

DEMONSTRATION

on

APPLICATIONS OF SOFT COMPUTING TOOLS IN ELECTRICAL ENGINEERING LAB

By

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DEPT. OF E.E.E, VEMU ITCHITTOOR

Vision of the institute

To be a premier institute for professional education producing dynamic and vibrant force of technocrat with competent skills, innovative ideas and leadership qualities to serve the society with ethical and benevolent approach.

Mission of the institute

Mission_1: To create a learning environment with state-of-the-art infrastructure, well equipped laboratories, research facilities and qualified senior faculty to impart high quality technical education.

Mission_2: To facilitate the learners to foster innovative ideas, inculcate competent research and consultancy skills through Industry-Institute Interaction.

Mission_3: To develop hard work, honesty, leadership qualities and sense of direction in rural youth by providing value based education.

Vision of the Department

To produce professionally deft and intellectually adept Electrical and Electronics Engineers and equip them with the latest technological skills, research & consultancy competencies along with social responsibility, ethics, Lifelong Learning and leadership qualities.

Mission of the Department

Mission_1: To produce competent Electrical and Electronics Engineers with strong core knowledge, design experience & exposure to research by providing quality teaching and learning environment..

Mission_2: To train the students in emerging technologies through state - of - the art laboratories and thus bridge the gap between Industry and academia.

Mission_3: To inculcate learners with interpersonal skills, team work, social values, leadership qualities and professional ethics for a holistic engineering professional practice through value based education

Programme Educational Objectives (PEOs)

PEO_1: Provide sound foundation in mathematics, science and engineering fundamentals to analyze, formulate and solve complex engineering problems.

PEO_2: Have multi-disciplinary Knowledge and innovative skills to design and develop Electrical & Electronics products and allied systems.

PEO_3: Acquire the latest technological skills and motivation to pursue higher studies leading to research.

PEO_4: Possess good communication skills, team spirit, ethics, modern tools usage and the life-long learning needed for a successful professional career.

- PO_1: Engineering knowledge:** Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.
- PO_2: Problem analysis:** Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.
- PO_3: Design/development of solutions:** Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.
- PO_4: Conduct investigations of complex problems:** Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.
- PO_5: Modern tool usage:** Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.
- PO_6: The engineer and society:** Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.
- PO_7: Environment and sustainability:** Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.
- PO_8: Ethics:** Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.
- PO_9: Individual and team work:** Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.
- PO_10: Communication:** Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.
- PO_11: Project management and finance:** Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.
- PO_12: Life-long learning:** Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

Programme Specific Outcome(PSOs)

PSO_1: Higher Education: Apply the fundamental knowledge of Mathematics, Science, Electrical and Electronics Engineering to pursue higher education in the areas of Electrical Circuits, Electrical Machines, Electrical Drives, Power Electronics, Control Systems and Power Systems.

PSO_2: Employment: Get employed in Public/Private sectors by applying the knowledge in the domains of design and operation of Electronic Systems, Microprocessor based control systems, Power systems, Energy auditing etc.



JAWAHARLAL NEHRU TECHNOLOGICAL UNIVERSITY ANANTAPUR
III B.Tech. II-Sem (EEE)

(20A02606) APPLICATIONS OF SOFT COMPUTING TOOLS IN ELECTRICAL ENGINEERING LAB

DEPT OF ELECTRICAL AND ELECTRONICS ENGINEERING

Course Outcomes:

CO1. Apply the concepts to design MATLAB models.

CO2. Analyse various Electrical engineering applications through MATLAB.

CO3. Develop real time models using MATLAB.

List of Experiments:

1. Transient analysis of given electrical network
2. Simulation of 1-phase and 3-phase transformers
3. Implementation of buck and boost dc-dc converters
4. Study on the design of PI controllers and stability analysis for a DC-DC buck Converter
5. Sine-PWM techniques for single-phase half-bridge, full-bridge and three-phase inverters
6. Economic Load Dispatch of (i) Thermal Units and (ii) Thermal Plants using Conventional method
7. Transient Stability Analysis of Power Systems using Equal Area Criterion (EAC)

8.Reactive Power Control in a transmission system (Ferranti effect, Effect of shunt Inductor)

9.Fault studies using Zbus matrix

10.Design of virtual PMU

11.Simulink Model For Two Area Load Frequency Control

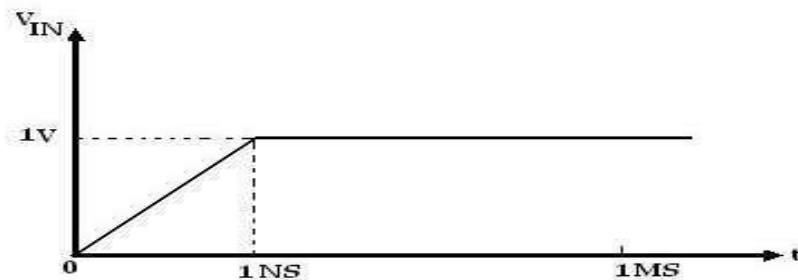
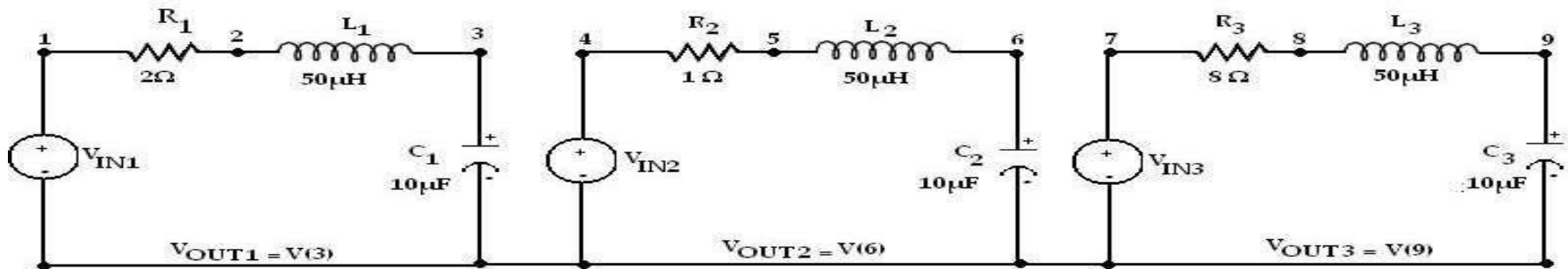
12.MATLAB Program to Find Optimum Loading Of Generators with Penalty Factors

Transient analysis of given electrical network

S.NO	TYPE OF SOURCE	REPRESENTATION OF SOURCE	DECLARATION FORMAT
1	STEP RESPONSE	PWL	STEP (Time at a Point) (Voltage at a Point)
2	TRANSIENT ANALYSIS	.TRAN	.TRAN TStep Tstop [TStart TMax] [UIC]
3	PROBE STATEMENT	.PROBE	It is a wave form analyzer
4	PLOT STATEMENT	.PLOT	.PLOT (Output Variables) {(Lower limit

DATA REQUIRED FOR DRAWING THE CIRCUIT DIAGRAM:

For example, Three RLC circuits with $R=2\Omega$, 1Ω , and 8Ω respectively, with L having the values of $50\mu\text{H}$ each, with C having the values of $10\mu\text{F}$ each. The inputs are identical Step Response. The Step having the Time at points as 1nsec and 1msec respectively and Voltage at a point as 1V respectively. Use PSPICE to plot and calculate the transient response from 0 to $400\mu\text{seconds}$ with an increment of $1\mu\text{second}$. Plot the voltages across the capacitors.



PROGRAM

VIN1 1 0 PWL(0 0 1NS 1V 1MS 1V)

VIN2 4 0 PWL(0 0 1NS 1V 1MS 1V)

VIN3 7 0 PWL(0 0 1NS 1V 1MS 1V)

R1 1 2 2

R2 4 5 1

R3 7 8 8

L1 2 3 50UH

L2 5 6 50UH

L3 8 9 50UH

C1 3 0 10UF

C2 6 0 10UF

C3 9 0 10UF

.TRAN 1US 400US

.PLOT TRAN V(3) V(6) V(9)

.PROBE

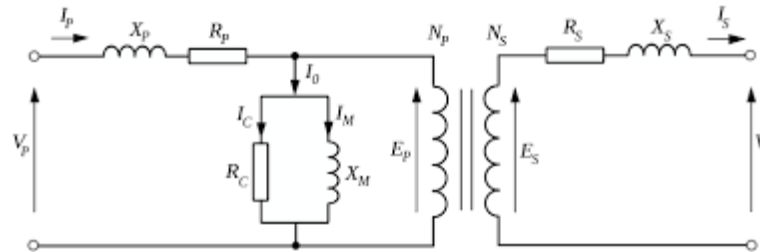
.END

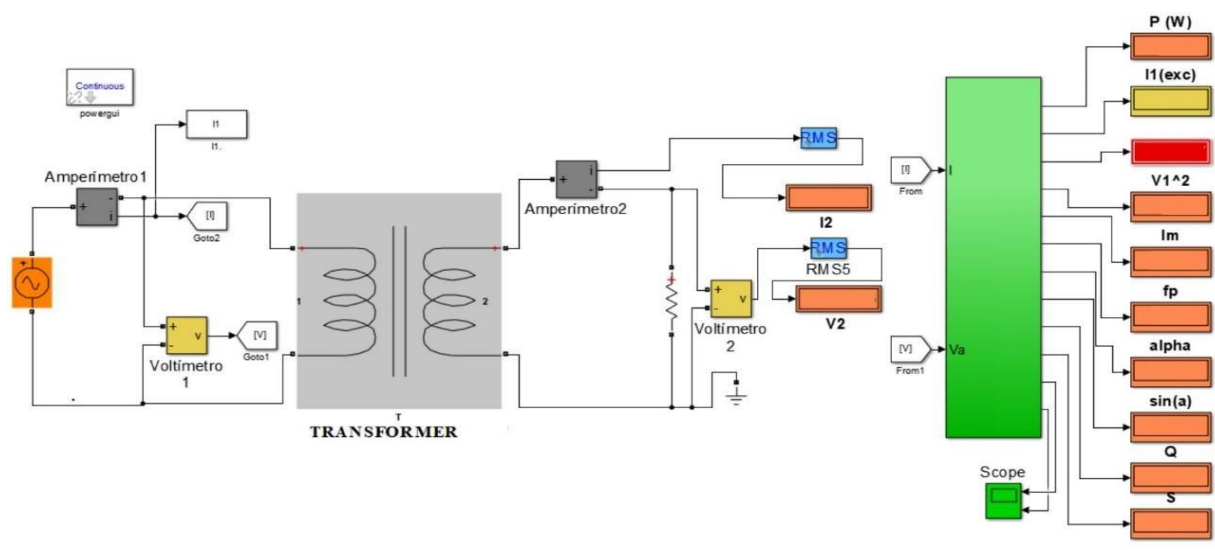
SIMULATION OF 1-PHASE AND 3-PHASE TRANSFORMERS

APPARATUS REQUIRED:

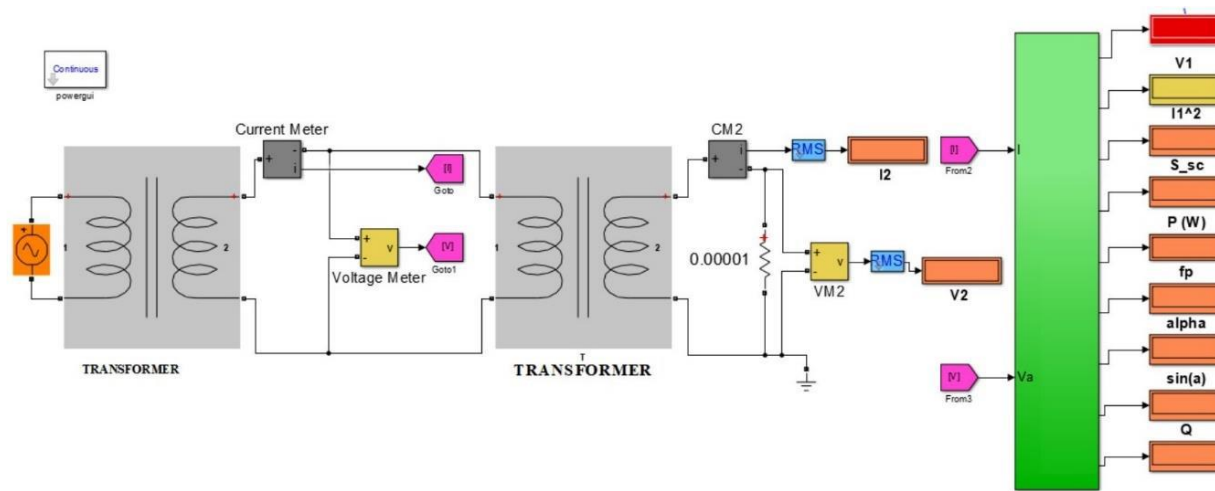
S.No	Name Of The Equipment	Quantity
1	Voltmeter	1NO
2	Ammeter	1NO
3	Wattmeter	1NO
4	Load	1NO

CIRCUIT DIAGRAM:





Modeling of open-circuit test on transformer

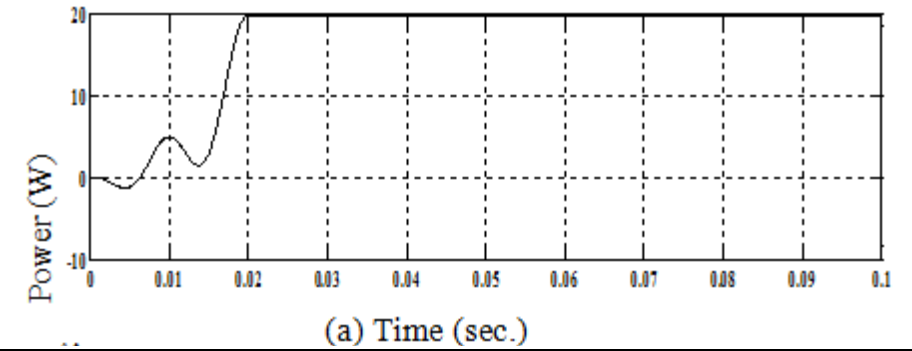


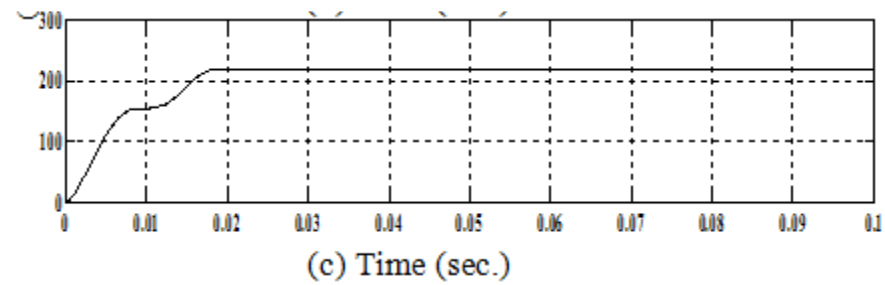
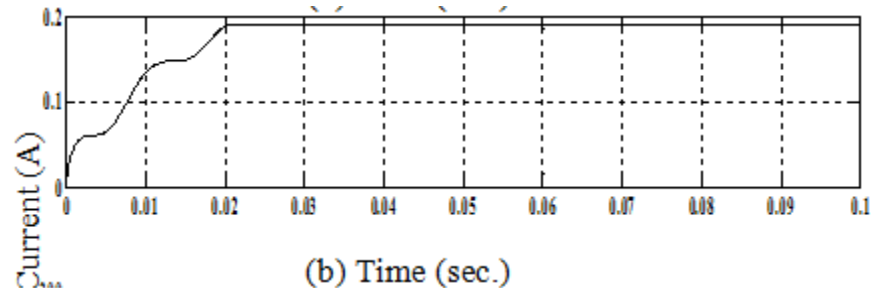
Modeling of short-circuit test on transformer

