Power System Stability using Doubly-Fed Induction Generator and Unified Power Flow Controller

M.Muthuvel[1], Dr.G.Udhayakumar[2]
[1]PG Scholar, Department of Electrical and Electronics Engineering, Valliammai Engineering College,
Kattankulathur, Kancheepuram, Chennai, India.
[2]Associate Professor Department of Electrical and Electronics Engineering, Valliammai Engineering College,
Kattankulathur, Kancheepuram, Chennai, India.

Abstract-This paper deals with the importance of real and reactive power loss which keeps on increasing with booming demand for electrical power due to domestic and industrial utilities in power system network. There are many effective ways of delivering electrical energy with reduced losses that utilizes technologies like Flexible AC Transmission System devices and renewable sources of energy like wind power, Solar Photovoltaic, etc. These methods also help in maintaining the voltage profile of power system (0.9 per unit-1.1 per unit). The proposed methodology in this paper is integration of Double Fed Induction Generator with Unified Power Flow Controller in a 30 bus system to reduce real, reactive power loss and also to improve the voltage profile. IEEE 30 bus system is utilized here to perform this analysis with the help of Power System Analysis Tool box in Mat-Lab.

Keywords-DFIG, Voltage magnitude, real power loss, reactive power loss, UPFC.

---

1. INTRODUCTION

Power supply system can produce and consume two types of powers, active and reactive power. Real power or active power means the useful power given to any load. It does useful work like powering lamps, fans, and all inductive loads. The unit of active power measured in units of watts (W). Reactive power primarily exists in all AC circuits where the voltage and current are not in phase with each other. It accomplishes to move active power in transmission and distribution line from one place to another place. The primary sources of reactive power are inductive and capacitive loads. It is measured in units of volt-ampere reactive (VAR).These active and reactive power has to be efficiently used without any losses.

If the power demand is more than the capacity of transmission lines, current drawn from supply lines gets maximized, which causes voltage to fall considerably below 0.9 p.u. This low voltage when gets decreased further, it leads the generator to trip, motors gets overheated and also causes other equipment failures. To overcome this problem, one of the efficient methods is to supply real and reactive power to the load by incorporating FACTs devices and DFIG. Capacity of these devices depends on amount of apparent power to be supplied and the total amount of power generation capacity.

This paper performs power flow analysis in four stages

1. Introduction
2. Methodology
3. Results and discussion
4. Conclusion.

Labiba ADJOUDJ, Fatiha LAKDJA and Fatima Zohra GHERBI [1] published a paper on impact assessment of wind turbine based on double feed induction generator and FACTS devices on power systems that analyzed the effect of integrating wind generation and doubly fed induction generators (DFIG) and Flexible AC Transmission System (FACTS) on the voltage instability and active power losses of network on IEEE 30 bus system. Therefore, we must choose among the various types of FACTS devices, those with specific applications such as maintaining the voltage profile at the desired value and the control of active, reactive power flow.

Bindeshwar Singh, V.Mukherjee , PrabhakarTiwari [2] published a paper on impact assessment of Distributed Generation and FACTS controllers in power systems which reviews the work from the view point of different performance characteristics like such as minimization of active and reactive power losses , reduction in cost of system, more flexible operation and control, increase in overall system efficiency, enhanced reliability, relieved transmission and distribution congestion, enhanced power quality of system, improved voltage profile ,increased loadability of systems, improved power system stability, reduced power system oscillations, and improved environmental conditions. It also provided the reactive power support in emergency cases under fault conditions & sudden change in field excitation of alternators or load increase in power system. Bindeshwar Singh and Bindu Jee Gyanish [3] published a paper on impact assessment of DG in distribution systems from minimization of total real power loss viewpoint by using optimal power flow that represents the enhancement and impacts of the system losses, voltage profile and cost by using distributed generations (DGs) of different size in distribution network. It focused mainly on analyzing the impact of DG installation on distribution network operation including system voltage profile analysis, real and reactive power losses and cost of the system. M.C.Ramachandran and Dr.K.Elango [4] published a paper on minimizing the transmission Loss in power system with integration of DG and compensator. The proposed idea was based on increased capacity of installing DG into the main power systems and to rectify the problems that caused uncertainties in transmission System. It also helped in maintaining the voltage profile and to reduce the active power loss. A general introduction to double fed induction generator has been done on [5] and basic working and simulation of UPFC has been explained on [6]. Yamin HY, Shahidehpour SM.[7] published a paper on transmission congestion management in deregulated energy market that explained the various ways to tackle voltage profile collapse in peak demand scenarios. Durga Gautam, Nadarajah Mithulananthan[8] published a paper on optimal placement of distributed generation in deregulated market and its effective usage. Anusha Pillay, S. Prabhakar Karthikeyan ,D.P. Kothari[9] presented a review paper on transmission congestion management that explained almost all types of congestion management techniques. R. Srinivasa Rao , V. Srinivasa Rao[10] published a paper on generalized approach for determination of optimal location and performance analysis of FACTS devices which provided a clear cut idea about placement of various FACTS devices based on performance index and sensitivity analysis.

