s));
  B1=(expm(A_off*(T-(D*T)-T_s)))*(expm(A_on*D*T))*((expm(A_off*T_s))-I_den)*(inv(A_off))*B;
  B2=(expm(A_off*(T-(D*T)-T_s)))*((expm(A_on*D*T))-I_den)*(inv(A_on))*B;
  B3=((expm(A_off*(T-(D*T)-T_s)))-I_den)*(inv(A_off))*B;  B_LS=B1+B2+B3;
  x_n1=A_LS*x_n+B_LS*Vin;
  t1=t1+T;  t1_scale=t1*1e3;   x_n=x_n1; V_o_s=C_m*x_n;  Vsam= V_o_s;
  figure(1)
  plot(t1_scale,x_n(1),'o','Linewidth', 2);    hold on; grid on;
end
```

Steps to Verify Large-Signal DT Model using MATLAB (contd…)



Steps to Verify Large-Signal DT Model using MATLAB (contd…)



CONCLUSION

- Recall of digital control architectures and MATLAB models
- Steps for simulation using MATLAB detailed switch models and discrete-time large-signal models
- MATLAB codes and step-by-step methods for model validation
- Validation case studies using a Boost Converter

THANK YOU !