PROCEDURE:

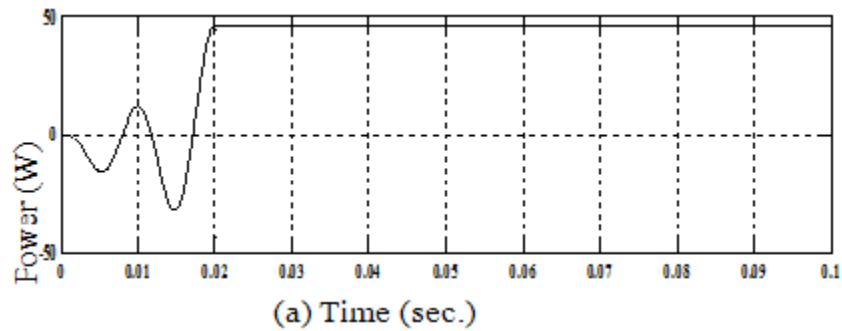
1. Open PSPICE A/D windows
2. Create a new circuit file

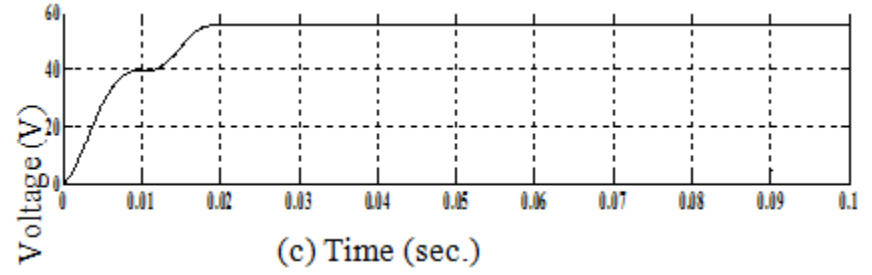
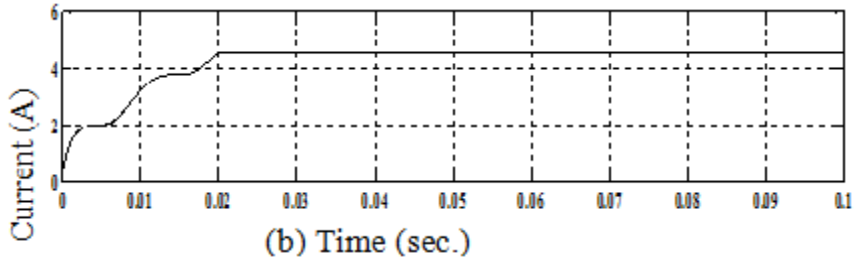
3. Enter the program representing the nodal interconnections of various components
4. Run the program
5. Observe the response through all the elements in the output file
6. Observe the required outputs (Graphs) in output window.



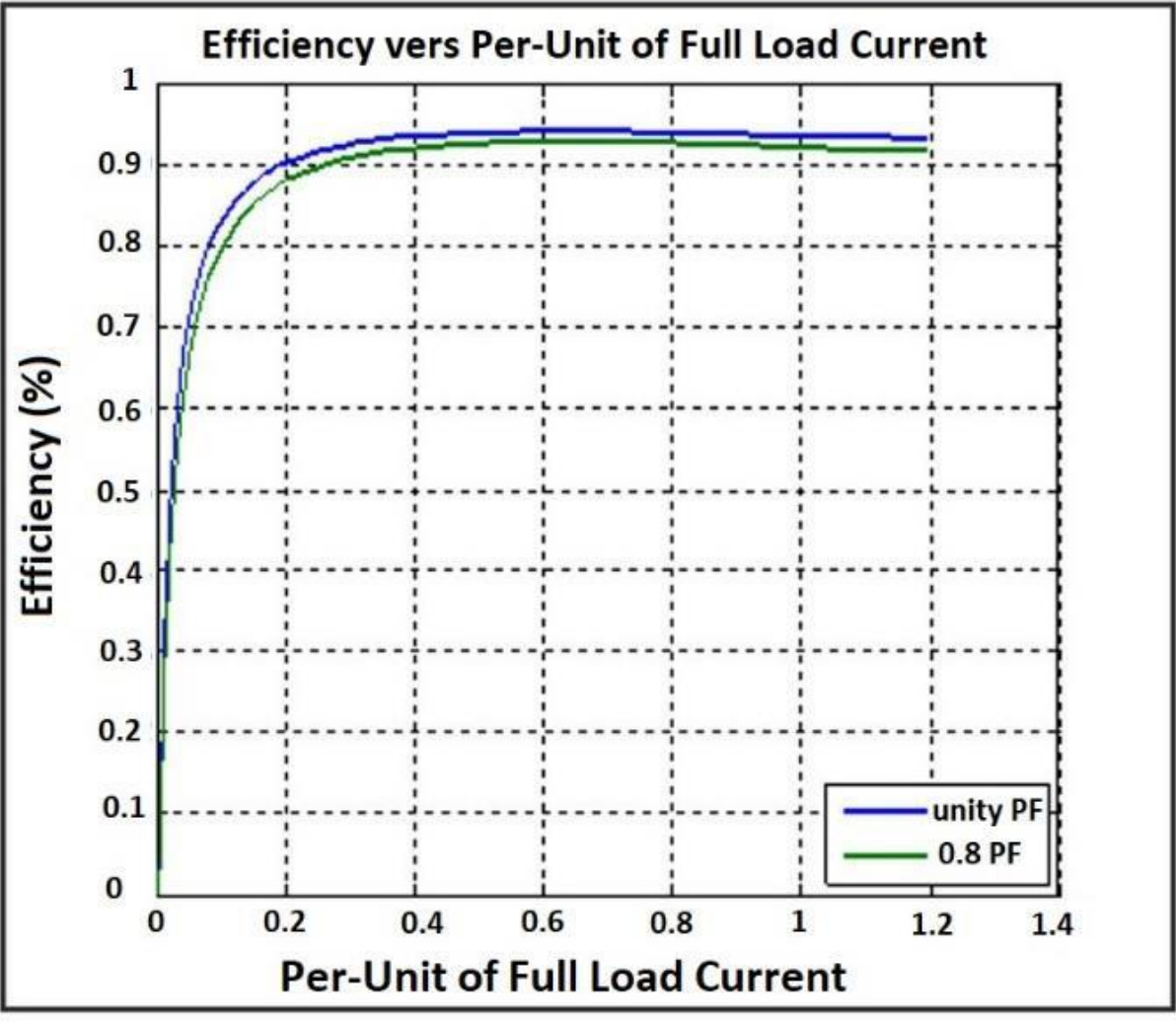


Transformer open-circuit simulation results, (a) Open-circuit power vs. time,
 (b) Open-circuit current vs. time, (c) Open-circuit voltage vs. time





Simulation results of transformer short-circuit test, (a) Short-circuit power vs time,
b) Short-circuit current vs time, (c) Short-circuit voltage vs time



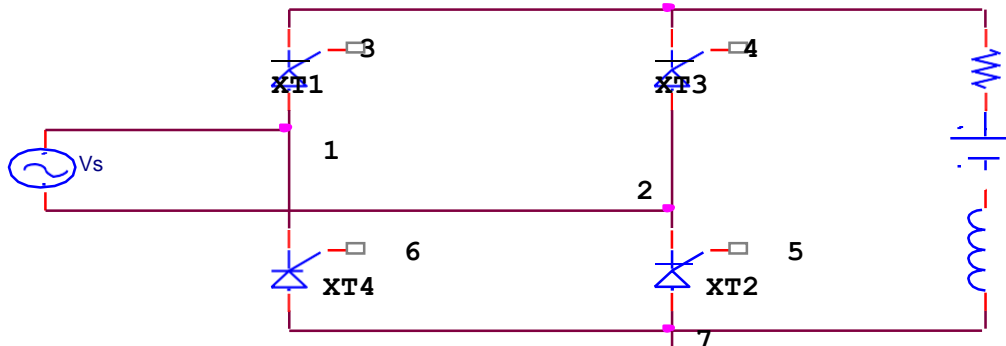
Load test (efficiency vs. load current)

RESULT:

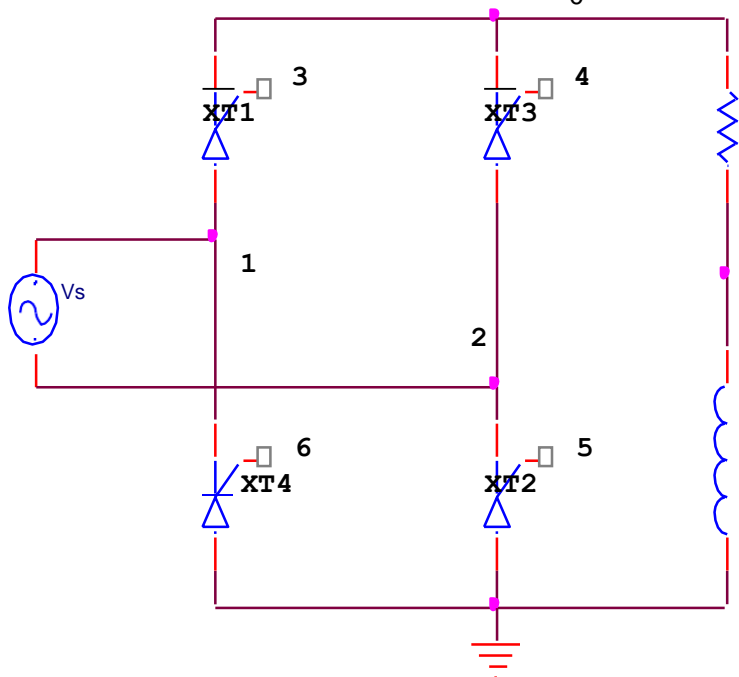
PSPICE ANALYSIS OF SINGLE PHASE FULL CONVERTER WITH RL & RLE LOADS

Single Phase full converter with RL load

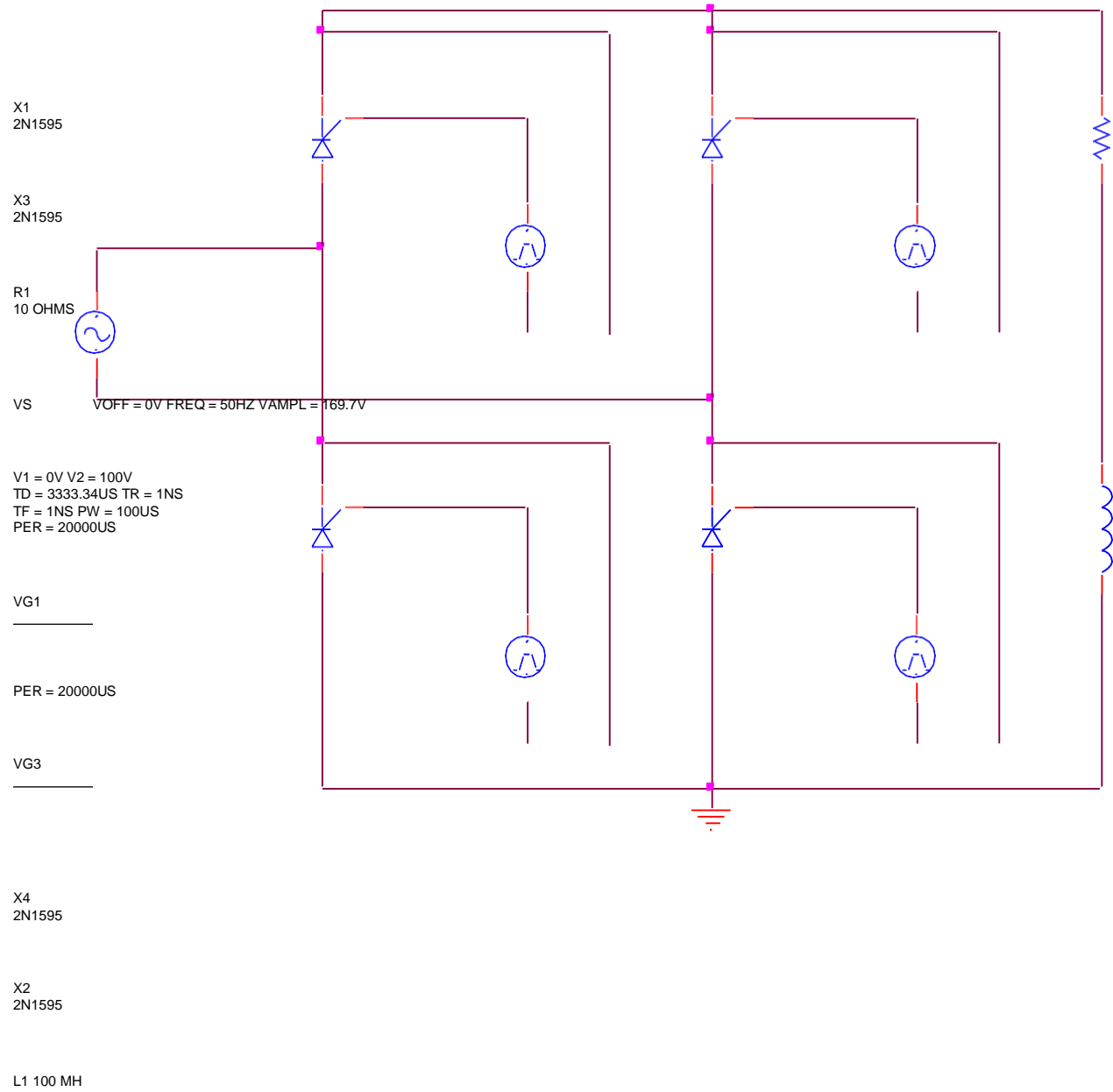
Single Phase full converter with RLE load



R
10 OHMS
8
L 100MH
0



Single Phase full converter with RL load



PER = 20000US

Single Phase full converter with RLE load

VG3
E

100 V

X4
2N1595

X2
2N1595

L1 100 MH

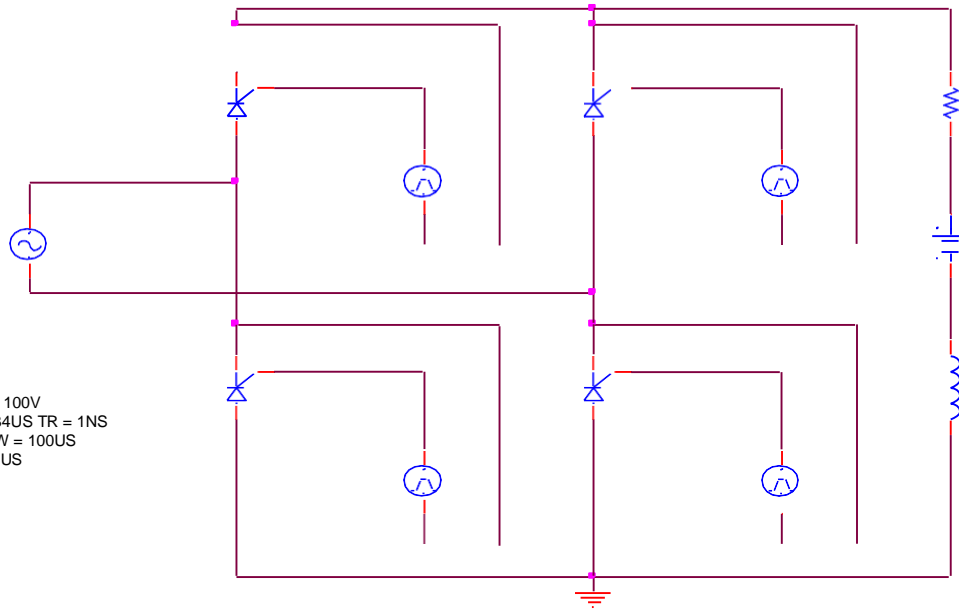
V1 = 0V V2 = 100V
TD = 13333.34US TR = 1NS
TF = 1NS PW = 100US
PER = 20000US