This paper contributes in a way of integrating DFIG and Unified Power Flow Controller in a modified 30 bus system for effective energy (active and reactive power) usage and maintaining the voltage profile.

1.1 PROBLEM IDENTIFICATION

In IEEE-30 bus system, at regular conditions all bus voltage lie in between 0.9 p.u < v<1.1 p.u . Violation of voltage levels below the acceptable range & increased loss of real and reactive power can occur when there is sudden increase in demand of load that can’t be compensated by the base system. So integration of DFIG and UPFC in 30 bus system is much needed to rectify this problem.

1.2 PSAT Tool Box

Power System Analysis Tool-box (PSAT) is one of the Mat lab toolbox used for power system analysis and control. It can execute both static and dynamic analysis control. The heart of this tool box core is the power flow routine, which a takes control of state variable initialization. If the power flow has been solved, then static and/or dynamic analysis can be performed. All operations are under the control of graphical user interface. Simulink based library yields a user friendly tool for network design.

It includes the various functions mentioned below:
1. Power flow
2. Continuation power flow
3. Optimal power flow
4. Small signal stability analysis
5. Time domain simulation
6. Phasor measurement unit placement.
7. Graphical user interface
8. Graphical network editor

Applications
1. PSAT is more suitable for teaching and explaining basic power system analysis and control system concepts.
2. PSAT is useful for research purpose allows easy and fast executions.
3. It also helps in prototyping of new models and algorithm.

1.3 DFIG

Doubly-fed induction generators are electric generators that have windings on stationary and rotating parts, where both windings can be able to transfer power between shaft and electrical system. The industrial and population growth, had lead to increased energy consumption over the last three decades. The most important issue has been depletion of resources like coal, gas and petroleum at a very fast rate and it has made many countries around the globe to think about their alternative natural resources which are inexhaustible, sustainable and eco-friendly. Among various non-conventional resources for electricity, wind generation has attracted great positive impact in the past few decades and it is undoubtedly the most rapidly growing renewable energy source.Usage of simple squirrel cage induction machine has been reduced in recent times.

