International Journal of Enhanced Research in Science Technology & Engineering, ISSN: 2319-7463
Vol. 3 Issue 11, November-2014, pp: (249-256), Impact Factor: 1.252, Available online at: www.erpublications.com

Voltage sag and Harmonics Mitigation in Grid Connected WECS using UPFC in ETAP

J. Hephzibah Jose Queen[1] , J. Sellamani[2], S. Pradeep[3],
P. Senthil Kumar[4], S. S. Nandhakumar[5]
[1]Assistant Professor, Department of Electrical and Electronics Engineering,
Maharaja Institute of Technology, Coimbatore
[2,3,4,5]Final Year, Department of Electrical and Electronics Engineering, Maharaja Institute of Technology, Coimbatore

Abstract: This paper demonstrates the mitigation of power quality issues in a grid connected wind energy conversion system using UPFC. The procedure to compensate the power quality issues like voltage sag and harmonics are presented. A Frame work for 25 bus test system is developed in the ETAP & load flow analysis &harmonic analysis is performed. It is observed that the UPFC is effective in compensating the power quality issues for the situation considered.

Keywords: Unified Power Flow Controller, Electrical Transient Analysis Program, Wind Energy Conversion System and Doubly Fed Induction Generator.

Introduction

Wind energy is one of the most important and promising source of renewable energy all over the world with an average growth rate of 30%, mainly because it reduces the environmental pollution caused by traditional power plants. India occupies the 5th place in the world in wind energy generation after USA, Germany, Spain, and China and as of 31 December 2013 the installed capacity of wind power in India was 20149 MW. The design and successful operation of large-scale wind powered generators face a number of formidable problems. If the system is designed to produce AC power, a constant angular velocity and force is desirable. Unfortunately, the wind velocity is neither constant in magnitude and direction nor constant from the top to bottom of a large rotor. This imposes severe cyclic loads on the turbine blades, creating fatigue problems. The Doubly Fed Induction Generator (DFIG) based wind turbine with variable-speed variable-pitch control scheme is the most popular wind power generator in the wind power industry. This machine can be operated either in grid connected or in standalone mode. Integrating Wind Energy Conversion system with grid causes power quality issues like voltage fluctuations, frequency deviations and deterioration of power quality[2]. The main objective of the paper is to mitigate the power quality issues of a grid connected Wind Energy conversion system (WECS) and To minimize the power quality issues by integrating FACTS device like Unified Power Flow Controller (UPFC) in Electrical Transient Analysis Program.

This paper comprises of the following sections. Section 2 describes about the wind energy conversion system. Section 3 deals with power quality issues like voltage sag &harmonics in a grid connected wind energy conversation the details ion system. Section 4 presents details about unified power flow controller. Section 5 demonstrates the simulation results of a 25 bus test system. Section 6 presents the conclusion of this paper.

I. WIND ENERGY COVERSION SYSTEM

A. Grid connected wind energy conversion system

Electricity generation is the most important application of wind energy today. The major components of a typical WECS include a wind turbine, generator, interconnection apparatuses and control systems [9]. The general block diagram of WECS is shown in Figure 1.

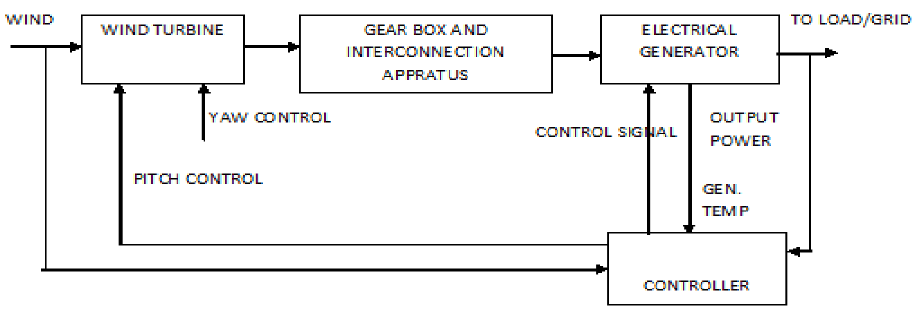

Figure 1 Block diagram of a WECS

B. Generator for Wind Energy Conversion System

The commonly used three types of generator with commercial wind turbines are

- Fixed speed directly grid coupled squirrel-cage induction generator.
- Variable-speed DFIG
- Variable-speed based on direct-drive synchronous generator.