VG4

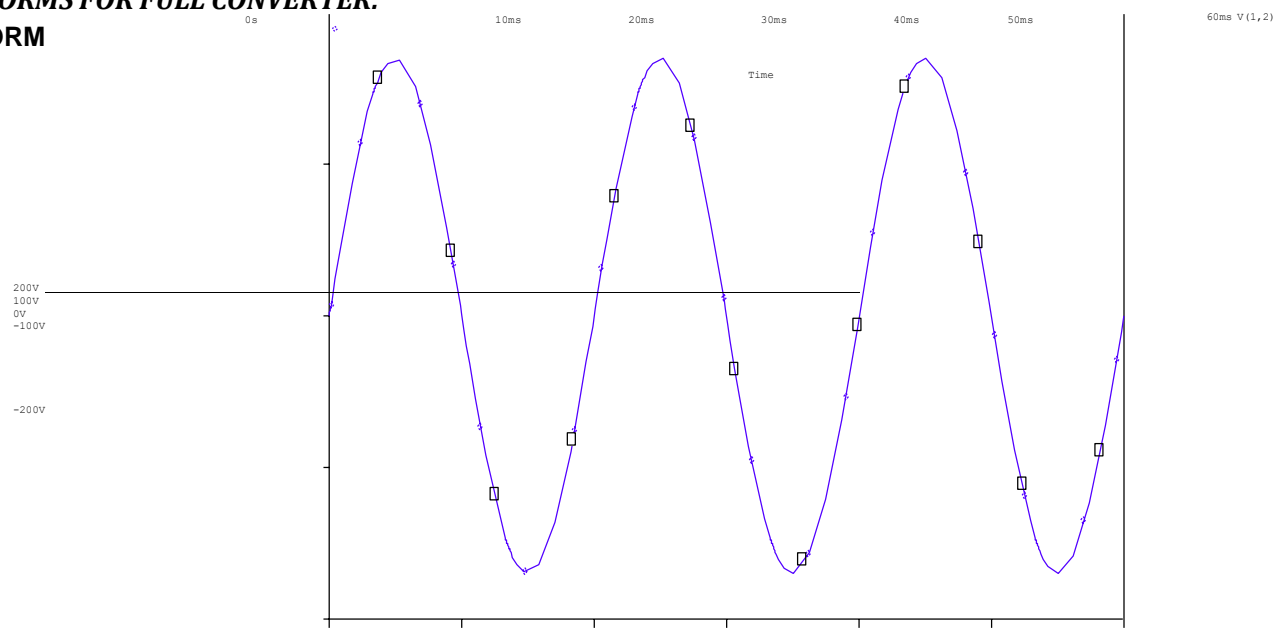
V1 = 0V V2 = 100V
TD = 3333.34US TR = 1NS
TF = 1NS PW = 100US
PER = 20000US

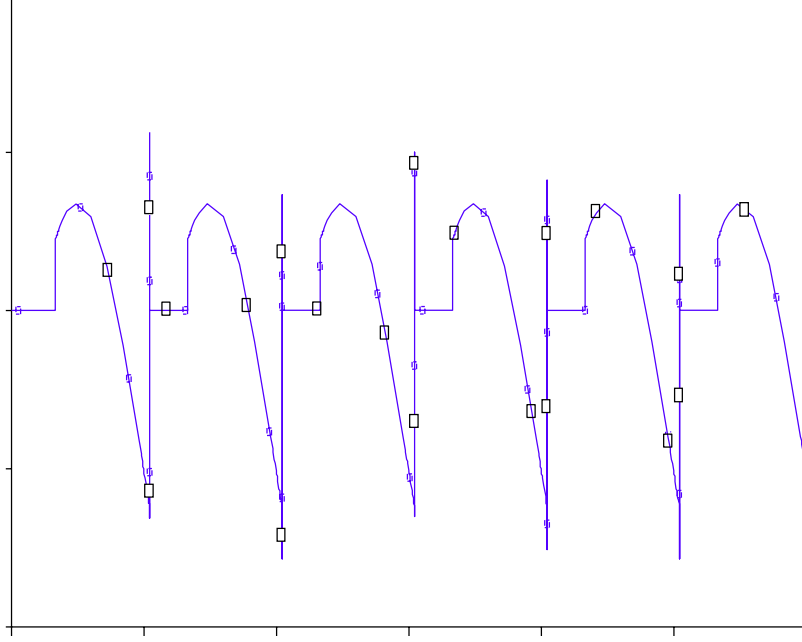
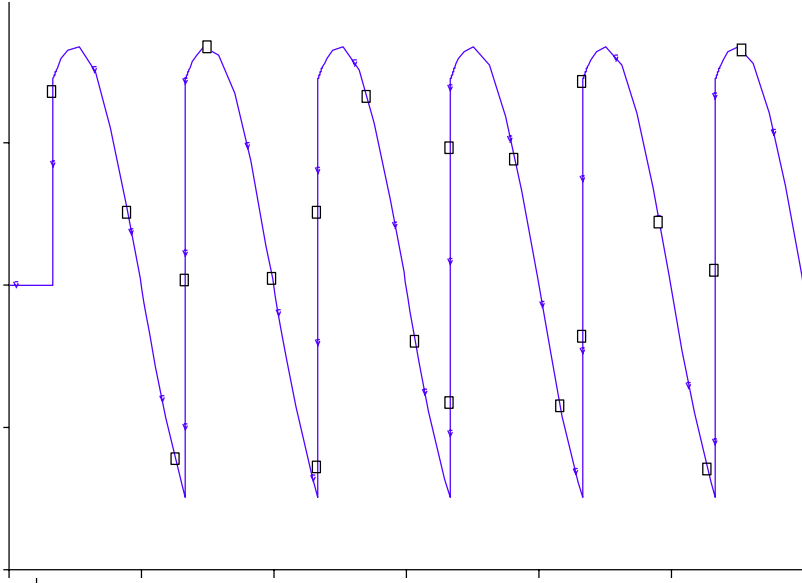
VG2

-

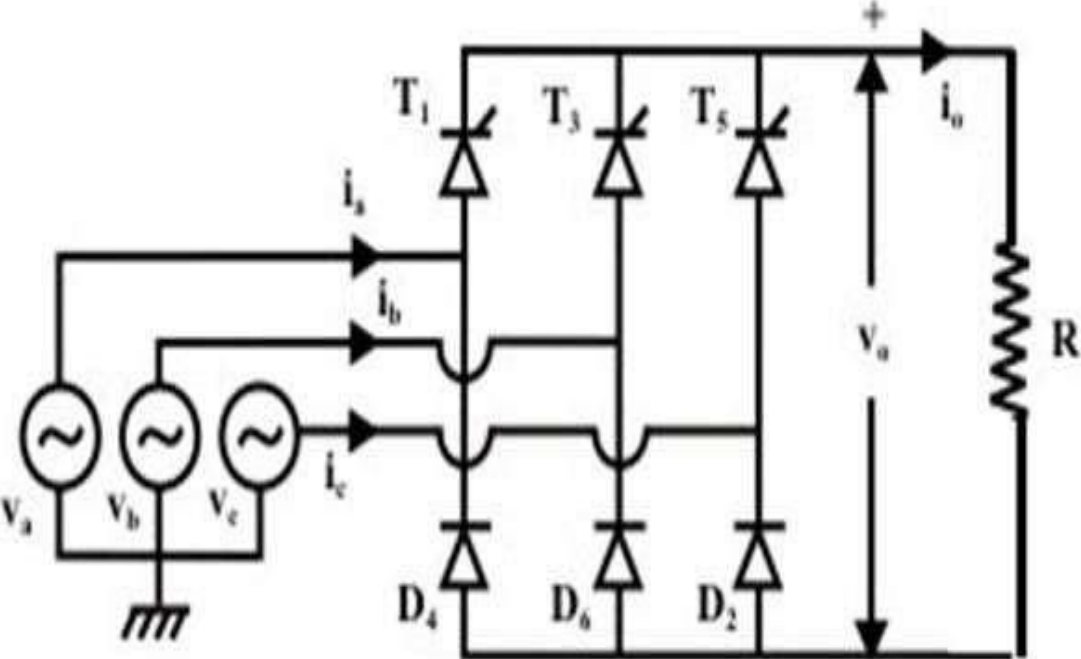


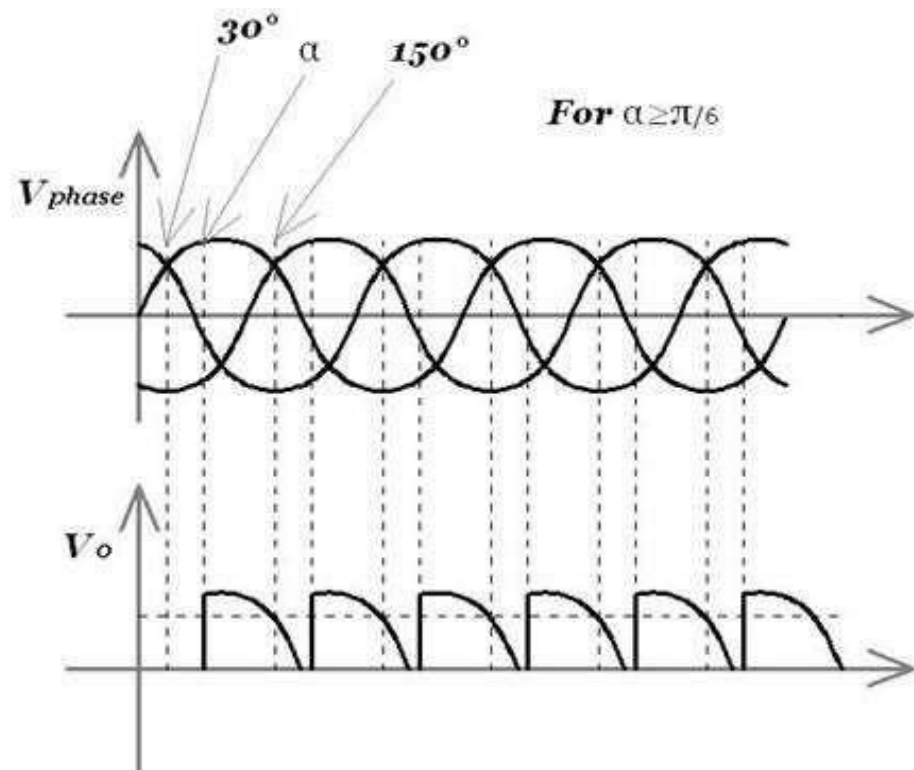
**MODEL WAVEFORMS FOR FULL CONVERTER:
INPUT WAVEFORM**



