PAPER • OPEN ACCESS

Real-Time-Simulation of IEEE-5-Bus Network on OPAL-RT-OP4510 Simulator

To cite this article: Anjali Atul Bhandakkar and Lini Mathew Dr. 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **331** 012028

View the article online for updates and enhancements.

Related content

- Wearable Sensors: Medical IoT systems: architecture and security
  S C Mukhopadhyay and T Islam

- Modelling transport in single electron transistor
  Dinh Sy Hien, Huynh Lam Thu Thao and Le Hoang Minh

- Control Design for a Motion Cueing on Driving Simulator
  Jorge de-J. Lozoya-Santos, Juan C. Tudon-Martinez and Julio Salinas

IOP ebooks™

Bringing you innovative digital publishing with leading voices to create your essential collection of books in STEM research.

Start exploring the collection - download the first chapter of every title for free.

Real-Time-Simulation of IEEE-5-Bus Network on OPAL-RT-OP4510 Simulator

Anjali Atul Bhandakkar[1], and Dr. Lini Mathew[2]

[1] PhD. Scholar, Electrical Engineering Department, NITTTR, Chandigarh, India.

[2] Associate Prof., Electrical Engineering Department, NITTTR, Chandigarh, India.

bhandakkar13@gmail.com, lenimathew@yahoo.com

Abstract: The Real-Time Simulator tools have high computing technologies, improved performance. They are widely used for design and improvement of electrical systems. The advancement of the software tools like MATLAB/SIMULINK with its Real-Time Workshop (RTW) and Real-Time Windows Target (RTWT), real-time simulators are used extensively in many engineering fields, such as industry, education, and research institutions. OPAL-RT-OP4510 is a Real-Time Simulator which is used in both industry and academia. In this paper, the real-time simulation of IEEE-5-Bus network is carried out by means of OPAL-RT-OP4510 with CRO and other hardware. The performance of the network is observed with the introduction of fault at various locations. The waveforms of voltage, current, active and reactive power are observed in the MATLAB simulation environment and on the CRO. Also, Load Flow Analysis (LFA) of IEEE-5-Bus network is computed using MATLAB/Simulink power-gui load flow tool.

1. Introduction

The powerful computer with affordable cost has led to the emergence of highly sophisticated simulation software applications that enable simulation of dynamic systems and related controls, and also automatic code generation for implementation in industrial controllers [1]. OPAL-RT-OP4510 is a Real-Time (RT) simulator with 4 cores. RT-LAB system is one of the features of the OPAL-RT-OP4510 Simulator. It has basically two parts. One is host computer and another is RT simulator. Host computer edits Simulink model compiles with RT-LAB and gives user interface. The RT simulator does the real-time model execution. It has REDHAT as an operating system and provides telnet communication with the host [2]. If the execution time, for the simulation of the system is shorter or equal to the selected time step, the simulation is considered to be real-time. If it is greater than its time step size for one or more time-steps, overruns occur and the simulation is considered as non-real-time or offline. In the latter case, either the time-step can be increased or the system model can be simplified to run it in real time. [3].

Power-flow studies are of great importance in planning and designing the future expansion of power systems as well as in determining the best operation of existing systems [4]. Some of the computational tools available for conducting the LFA for a power system network are Educational Simulation Tool (EST), MatPower, Power Analysis Toolbox (PAT), SimPowerSystems (SPS), MatEMTP, and Voltage Stability Toolbox (VST) [5]. Traditionally LFA is computed by means of

methods such as Gauss-Siedal Method, Newton-Raphson Method (NRM), Decoupled Method and Fast Decoupled Method. Among these methods, NRM is very popular due to its fast convergence with a less number of iterations and due to this characteristics, it has proved most successful in large power flow studies [6]. MATLAB/Simulink uses NRM by default for load flow computation.

The contents of this paper are, Section II details the IEEE-5-Bus network its data sheet and parameter calculation for Simulink model. Section III gives a procedure for development of a MATLAB / Simulink model compatible to OPAL-RT-OP4510, and LFA using power-gui. Section IV gives results and discussion and Section V gives the conclusions.

2. IEEE-5-Bus Network

The single line diagram of IEEE-5-Bus network is shown in Fig.1. The transmission line parameters, generation, and loads are given in per unit value. The network details are:
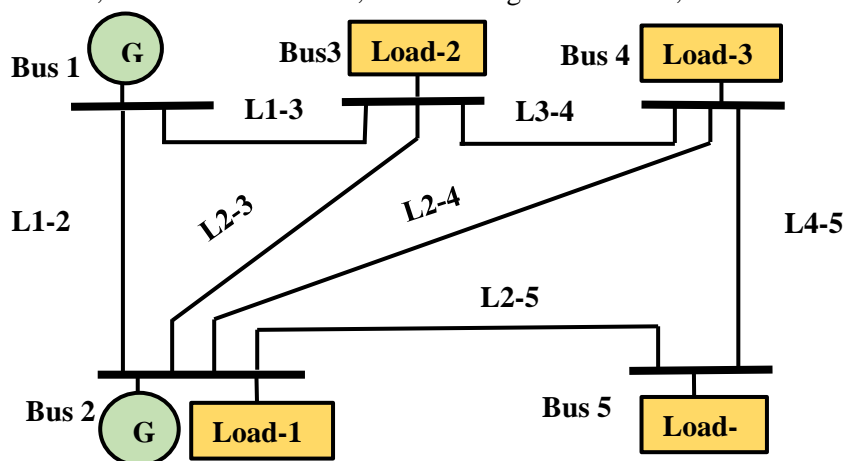Number of lines = 7, Number of buses = 5, Number of generators = 2, and Number of loads = 4.

Fig.1. IEEE-5-Bus Network

Transmission line parameters of IEEE-5-Bus are given in per unit value in Table 1.

Table 1. Transmission line parameters of IEEE-5-Bus in per unit value.