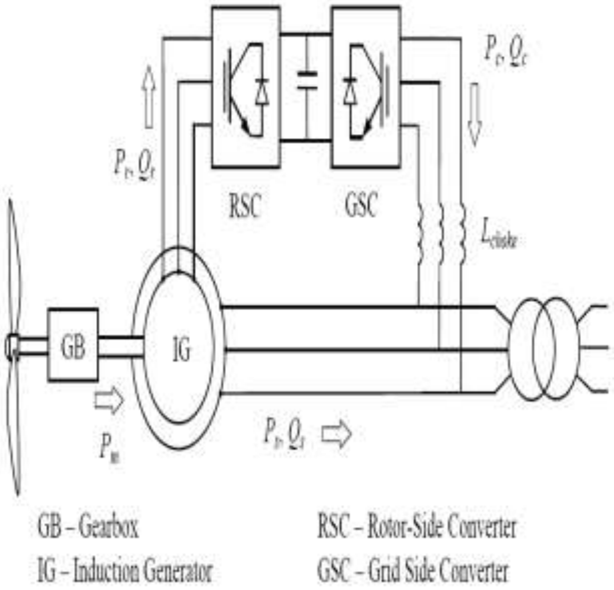

Fig 1.1 Double Fed Induction Generator

Meanwhile with the help of doubly-fed electric machines we can be able to control both real and reactive power of the machine, limit the power output and can control voltage and speed. DFIG had entered into common use only recently with the advancement of wind power technologies for power generation. They are variable speed three-phase wound-rotor induction machines with more merits and advancements over other types of generators. Doubly-fed electric machines are electric generators that consist of windings on both stationary and rotating parts, where both windings can transfer considerable amount of power between shaft and electrical system.

The main principle of the Doubly-Fed Induction Generator is that rotor windings are connected to the grid through slip rings and back-to-back voltage source converters that control both the rotor and the grid currents. Thus, rotor frequency can vary smoothly from the grid frequency. The converter is used to control the rotor currents, and to adjust the active and reactive power fed to the grid from the stator which is independent of the rotational speed of the generator. In a conventional three-phase synchronous generator, which consists of an external mechanical source like prime mover rotating the generator rotor, the magnetic field in the generator rotor produced by the dc current fed into the rotor winding rotates synchronously with speed of the rotor. Eventually, the magnetic flux changes nonstop and it passes through the stator windings inducing an alternating voltage across the stator windings. The operating principle applicable in a doubly-fed induction generator is the same as the conventional induction generator. The only difference between the two equipments is that the magnetic field which is created in the rotor is not static (as it is created using three-phase ac current instead of dc current), but it rotates at a speed proportional to the frequency of the ac currents supplied into the rotor windings. This states that the magnetic field that pass through the generator stator windings not only rotates due to the rotation of the generator rotor, but also due to the rotational effect caused by the ac currents fed into the rotor windings. So in a DFIG, both the rotational speed of the rotor and the frequency of the ac currents that gets supplied into the rotor windings determine the speed of the rotating magnetic field passing through stator the stator windings, and so the frequency of the alternating voltage gets induced across the stator windings.

1.4 UPFC

UPFC consists of two back to back converters called shunt converter and series converter that are operated from a DC link provided by a dc storage capacitor. This type of arrangement operate as an ideal ac to ac converter in which the real power can smoothly flow either in direction between the ac terminals of the two converts and each converter can individually generate or absorb reactive power as its own ac output terminal. Shunt converter is connected to in shunt to the transmission line through a shunt transformer and another converter is connected in series through a series transformer. The dc terminals of two converters are coupled and this creates a path for active power exchange between the converters. These converters 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 supplied voltage acts as a synchronous ac voltage source. The transmission line current flows through this voltage source that can result in reactive and active power exchange between itself and the ac system. The reactive power exchanged at the dc terminal is produced internally by the converter

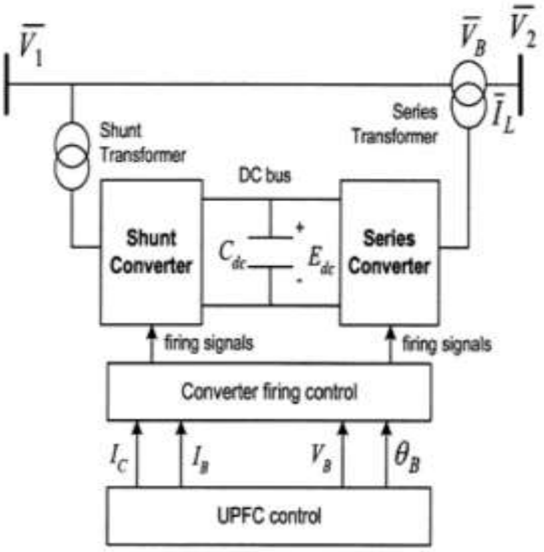

Fig 1.2 Schematic diagram of UPFC

. . The real power interchanged at the ac terminal is converted back into its dc power which appears at the dc link as real power demand .Shunt converter is used to supply or absorb the real power demanded by series converter at the common dc link to support real power exchange resulting from the series voltage injection.

