COMPARISON OF DIFFERENT SOFTWARE PACKAGES IN POWER FLOW AND SHORT-CIRCUIT SIMULATION STUDIES

A Project

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in

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by

Rubina Shaikh

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Rubina Shaikh

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Dr. Preetham Kumar Date

Department of Electrical and Electronic Engineering

Abstract

of

COMPARISON OF DIFFERENT SOFTWARE PACKAGES IN POWER FLOW AND SHORT-CIRCUIT SIMULATION STUDIES

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Statement of Problem

The purpose of this project is to conduct “power flow” and “short-circuit” simulations using three software packages. The first software is “ETAP” [1], which is a commercial-grade package provided to the Electrical and Electronic Engineering Department at no cost for up to 25 nodes. The second software is “PSLF” [2], which is also a commercial-grade package for power transmission system planning, and the third package is “RadiRing” [3], which has been developed at Sacramento State for the use of students and faculty with no restrictions in the number of buses. Since in general obtaining commercial-grade packages with no restriction in the physical size requires substantial costs associated with licensing and service agreements, *it is desirable to determine if the performance and accuracy of the software package developed at house (such as “RadiRing”) are acceptable for use by the students and faculty for educational and research activities.* As a result, this project aims at comparison of the results of two basic

power system analyses, named as “power flow” and “short-circuit” calculations using transmission and distribution benchmark systems. As known, power flow and short circuit studies are two key types of analyzes to determine system’s proper operation and to ensure that transmission and distribution equipment meet the present and future design requirements.

Sources of Data

- IEEE 14 Bus System for Transmission Network [4]
- IEEE 13 Bus System for Distribution Network [5]
- Using ETAP [1], PSLF [2] and RadiRing [3] to conduct “power flow”, and ETAP and RadiRing to conduct “short-circuit” simulations of the test systems. (Note: PSLF was not used for “short-circuit” simulations due to lack of license for short-circuit)

Conclusions Reached

The modeling and simulation for power flow study using RadiRing, ETAP and PSLF has been conducted and analyzed. The power flow study indicates that there is no difference in voltage magnitude and voltage angle results obtained from all three software packages using similar accuracy thresholds.

The modeling and simulation for short circuit studies using RadiRing and ETAP indicate that the results are very close in RadiRing's transient mode analysis compared to ETAP's 30 cycle mode (known as Min short-circuit current). The difference in results between the two software packages is due to the difference in the modeling of system impedances under faulted conditions. Hence, it can be concluded that "RadiRing" can achieve acceptable performance and accuracy in comparison to ETAP and PSLF for educational and research activities.

_______________________, Committee Chair
Mahyar Zarghami

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Date

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CHAPTER 1

INTRODUCTION

This project analyzes an IEEE 14-bus system [4] for transmission network and an IEEE 13-node system [5] for distribution network, and compares the results of “power flow” and “short-circuit” calculations using different software packages including ETAP [1], PSLF [2] and RadiRing [3].

The **power flow** study analyzes the flow of power from sources through the power network to its consumers [6]. The study provides network voltage profile, and real and reactive power flows of the network under steady state conditions. Calculation of the voltage magnitudes is essential to determine if the voltage profile of the system is within specified limits. Similarly, finding active and reactive power flows through system lines and transformers is important to see whether these flows are within acceptable values. “A **short circuit** is an accidental electrical contact between two or more conductors” [7], commonly prevented by using circuit breakers and fuses to isolate faults. The short circuit study is the analysis to establish the currents and voltages for a network that experienced a fault condition [7]. The short circuit study determines the magnitude of the currents during an electrical fault and verifies the existing busbar short circuit ratings to be adequate to withstand the fault current and to select the most suitable protective equipment.

In order to perform the power flow and short circuit studies, single line diagram are drawn and data is entered in corresponding environments to provide the configuration of the systems under analysis. This report presents comparative values of the bus voltages and angles under balanced three- phase steady state conditions, using different software packages including ETAP, PSLF and RadiRing.

CHAPTER 2

SOFTWARE USED FOR STUDY

Licensing and service agreements for commercial-grade software packages with no restriction in the physical size requires substantial upfront costs and annual maintenance fees which makes them difficult to obtain for educational and academic purposes. This study is conducted to determine feasibility and accuracy of the alternative software package, ***"RadiRing"***, which can accomplish necessary functions of performing power flow and short circuit studies for both transmission and distribution networks without incurring a huge cost as the traditional commercial software packages. "RadiRing" has been developed and utilized at California State University, Sacramento, and this study is aimed to determine if the performance and accuracy of the developed package are acceptable for use by students and faculty for educational and research activities. This project will compare values of bus voltages and angles (in the power flow), and short-circuit currents at different system buses (in the short-circuit study). Two systems, IEEE 14-Bus [4] and IEEE 13-Node [5] were simulated.

The following three (3) software packages were used in this project:

a) ETAP

b) PSLF (for power flow study only)

c) RADIRING

a) ETAP

ETAP is a comprehensive enterprise solution for power system analysis and is used for design, simulation, operation, control, optimization, and automation of generation, transmission, distribution, and industrial power systems. ETAP offers multiple solutions including load flow and short circuit analyses. Its user-friendly network topology builder allows including a node-branch or a bus-breaker representation of a utility power system [1].

b) PSLF

The GE Positive Sequence Load Flow (PSLF) software is used for studying power system transmission networks and equipment performance in both steady state and dynamic environments. The software can handle system models of up to 60,000 buses. System modeling is detailed and comprehensive, and all data is accessible at all times. Different features of the package are provided through user interfaces and allow the user to switch smoothly between them [2].

c) RADIRING

The RADIRING software package was developed at Sacramento State for the use of students and faculty with no restrictions in the number of buses for power flow and short circuit analysis of balanced power systems in steady-state [3]. It is a much simpler software to use with fewer data entry points.

CHAPTER 3

ANALYSIS OF THE DATA

Several data points were analyzed in the Power Flow and Short Circuit Studies of the 14-Bus Transmission Network and 13-Node Distribution Networks. Each bus in the system has four major variables:

i) voltage magnitude (V),

ii) voltage angle (δ),

iii) net real power (P), and

iv) net reactive power (Q).

Each bus, during power flow analysis, has two known and two unknown variables from the above list. Buses are classified as one of the following types: [6]

i) Load Buses (P_Q Bus): In this type, real and reactive powers are specified and the bus voltage will be calculated. All buses with no generators are load buses. V and δ are unknown.

ii) Voltage Controlled Buses (P_V Bus): The magnitude of the voltage at the bus is kept constant by adjusting the field current of a synchronous generator. Real power generation for each generator is assigned. Q and δ are unknown

iii) Slack or Swing Bus: It is a special generator bus in which voltage magnitude and phase are assumed to be fixed. P and Q are unknown.