From Bus	To Bus	Transmission line Resistance	Transmission line Reactance	Transmission line Conductance	Transmission line Susceptance
1	2	0.02	0.06	0	0.06
1	3	0.08	0.24	0	0.05
2	3	0.06	0.18	0	0.04
2	4	0.06	0.18	0	0.04
2	5	0.04	0.12	0	0.03
3	4	0.01	0.03	0	0.02
4	5	0.08	0.24	0	0.05

By selecting a (suitable) base MVA of 100 MVA (S_b) and base kV of 230 kV (V_b) and using basic per unit concepts of impedance calculation, the values of positive sequence and zero sequence resistance, inductance, capacitance, and transmission line length are calculated and tabulated in Table 2. Length calculation of the transmission line between bus-1 to bus-2 is as follows.

- R=0.02 , X=0.06 , B=0.06 (as per given data-sheet)Length of transmission line $= \left(\frac{\sqrt{X}*\sqrt{B}}{2\pi f}\right) *$

  $(Velocity\ of\ LIGHT\ in\ km/sec)$

- Length of transmission line =47 km

Table 2. Actual values of positive sequence and zero sequence parameters of the transmission line.

Bus	Length of Trans. Line km	Positive Seq. R (Ω/km)	Zero Seq. R (Ω/km)	Positive Seq. L (H/km)	Zero Seq. L (H/km)	Positive Seq. C (F/km)	Zero Seq. C (F/km)
1-2	47	0.22	0.66	0.0017	0.0052	6.3×10^{-9}	1.89×10^{-8}
1-3	87	0.48	1.45	0.0038	0.0115	2.87×10^{-9}	8.62×10^{-9}
2-3	67	0.46	1.40	0.0037	0.0112	2.97×10^{-9}	8.91×10^{-9}
2-4	67	0.46	1.40	0.0037	0.0112	2.97×10^{-9}	8.91×10^{-9}
2-5	47	0.44	1.32	0.0035	0.0105	3.15×10^{-9}	9.45×10^{-9}
3-4	19	0.27	0.813	0.0021	0.0064	5.14×10^{-9}	1.54×10^{-9}
4-5	87	0.48	1.455	0.0038	0.0115	2.87×10^{-9}	8.62×10^{-9}

Table 3 shows Generation-Load at the bus in per unit values as per the data –sheet. The actual values generation, load are tabulated in Table 4. Also the initial values of nodal bus voltages, their phase angles are given in Table 5. Actual values of voltage are to be used in the MATLAB/Simulink model. Load Flow Bus is to be connected to the buses where voltage and angle are required to be computed by load flow tool in the Simulink model.

Table 3. Generation, load at the bus in per unit values

Bus	P_G	Q_G	Q-Max	Q-Min	P_L	Q_L
1	0	0	5	5	0	0
2	0.4	0	3	-3	0.2	0.1
3	0	0	0	0	0.45	0.15
4	0	0	0	0	0.4	0.05
5	0	0	0	0	0.6	0.1

Table 4. Actual values of generation, load at the bus

Bus	P_G (W)	Q_G (VAR)	Q-Max (VAR)	Q-Min (VAR)	P_L (W)	Q_L (VAR)
1	0	0	500×10^6	500×10^6	0	0
2	40×10^6	0	300×10^6	-300×10^6	20×10^6	10×10^6
3	0	0	0	0	45×10^6	15×10^6
4	0	0	0	0	40×10^6	5×10^6
5	0	0	0	0	60×10^6	10×10^6

Table 5. Bus-type, initial voltage, and angle at the IEEE-5-bus network

Bus No.	1	2	3	4	5
Bus Type	Slack	PV	PQ	PQ	PQ
Initial V-magnitude	1.06	1	1	1	1
Initial V-angle	0	0	0	0	0

3. Matlab / Simulink Model Compatible In OPAL-RT-OP4510

The IEEE-5-Bus network has been developed in MATLAB/Simulink environment using the calculated values of transmission line parameters, generation, and load at the respective bus, initial values of voltage, angle and bus type. Real-time simulation of the electric power system is the reproduction of output (voltage/currents) waveforms, with the desired accuracy, and these V/ I wave forms are representative of the behavior of the real power system being modeled. To achieve such a goal, a real-time simulator needs to solve the model equations for one time-step, within the same time as in a real-world clock. Therefore, it produces outputs at discrete time intervals, where the system states are computed at certain discrete times using a fixed time-step [3].

The IEEE-5-Bus network with, breakers, faults are connected in the master subsystem. The control over the variation in breaker position, type of fault is kept in console subsystem. As the network is not too big, it does not require slave subsystem. The block-diagram of subsystems of OPAL-RT-OP4510 with their functionalities are shown in Fig.2.
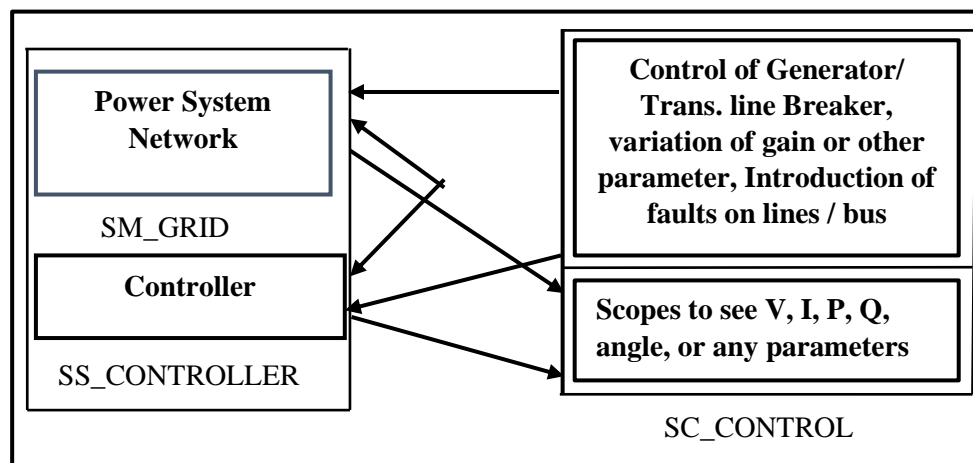
Fig. 2. Functionality of OPAL-RT-OP4510