This dc link power demand of series converter is converted back to ac by shunt converter and coupled to the transmission line bus via shunt connected transformer. In addition, shunt converter can also generate or absorb controllable reactive power if it is required and thereby provide independent shunt reactive compensation for the line. Eventually, there can be no reactive power flow through the UPFC dc link.The main reason for opting UPFC in this paper is the superior performance over other FACTS devices when it comes to voltage control, transient stability control, dynamic stability control and load flow control.

Table 1.1 Comparative Analysis of Facts devices

Facts devices	Load flow control	Transient stability	Dynamic stability	Voltage control
SVC	Good	Best	Good	Better
STATCOM	Good	Best	Better	Better
TCSC	Better	Good	Best	Better
UPFC	Best	Best	Best	Best

2. METHODOLOGY

2.1 IEEE 30 BUS SYSTEM

Power flow is carried out in a 30 bus system which consists of 30 buses, 38 lines, 3 transformers, 6 generators and 12 loads. PSAT performs power flow analysis that finally gives the voltage profile, line flows, total real power and reactive power generation, total real and reactive power loss along with individual bus generation and load details. Power flow results of base IEEE 30 bus system show the total generation, load and losses. From the table 2.2 it has been observed that the total generation of real power is 291.78 MW and reactive power generation is 123.17 MVAR with real power loss of about 4.42 % and reactive power loss of about 18.48%.

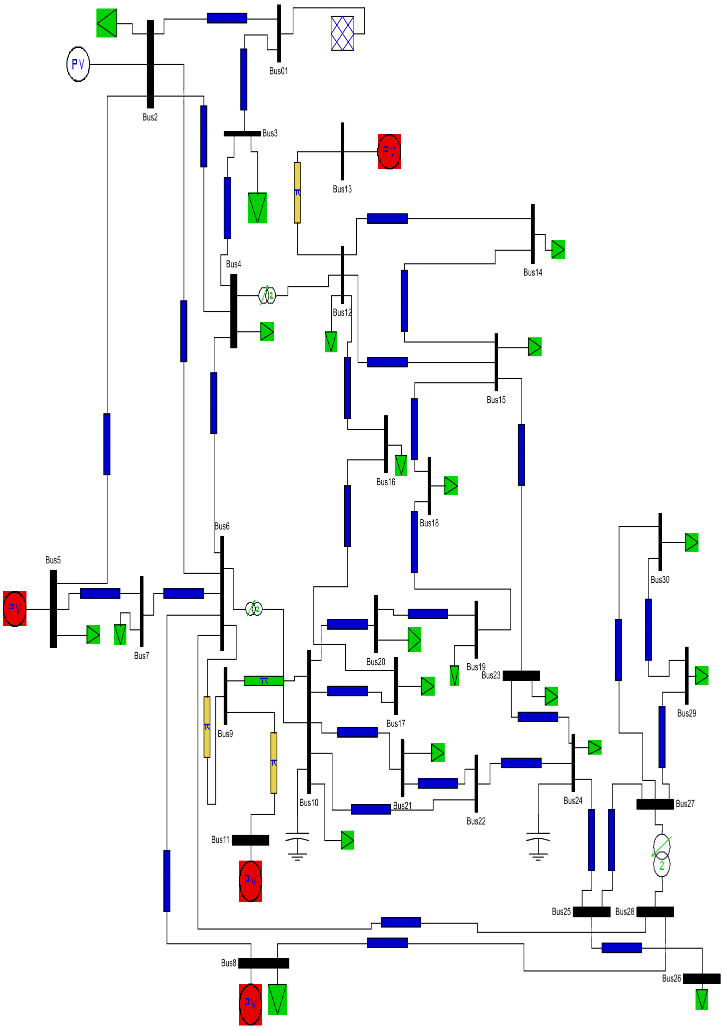

Fig 2.1 PSAT representation of IEEE 30 bus system

Table 2.1 Voltage Profile of IEEE 30 bus system

Bus No	Voltage magnitude
Bus 1	1.06
Bus 2	1.045
Bus 3	1.032
Bus 4	1.025
Bus 5	1.010
Bus 6	1.013
Bus 7	1.005
Bus 8	1.00
Bus 9	1.037
Bus 10	1.027
Bus 11	1.082
Bus 12	1.026
Bus 13	1.071
Bus 14	0.982
Bus 15	0.969
Bus 16	1.004
Bus 17	1.003