IEEE 14-BUS TRANSMISSION NETWORK

The data given is on 100MVA base. This system includes 14 buses, 5 transformers, 1 compensator, 2 generators, 11 loads and 3 synchronous condensers [4]. Analysis for power flow was performed using ETAP, PSLF and RadiRing, and results were compared.

Figure 1 IEEE 14 BUS: ETAP – One Line Diagram for Power Flow Study:

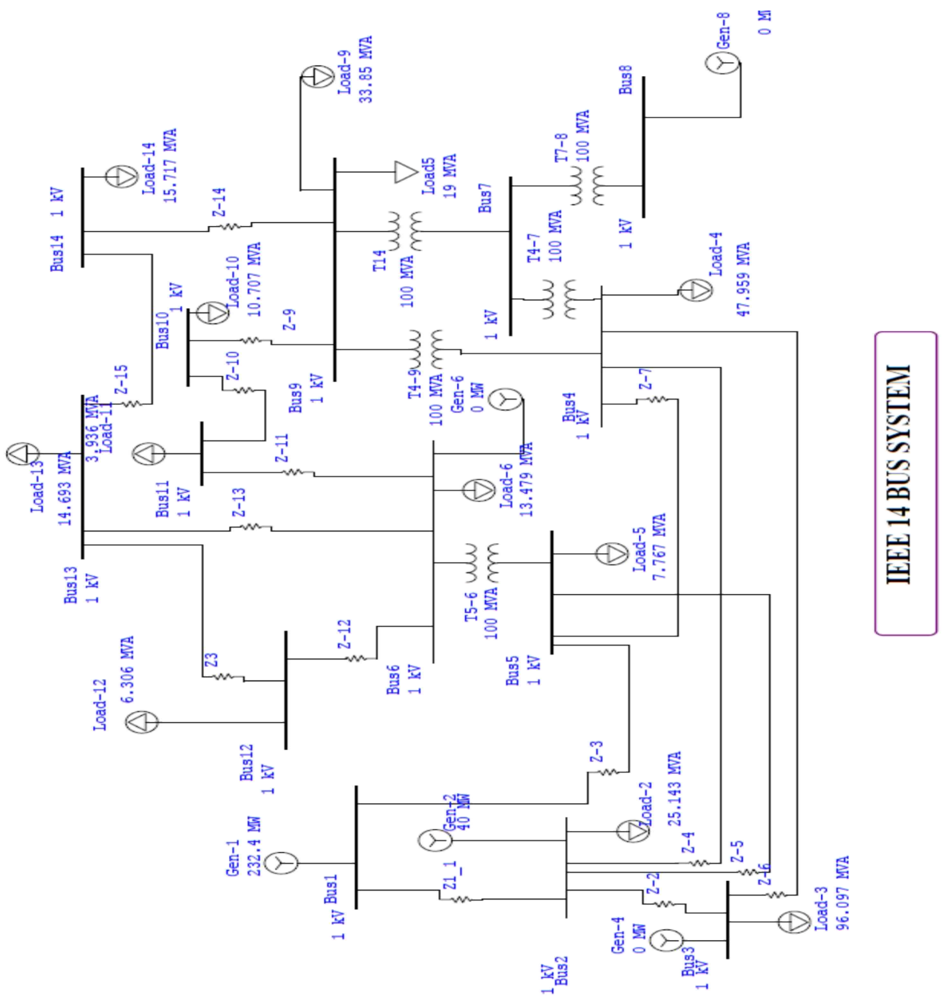


Figure 2 IEEE 14 BUS: PSLF – One Line Diagram for Power Flow Study:

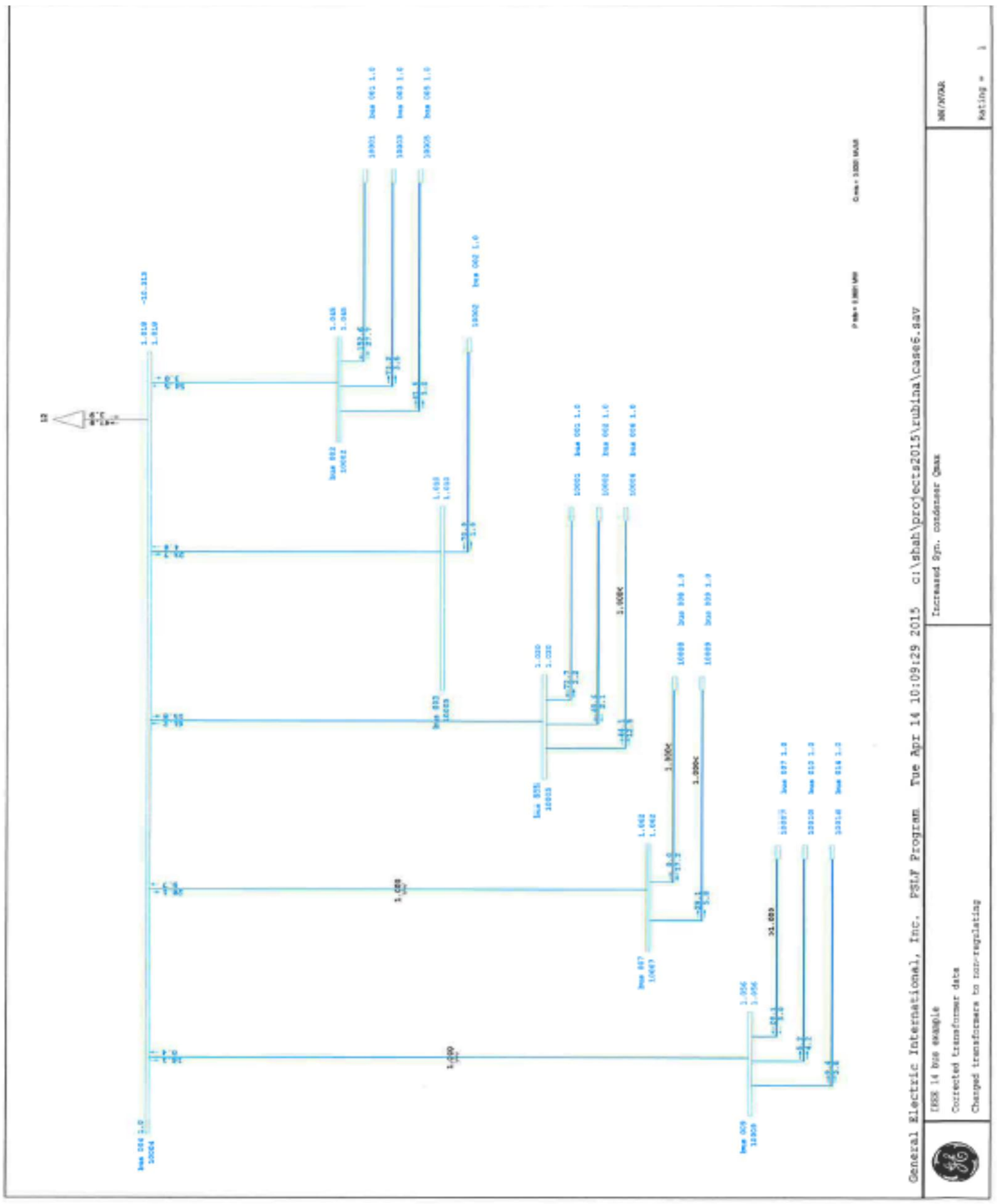
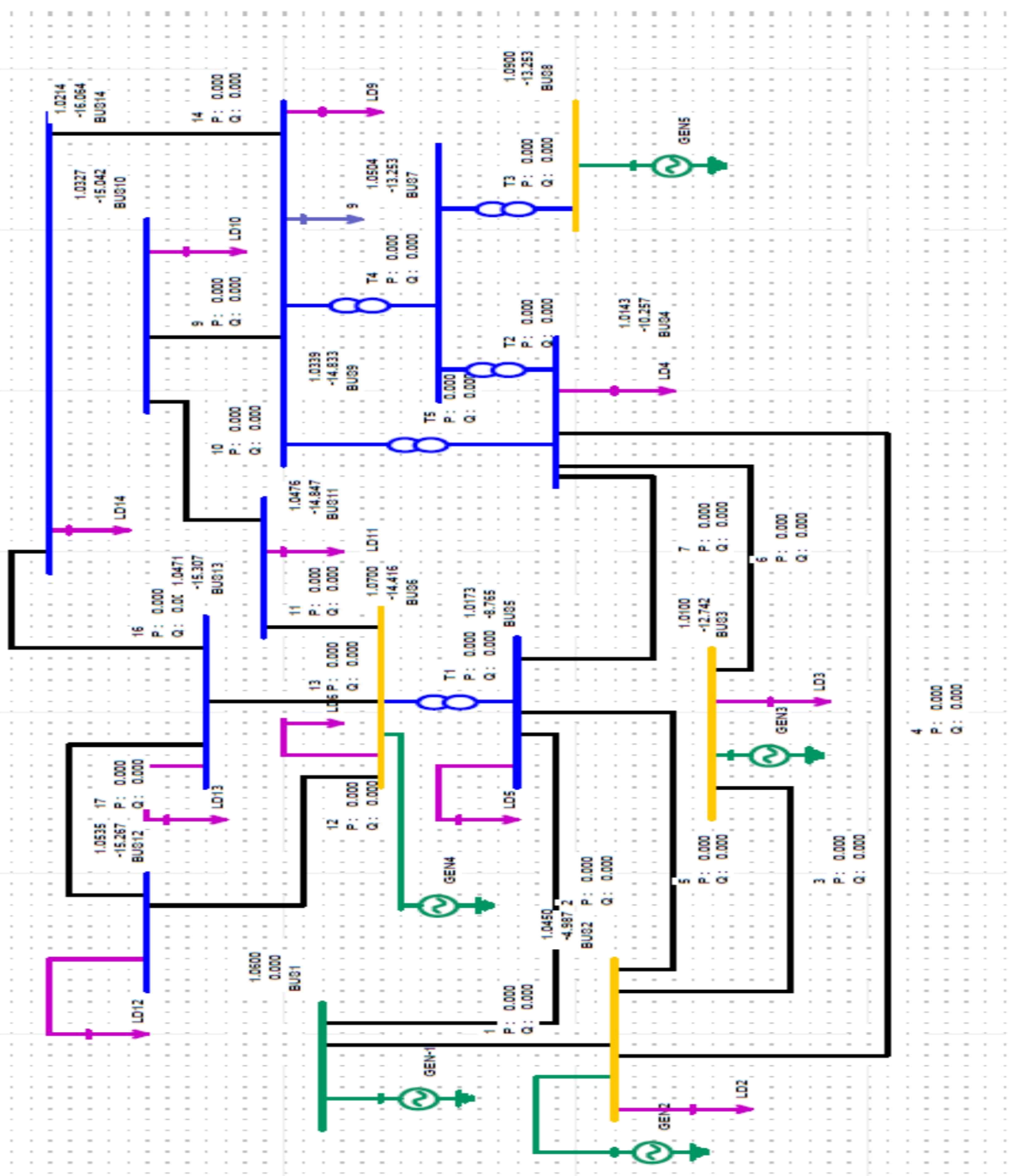


Figure 3 IEEE 14 BUS: RadiRing – One Line Diagram for Power Flow Study:



IEEE 13-NODE DISTRIBUTION NETWORK

This system includes 13 buses, 2 transformers, 1 generator, and 10 loads [5]. Analysis for power flow was performed using ETAP, PSLF and RadiRing, and results were compared. For performing power flow study, impedances and loads were converted into a balanced system using MATLAB. The following equations were used for finding sequence matrices [6].

$$\text{alfa} = \exp\left(\text{j} * 120 * \frac{\text{pi}}{180}\right)$$

$$A = [1\ 1\ 1; 1\ \text{alfa}^2\text{alfa};\ 1\ \text{alfa alfa}^2]$$

$$\text{Z012} = \text{inv(A)} * \text{Z} * \text{A}$$

Figure 4 IEEE 13 NODE: ETAP – One Line Diagram for Power Flow Study:

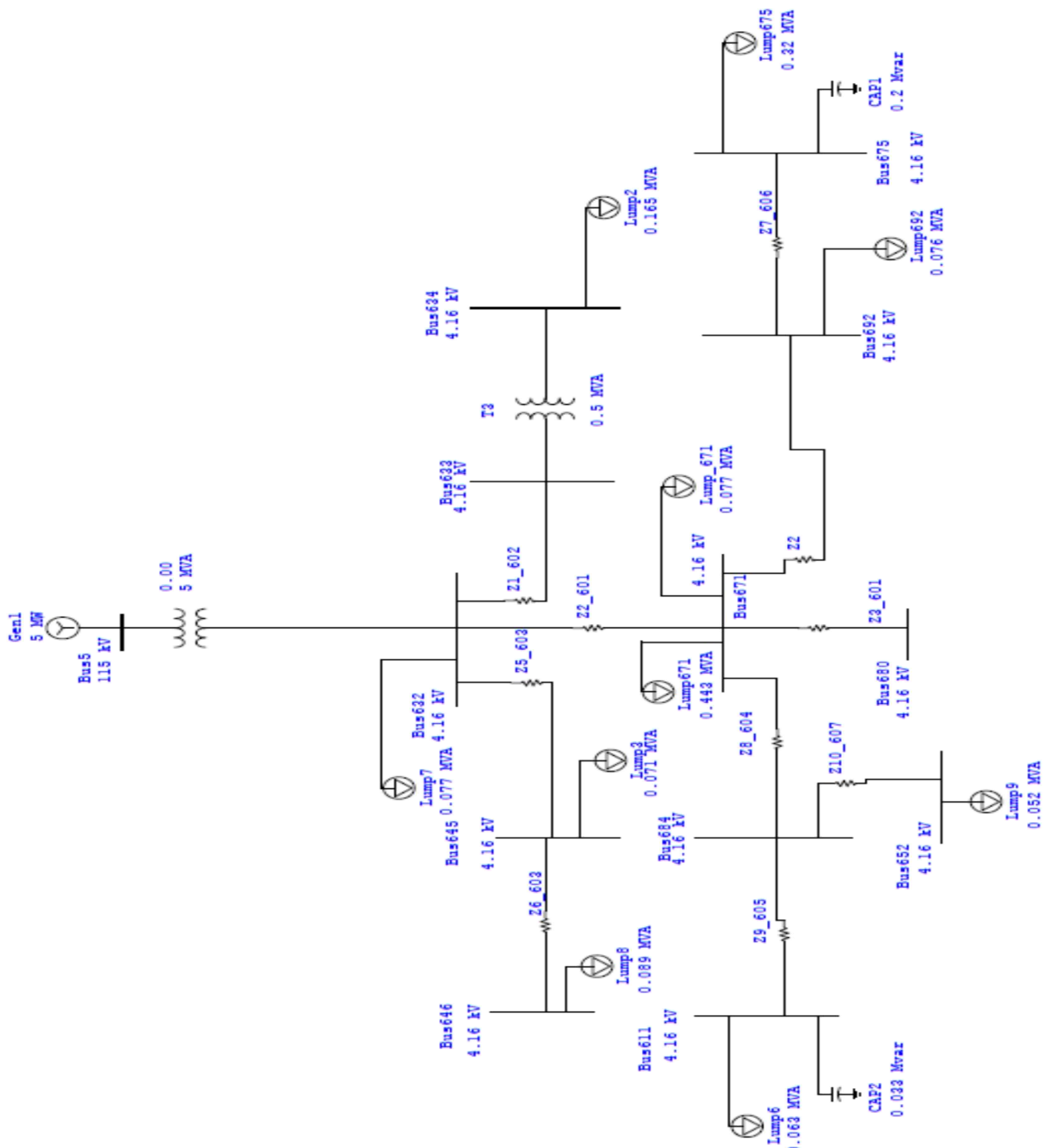


Figure 5 IEEE 13 NODE: PSLF – One Line Diagram for Power Flow Study:

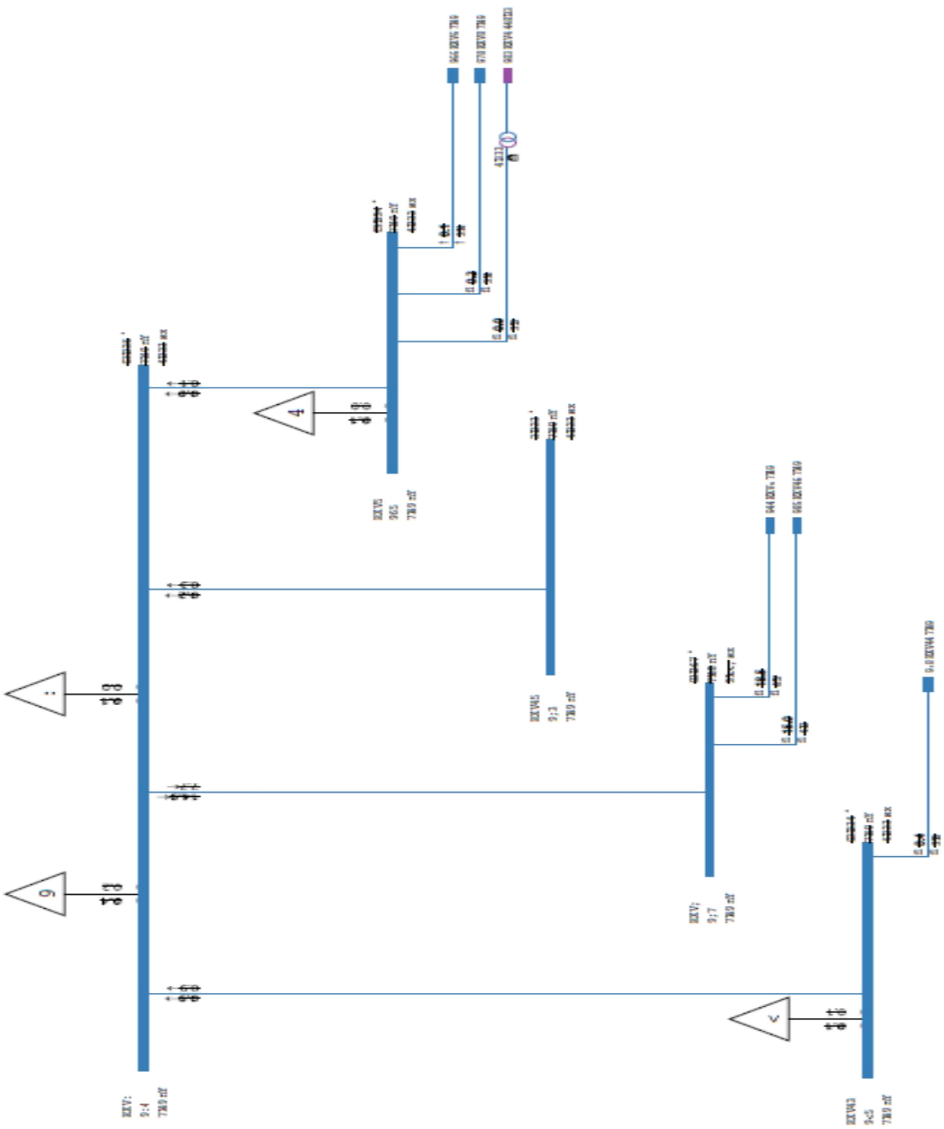
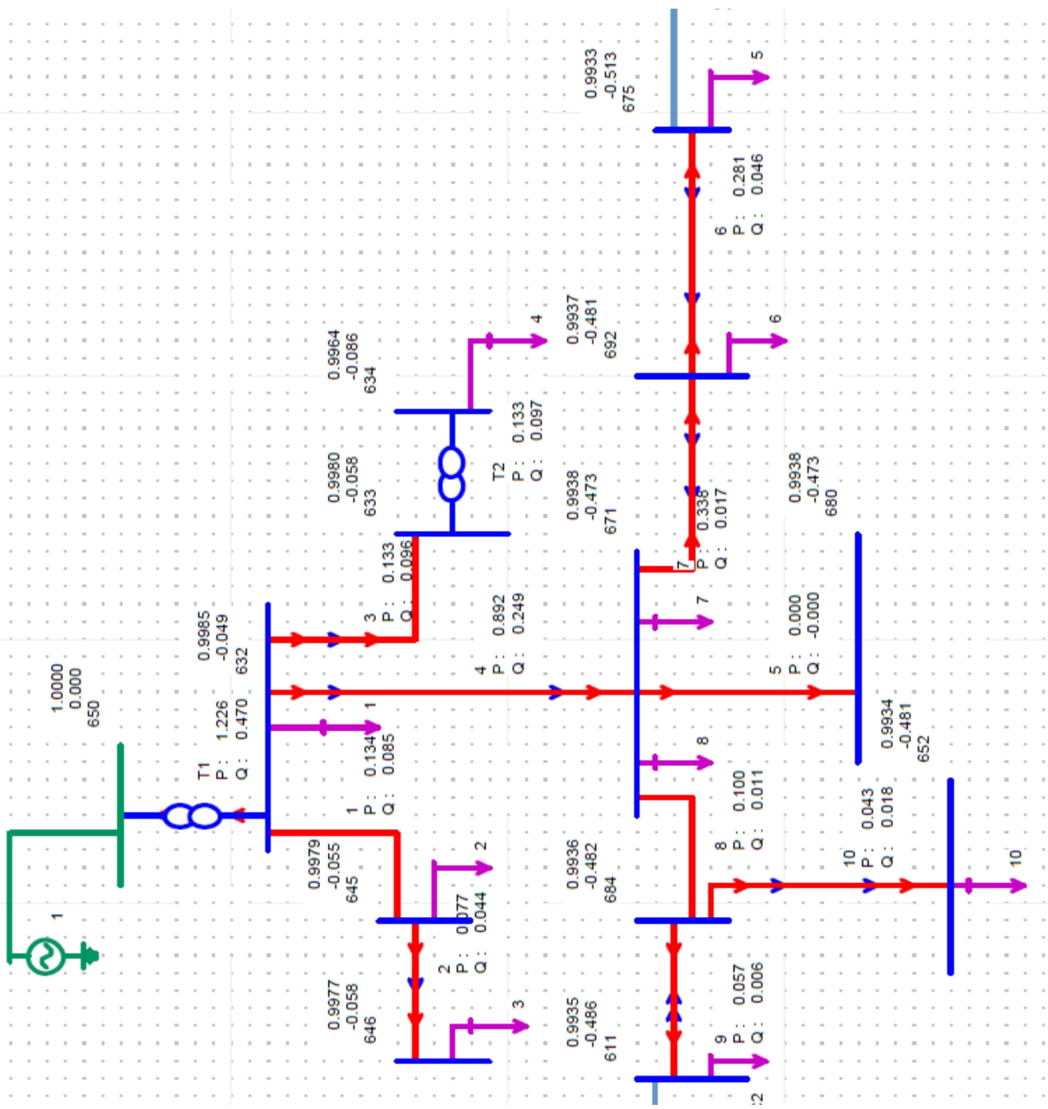