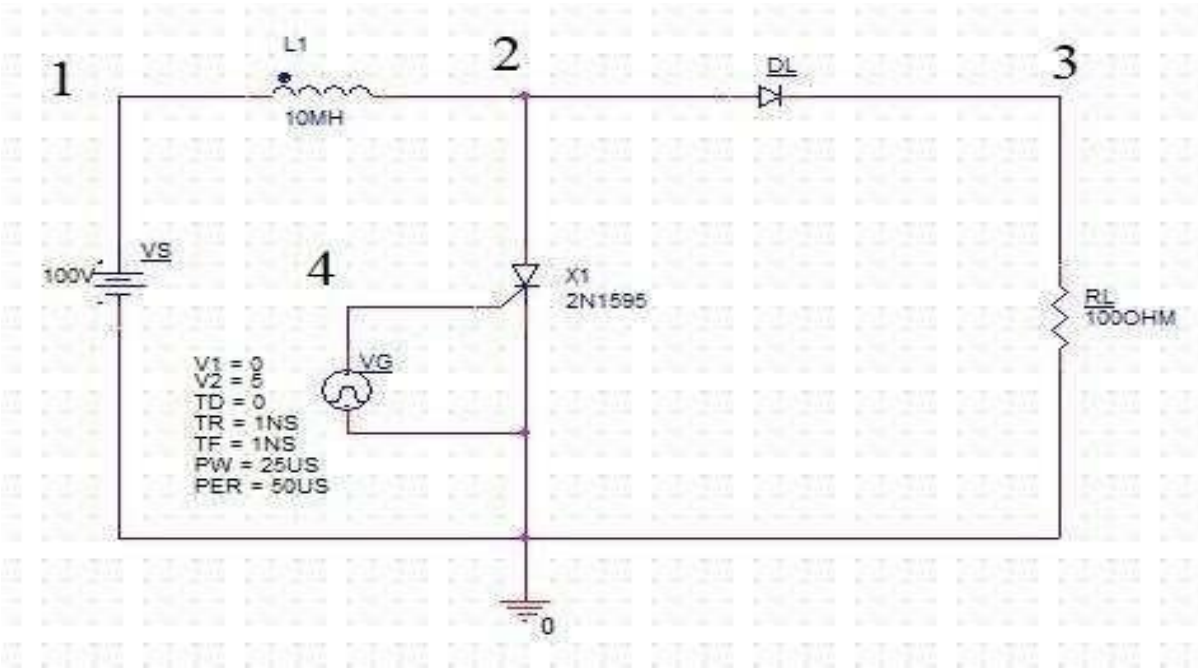


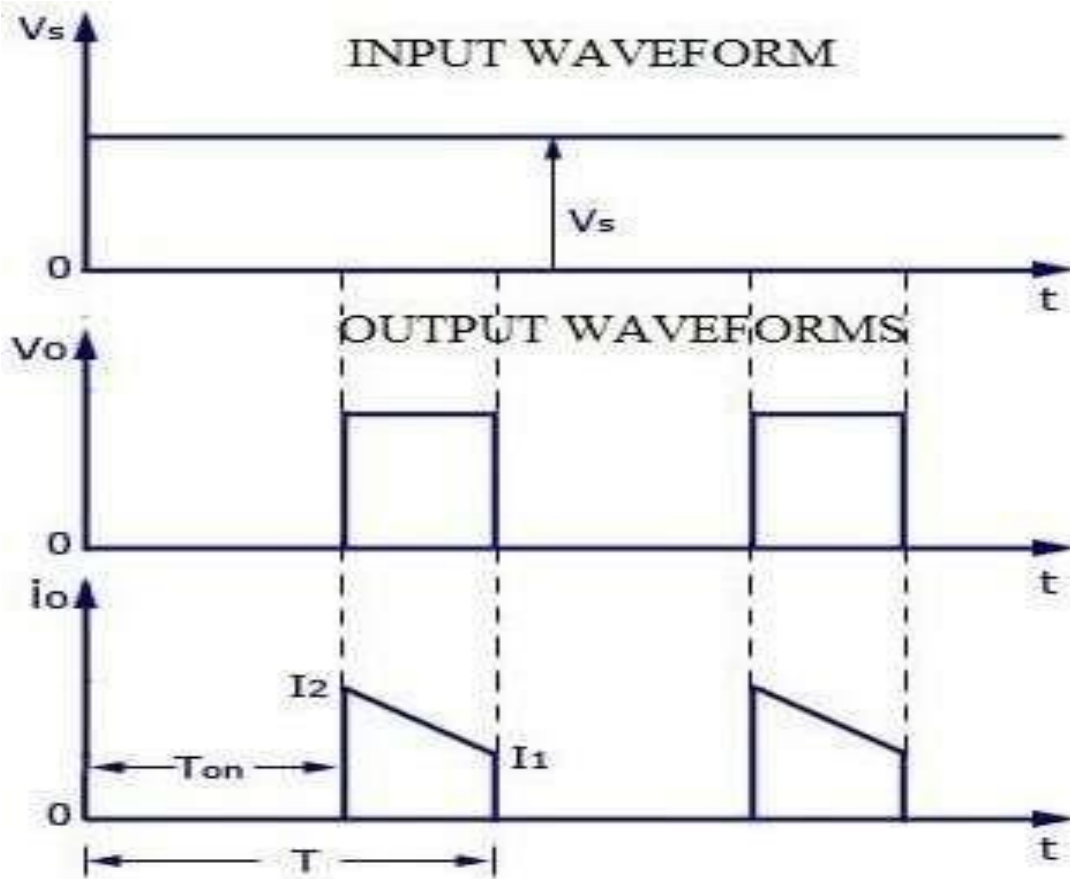
THREE PHASE HALF CONTROLLED BRIDGE CONVERTER WITH R LOAD



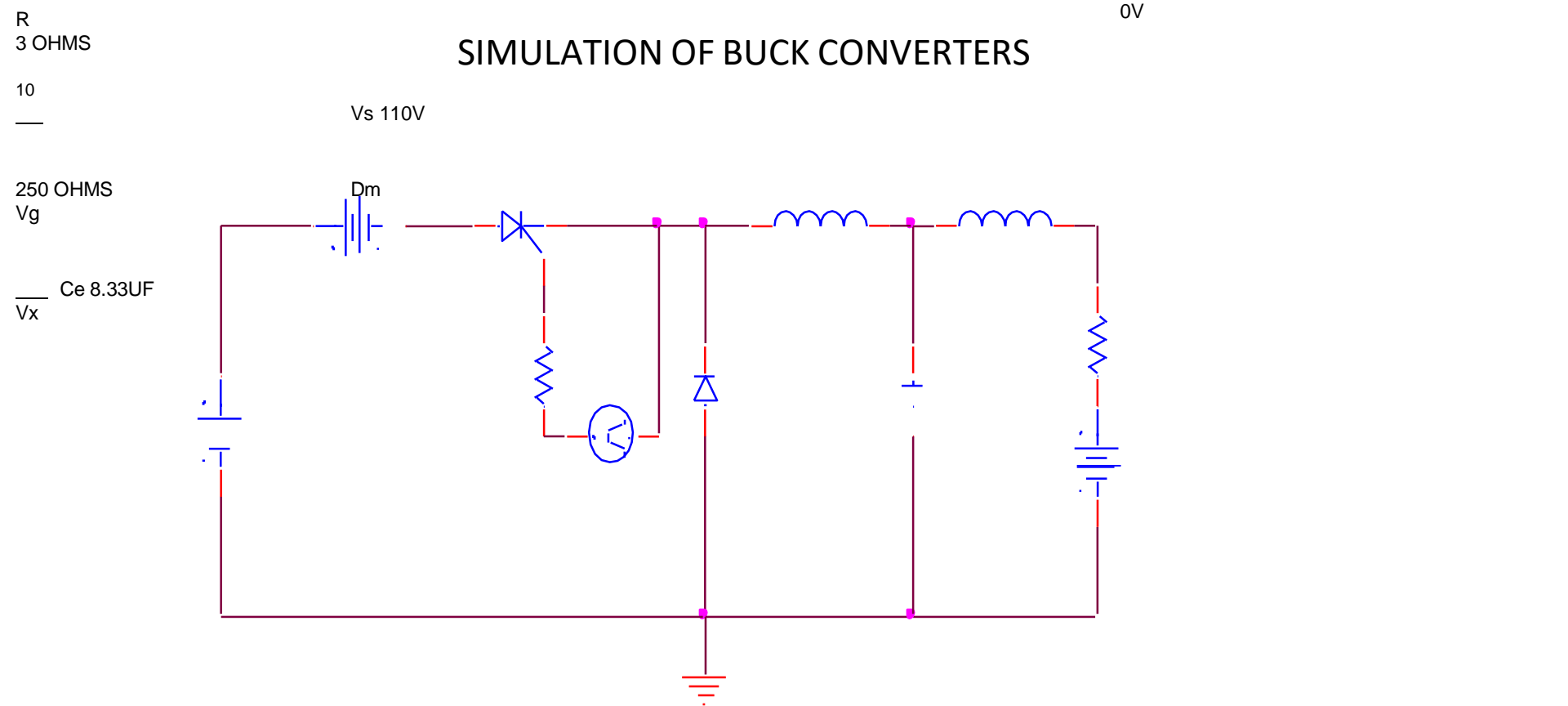


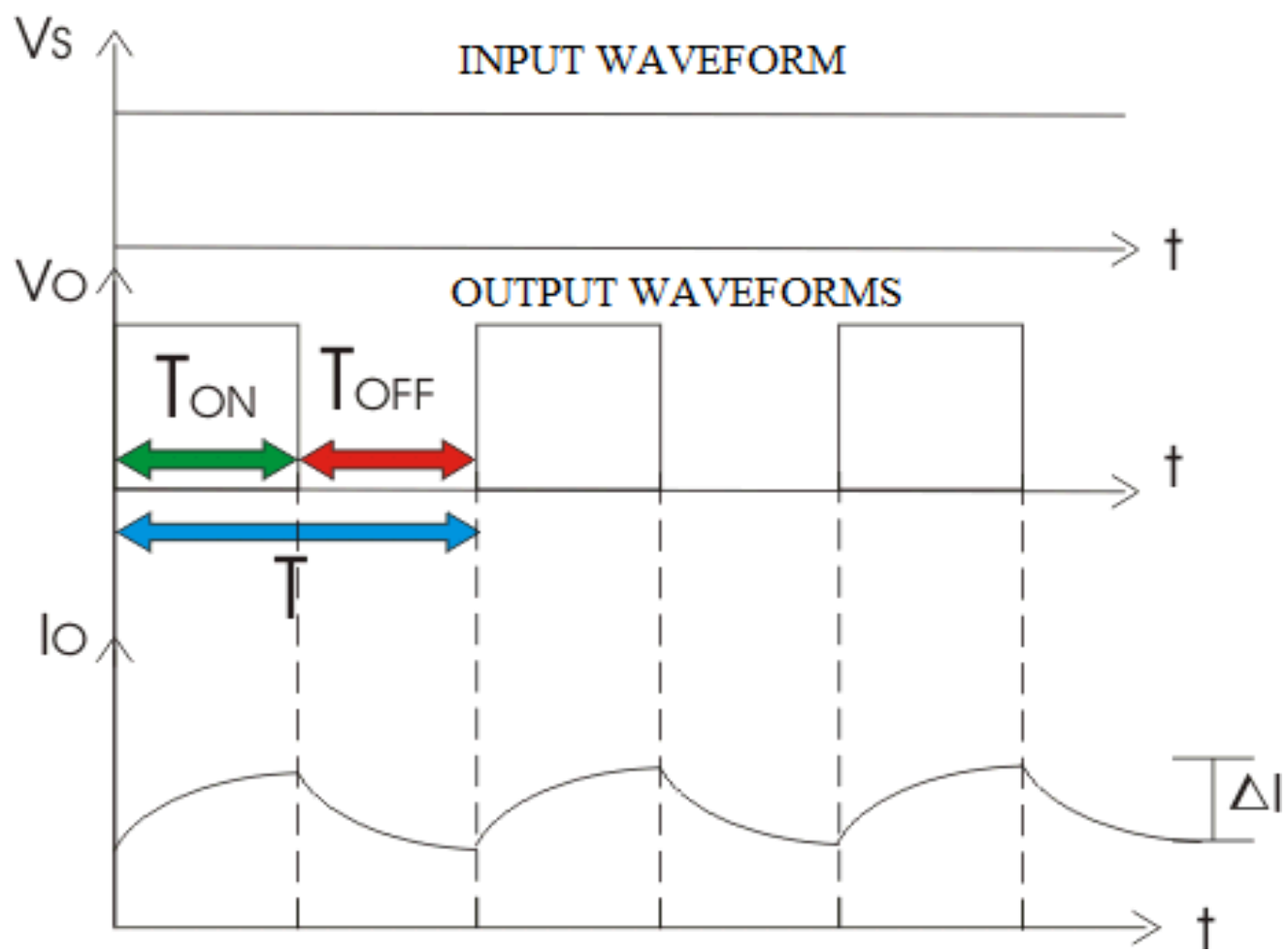
SIMULATION OF BOOST CONVERTERS



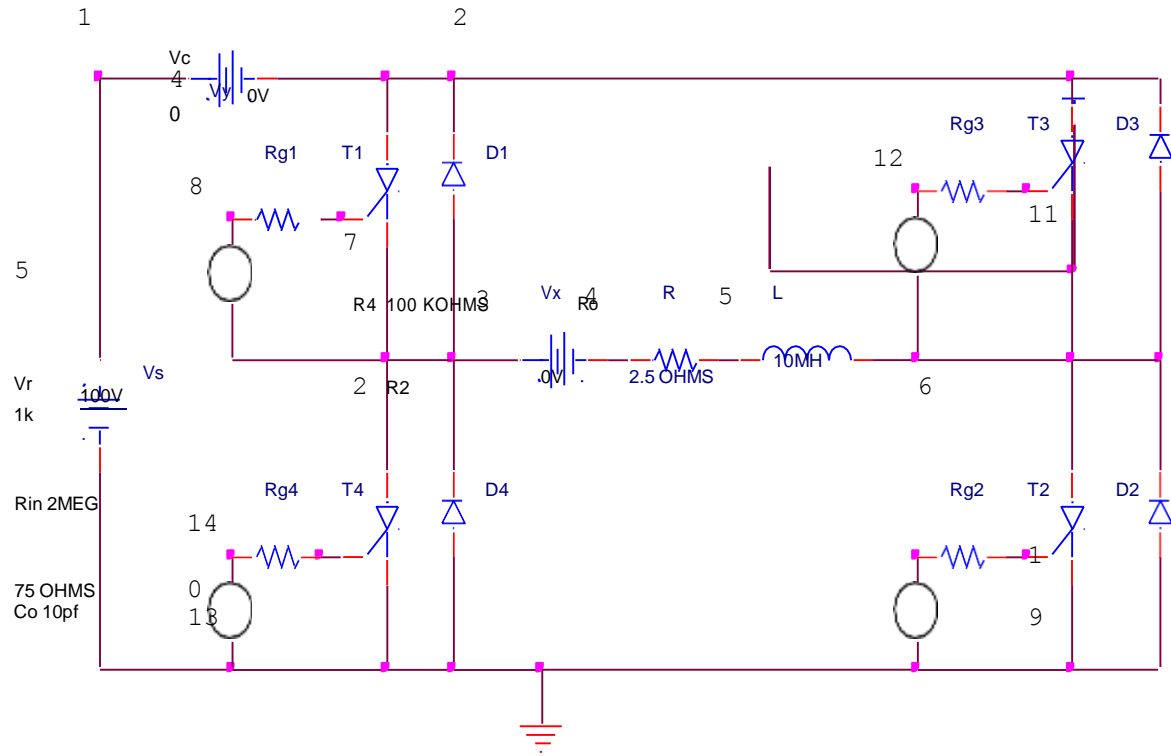


SIMULATION OF BUCK CONVERTERS

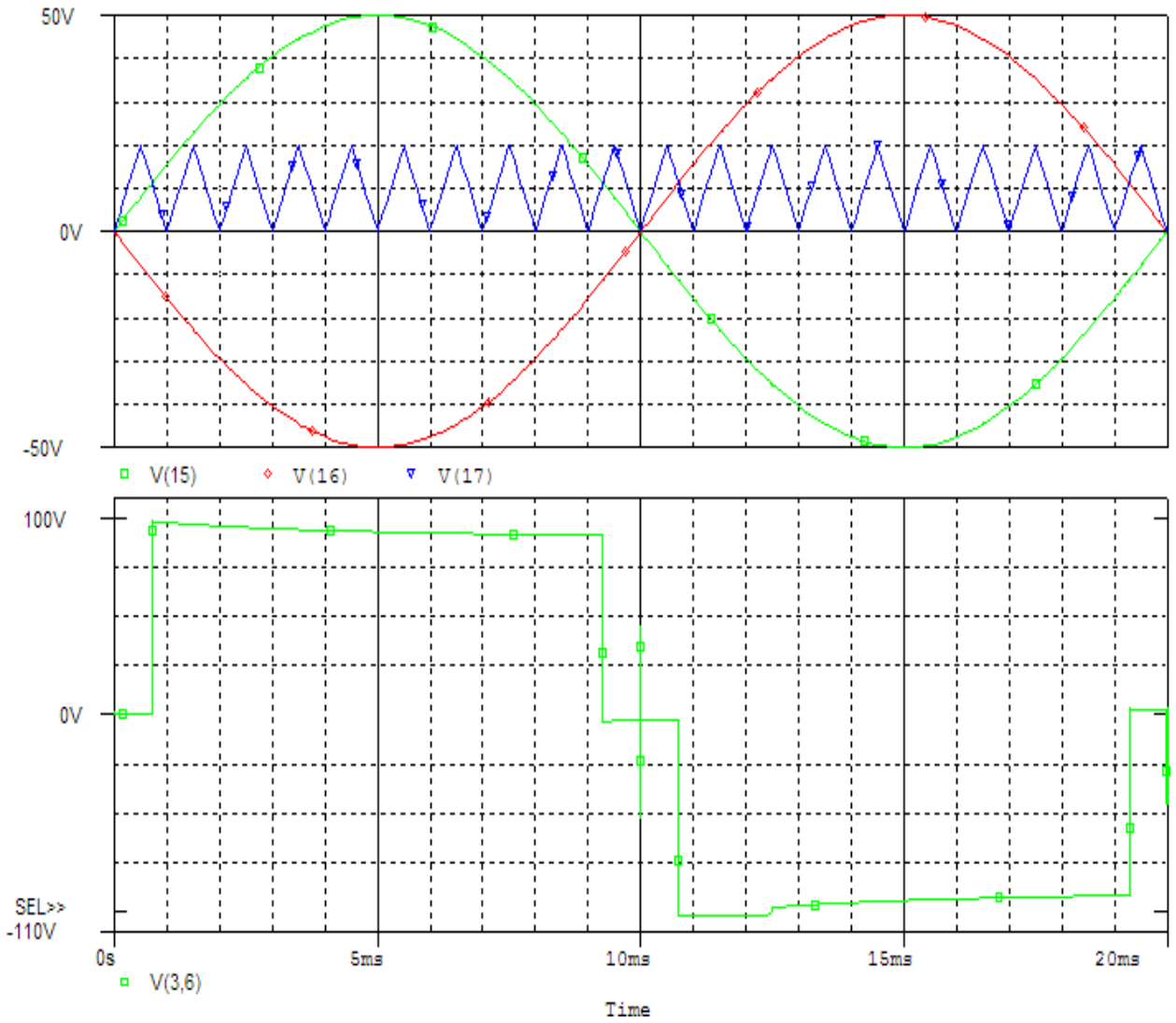