In this paper, we have implemented DFIG because of its advantages like reduced inverter cost, because inverter rating is typically 25% of total system power of the inverter and it has Improved system efficiency. The other main advantage is that the Power-factor control can be implemented at lower cost, because the DFIG system is a four-quadrant converter and induction machine.

II. Power Quality Issues in Grid Connected WECS

Power quality means voltage is continuous and purely sinusoidal with a constant amplitude and frequency. The power quality depends on the interaction between the grid and wind turbine and it can be expressed in terms of physical characteristics such as voltage stability, frequency stability and phase imbalance. Voltage stability can be sub divided into slow voltage variations, voltage dips, flicker , transients and harmonic distortions.

A. Volatge Sag

According to the IEEE Std. 1995-2009 voltage sag is defined as "A decrease in rms voltage or current at the power frequency for duration of 0.5 cycles to 1 minute".

Power quality is usually defined as any problem manifested in voltage, current, or frequency deviations [2]

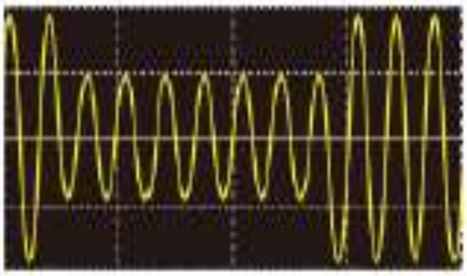

Figure 2 Representation of Voltage Sag

Voltage quality is ultimately of main concern. The most common types of voltage abnormalities are: harmonics, voltage sags, voltage swells and short interruptions. In this paper the voltage sag &harmonics are considered.

B. Classification of Volatge Sag

With respect to an outage or interruption, sag is differentiated by the amplitude being greater than or equal to 0.1 per unit (of nominal voltage). The IEEE 1159 document further categorizes the duration values into: Instantaneous, momentary, and temporary, as illustrated in the following table 1.

Table 1 Classification of voltage sag

Categories	Typical Duration	Typical Magnitude
Instantaneous	0.5-30 cycles	0.1-0.9 p.u
Momentary	0.5-3 seconds	0.1-0.9 p.u
Temporary	3 sec-1 minute	0.1-0.9 p.u

C. Harmonics

Harmonics are the periodic steady state distortions of the sine wave due to equipment's generating frequency other than the standard 60 cycles per second.

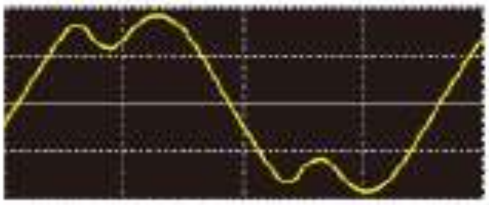

Figure 3 Representations of Harmonics

D. Harmonic Indices

The given two are the indices for measuring harmonic content of a waveform.

i) Total Harmonic Distortion (THD)
ii) Total Demand Distortion (TDD)

I. Total Harmonic Distortion (THD)

The Total harmonic distortion is the measure of the effective values of the harmonic components of a distorted waveform. It is the potential heating value of the harmonic relative to the fundamental.
This index can be calculated for either voltage or current.

$$\mathbf{THD}=\sqrt{\frac{\sum_{h=1}^{h_{max}} M_h^2}{M_1}} \quad \mathbf{(1)}$$

Where,
M_h is the rms value of harmonic component h of the quantity M.
The Total Harmonic Distortion (THD) is related to the rms value of the waveform as follow.

$$\mathbf{RMS}=\sqrt{\frac{\sum_{h=1}^{h_{max}} M_h^2}{M_1}} = M_1\sqrt{1+(THD)^2} \quad \mathbf{(2)}$$

THD can provide a good idea of the extra heat realized when the distorted voltage is applied across a resistive load.