Figure 6 IEEE 13 NODE: RadiRing – One Line Diagram for Power Flow Study:



CHAPTER 4

RESULTS OF POWER FLOW STUDY

IEEE 14-BUS TRANSMISSION NETWORK

TABLE 1 IEEE 14-BUS : POWER FLOW RESULTS FOR VOLTAGE MAGNITUDE (pu) AND ANGLE

COMPARISON BETWEEN PSLF, ETAP and RADIRING

		PSLF	ETAP	RadiRing	PSLF	ETAP	RadiRing
Bus ID	**Vsched**	**V pu**	**V pu**	**Vpu**	**Deg**	**Deg**	**Deg**
Bus 1	1.06	1.06	1.06	1.06	0	0	0
Bus 2	1.045	1.045	1.045	1.045	-4.98	-4.98	-4.98
Bus 3	1.01	1.01	1.01	1.01	-12.73	-12.73	-12.74
Bus 4	1.019	1.0177	1.0177	1.0177	-10.31	-10.31	-10.31
Bus 5	1.02	1.0195	1.0195	1.0195	-8.77	-8.77	-8.76
Bus 6	1.07	1.07	1.07	1.07	-14.22	-14.22	-14.22
Bus 7	1.062	1.0615	1.0615	1.0615	-13.36	-13.36	-13.36
Bus 8	1.09	1.09	1.09	1.09	-13.36	-13.36	-13.36
Bus 9	1.056	1.0559	1.0559	1.0559	-14.94	-14.94	-14.94
Bus 10	1.051	1.051	1.051	1.051	-15.1	-15.1	-15.1
Bus 11	1.057	1.0569	1.0569	1.0569	-14.79	-14.79	-14.79
Bus 12	1.055	1.0552	1.0552	1.0552	-15.08	-15.08	-15.08
Bus 13	1.05	1.0504	1.0504	1.0504	-15.16	-15.16	-15.16
Bus 14	1.036	1.0355	1.0355	1.0355	-16.03	-16.03	-16.03

RESULTS:

Table 1 shows the comparison of results of Voltage Magnitude (V pu) and Voltage Angle (Deg) between RadiRing, and ETAP and PSLF. It is clear from the results that all bus voltage values and angles are identical for all software packages.

IEEE 14-BUS TRANSMISSION NETWORK

TABLE 2 IEEE 14-BUS : POWER FLOW RESULTS FOR P MW AND Q MVAR-COMPARISON BETWEEN PSLF, ETAP and RADIRING

	PSLF		**ETAP**		**RadiRing**	
Line ID	**P MW**	**Qmvar**	**P MW**	**Qmvar**	**P MW**	**Qmvar**
1_2	156.90	-20.40	156.88	-20.40	157.03	-20.43
1_5	75.50	3.90	75.50	3.85	75.50	3.85
2_3	73.20	3.60	73.23	3.56	73.23	3.56
2_4	56.10	-1.60	56.13	-1.55	56.10	-3.00
2_5	41.50	1.20	41.51	1.197	41.50	1.17
3_4	23.50	-4.70	23.65	-4.82	23.65	-4.47
4_5	61.20	-14.40	61.60	-14.29	61.60	-14.82
4_7	28.10	-10.50	28.07	-11.23	28.07	-11.38
4_9	16.10	-1.70	16.07	-1.73	16.08	-1.73
5_6	44.10	12.50	44.09	12.43	44.08	12.47
6_11	7.40	3.60	7.35	3.56	7.78	3.56
6_12	7.80	2.50	7.78	2.50	7.78	2.50
6_13	17.70	7.20	17.75	7.22	17.74	7.20
7_8	0.00	-17.20	0.00	-17.20	0.00	-17.62
7_9	28.10	5.80	28.07	5.77	213.1	25.90
9_10	5.20	4.20	5.22	4.212	5.22	4.29
9_14	9.40	3.60	9.42	3.60	9.42	3.61
10_11	3.80	1.60	3.80	1.65	3.79	1.65
12_13	1.60	0.80	1.61	0.755	1.64	0.75
13_14	5.60	1.70	5.64	1.75	5.46	1.74

RESULTS:

Table 2 shows the comparison of results of Real Power (P MW) and Reactive Power (Q MVar) between RadiRing, and ETAP and PSLF. It is clear from the results that all branch flow values are very close for all software packages.