The master subsystem SM_NET and console subsystem SC_SCOPE connected in top-level OPAL-RT model are shown in Fig.3.
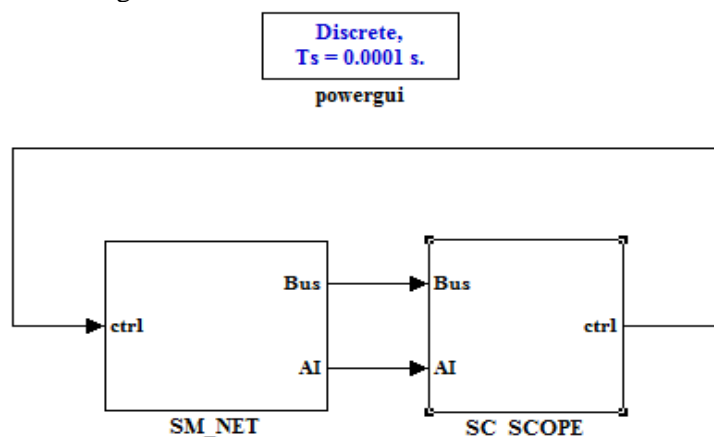
Fig. 3 Top Level Model of OPAL-RT

The details of master subsystem SM_NET are shown in Fig.4. The console subsystem SC_SCOPE and the breaker control system are shown in Fig. 5(a) and Fig. 5(b).
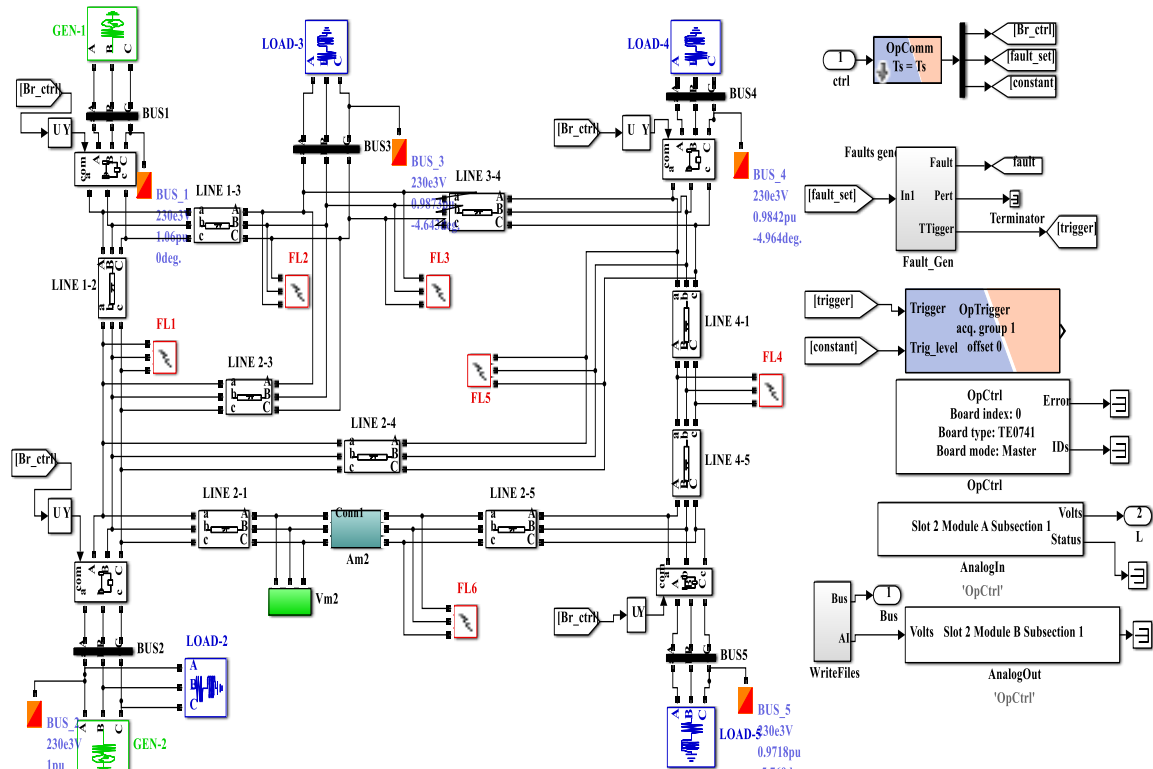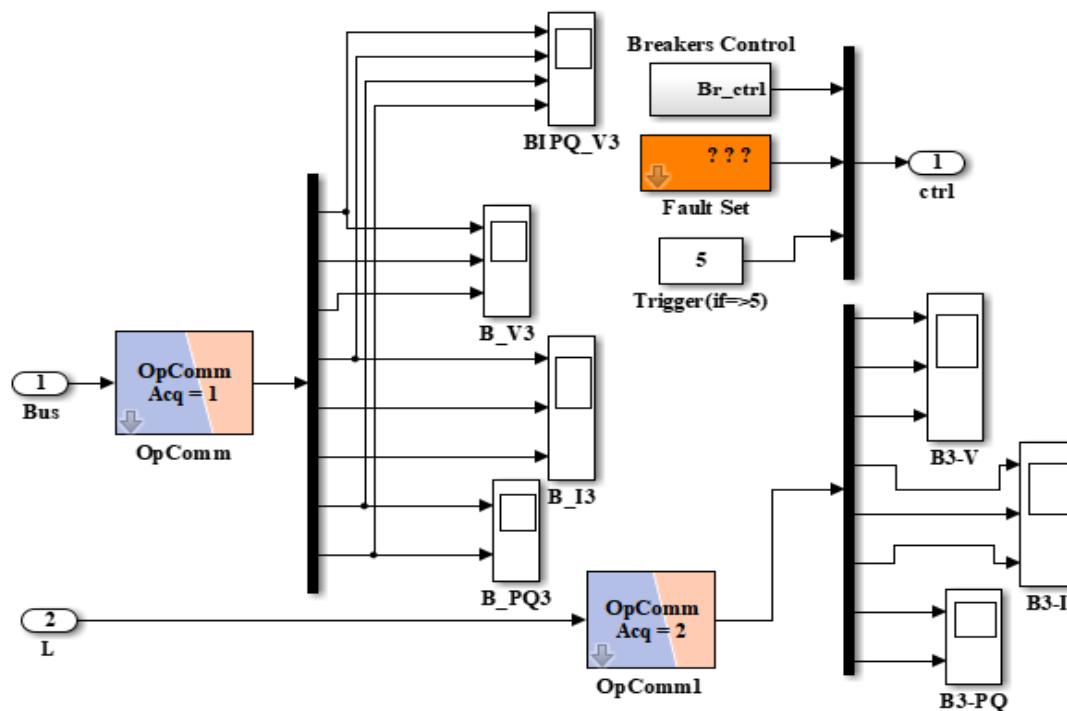