II. Total Demand Distortion (TDD)

THD value can often be misleading. A small current may have a high THD but it does not produce significant threat to the system. For example may adjustable speed drives will exhibit high THD values for the input current at very light loads. To avoid difficulty, THD is referred to the fundamental of the peak demand load current rather than the fundamental of the present sample. It is known as Total Demand Distortion.

$$\mathbf{TDD}=\sqrt{\frac{\sum_{h=2}^{h_{max}} I_h^2}{I_L}} \quad \mathbf{(3)}$$

Where, I_L is the peak or maximum demand load current at the fundamental frequency component measures at the point of common coupling (PCC).

III. Unified Power Flow Controller

The Unified power flow controller (UPFC) concept was proposed by Gyugyi in 1991. The Electric Power research Institute (EPRI) formulated the Flexible AC transmission voltage and power flow and reduces dynamic disturbances. Usually the main purpose of FACTS Transmission system limits power flow over a transmission system is limited by some following [3].

- System stability
- Loop flows
- Voltage limits
- Thermal limits of either lines or terminal equipment
- High short circuit level limits

A. Voltage source converters used in UPFC

i) STATCOM

A static synchronous generator operated as a shunt connected static var compensator whose capacitive or inductive output current can be controlled independent of the ac system voltage. For the voltage-sourced converter, its ac output voltage is controlled such that it is just right for the required reactive current flow for any ac bus voltage dc capacitor voltage is automatically adjusted as require serving as a voltage source for the converter [5]. STATCOM also designed to act as an active filter to absorb system harmonics.

International Journal of Enhanced Research in Science Technology & Engineering, ISSN: 2319-7463
Vol. 3 Issue 11, November-2014, pp: (249-256), Impact Factor: 1.252, Available online at: www.erpublications.com

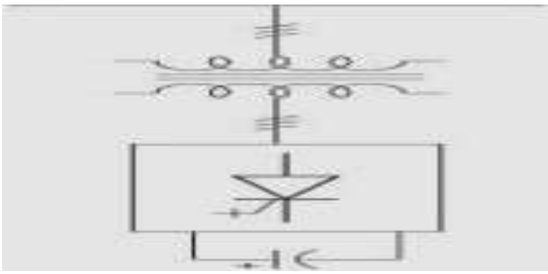

Figure 4 Shunt connected controller (STATCOM)

ii) SSSC

A Static synchronous series generator operated without an external electric energy source as a series compensator whose output voltage is in quadrature with and controlled independently of the line current for the purpose of increasing or decreasing overall reactive voltage drop across the line and thereby controlling the transmitted electric power. The SSSC may include transiently rated energy storage or energy absorbing devices to enhance the dynamic behavior of the power system by additional temporary real power compensation to increase or decrease momentarily the overall real voltage drop across the line.

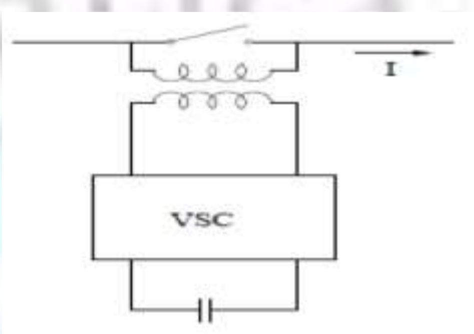

Figure 5 Schematic Diagram of SSSC

B. Basic principle of UPFC

As Shown in the figure 6, UPFC consist of two back to back converters named VSC1 and VSC2, are operated from a DC link provided by a dc storage capacitor. These arrangements operate as an ideal ac to ac converter in which the real power can freely flow either in direction between the ac terminals of the two converts and each converter can independently generate or absorb reactive power as its own ac output terminal.