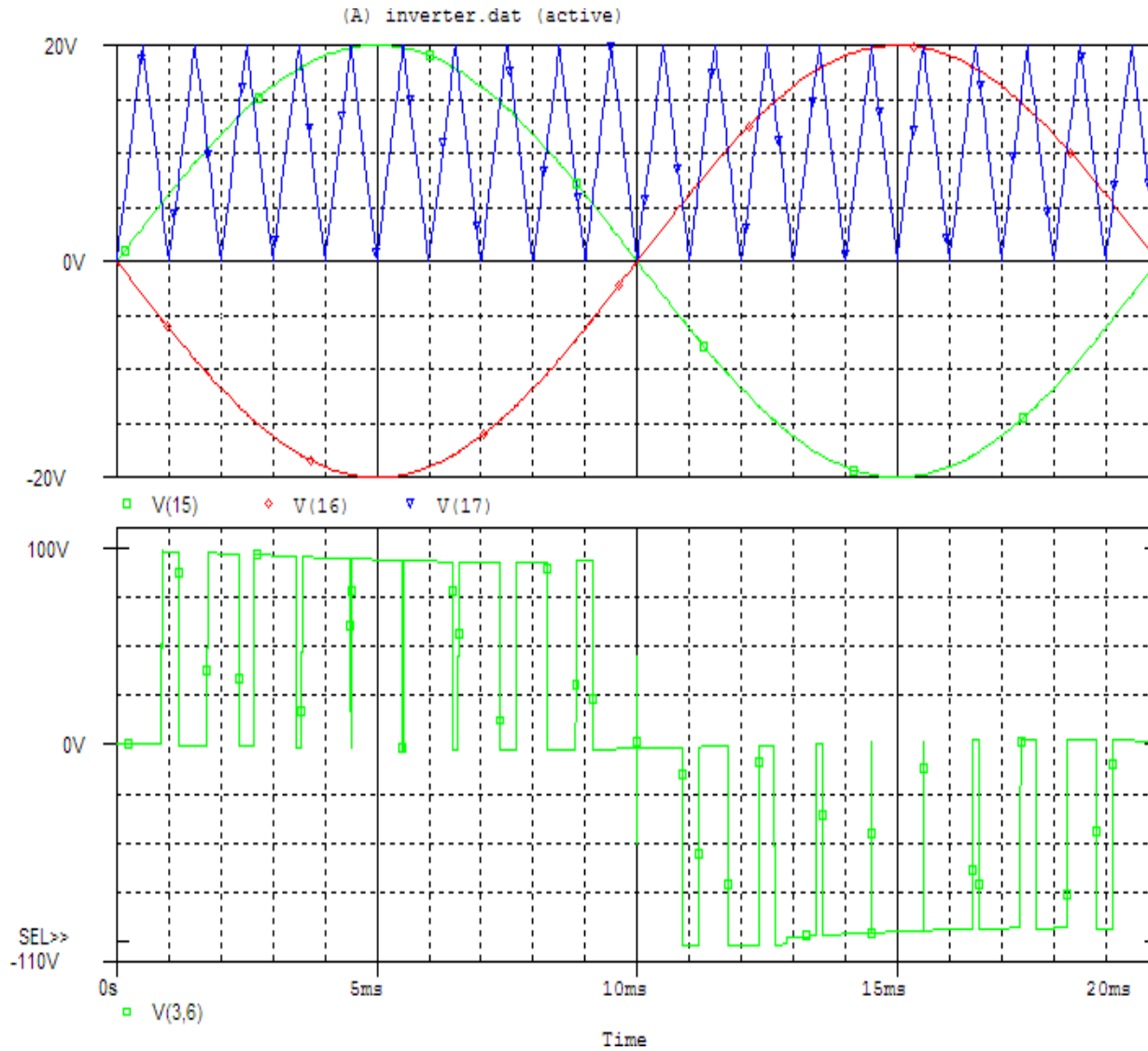


SINGLE PHASE INVERTER WITH PWM CONTROL

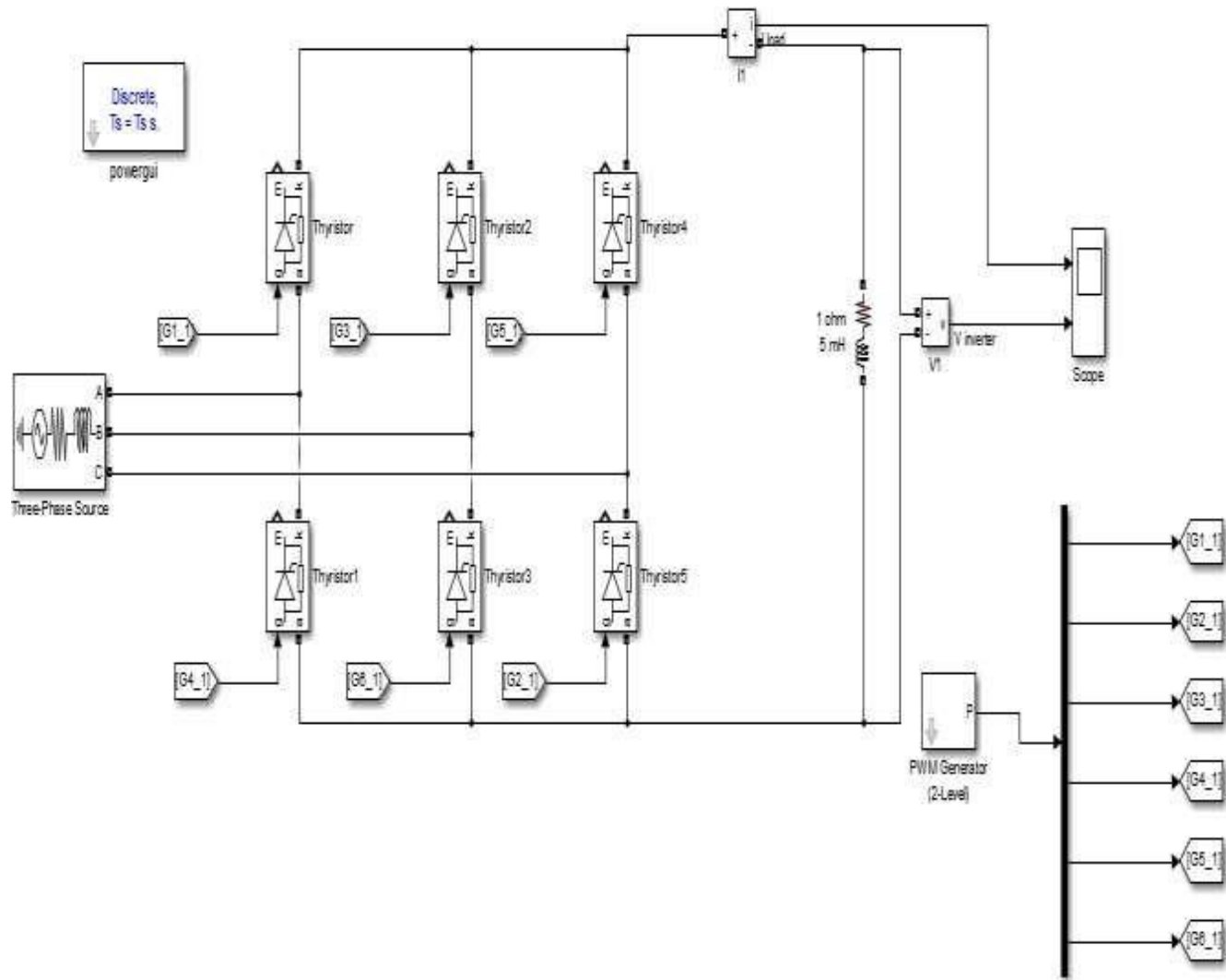


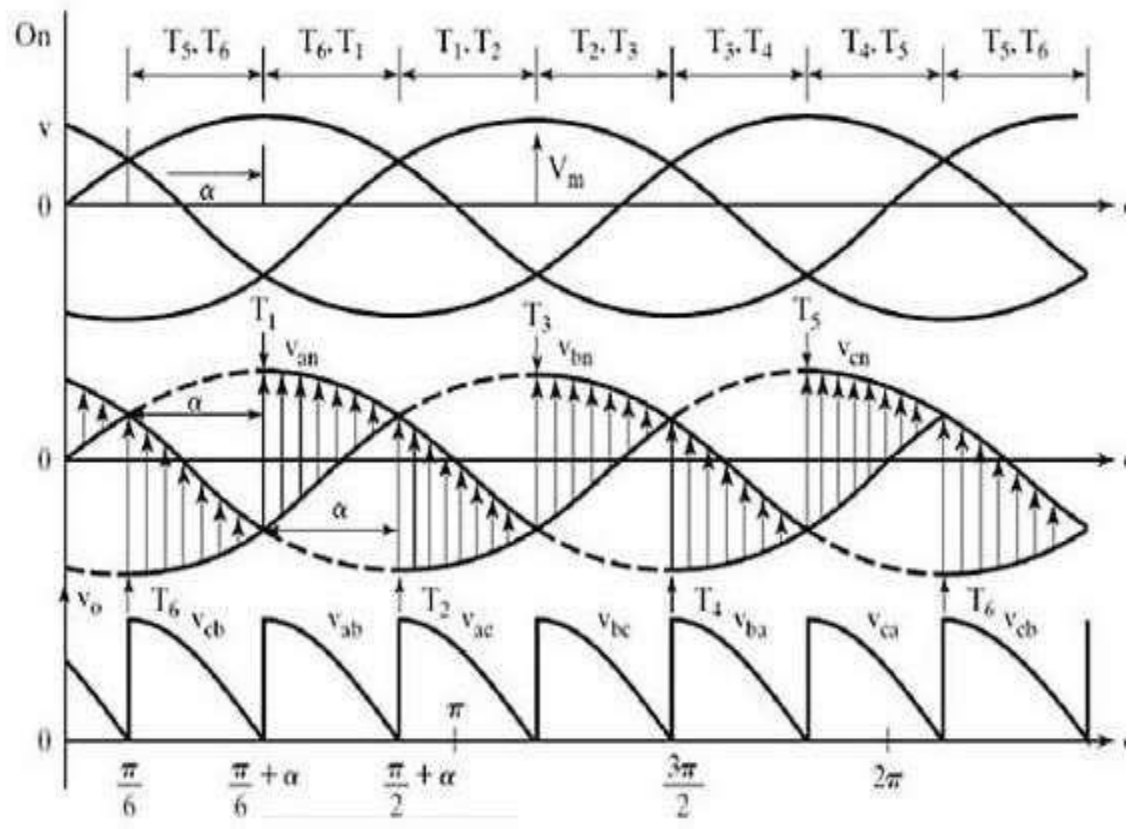
(A) inverter.dat (active)



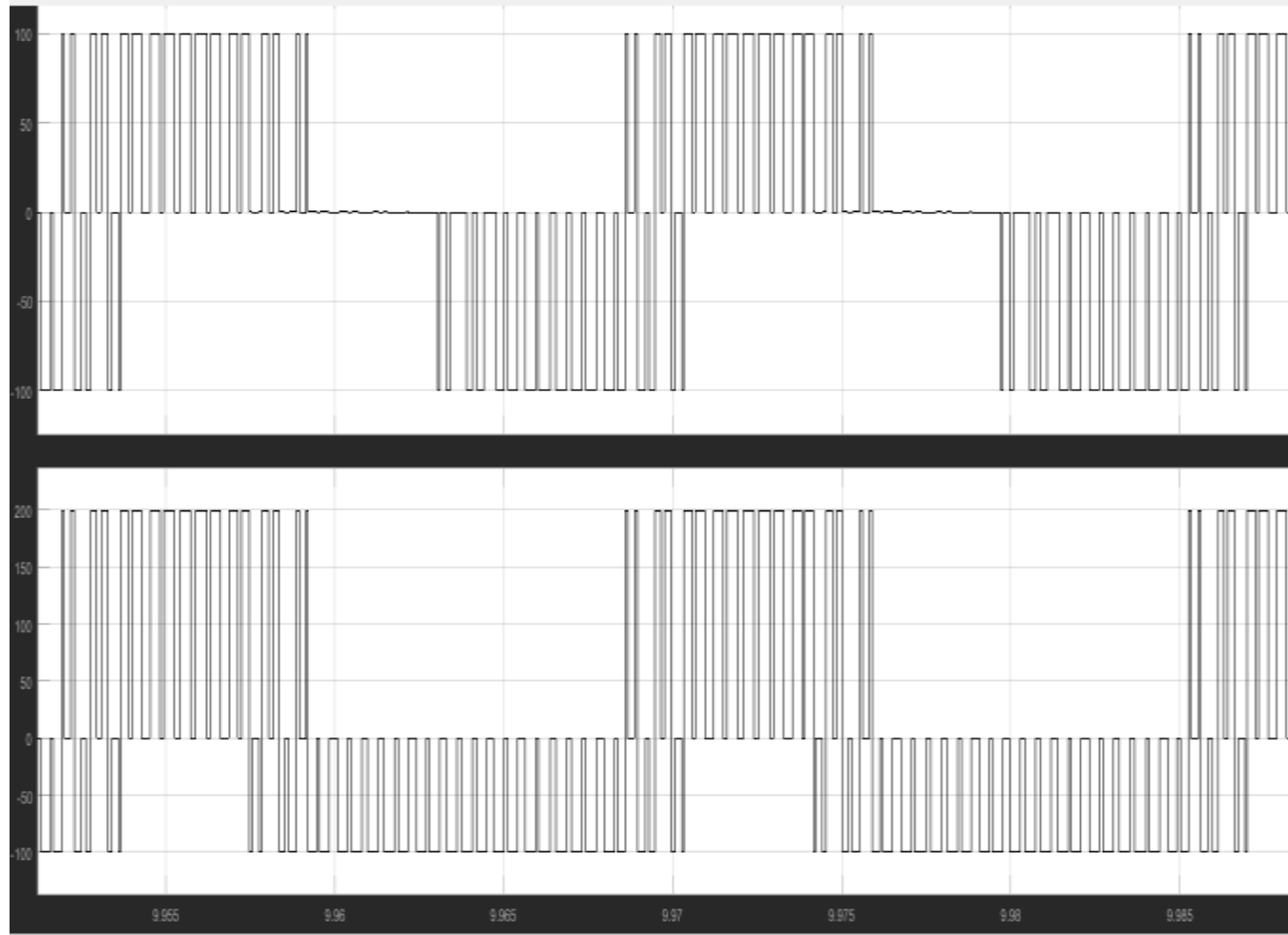


SIMULATION OF THREE PHASE FULL CONVERTER AND PWM INVERTER





Data may be missing. Try unchecking 'Limit data points to last' from the Configuration Properties Logging tab.