Fig. 4 Master Subsystem, SM_NET

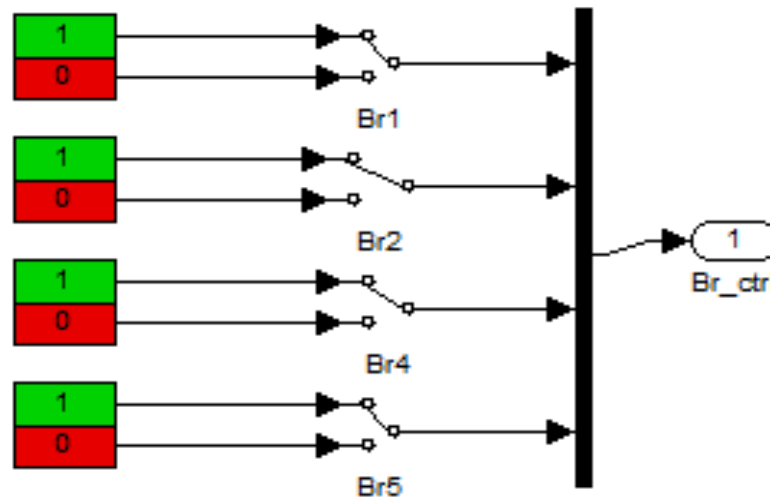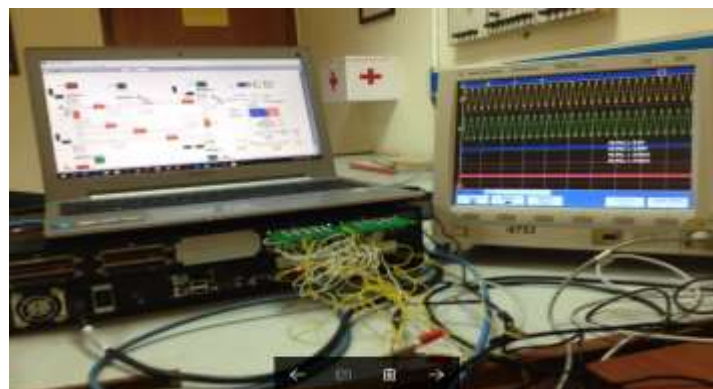**Fig. 5 (a) Console Subsystem SC_SCOPE**

Fig. 5 (b) Breaker Control Subsystem

The photograph of the OPAL-RT-OP4510 Simulator, the outport connector and the whole hardware setup with the laptop (host computer) and CRO are shown in Fig. 6.

(b)

(a)

(c)

Fig. 6 Photograph showing (a) OPAL-RT-OP4510 Simulator, (b) I/O connectors, (c) laptop (host computer) and CRO

The Simulink model in real time with the OPAL-RT environment has been built and executed employing the OPAL-RT-OP4510 Simulator. The signals such as voltage, current, active power, reactive power have been observed on CRO

4. Results and Discussion

Results of LFA computed by power-gui and V, I, P, Q waveforms obtained during Real-Time simulation are discussed separately parts in this section.

4.1 LFA of IEEE-5-Bus network

It is computed using power-gui (off-line) Load Flow Tool. The generated report shows that LFA converged in 2 iterations. The Load Flow Bus is required to be connected where ever voltage and angle is to be computed. After performing LF, the magnitude of voltage in per unit and its angle is displayed by the load flow-bus. The significant parameters of LFA obtained from power-gui-Load Flow tab are given in Table 6.

Table 6. Significant Parameters of LFA

Bus	Bus Type	Voltage (pu)	Angle in degree	P (MW)	Q (MVAR)
1	Slack	1.06	0.00	131.43	90.89
2	PQ	1.00	-2.07	20.00	10.00
2	PV	1.00	-2.07	40.00	-61.64
3	PQ	0.99	-4.64	45.00	15.00
4	PQ	0.98	-4.96	40.00	5.00
5	PQ	0.97	-5.77	60.00	10.00

4.2 Real-time-Simulation

Using the outport device, the signals such as voltage (V), current (I), active power (P), reactive power (Q) are taken out from OPAL-RT- OP4510 Simulator. To view them on CRO, gains of appropriate values are used to scale down the magnitudes. The voltage signal has the magnitude of 230 kV, the current has the magnitude of 220 A, active power has 60 MW and reactive power has 10 MVAR, (as per LFA). The gain for voltage signal used in the model is of $1/10^4$, the current signal is 1/100, active and reactive power is of $1/10^7$. The channel-1indicates voltage, channel- 2 current, channel-3 active power, channel-4 reactive power signals.