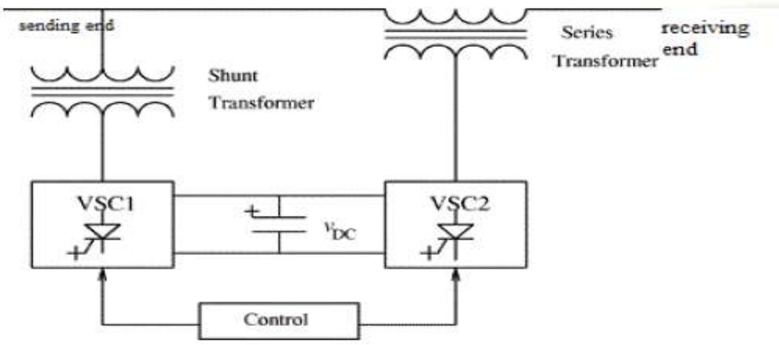

Figure 6 Basic UPFC scheme

One VSC is connected to in shunt to the transmission line via a shunt transformer and other one is connected in series through a series transformer. The DC terminal of two VSCs is coupled and this creates a path for active power exchange between the converters. VSC provide the main function of UPFC by injecting a voltage with controllable magnitude and phase angle in series with the line via an injection transformer. This injected voltage act as a synchronous ac voltage source.

The transmission line current flows through this voltage source resulting in reactive and active power exchange between it and the ac system. The reactive power exchanged at the dc terminal is generated internally by the converter. The real power exchanged at the ac terminal is converted into dc power which appears at the dc link as a real power demand and VSC1 is to supply or absorb the real power demanded by converter2 at the common dc link to support real power exchange resulting from the series voltage injection. This dc link power demand of VSC2 is converted back to ac by VSC1 and coupled to the transmission line bus via shunt connected transformer. In addition, VSC1 can also generate or absorb controllable reactive power if it is required and thereby provide independent shunt reactive compensation for the line. Thus VSC1 can be operated at a unity power factor or to be controlled to have a reactive power exchange with the line independent of the reactive power exchanged by VSC1. Obviously, there can be no reactive power flow through the UPFC dc link.

IV. SIMULATION AND RESULTS

A. Simulation diagram without UPFC

The Figure 7 depicts the Simulation diagram of a 25 BUS test system with three Wind Energy Conversion System integrated to the buses 14,16 &25.

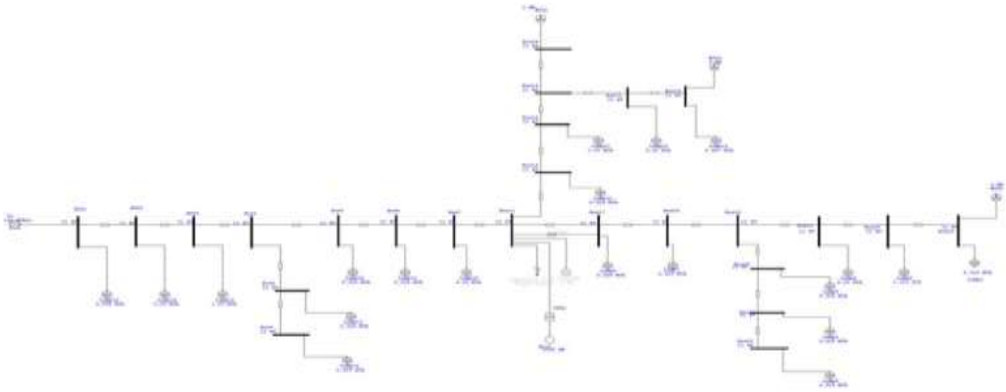

Figure 7 Simulation Diagram of test system without UPFC

B. Load Flow results of 25 bus test system without UPFC

The Table 2 shows the Load flow results of 25 bus test system without connecting the Unified Power flow controller in ETAP Platform. From the Table 2, its clear that many buses have low voltage profile.