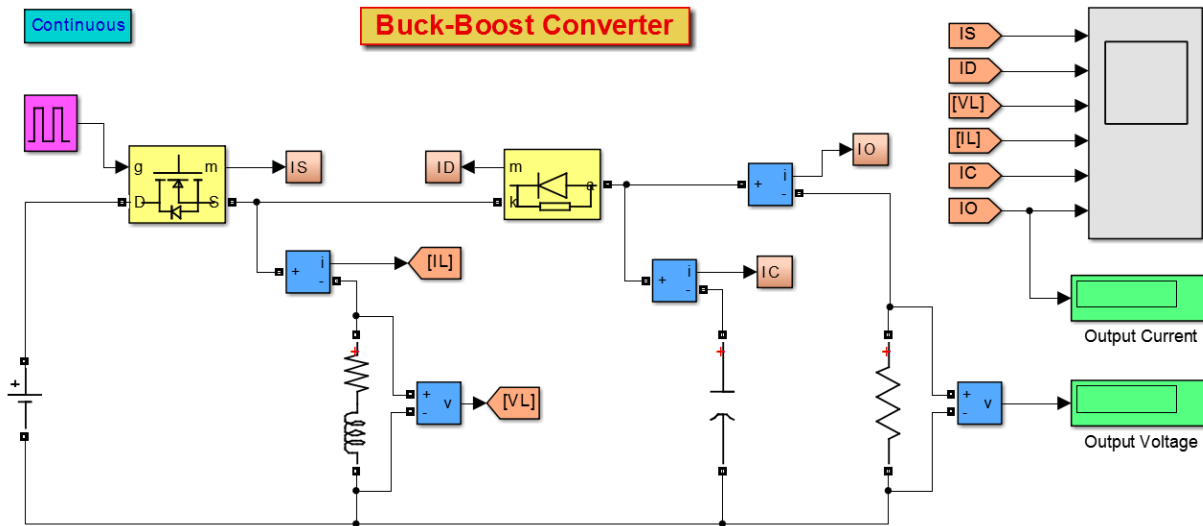


STUDY ON THE DESIGN OF PI CONTROLLERS AND STABILITY ANALYSIS FOR A DC-DC BUCK CONVERTER

SOFTWARE REQUIRED:

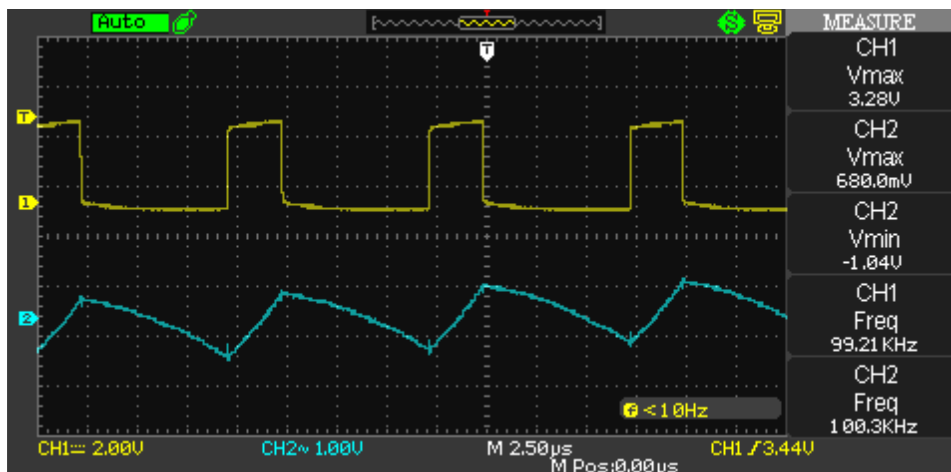
PSPICE – Personal Computer Simulated Program with Integrated Circuit Emphasis.

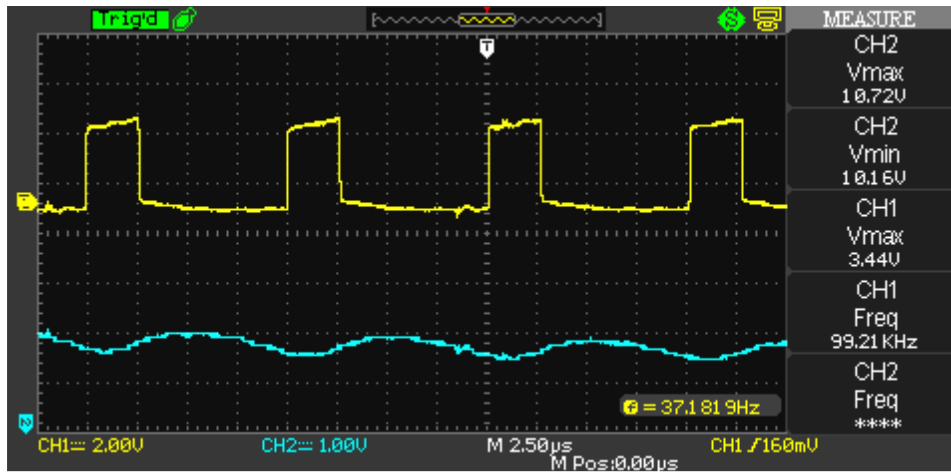
CIRCUIT DIAGRAM:



PROCEDURE:

1. Open PSpice A/D windows
2. Create a new circuit file
3. Enter the program representing the nodal interconnections of various components
4. Run the program
5. Observe the response through all the elements in the output file
6. Observe the voltage, current graph of any in probe window.





Experimental Results for $V_i=48V$ and $R=10\Omega$
 (a) PWM, Inductance Current (b) PWM, Output Voltage

Economic Load Dispatch of (i) Thermal Units and (ii) Thermal Plants using Conventional method

APPARATUS:

Desktop Computers with MATLAB software

Statement of Economic Dispatch Problem:

In a power system, with negligible transmission losses and with N number of spinning thermal generating units the total system load PD at a particular interval can be met by different sets of generation schedules.

$PG_1(K), PG_2(K), \dots, PGN(K) \quad k=1, 2, \dots, NS$

Out of these NS sets of generation schedules, the system operator has to choose that set of schedule which minimizes the system operating cost which is essentially the sum of the production costs of all the generating units. This economic dispatch problem is mathematically stated as an optimization problem. Given the number of available generating units Ns their production cost function, their operating limits and the system load PD.

To determine the set of generating schedule PG,

$$\text{Min } F_T = \sum_{i=1}^N F_i(P_{Gi}) \quad (1)$$

$$\text{where } F_i(P_{Gi}) = a_i P_{Gi}^2 + b_i P_{Gi} + c_i \quad i=1, 2, \dots, N \quad (2)$$

$$\Phi = \sum_{i=1}^N P_{Gi} - P_D = 0 \quad (3)$$

$$P_{Gi}^{\min} \leq P_{Gi} \leq P_{Gi}^{\max} \quad (4)$$

where a_i, b_i and c_i are constants.

The ED problem is given by the equations . By omitting the inequality constraint the reduced ED problem may be restated as an unconstrained optimization problem by augmenting the objective function with the constraint function Φ multiplied by Lagrange multiplier λ to obtain the Lagrange function L as,

The solution to ED problem can be obtained by solving simultaneously the necessary conditions and which state that the economic generation schedules not only satisfy the system power balance

equation but also demand that the incremental cost rates of all the units be equal to λ which can be interpreted as “incremental cost of received power” when the inequality constraints are included in the ED problem the necessary condition gets modified as The solution to the ED problem with the production cost function assumed to be a quadratic function, equation , can be obtained by simultaneously solving and using a direct method as given below,
 Substituting Equation in Equation we obtain The method of solution involves computing λ using equation and then computing the economic schedules P_{Gi} ; $i=1,2,\dots,N$ using equation . In order to satisfy the operating limits the following iterative algorithm is to be used.

ALGORITHM:

- Step 1:** Choose appropriate value of Lagrangian multiplier λ
- Step 2:** Start iteration iter=0
- Step 3:** Iteration iter=iter+1
- Step 4:** Solve for power generated by i^{th} unit using equation
- Step 5:** Check if any P_i is beyond or below the inequality constant
 If $P_i < P_{i,min}$, fix $P_i = P_{i,min}$
 If $P_i > P_{i,max}$, fix $P_i = P_{i,max}$
- Step 6:** Calculate the power loss using the equation
- Step 7:** Calculate power mismatch using the formula,
- Step 8:** If, then increment λ , $\lambda_{new} = \lambda + 0.001$ and go to step 3 else go to step 9
- Step 9:** If, then decrement λ , $\lambda_{new} = \lambda - 0.001$ and go to step 3 else go to step 10
- Step 10:** If ΔP is less than tolerance value , print the values of generated power and losses
- Step 11:** Stop

MATLAB Program:

```

clc;
clear all; % a b c fc max min 49 | P a g e
    
```

```

data= [0.00142 7.20 510 1.1 600 150
0.00194 7.85 310 1 400 100
0.00482 7.97 78 1 200 050];
ng=length(data(:,1));
a=data(:,1);
b=data(:,2);
c=data(:,3);
fc=data(:,4);
pmax=data(:,5);
pmin=data(:,6);
% loss=[0.00003 0.00009 0.00012];
loss=[ 0 0 0];
C=fc.*c; B=fc.*b; A=fc.*a;
la=1; pd=850; acc=0.2;
diff=1;
145
while acc<(abs(diff));
for i=1:ng;
p(i)= (la-B(i))/(2*(la*loss(i)+A(i)));
if p(i)<pmin(i);
p(i)=pmin(i);
end;
if p(i)>pmax(i);
p(i)=pmax(i);
end;
end;
LS=sum((p.*p).*loss);
diff=(pd+LS-sum(p));
if diff>0
la=la+0.001;
else la=la-0.001;

```

end;
end;
PowerShared=p
Lambda=la
Loss=LS

OUTPUT:

a). When loss = [0.00003 0.00009 0.00012]
Power Shared = 435.1026 299.9085 130.6311
Lambda = 9.5290
Loss = 15.8222
b). When loss = 0
Power Shared = 393.0858 334.5361 122.1992
Lambda = 9.1490
Loss = 0

TRANSIENT STABILITY ANALYSIS

APPARATUS:

Desktop Computers with MATLAB software

Transient stability: When a power system is under steady state, the load plus transmission loss equals to the generation in the system. The generating units run a synchronous speed and system frequency, voltage, current and power flows are steady. When a large disturbance such as three phase fault, loss of load, loss of generation etc., occurs the power balance is upset and the generating units rotors experience either acceleration or deceleration. The system may come back to a steady state condition maintaining synchronism or it may break into subsystems or one or more machines may pull out of synchronism. In the former case the system is said to be stable and in the later case it is said to be unstable.

Reactive power $Q_e = \sin(\cos^{-1}(p.f))$

Stator current, $I_t = S^*/E_t^*$

$= P_e - jQ_e/E_t^*$

Voltage behind transient condition

Voltage of infinite bus

Angular separation between E_I and E_B

Pre-fault Operation:

During Fault Condition:

Find out X from the equivalent circuit during fault condition

Post fault Condition:

Find out X from the equivalent circuit during post fault condition

Critical Clearing Angle:

Critical Clearing Time:

MATLAB PROGRAM:

a) $P_m = 0.8$; $E = 1.17$; $V = 1.0$;

$X_1 = 0.65$; $X_2 = \text{inf}$; $X_3 = 0.65$;

`eacfault(Pm, E, V, X1, X2, X3)`

b) $P_m = 0.8$; $E = 1.17$; $V = 1.0$;

$X_1 = 0.65$; $X_2 = 1.8$; $X_3 = 0.8$;

`eacfault(Pm, E, V, X1, X2, X3)`

eacfault

```
function eacfault(Pm, E, V, X1, X2, X3)
```

```
if exist('Pm')~=1
```

```
Pm = input('Generator output power in p.u. Pm = '); else, end
```

```
if exist('E')~=1
```

```
E = input('Generator e.m.f. in p.u. E = '); else, end
```

```
if exist('V')~=1
```

```
V = input('Infinite bus-bar voltage in p.u. V = '); else, end
```

```
if exist('X1')~=1
```

```
X1 = input('Reactance before Fault in p.u. X1 = '); else, end
```

```
if exist('X2')~=1
```

```
X2 = input('Reactance during Fault in p.u. X2 = '); else, end
```

```
if exist('X3')~=1
```

```
X3 = input('Reactance after Fault in p.u. X3 = '); else, end
```

```
Pe1max = E*V/X1; Pe2max=E*V/X2; Pe3max=E*V/X3;
```

```
delta = 0:.01:pi;
```

```
Pe1 = Pe1max*sin(delta); Pe2 = Pe2max*sin(delta); Pe3 = Pe3max*sin(delta);
```

```
d0 =asin(Pm/Pe1max); dmax = pi-asin(Pm/Pe3max);
```

```
cosdc = (Pm*(dmax-d0)+Pe3max*cos(dmax)-Pe2max*cos(d0))/(Pe3max-Pe2max);
```

```
if abs(cosdc) > 1
```

```
fprintf('No critical clearing angle could be found.\n')
```

```
fprintf('system can remain stable during this disturbance.\n\n')
```

```
return
```



```

else, end
dc=acos(cosdc);
if dc >dmax
fprintf('No critical clearing angle could be found.\n')
fprintf('System can remain stable during this disturbance.\n\n')
return
else, end
Pmx=[0 pi-d0]*180/pi; Pmy=[Pm Pm];
x0=[d0 d0]*180/pi; y0=[0 Pm]; xc=[dc dc]*180/pi; yc=[0 Pe3max*sin(dc)];
xm=[dmaxdmax]*180/pi; ym=[0 Pe3max*sin(dmax)];
d0=d0*180/pi; dmax=dmax*180/pi; dc=dc*180/pi;
x=(d0:.1:dc);
y=Pe2max*sin(x*pi/180);
y1=Pe2max*sin(d0*pi/180);
y2=Pe2max*sin(dc*pi/180); 44 | P a g e

```

```

x=[d0 x dc];
y=[Pm y Pm];
xx=dc:.1:dmax;
h=Pe3max*sin(xx*pi/180);
xx=[dc xx dmax];
hh=[Pm h Pm];
delta=delta*180/pi;
if X2 == inf
fprintf('\nFor this case tc can be found from analytical formula. \n')
H=input('To find tc enter Inertia Constant H, (or 0 to skip) H = ');
if H ~= 0
d0r=d0*pi/180; dcr=dc*pi/180;
tc = sqrt(2*H*(dcr-d0r)/(pi*60*Pm));
else, end
else, end
%clc
fprintf('\nInitial power angle = %7.3f \n', d0)
fprintf('Maximum angle swing = %7.3f \n', dmax)
fprintf('Critical clearing angle = %7.3f \n\n', dc)
if X2==inf & H~=0
fprintf('Critical clearing time = %7.3f sec. \n\n', tc)
else, end
h = figure; figure(h);
fill(x,y,'m')
hold;
fill(xx,hh,'c')
plot(delta, Pe1,'-', delta, Pe2,'r-', delta, Pe3,'g-', Pmx, Pmy,'b-', x0,y0,
xc,yc, xm,ym), grid
Title('Application of equal area criterion to a critically cleared system')
xlabel('Power angle, degree'), ylabel(' Power, per unit')
text(5, 1.07*Pm, 'Pm')

```

```
text(50, 1.05*Pe1max,['Critical clearing angle = ',num2str(dc)])
axis([0 180 0 1.1*Pe1max])
hold off;
```

OUTPUT:

a) To find t_c enter Inertia Constant H, (or 0 to skip) H = 5
 Initial power angle = 26.388
 Maximum angle swing = 153.612
 Critical clearing angle = 84.775
 Critical clearing time = 0.260 sec.

MATLAB PROGRAM:

```
E=1.35; V=1.0; H=9.94; X=0.65; Pm=0.6; D=0.138; f0=60;
Pmax=E*V/X, d0=asin(Pm/Pmax)
Ps=Pmax*cos(d0)
wn=sqrt(pi*60/H*Ps)
z=D/2*sqrt(pi*60/(H*Ps))
wd=wn*sqrt(1-z^2),fd=wd/(2*pi)
tau=1/(z*wn)
th=acos(z)
Dd0=10*pi/180;
t=0:.01:3;
Dd=Dd0/sqrt(1-z^2)*exp(-z*wn*t).*sin(wd*t+th);
d=(d0+Dd)*180/pi;
Dw=-wn*Dd0/sqrt(1-z^2)*exp(-z*wn*t).*sin(wd*t);
f=f0+Dw/(2*pi);
subplot(2,1,1),plot(t,d),grid
xlabel('t sec'),ylabel('Delta degree')
```

```
subplot(2,1,2),plot(t,f),grid  
xlabel('t sec'),ylabel('frequency hertz')  
subplot(111)
```

OUTPUT:

Pmax = 2.0769

d0 = 0.2931

Ps = 1.9884

wn = 6.1405

z = 0.2131

wd = 5.9995

fd = 0.9549

tau = 0.7643

th = 1.3561

REACTIVE POWER CONTROL IN A TRANSMISSION SYSTEM (FERRANTI EFFECT, EFFECT OF SHUNT INDUCTOR)

PROBLEM:

A 3-Phase 50 Hz transmission line is 5000 km long. The line parameters are $R=0.125\Omega/\text{km}$, $X=0.4\Omega/\text{km}$ and $Y=2.8*10^{-6}\text{ mho}/\text{km}$. If the line is open circuited with a receiving end voltage of 220KV, find the rms value and phase angle of the following. Use the receiving-end line to neutral voltage as reference.