IEEE 13-NODE DISTRIBUTION NETWORK

TABLE 3 IEEE 13-NODE: POWER FLOW RESULTS FOR VOLTAGE MAGNITUDE (pu) and ANGLE (degrees)

COMPARISON BETWEEN PSLF, ETAP and RADIRING

		PSLF	**ETAP**	**RadiRing**	**PSLF**	**ETAP**	**RadiRing**
Bus ID	**Vsched**	**V pu**	**V pu**	**Vpu**	**Deg**	**Deg**	**Deg**
Bus 650	1.0	1.0	1.0	1.0	0	0	0
Bus 632	1.0	0.9985	0.9985	0.9985	-0.05	-0.05	-0.05
Bus 633	1.0	0.998	0.998	0.998	-0.058	-0.058	-0.058
Bus634	1.0	0.9964	0.9964	0.9964	-0.086	-0.086	-0.086
Bus 645	1.0	0.9979	0.9979	0.9979	-0.055	-0.055	-0.055
Bus 646	1.0	0.9977	0.9977	0.9977	-0.058	-0.058	-0.058
Bus 671	1.0	0.9938	0.9938	0.9938	-0.473	-0.473	-0.473
Bus 680	1.0	0.9938	0.9938	0.9938	-0.473	-0.473	-0.473
Bus 684	1.0	0.9936	0.9936	0.9936	-0.482	-0.482	-0.482
Bus 692	1.0	0.9937	0.9937	0.9937	-0.481	-0.481	-0.481
Bus 675	1.0	0.9933	0.9933	0.9933	-0.513	-0.513	-0.513
Bus 611	1.0	0.9935	0.9935	0.9935	-0.486	-0.486	-0.486
Bus 652	1.0	0.9934	0.9934	0.9934	-0.481	-0.481	-0.481

RESULTS:

Table 3 shows the comparison of results of Voltage Magnitude (V pu) and Voltage Angle (Deg) between RadiRing, and ETAP and PSLF. It is clear from the results that all bus voltage values are identical for all software packages.

IEEE 13-NODE DISTRIBUTION NETWORK

TABLE 4 IEEE 13-NODE: POWER FLOW RESULTS FOR P MW AND Q MVAR-COMPARISON BETWEEN PSLF, ETAP and RADIRING

	PSLF		ETAP		RadiRing	
Line ID	**P MW**	**Qmvar**	**P MW**	**Qmvar**	**P MW**	**Qmvar**
650-632	1.225	0.469	1.227	0.470	1.225	0.469
632-633	0.133	0.096	0.133	0.097	0.133	0.096
633-634	0.133	0.097	0.133	0.097	0.133	0.097
632-645	0.134	0.085	0.134	0.086	0.134	0.085
645-646	0.077	0.044	0.077	0.044	0.077	0.044
632-671	0.892	0.249	0.892	0.250	0.892	0.249
671-680	0.000	-0.003	0.00	-0.003	0.000	-0.003
671-684	0.100	0.011	0.100	0.011	0.100	0.011
671-692	0.338	-0.018	0.338	-0.017	0.338	-0.018
675-692	0.281	0.046	0.281	0.046	0.281	0.046
611-684	0.057	-0.006	0.057	-0.006	0.057	-0.006
652-684	0.043	0.029	0.043	0.029	0.043	0.029

RESULTS:

Table 4 shows the comparison of results of Real Power (P MW) and Reactive Power (Q MVar) between RadiRing, and ETAP and PSLF. It is clear from the results that all branch flow values are very close for all software packages.

CHAPTER 5

RESULTS OF SHORT CIRCUIT STUDY

For short-circuit (SC) calculations in RadiRing, a method based on academic textbooks (such as Saadat [6]) has been adopted, which includes networks with only round-rotor synchronous machines. In RadiRing, short-circuit calculations are done in three different network states known as Subtransient, Transient, and Steady-State.

In a round-rotor machines, the positive sequence reactances are Xd, Xd′ and Xd″, for the steady-state, transient and subtransient modes, respectively. The negative sequence reactance of the machine can be approximated with its subtransient reactance in all modes:

$X_2 \sim Xd''$

Also, the zero sequence reactance of the machine can be approximated by its leakage reactance:

$X_0 \sim X_l$

where:

$X_d + X_l = X_{ar}$

(X_{ar} is the armature reaction reactance).

ETAP uses more complicated, yet more comprehensive models for different types of generators and motors, including both round-rotor and salient-pole machines. Moreover, ETAP provides short-circuit calculations based on IEC [8], ANSI [9], and GOST [10] standards. In this project, a comparison between RadiRing and ETAP based on ETAP's ANSI standard method has been done. Based on the ANSI's short-circuit studies, short-circuit currents for ½ cycle (Max), ½-4 cycle (4~), and 30 cycle (Min) are calculated. Based on these calculations, for round-rotor synchronous generators, the subtransient reactance of the generators is used in the ½ and ½-cycle states, and the transient reactance is used for 30 cycle state [1]. Calculation of short-circuit currents for ½ cycle (Max) and ½-4 cycle (4~) states is based on the X/R ratio of the generators and is out of the scope of this project, since this method has not been used in RadiRing.

Based on the above descriptions, RadiRing and ETAP results can be only compared between RadiRing's "transient state" and ETAP's ANSI "30 cycle (Min)" state. For this purpose, and in order to get similar results between ETAP and RadiRing, the parameter Xd' (generator's transient reactance) and Ra (armature's resistance) need to be matched between the two software packages. Moreover, in RadiRing, contribution of "calculated bus voltage from power flow", "equivalent load impedances", and "compensator impedances" have not been considered. This is done by unchecking the corresponding items in the "Dialog for setting short-circuit options" under "Options, Short-Circuit" menu.

It is important to note that short-circuit results of this study are based on "no –load pre-fault conditions with all voltages equal to 1 pu with the same angles".

IEEE 14-BUS TRANSMISSION NETWORK

TABLE 5 IEEE 14-Bus Transmission Network: SC Balanced

	BALANCED (BAL)				
	Ifault (kA)	Angle (D)	Ifault (kA)	Angle (D)	Error kA (%)
	RadiRing		ETAP		
bus 1	869.67732	-84.21361	878.1	-85	0.9591942
bus 2	1018.6405	-83.9855	1028	-85.7	0.9104529
bus 3	738.28978	-82.2782	741.4	-84.4	0.4195068
bus 4	765.18389	-80.98215	772.4	-82.1	0.9342447
bus 5	744.4195	-81.59401	751.6	-82.6	0.9553617
bus 6	628.87387	-84.68418	629.9	-86.9	0.1629038
bus 7	478.26923	-85.01789	479.4	-86	0.235871
bus 8	541.44518	-86.25442	542.5	-88.8	0.1944367
bus 9	393.40283	-82.37618	394.6	-83.1	0.3033893
bus 10	305.93546	-77.3486	307	-77.9	0.3467571
bus 11	285.29693	-73.47343	286.5	-74.2	0.4199214
bus 12	231.71769	-66.72806	232.9	-67.5	0.5076469
bus 13	326.43196	-72.47844	328.2	-73.5	0.5387087
bus 14	210.06822	-70.89811	210.8	-71.3	0.3471441
				max error	0.9591942

RESULTS:

Table 5 shows comparison of short-circuit results in Balanced (BAL) SC type, between RadiRing's transient and ETAP's min (30 cycle) states, for Current (I-fault kA) and Angle (degrees). Values obtained are very close with maximum percentage (%) of error calculated less than 1% for I-fault (kA).