These signals are fed back to MATLAB environment through import device and observed in the console subsystem. It is found that the magnitudes of signals on CRO and in MATLAB environment are equal. Fig. 7 shows the waveforms of V, I, P, Q, on CRO as well as in the MATLAB environment in the console subsystem during a healthy condition of the network.
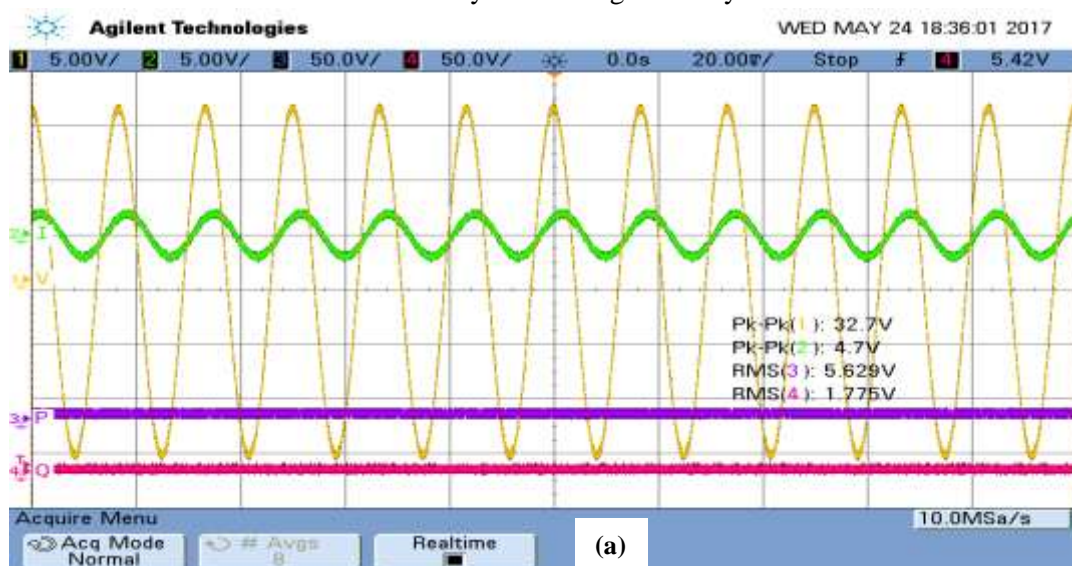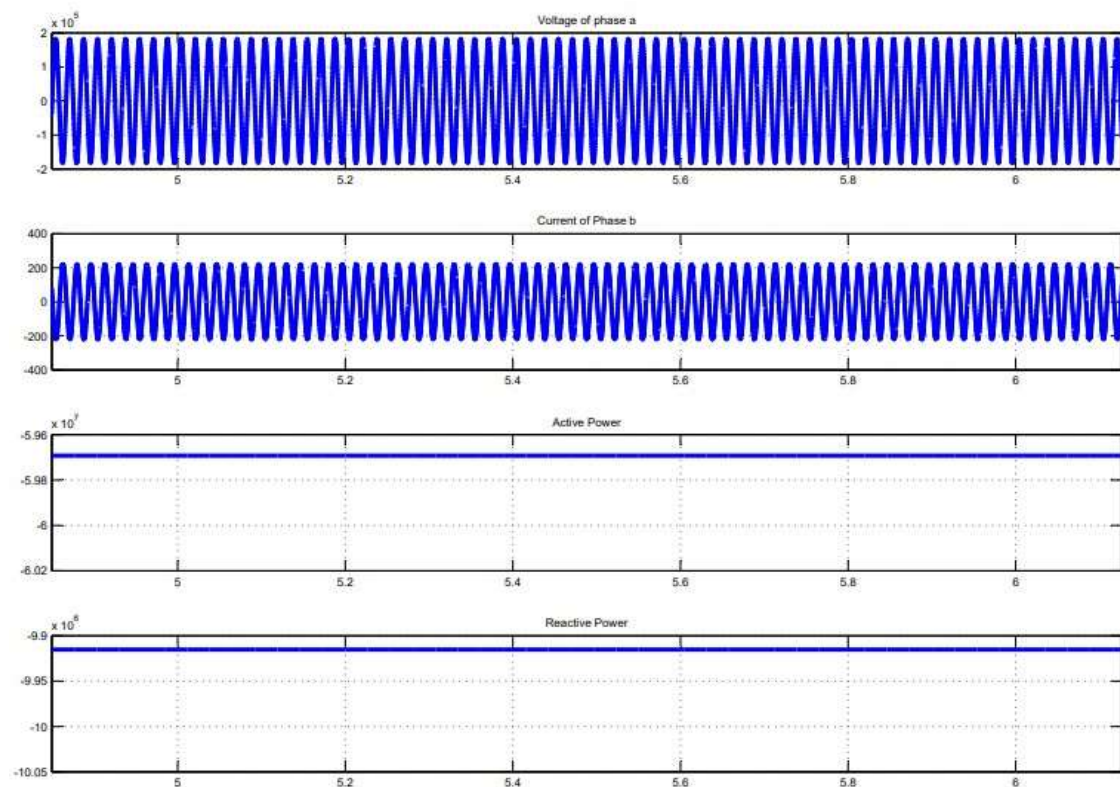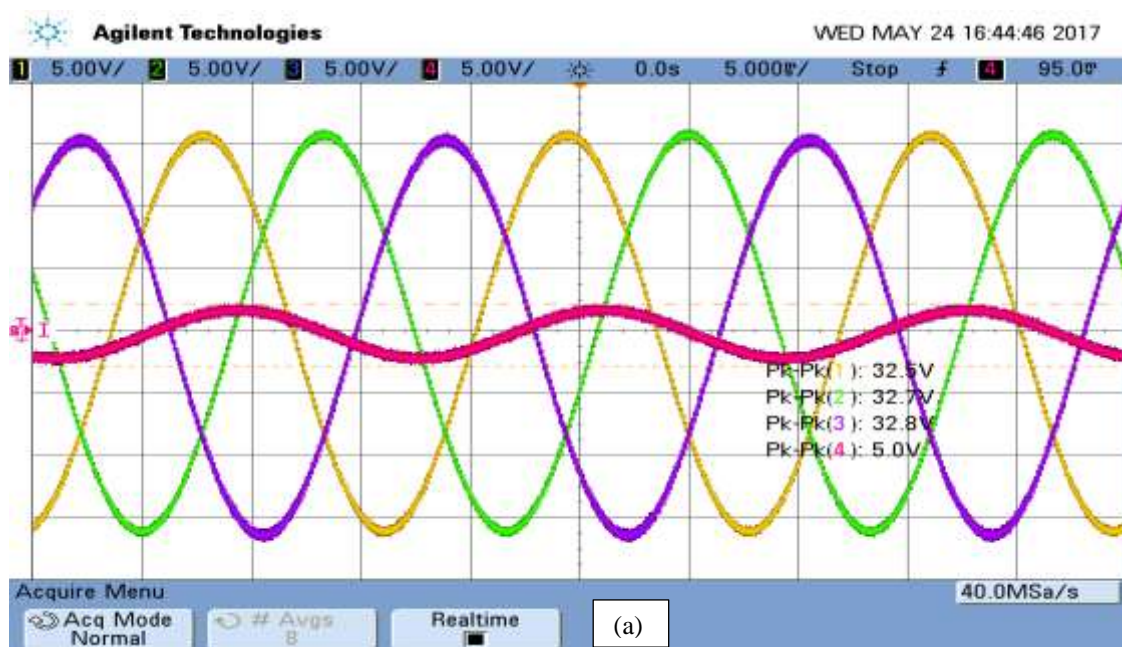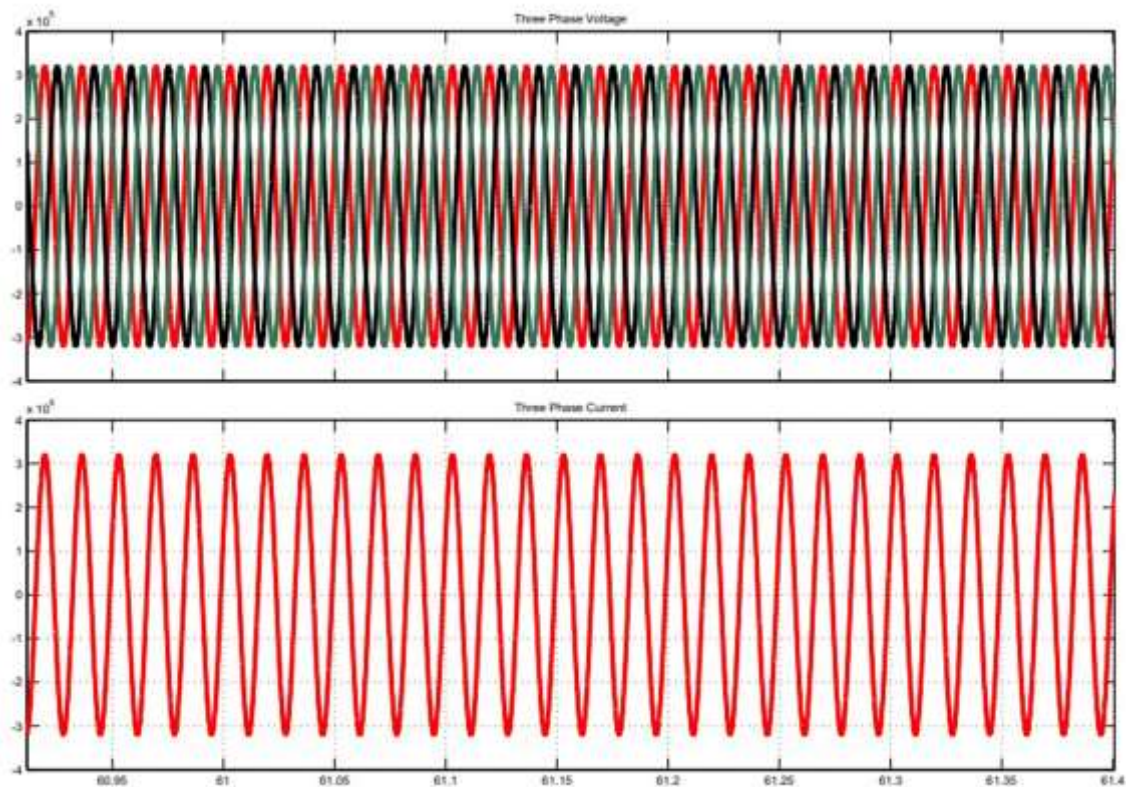
(b)