- (a) The incident and reflected voltages to neutral at the receiving-end.
- (b) The incident and reflected voltages to neutral at 200 km from the receiving end.
- (c) The resultant voltage at 200 km from the receiving end.

Solve the problem theoretically. Vary the length of the long transmission line in steps of 10 KM from zero (receiving end) to 5000KM (sending end), and plot the sending end voltage phasor using MATLAB.

MATLAB PROGRAM:

```
% Program to illustrate Ferranti effect
% it simulates the effect by varying the length of transmission line from
% zero(receiving end) to 5000km in steps of 10km
% and plots the sending end voltage phasor
```

```
clc
clear all
VR=220e3/sqrt(3);
alpha=0.163e-3;
beta=1.0683e-3;
L=5000;
k=1;
for i=0:10:L,
VS=(VR/2)*exp(alpha*i)*exp(j*beta*i)+(VR/2)*exp(-alpha*i)*exp(-j*beta*i);
X(k)=real(VS);
Y(k)=imag(VS);
k=k+1;
p(k)=VS;
q(k)=i;
end
figure(1);
plot(p,q)
figure(2);
plot(X,Y)
```

FAULT STUDIES USING ZBUS MATRIX

APPARATUS:

Desktop Computers with MATLAB software

Type 1 modification:

In type 1 modification, an impedance Z_b is added between a new bus p and the reference bus as shown in Figure 1

Figure 1: Addition of impedance between new bus and reference bus

Let the current through bus „ p “ be I_p , then the voltage across the bus p is given by,

$$V_p = I_p Z_b$$

The potential at other buses remains unaltered and the system equations can be written as,

Type 2 modification:

In type 2 modification, an impedance Z_b is added between a new bus p and an existing bus k as shown in Figure 2. The voltages across the bus k and p can be expressed as,

$$V_{k(\text{new})} = V_k + I_p Z_{kk}$$

$$V_p = V_{k(\text{new})} + I_p Z_p = V_k + I_p (Z_b + Z_{kk})$$

where, V_k is the voltage across bus k before the addition of impedance Z_b

Z_{kk} is the sum of all impedance connected to bus k .

Figure 2: Addition of impedance between new bus and existing bus

The system of equations can be expressed as,

Type 3 Modification:

In this modification, an impedance Z_b is added between an existing bus k and a reference bus.

Then the following steps are to be followed:

1. Add Z_b between a new bus p and the existing bus k and the modifications are done as in type 2.
2. Connect bus p to the reference bus by letting $V_p = 0$.

To retain the symmetry of the Bus Impedance Matrix, network reduction technique can be used to remove the excess row or column.

Type 4 Modification:

In this type of modification, an impedance Z_b is added between two existing buses j and k as shown in Figure 3. From Figure 3, the relation between the voltages of bus k and j can be written as,

$$V_k - V_j = I_b Z_b$$

Figure 3: Addition of impedance between two existing buses

The voltages across all the buses connected to the network changes due to the addition of impedance Z_b and they can be expressed as,

$$\begin{aligned}
 V_1 &= Z_{11}I_1 + Z_{12}I_2 + \dots + Z_{1j}(I_j + I_b) + Z_{1k}(I_k - I_b) + \dots \\
 V_2 &= Z_{21}I_1 + Z_{22}I_2 + \dots + Z_{2j}(I_j + I_b) + Z_{2k}(I_k - I_b) + \dots \\
 V_j &= Z_{j1}I_1 + Z_{j2}I_2 + \dots + Z_{jj}(I_j + I_b) + Z_{jk}(I_k - I_b) + \dots \\
 V_k &= Z_{k1}I_1 + Z_{k2}I_2 + \dots + Z_{kj}(I_j + I_b) + Z_{kk}(I_k - I_b) + \dots \\
 V_n &= Z_{n1}I_1 + Z_{n2}I_2 + \dots + Z_{nj}(I_j + I_b) + Z_{nk}(I_k - I_b) + \dots
 \end{aligned}$$

The system of equations can be rewritten as,

where,

$$Z_{bb} = Z_{jj} + Z_{kk} - 2 Z_{jk} + Z_b$$

Procedure for formation of Z_{bus} matrix:

Step1: Number the nodes of the given network, starting with those nodes at the ends of branches connected to the reference node.

Step2: Start with a network composed of all those branches connected to the reference node.

Step3: Add a new node to the i th node of the existing network.

Step4: Add a branch between i th and j th nodes. Continue until all the remaining branches are connected.

MATLAB PROGRAM:

```
clc;
clear all;
nb=input('Enter the number of buses');
Zbusm=null(nb,nb);
ele=input('Enter the number of elements:');
dim=0;
for i=1:ele
disp(' ');
disp('1.Addition of Branch 2.Addition of Link');
```

```

ch=input('Enter your choice:');
p=input('enter p value');
q=input('enter q value');
val=input('Enter value to be added;');
switch(ch)
case 1
dim=dim+1;
if p==0||q==0
for row=1:dim
for col=1:dim
Zbusm(dim,dim)=val;
Zbusm(dim+1:end,dim+1:end)=0;
end;
end;
else
for i=1:dim
Zbusm(q,i)=Zbusm(p,i);
Zbusm(i,q)=Zbusm(q,i);
end;
Zbusm(q,q)=Zbusm(p,q)+val;
end;
%end;
case 2
Zbusrm=null(dim,dim);
li=dim+1;
if p==0
for i=1:li
Zbusm(li,i)=-Zbusm(q,i);
Zbusm(i,li)=Zbusm(li,i);
end;
%end

```

```

Zbusm(li,li)=-Zbusm(q,li)+val;
else
for i=1:li
Zbusm(li,i)=Zbusm(p,i)-Zbusm(q,i);
Zbusm(i,li)=Zbusm(li,i);
end;
Zbusm(li,li)=Zbusm(p,li)-Zbusm(q,li)+val
for i=1:dim
for j=1:dim
Zbusrm(i,j)=Zbusm(i,j)-(((Zbusm(i,li))*Zbusm(li,j))/Zbusm(li,li));
end;
end;
disp(Zbusrm);
Zbusm=Zbusrm
end;
end;
end

```

OUTPUT:

Enter the number of buses: 3

Enter the number of elements:5

1. Addition of Branch 2.Addition of Link

Enter your choice:1

enter p value0

enter q value1 26 | Page

Enter value to be added: 0.2
1.Addition of Branch 2.Addition of Link
Enter your choice:1
enter p value0
enter q value2
Enter value to be added;0.4
1.Addition of Branch 2.Addition of Link
Enter your choice:1
enter p value1
enter q value3
Enter value to be added;0.4
Zbusm =
0.2000 0 0.2000
0 0.4000 0
0.2000 0 0.6000
1.Addition of Branch 2.Addition of Link
Enter your choice:2
enter p value1
enter q value2
Enter value to be added;0.8
Zbusm =
0.2000 0 0.2000 0.2000
0 0.4000 0 -0.4000
0.2000 0 0.6000 0.2000
0.2000 -0.4000 0.2000 1.4000
0.1714 0.0571 0.1714
0.0571 0.2857 0.0571
0.1714 0.0571 0.5714
Zbusm =
0.1714 0.0571 0.1714
0.0571 0.2857 0.0571

0.1714 0.0571 0.5714

1.Addition of Branch 2.Addition of Link

Enter your choice:2

enter p value2

enter q value3

Enter value to be added;0.4

Zbusm =

0.1714 0.0571 0.1714 -0.1143

0.0571 0.2857 0.0571 0.2286

0.1714 0.0571 0.5714 -0.5143

-0.1143 0.2286 -0.5143 1.1429

0.1600 0.0800 0.1200

0.0800 0.2400 0.1600

0.1200 0.1600 0.3400

Zbusm =

0.1600 0.0800 0.1200

0.0800 0.2400 0.1600

0.1200 0.1600 0.3400

DESIGN OF VIRTUAL PMU

1. Characterization of the Calibrator

As mentioned in the previous section, the first operation to be accomplished is the characterization of the calibrator, which is presented herein. The final goal is to assess the uncertainty that can be reasonably associated with the reference test waveform generated by the calibrator. Once this operation has been performed, the virtual PMU performance can finally be evaluated. The present article only deals with the steady-state characterization for the M-class PMU because the P-class has less strict requirements, hence it is included in the M-class. The virtual PMU, in accordance with its standard IEC 60255-118-1 [47], has a reporting rate of 1 frame per second (fps); consequently, the dynamic performance requirements and the out-of-band requirements do not apply.

The remainder of this section contains: first, the calibrator concept and hardware are presented in

[Section 1.1](#); second, the designed characterization tests for the calibrator are described in [Section 2.2](#); finally, the characterization results are commented on and arranged to provide the accuracy specifications of the calibrator in [Section 2.3](#).

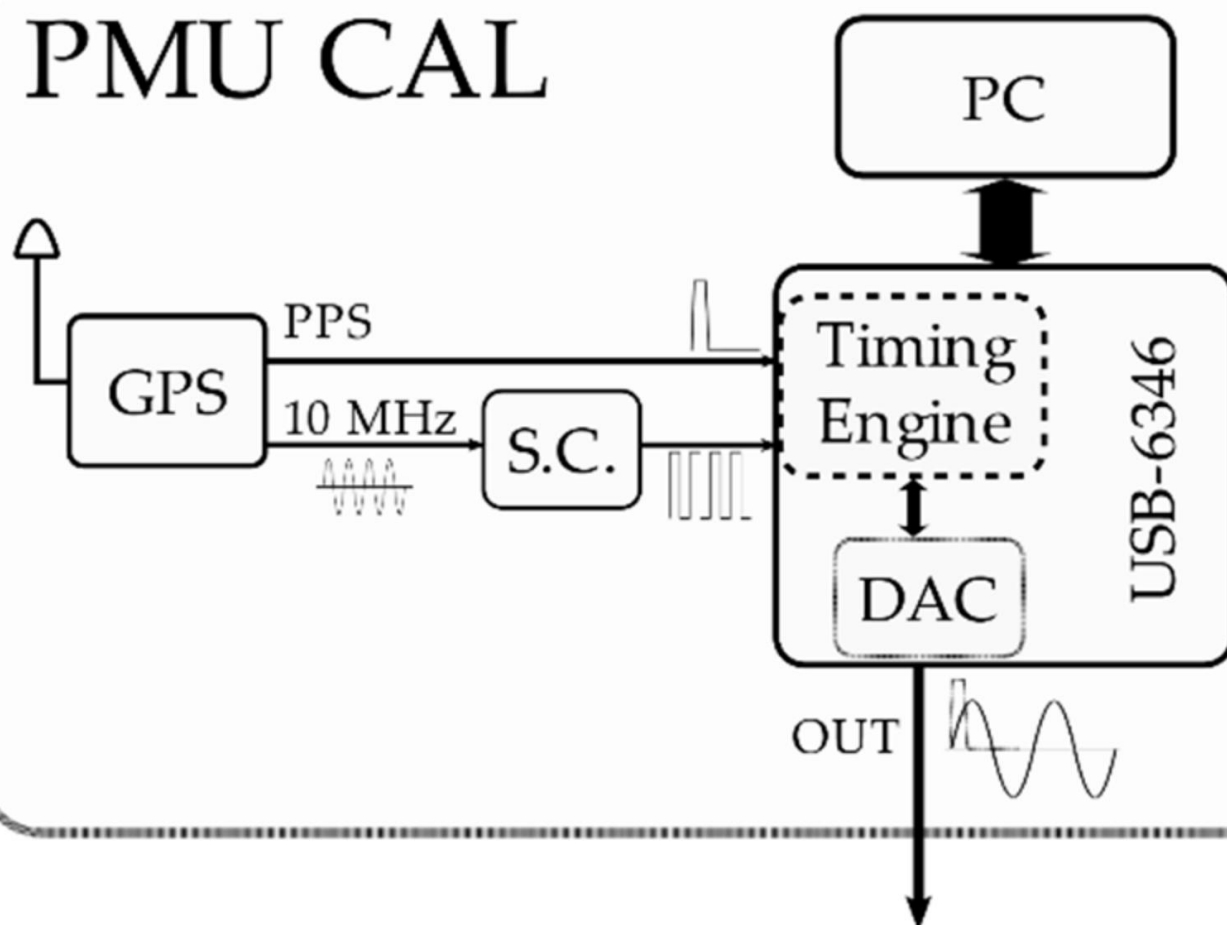
2.1. The Calibrator Hardware Architecture

The standard prescribes the verification of some parameters that quantify the deviation of the synchrophasor measured by the tested PMU from the reference one. These parameters are the Total Vector Error (TVE), the Frequency Error (FE), and the Rate Of Change Of Frequency (ROCOF) Error (RFE). The uncertainty affecting the reference synchrophasor should be at least one order of magnitude smaller than the one expected from the tested PMU. To conduct this kind of evaluation, a PMU test system (or PMU calibrator) is needed. In recent years, many have faced the problem of PMU calibration. Besides the research on the definition of accurate phasor estimation algorithms, the implementation of reference class hardware test systems is of key importance to the successful deployment of PMUs in Smart Grids. Researchers and national metrological institutes have developed in-house test facilities and employed off-the-shelf solutions. The architecture of PMU calibrators is quite consolidated. Basically, the PMU calibrator generates the test waveforms through an analog output stage and feeds them to the PMU under test; simultaneously, the calibrator returns the generated waveform to produce the reference synchrophasor. Both the generation and the acquisition stages are driven by a timing stage distinguished by stable clocks and triggers referenced to an absolute timing source, such as a GPS clock or an atomic clock. The main reason behind this kind of design, in which a reference PMU is actually implemented, is the fact that it also allows the calibration of other calibrators

For the purpose of the present work, this aspect is not necessary: thus, the calibrator architecture has been kept as simple as possible. In fact, it is a generator capable of producing an accurate waveform from the magnitude and timing point of view, equivalent to the reference synchrophasor. The components are sketched in [Figure 2](#): (i) an accurate GPS disciplined oscillator

Trimble Thunderbolt E [63] providing the pulse-per second (PPS) signal and a disciplined 10 MHz reference clock signal; (ii) an NI USB-6346 multifunction I/O device , which employs as timing and synchronization sources both the PPS and the 10 MHz signals and outputs the test waveforms from the analog output channel; (iii) a PC running the calibrator software and the calibrator characterization test software, both developed in LabVIEW. The characteristics of the analog output channel (OUT) DAC are summarized in [Table 1](#), whereas the characteristics of the GPS disciplined oscillator are shown in [Table 2](#).