Table 2 Load Flow result of 25 bus system without UPFC

S.NO	BUS NO	VOLTAGE in p.u.
1	1	9.1194
2	2	1
3	3	9.6591
4	4	9.3720
5	5	8.5819
6	6	8.4061
7	7	8.1888
8	8	9.1061
9	9	9.0995
10	10	8.0430
11	11	8.0309
12	12	8.0276
13	13	8.0542
14	14	8.0594
15	15	8.0721
16	16	7.9684
17	17	7.9010
18	18	7.8409
19	19	7.8187
20	20	7.8039
21	21	7.7965
22	22	7.8031
23	23	7.8118
24	24	7.8285
25	25	8.0775

C. Harmonic analysis of 25 bus test sytem without UPFC

The Figure 8 illustrates the waveform which is disrupted due to harmonic contents. The waveform below is obtained by performing the harmonic analysis in 25 Bus test system without UPFC in ETAP software.

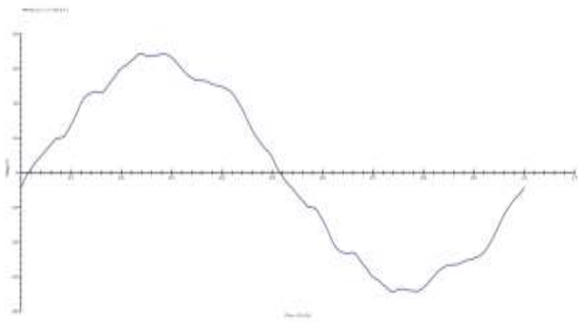

Figure 8. Waveform obtained from Harmonic Analysis without UPFC.

D. Simulation diagram with UPFC

The Figure 9 depicts the Simulation diagram of a 25 BUS test system with three Wind Energy Conversion System integrated to the buses 14 ,16 &25 and UPFC is connected to Bus 11at the point of common coupling.

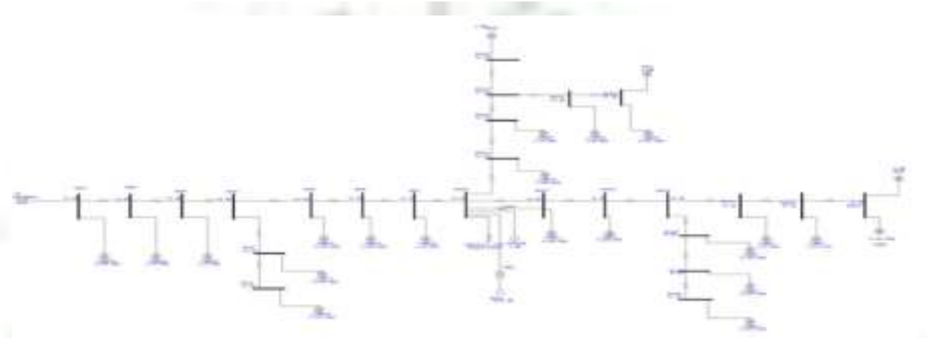

Figure 9 Simulation Diagram of test system with UPFC

E. Load Flow results of 25 bus test system with UPFC

Table 3 Load Flow result of 25 bus system with UPFC

S.NO	BUS NO	VOLTAGE in p.u.
1	1	9.9396
2	2	1
3	3	9.588
4	4	9.9450
5	5	9.9543
6	6	9.9579
7	7	9.9655
8	8	9.9342
9	9	9.9315
10	10	1
11	11	9.9315
12	12	1
13	13	9.941
14	14	9.910
15	15	9.9982
16	16	9.986
17	17	1
18	18	1
19	19	9.9741
20	20	9.9508
21	21	9.9428
22	22	9.9374
23	23	9.9347
24	24	9.9356
25	25	9.9372

The Table 3 shows the Load flow results of 25 bus test system with the Unified Power flow controller in ETAP Platform. From the Table 3, it's clear that UPFC has minimized the voltage sag problem and improved the voltage profile of bus system considerably within the permissible limits especially bus 4-25 which has suffered from voltage sag problem.

F. Harmonic analysis of 25 bus test sytem with UPFC

The Figure 10 illustrates the waveform obtained by performing the harmonic analysis in 25 Bus test system with UPFC.The detected harmonic contents are of order 5,7,&11. From the waveform it's clear that the UPFC has controlled the harmonic content in the fundamental waveform.