TABLE 6 IEEE 14-Bus Transmission Network: SC Single Line to Ground

	SINGLE LINE TO GROUND (SLG)				
	Ifault (kA)	Angle (D)	Ifault (kA)	Angle (D)	Error kA (%)
	RadiRing		ETAP		
bus 1	1263.583	-83.96414	1275	-84.9	0.8954499
bus 2	1477.3087	-81.83853	1491	-85.2	0.9182598
bus 3	1071.0616	-80.5197	1077	-84.8	0.5513821
bus 4	915.88033	-78.80408	924.6	-80.2	0.9430751
bus 5	891.50057	-79.69765	899.7	-81	0.9113517
bus 6	931.53517	-82.65836	936.5	-87.2	0.5301471
bus 7	546.35901	-84.58439	547.4	-85.8	0.1901705
bus 8	826.70458	-83.83272	831.8	-88.7	0.6125778
bus 9	433.98129	-81.46743	435.4	-82.3	0.3258398
bus 10	331.32442	-76.04077	332.7	-76.7	0.413459
bus 11	315.10839	-71.40092	317.2	-72.3	0.6593971
bus 12	258.35951	-64.02577	260.5	-65.1	0.8216867
bus 13	379.53084	-69.45285	383.3	-71	0.9833453
bus 14	222.95236	-69.47417	223.9	-70	0.4232413
				max error	0.9833453

RESULTS:

Table 6 shows comparison of short-circuit results in Single Line to Ground (SLG) SC type, between RadiRing's transient and ETAP's min (30 cycle) states, for Current (I-fault kA) and Angle (degrees). Values obtained are very close with maximum percentage (%) of error calculated less than 1% for I-fault (kA).

TABLE 7 IEEE 14-Bus Transmission Network: SC Double Line

	DOUBLE LINE (DL)				
	Ifault (kA)	Angle (D)	Ifault (kA)	Angle (D)	Error kA (%)
	RadiRing		ETAP		
bus 1	1025.201	-174.0508	1035	-174.9	0.946766
bus 2	1196.999	-172.2591	1208	-175.3	0.9106813
bus 3	870.38168	-170.804	875.7	-174.7	0.6073218
bus 4	768.13646	-169.2113	775.5	-170.5	0.9495213
bus 5	747.69134	-170.054	754.7	-171.3	0.9286678
bus 6	753.46831	-172.9984	757.1	-177.1	0.4796846
bus 7	462.47121	-174.6646	463.4	-175.8	0.2004302
bus 8	663.09283	-174.3143	666.6	-178.7	0.5261287
bus 9	369.60273	-171.6202	370.8	-172.4	0.3228892
bus 10	283.14572	-166.2544	284.3	-166.9	0.4060081
bus 11	268.5786	-161.7292	270.3	-162.6	0.6368475
bus 12	220.0125	-154.4467	221.8	-155.5	0.8059078
bus 13	320.92462	-159.9382	323.9	-161.4	0.9186118
bus 14	191.2316	-159.7	192	-160.2	0.4002088
				max error	0.9495213

RESULTS:

Table 7 shows comparison of short-circuit results in Double Line (DL) SC type, between RadiRing's transient and ETAP's min (30 cycle) states, for Current (I-fault kA) and Angle (degrees). Values obtained are very close with maximum percentage (%) of error calculated less than 1% for I-fault (kA).

TABLE 8 IEEE 14-Bus Transmission Network: SC Double Line to Ground

	DOUBLE LINE TO GROUND (DLG)				
	Ifault (kA)	Angle (D)	Ifault (kA)	Angle (D)	Error kA (%)
	RadiRing		ETAP		
bus 1	1035.4928	159.80309	1046	159	1.0045111
bus 2	1198.6525	160.65912	1221	158.3	1.830262
bus 3	869.57859	162.50155	885	159.5	1.7425323
bus 4	829.64675	161.22447	838.1	160	1.0086202
bus 5	807.92973	160.49985	816.1	159.4	1.0011354
bus 6	745.9795	160.51346	758.5	157.4	1.650692
bus 7	509.72384	156.07466	511.1	155	0.2692546
bus 8	649.50836	159.42847	661	156	1.7385238
bus 9	411.89939	158.67802	413.3	157.9	0.3388851
bus 10	317.22149	163.78494	318.5	163.2	0.4014149
bus 11	297.97034	168.20578	299.8	167.4	0.6102952
bus 12	242.64693	175.3598	244.5	174.5	0.7579035
bus 13	348.10337	170.09009	351.2	168.9	0.8817291
bus 14	215.65408	170.17445	216.5	169.7	0.3907245
				max error	1.830262

RESULTS:

Table 8 shows comparison of short-circuit results in Double Line to Ground (DLG) SC type, between RadiRing's transient and ETAP's min (30 cycle) states, for Current (I-fault kA) and Angle (degrees). Values obtained are very close with maximum percentage (%) of error calculated less than 2% for I-fault (kA).

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TABLE 9 IEEE 13-Node Distribution Network: SC Balanced

	BALANCE (BAL)				
	Ifault (kA)	Angle (D)	Ifault (kA)	Angle (D)	Error kA (%)
	RadiRing		ETAP		
BUS 650	0.13187	-89.69	0.132	-87	0.098485
BUS 632	3.55071	-88.52	3.55	-85.9	0.02
BUS 633	3.29	-85.5	3.29	-83.1	0
BUS 634	2.73211	-79.51	2.72	-77.5	0.44522
BUS 645	3.29618	-84.48	3.29	-82	0.18784
BUS 646	3.15359	-82.24	3.14	-79.9	0.4328
BUS 671	2.87349	-85.4495	2.87	-83.3	0.1216
BUS 692	2.84897	-85.2519	2.84	-83.2	0.31585
BUS 675	2.75009	-83.2922	2.74	-81.3	0.36825
BUS 684	2.76623	-83.4924	2.76	-81.5	0.22572
BUS 611	2.69703	-81.311	2.69	-79.3	0.26134
BUS 680	2.6226	-84.3169	2.62	-82.4	0.09924
BUS 652	2.69104	-80.6266	2.68	-78.7	0.41194
				max error	0.44522

RESULTS:

Table 9 shows comparison of short-circuit results in Balanced (BAL) SC type, between RadiRing's transient and ETAP's min (30 cycle) states, for Current (I-fault kA) and Angle (degrees). Values obtained are very close with maximum percentage (%) of error calculated less than 0.45% for I-fault (kA).