Fig. 7 Wave forms of V, I, P, Q during Healthy Condition (a) on CRO and (b) on host computer (console)

Fig .8 shows three phase voltages and current of phase-a on CRO which has nearly same value as that of seen in MATLAB environment during healthy condition.


(a)

(b)

Fig. 8 Wave forms of Three Phase Voltage and Current during Healthy Condition (a) on CRO and (b) on host computer (console)

The investigator has introduced two types of faults such as (i) L-G, (ii) LLLG into the system and the performance of the IEEE-5-Bus network is analyzed. Fig. 9 shows waveforms of V, I during L-G fault on phase-a, on CRO as well as in the MATLAB environment in the console subsystem

The Fig.9 clearly indicates that during LG fault on phase a, voltage of phase a falls to nearly 300 V and current rises up to 4000 A then becomes 3000 A. The fault start time, its duration of persistence, and its interval of repetition can be varied from the console.
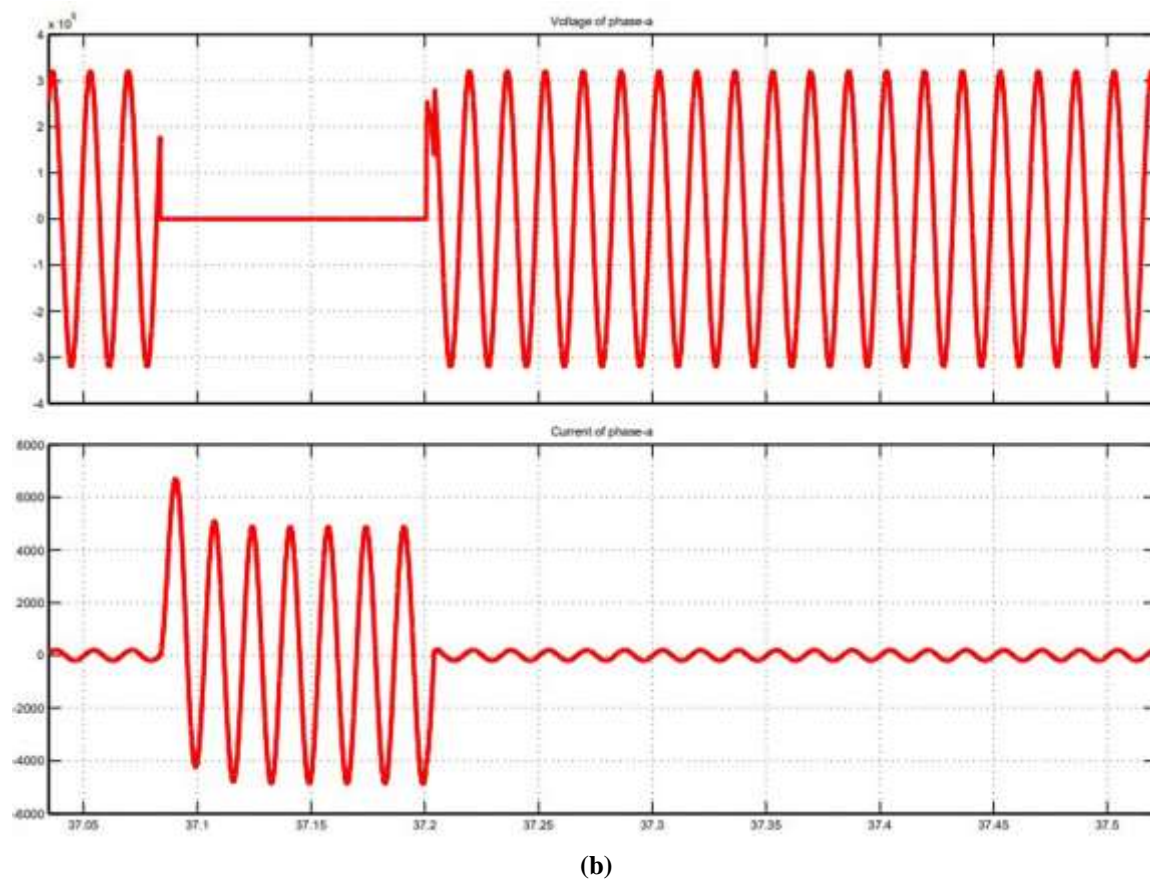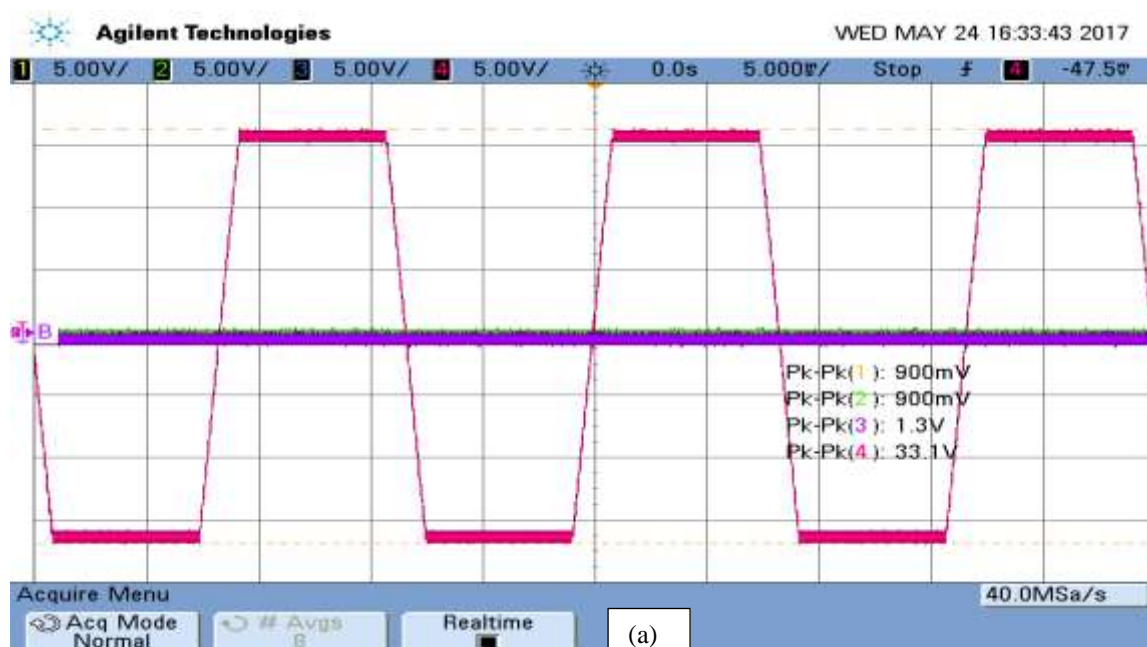
(b)
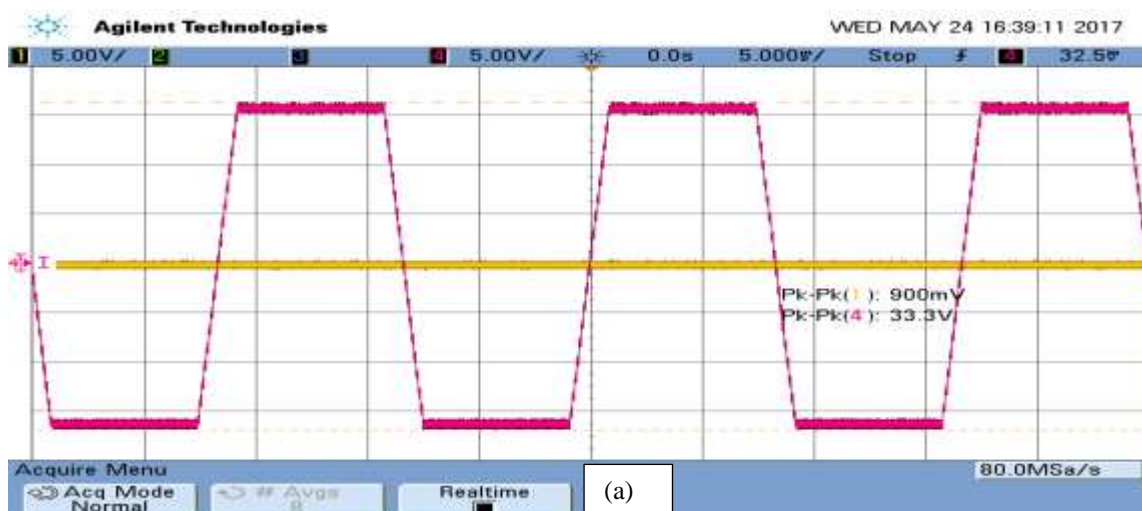
Fig. 9 Wave forms of V, I during L-G fault on phase-a (a) on CRO and (b) on host computer (console)