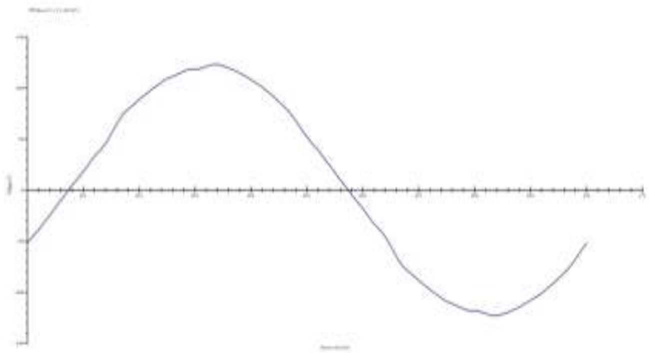

Figure 10 Waveform obtained from Harmonic Analysis with UPFC.

The results prove that the UPFC has improved the power quality issues faced by the Test system integrated with Wind Energy Conversion system.

G. INFERENCE

From Table2 and Table3, its found that the compensation of voltage sag is done after adding UPFC to the 11^{th} bus and the voltage magnitude has reached its specified limits. From the Figure 9 & Figure 10, it is clear that the harmonic contents are mitigated satisfactorily in a UPFC connected wind energy conversion system 5^{th}, 7^{th}, 8^{th} & 11^{th} order harmonics were decreased effectively.

V. CONCLUSION

In this paper, the mitigation of the voltage sag and harmonics due to grid connected WECS is demonstrated. A procedure to compensate the power quality issues by connecting UPFC to the point of common coupling is also presented. A 25 bus test system model is developed in ETAP to accomplish the mitigation of voltage sag and harmonics using UPFC. The Results prove that the UPFC is effective in restoring the voltage magnitude and also reduces the harmonic content in a grid connected wind energy conversion system.

REFERENCES

[1]. Sankar .S, Arul .S, Balaji .S, "Simulation and Comparison of Various facts devices in power system", International Journal of Engineering Science and Operation And Control Of Wind Power Station Using Facts Controller, Vol.2, No.4.
[2]. Gutierrez .J, Ruiz .J, Saiz .P, Azcarate .I, Leturiondo L.A, and lazkano.D, "Power Quality in Grid connected Wind Turbines", University of The Basque Country , Spain .
[3]. Fugita and Watanaba "Control And Analysis of UPFC" , IEEE Transaction on Power Electronics Vol.14, No.6, pp.1021-1027,2008
[4]. Padiyar .K.R, Book on "FACTS controller power transmission&distribution",New age International publisher,2007.
[5]. Tara Kalyani .S and Tulasiram Das,Thesis on "Simulation of Real & Reactive Power Flow Control With UPFC Connected to a Transmission Line" , Jawaharlal Nehru Technological University, Hyderabad, India.
[6]. Bublat T and Gehlhaar.T, "Comparison of high technical demands on grid connected wind turbines defined in international Grid Codes", EWEC, 2008.
[7]. Erlich .I, Winter.W and Dittrich.A "Advanced Grid Requirements for the Integration of Wind Turbines into the German Transmission System", 2006.
[8]. Network and System Rules of the German Transmission System Operators, "Transmission code 2007", 2007 "EirGrid Grid Code", 2009.
[9]. Tarek Medalel Masaud and Sen P.K., "Modeling And Control Of Doubly Fed Induction Generator for Wind Power", IEEE Conference on North American Symposium (NAPS), pp. 1-8, 4-6 Aug 2011.
[10]. John Fletcher and Jin Yang, Book on " Introduction to the Doubly-Fed Induction Generator for Wind Power Applications", University of Strathclyde, Glasgow, UK,2010.