TABLE 10 IEEE 13-Node Distribution Network: SC Single Line to Ground

	SINGLE LINE TO GROUND (SLG)				
	Ifault (kA)	Angle (D)	Ifault (kA)	Angle (D)	Error kA (%)
	RadiRing		ETAP		
BUS 650	0.16707	-89.61	0.167	-86.2	0.04192
BUS 632	4.46701	-88.15	4.46	-84.8	0.15717
BUS 633	4.07193	-84.5	4.05	-81.5	0.54148
BUS 634	3.23242	-77.56	3.2	-75.2	1.01312
BUS 645	4.06631	-83.12	4.04	-80.1	0.65124
BUS 646	3.8469	-80.52	3.82	-77.7	0.70419
BUS 671	3.44367	-84.5479	3.43	-82	0.39854
BUS 692	3.40831	-84.3208	3.4	-81.8	0.24441
BUS 675	3.2653	-82.0323	3.25	-79.6	0.47077
BUS 684	3.28836	-82.2613	3.27	-79.9	0.56147
BUS 611	3.18756	-79.7189	3.17	-77.4	0.55394
BUS 680	3.08838	-83.3068	3.08	-81	0.27208
BUS 652	3.17792	-78.9153	3.16	-76.6	0.56709
					1.01312

RESULTS:

Table 10 shows comparison of short-circuit results in Single Line to Ground (SLG) SC type, between RadiRing's transient and ETAP's min (30 cycle) states, for Current (I-fault kA) and Angle (degrees). Values obtained are very close with maximum percentage (%) of error calculated less than 1.02% for I-fault (kA).

TABLE 11 IEEE 13-Node Distribution Network: SC Double Line

	DOUBLE LINE (DL)				
	Ifault (kA)	Angle (D)	Ifault (kA)	Angle (D)	Error kA (%)
	RadiRing		ETAP		
BUS 650	0.114	-179.6	0.114	-177	0
BUS 632	3.07501	-178.528	3.07	-175.9	0.16319
BUS 633	2.8566	-175.57	2.85	-173.1	0.23158
BUS 634	2.366	-169.51	2.35	-167.5	0.68085
BUS 645	2.85458	-174.42	2.85	-172	0.1607
BUS 646	2.73109	-172.24	2.72	-169.9	0.40772
BUS 671	2.48851	-175.45	2.49	-173.3	0.059839
BUS 692	2.46728	-175.252	2.46	-173.2	0.29593
BUS 675	2.38164	-173.292	2.38	-171.3	0.06891
BUS 684	2.39562	-173.492	2.39	-171.5	0.23515
BUS 611	2.3357	-171.311	2.33	-169.3	0.24464
BUS 680	2.27124	-174.317	2.27	-172.4	0.05463
BUS 652	2.33051	-170.627	2.32	-168.7	0.45302
					0.68085

RESULTS:

Table 11 shows comparison of short-circuit results in Double Line (DL) SC type, between RadiRing's transient and ETAP's min (30 cycle) states, for Current (I-fault kA) and Angle (degrees). Values obtained are very close with maximum percentage (%) of error calculated less than 0.69% for I-fault (kA).

TABLE 12 IEEE 13-Node Distribution Network: SC Double Line to Ground

	DOUBLE LINE TO GROUND (DLG)				
	Ifault (kA)	Angle (D)	Ifault (kA)	Angle (D)	Error kA (%)
	RadiRing		ETAP		
BUS 650	0.16163	135.4	0.164	139.3	1.445122
BUS 632	4.34116	137.5	4.4	141.2	1.337273
BUS 633	3.99273	142.74	4.02	146.1	0.678358
BUS 634	3.20508	152.61	3.2	155.2	-0.15875
BUS 645	4.00884	144.2	4.03	147.6	0.525062
BUS 646	3.81407	147.71	3.82	150.8	0.155236
BUS 671	3.34993	144.7258	3.37	147.4	0.595549
BUS 692	3.31696	145.072	3.33	147.7	0.391592
BUS 675	3.19662	147.8771	3.2	150.4	0.105625
BUS 684	3.21765	147.5701	3.23	150.1	0.382353
BUS 611	3.13954	150.5017	3.14	153	0.01465
BUS 680	3.00759	147.1184	3.02	149.5	0.410927
BUS 652	3.13691	151.3618	3.13	153.8	-0.22077
					1.445122

RESULTS:

Table 12 shows comparison of short-circuit results in Double Line to Ground (DLG) SC type, between RadiRing's transient and ETAP's min (30 cycle) states, for Current (I-fault kA) and Angle (degrees). Values obtained are very close with maximum percentage (%) of error calculated less than 1.45% for I-fault (kA).

CHAPTER 6

FINDINGS AND INTERPRETATIONS

A. Power Flow Study

Results for the power flow study of IEEE 14-Bus System for transmission network are shown in Tables 1 and 2, where values for Voltage Magnitude (V pu) and Voltage Angle (Deg) as well as real power (P MW) and reactive power (Q mvar) are compared. The values obtained from three different software packages, ETAP, PSLF and RadiRing are almost identical for (V pu) and (Deg.), and very close for (P MW) and (Q MVAr).

Results for power flow study of IEEE 13-Node System for distribution network are shown in Tables 3 and 4, where values for voltage magnitude (V pu) and voltage angle (Deg) as well as real power (P MW) and reactive power (Q mvar) are compared. The values obtained from three different software packages, ETAP, PSLF and RadiRing are almost identical for (V pu) and (Deg.), and very close for (P MW) and (Q mvar).

B. Short Circuit Study

Results for the short circuit study of IEEE 14-Bus System for transmission network are shown in Tables 5 - 8, where values for Bus Short Circuit Current - I-fault (kA) and Angle (degrees) are compared. These values are obtained for each of the following short-circuit types: Balanced (BAL), Single-line to ground (SLG), Double line (DL) and Double line to ground (DLG) for “Transient” mode in RadiRing and “Minimum (30 cycle)” State in ETAP. The results between ETAP and RadiRing are very close.

Similar results for the short circuit study of IEEE 13-Node for distribution network are shown in Tables 9 - 12.

Conclusion

In conclusion, the modeling and simulation for power flow using RadiRing, ETAP and PSLF software packages was carried out and analyzed. The power flow study indicates that there is no meaningful difference in the simulations between the three software packages. In addition, modeling and simulation for short circuit using RadiRing and ETAP software packages was carried and analyzed. The short circuit study indicates that there is no meaningful difference in Current (I-fault kA) between the two software packages.

Hence, the power flow and short circuit studies results demonstrate that the performance and accuracy of the ***"RadiRing"*** software package are acceptable for use by the students and faculty for educational and research activities.

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