PMU CAL



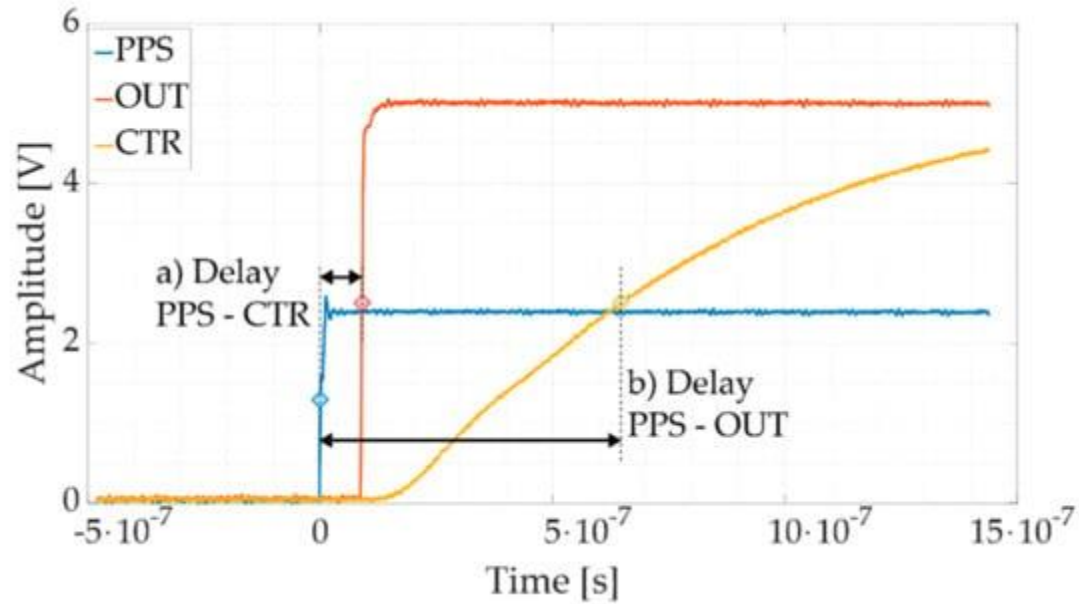
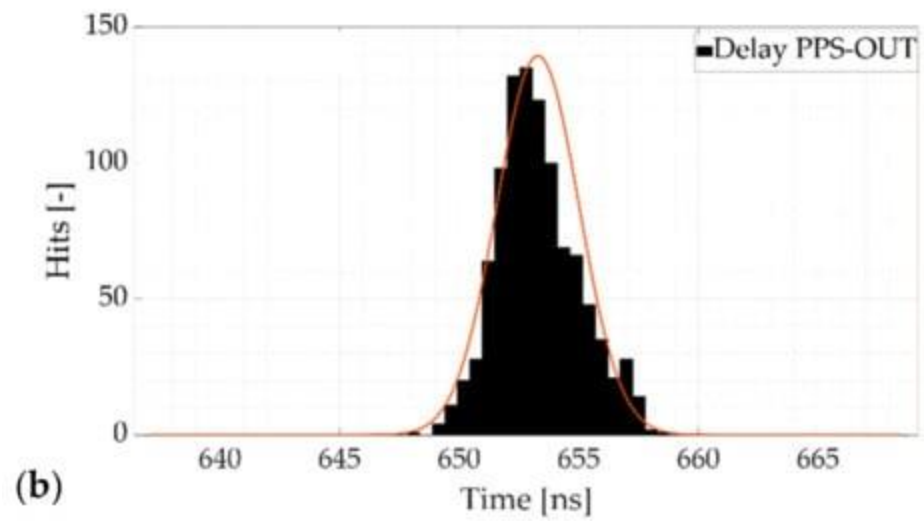
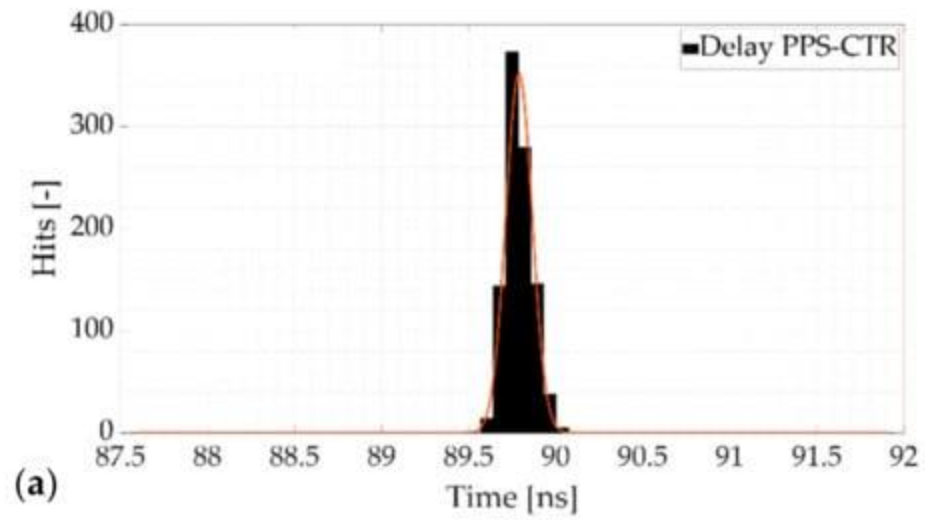


Figure 5. Oscilloscope waveform acquisitions for the board synchronization evaluation. The PPS signal (**blue**), the CTR signal (**red**), the OUT signal (**yellow**).



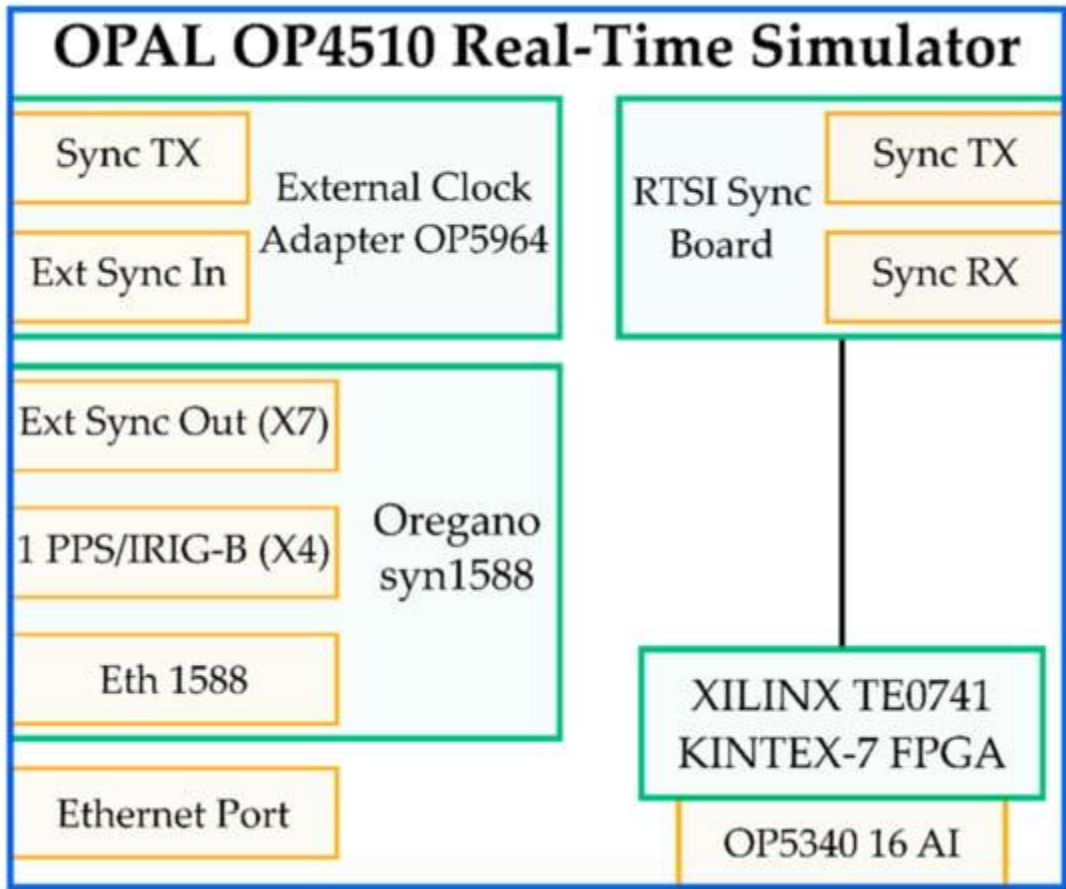


Figure 7. Main components of the OPAL OP4510 RTS.
 A brief description of the main components is given in what follows:

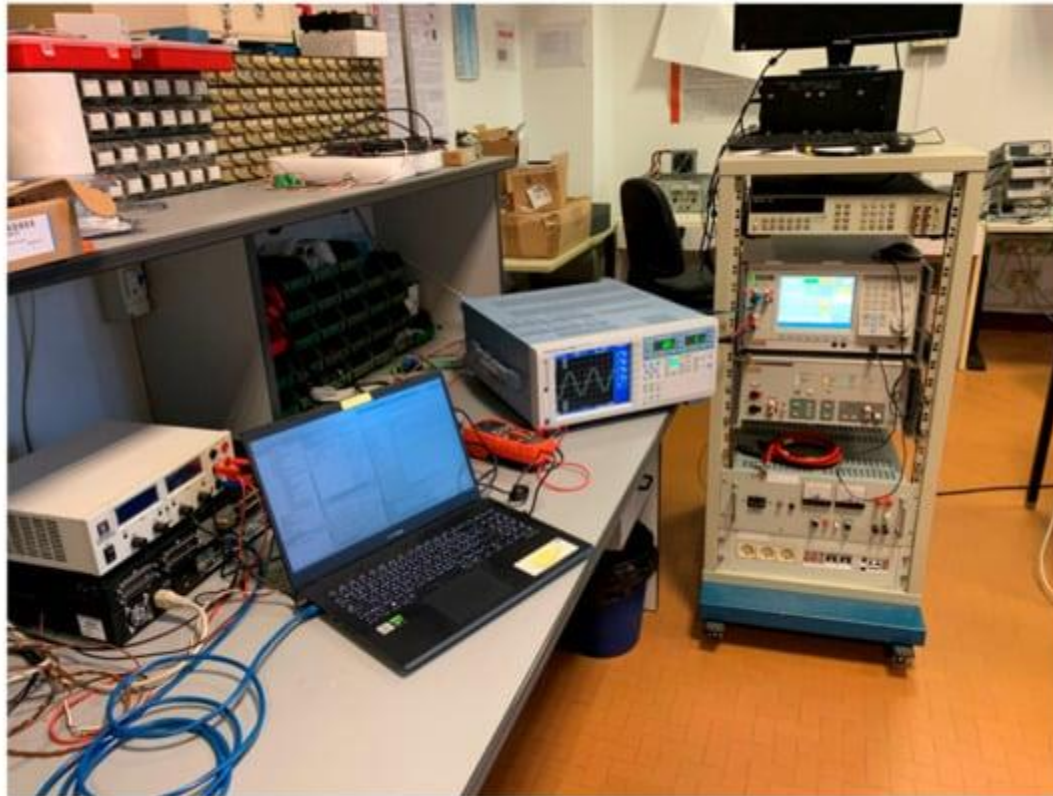
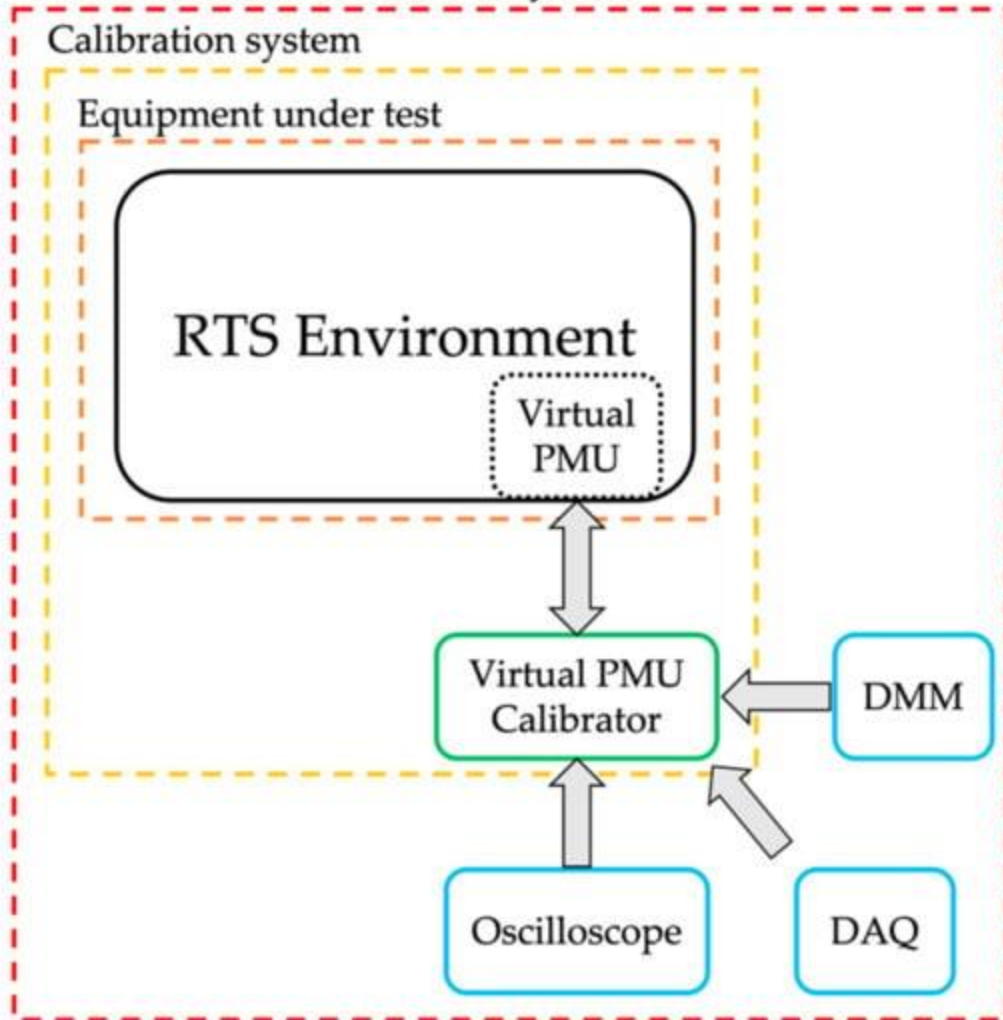


Figure 8. Picture taken of the laboratory environment during the RTS testing.

Assessment of the calibration system



Conclusions

The use of real-time simulators among researchers and utilities is increasing day after day. This allows enhancing the simulation capabilities, including the possibility to recreate complete digital models of the power network. However, the RTSs must ensure a high level of accuracy for their results to be reliable enough for the final users. This aspect is not always considered and sufficiently treated. The article has the aim of emphasizing and supporting, with rigorous experimental activity, the lack of methodology found in the literature.

A virtual PMU is then characterized by testing it like a physical PMU, hence by using the same tests defined in the dedicated standard. Furthermore, to complete the discussion, the complete characterization process of a PMU calibrator is described. The main result of the virtual PMU characterization is not the index remaining within or exceeding the limits. The main result is the experimental proof that the preliminary characterization of the virtual PMU is mandatory when an RTS environment must be used for simulating power networks. Such a result is confirmed by all the performed tests, and its importance can be extended to all activities involving an RTS, not necessarily correlated to power networks or electrical engineering in general.

DOs & DON'TS

- Do not displace monitor, keyboard, mouse etc.
- Do not use personal pen drives without permission.
- Students should not attempt to repair, open, tamper or interfere with any of the computer, cabling, or other equipment in the laboratory.

Safety Precautions

- Data will be preserved using UPS Backup.
- Equipped with Fire Extinguishers.
- Students and Faculty are instructed to follow Safety Instructions Chart in the Laboratories.
- Before inserting USB Stick, the Pen drives have to be scanned for any malicious content.
- The Lab is under CC Camera surveillance.
- Keep all the Computers Updated with antivirus software.
- Make Sure the Firewalls are enabled on each and every Computer.
- Miniature Circuit Breaker's (MCB's).
- Students inserting USB Stick have to be scanned for any malicious content.
- Students should not attempt to repair, open, tamper or interfere with any of the computer, cabling, or other equipment in the laboratory.
- Do not displace monitor, keyboard, mouse etc.
- Do not use personal pen drives without permission.



Fire Extinguishers



First Aid Box



Miniature Circuit Breaker's (MCB's).



CC Camera surveillance

Table 6.4.2 Safety Measures in the Laboratories

THANK YOU