International Journal of Enhanced Research in Science Technology & Engineering, ISSN: 2319-7463
Vol. 3 Issue 11, November-2014, pp: (249-256), Impact Factor: 1.252, Available online at: www.erpublications.com

APPENDIX

A. LINE DATA

Connected Bus ID		%Impedance, Pos. Seq., 100 MVA Base			
From Bus	To Bus	R	X	Z	Y
BUS2	BUS1	10.25	35.70	37.14	0.0004282
BUS3	BUS2	10.25	37.52	38.89	0.0004417
BUS4	BUS3	12.64	34.96	37.18	0.0004550
BUS7	BUS4	11.98	86.78	87.60	0.0003920
BUS8	BUS7	8.67	27.22	28.51	0.0002338
BUS9	BUS8	10.33	34.96	36.45	0.0003703
BUS4	BUS5	10.33	34.96	36.45	0.0003703
BUS5	BUS6	10.33	34.96	36.45	0.0003703
BUS10	BUS9	10.33	34.96	36.45	0.0003703
BUS11	BUS10	10.33	34.96	36.45	0.0003703
BUS12	BUS11	10.33	34.96	36.45	0.0003703
BUS13	BUS12	10.33	34.96	36.45	0.0003703
BUS15	BUS13	10.33	34.96	36.45	0.0003703
BUS16	BUS15	10.33	34.96	36.45	0.0003703
BUS17	BUS10	10.33	34.96	36.45	0.0003703
BUS18	BUS17	10.33	34.96	36.45	0.0003703
BUS19	BUS18	10.33	34.96	36.45	0.0003703
BUS23	BUS19	10.33	34.96	36.45	0.0003703
BUS19	BUS20	10.33	34.96	36.45	0.0003703
BUS20	BUS21	10.33	34.96	36.45	0.0003703
BUS21	BUS22	10.33	34.96	36.45	0.0003703
BUS24	BUS23	10.33	34.96	36.45	0.0003703
BUS25	BUS24	10.33	34.96	36.45	0.0003703
BUS14	BUS13	10.33	34.96	36.45	0.0003703

B. BUS DATA

Bus			Initial Voltage		Load							
					Constant kVA		Constant Z		Constant I		Generic	
ID	kV	Sub-sys	% Mag.	Ang.	MW	Mvar	MW	Mvar	MW	Mvar	MW	Mvar
BUS1	11.000	1	100.0	0.0	0.061	0.038	0.015	0.009				
BUS2	11.000	1	100.0	0.0	0.671	0.416	0.168	0.104				
BUS3	11.000	1	100.0	0.0	0.255	0.158	0.064	0.040				
BUS4	11.000	1	100.0	0.0								
BUS5	11.000	1	100.0	0.0	0.067	0.042	0.017	0.010				
BUS6	11.000	1	100.0	0.0	0.067	0.042	0.017	0.010				
BUS7	11.000	1	100.0	0.0	0.067	0.042	0.017	0.010				
BUS8	11.000	1	100.0	0.0	0.067	0.042	0.017	0.010				
BUS9	11.000	1	100.0	0.0	0.671	0.416	0.168	0.104				
BUS10	11.000	1	100.0	0.0								
BUS11	11.000	1	100.0	0.0	0.067	0.042	0.017	0.010				
BUS12	11.000	1	100.0	0.0	0.255	0.158	0.064	0.040				
BUS13	11.000	1	100.0	0.0								
BUS14	11.000	1	100.0	0.0								
BUS15	11.000	1	100.0	0.0	0.065	0.040	0.016	0.010				
BUS16	11.000	1	100.0	0.0	0.099	0.062	0.025	0.015				
BUS17	11.000	1	100.0	0.0	0.067	0.042	0.017	0.010				
BUS18	11.000	1	100.0	0.0	0.067	0.042	0.017	0.010				
BUS19	11.000	1	100.0	0.0								
BUS20	11.000	1	100.0	0.0	0.067	0.042	0.017	0.010				
BUS21	11.000	1	100.0	0.0	0.067	0.042	0.017	0.010				
BUS22	11.000	1	100.0	0.0	0.067	0.042	0.017	0.010				
BUS23	11.000	1	100.0	0.0	0.418	0.259	0.105	0.065				
BUS24	11.000	1	100.0	0.0	0.067	0.042	0.017	0.010				
BUS25	11.000	1	100.0	0.0	0.067	0.042	0.017	0.010				