Fig.10 shows waveforms of three-phase voltages and three phase currents during LLLG fault on transmission line 1-5. The magnitude of three voltage reduces nearly to zero and current rises to 7000 A then reduces to 5000 A. The same waveforms can also be seen on CRO.
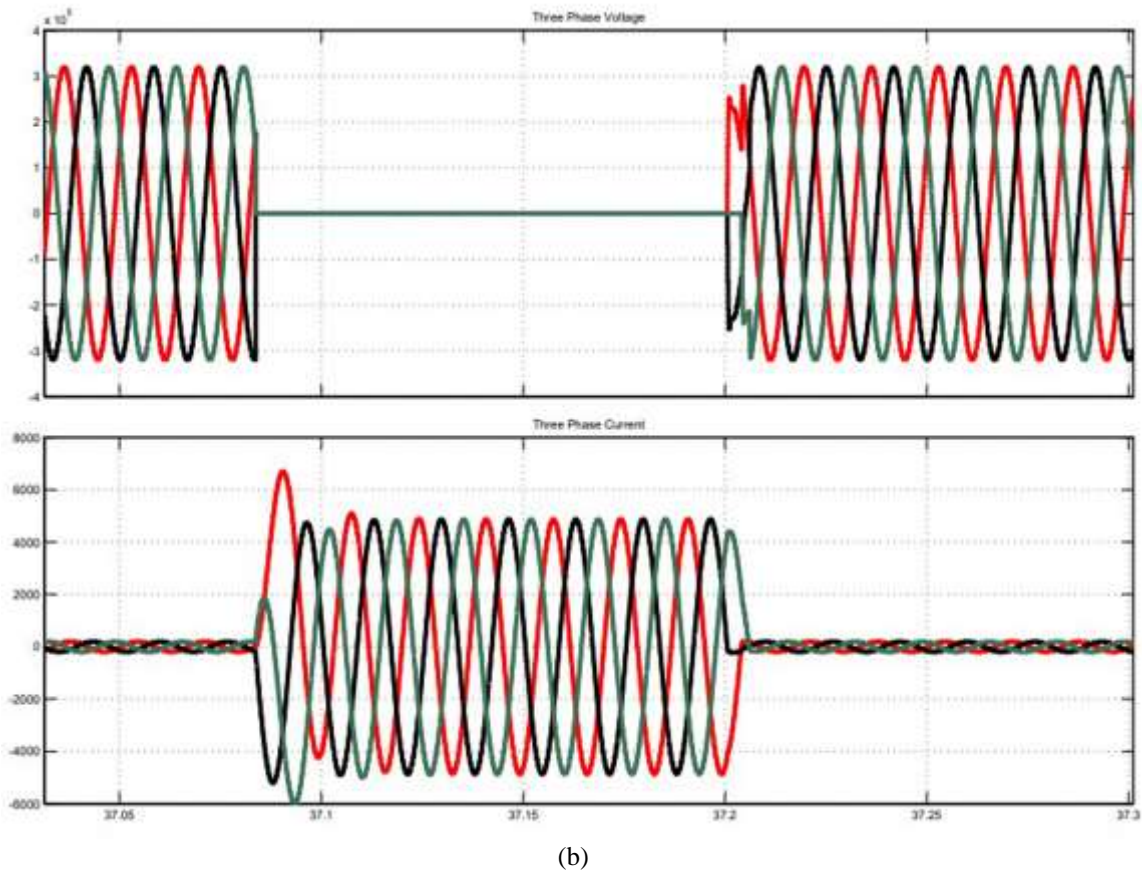
(b)

Fig. 10 Waveforms of V, I during LLLG fault on Line1-5 (a) on CRO and (b) in MATLAB environment

5.   Conclusion

By developing IEEE-5-Bus network model in MATLAB/Simulink and run in OPAL-RT-OP4510 following conclusions are drawn.

   i)   By regrouping the model in the master subsystem and console subsystem, and inserting OPAL-RT blocks, the MATLAB/Simulink model is made compatible to OPAL-RT-OP4510. During a healthy condition of the network, the magnitude of V, I, P, Q saw on CRO, and obtained by LFA are nearly same.

  ii)   During healthy as well as faulty conditions, the magnitude of the signals in MATLAB environment is similar to that seen on CRO.

 iii)   Interactions with plant, controller and protection systems, can be easily analyzed and tested during normal and a variety of fault conditions.

  iv)   The main idea using real-time control is to smoothen the transition from the non-real analysis and simulation to the real-time experiments and implementation. It has applications in large power system network, power electronics, automotive and aerospace. Thus OPAL-RT helps projects to move from imagination to real-time.

   v)   The future scope is the inclusion of FACTS devices in the network for improvement voltage profiles, and network stability, and load flow analysis of the system with it.

ACKNOWLEDGMENT

References:

[1]   P. M. Menghal and A. J. Laxmi, "Real-time simulation: Recent progress & challenges," *2012* International   Conference on Power, Signals, Controls and Computation*, Thrissur, Kerala, 2012,* pp. 1-6.

[2]   OPAL-RT-OP4510 User Manual and RT-LAB Block Library Reference Guide.

[3]   M. D. Omar Faruque *et al*., "Real-Time Simulation Technologies for Power Systems Design, Testing, and Analysis," in *IEEE Power and Energy Technology Systems Journal*, vol. 2, no. 2, pp. 63-73, June 2015.

[4]   J. J. Grainger, W. D. Stevenson, "Power System Analysis", McGraw-Hill, International Edition,1994.

[5]   R. Anand and V. Balaji, "Power Flow Analysis of Simulink IEEE 57 Bus Test System Model using   PSAT", Indian Journal of Science and Technology, Vol 8(23), September 2015

[6]   E. Acha, C. R. F.Esquivel, H. A. Perez, C.A. Comacho, "FACTS: Modelling and Simulation in Power network", First. edition, England: John Wiley & Sons, 2004.