Bus 18	0.936
Bus 19	0.938
Bus 20	0.958
Bus 21	0.988
Bus 22	0.990
Bus 23	0.935
Bus 24	0.928
Bus 25	0.937
Bus 26	0.920
Bus 27	0.964
Bus 28	0.996
Bus 29	0.918
Bus 30	0.902

Table 2.2 Power flow results: (IEEE 30 bus)

Real power generation	291.8 MW
Reactive power generation	123.17 MVAR
Real power load	278.9 MW
Reactive power load	100.42 MVAR
Real power loss	12 MW
Reactive power loss	22.7 MVAR

2.2 LOAD INCREMENT

Load is increased randomly at bus 14 and bus 5 that maximized the total base load from 278.9 MW to 311.5 MW. The power flow results form table 2.2 clearly shows that voltage magnitude has considerably reduced at bus 14 from 0.982 p.u to 0.861 p.u. Minor variation in voltage level occurs at bus 3,4,6,7,9,10,15,16,17,18,19,20,23,24,25,26,29 and 30.

Table 2.3 Voltage Profile of IEEE 30 bus system (12 % increased load)

Bus No	Voltage magnitude
Bus 1	1.06
Bus 2	1.045
Bus 3	1.026
Bus 4	1.018
Bus 5	1.010
Bus 6	1.008
Bus 7	1.001
Bus 8	1.000
Bus 9	1.033
Bus 10	1.024
Bus 11	1.082
Bus 12	1.013
Bus 13	1.071
Bus 14	0.861
Bus 15	0.946
Bus 16	0.994
Bus 17	0.998
Bus 18	0.921
Bus 19	0.928
Bus 20	0.949

Bus 21	0.984
Bus 22	0.986
Bus 23	0.898
Bus 24	0.916
Bus 25	0.928
Bus 26	0.910
Bus 27	0.958
Bus 28	0.991
Bus 29	0.913
Bus 30	0.897

Table 2.4 Power flow results: (12% increase in base load)

Real power generation	332.06 MW
Reactive power generation	151.39 MVAR
Real power load	311.5 MW
Reactive power load	100.66
Real power loss	20.55 MW
Reactive power loss	50.77 MVAR

2.3 MODIFIED IEEE 30 BUS WITH DFIG:

On observing the tabulation results in 2.3 it is clearly seen that voltage profile is very low 0.861 p.u at bus 14. So DFIG is connected to bus 14 through a separate bus 31 along with a transformer connected to it. Load is kept constant at 311.5 MW. DFIG generates 46 MW of real power which reduces total generation from 332.06 MW to 325.2 MW, real power losses reduces from 20.5 MW to 13.71 MW and reactive power loss decreases from 50.73 MVAR to 21.20 MVAR. Readings are shown in table 2.6.

Table 2.5 Voltage profile of Modified IEEE 30 bus with DFIG

Bus No	Voltage magnitude
Bus 1	1.06
Bus 2	1.045
Bus 3	1.034
Bus 4	1.028
Bus 5	1.010
Bus 6	1.015
Bus 7	1.006
Bus 8	1.00
Bus 9	1.035
Bus 10	1.024
Bus 11	1.082
Bus 12	1.028
Bus 13	1.071
Bus 14	1.004
Bus 15	0.958
Bus 16	0.998
Bus 17	0.998
Bus 18	0.927
Bus 19	0.932
Bus 20	0.952
Bus 21	0.984

Bus 22	0.986
Bus 23	0.945
Bus 24	0.921
Bus 25	0.932
Bus 26	0.915
Bus 27	0.960
Bus 28	0.990
Bus 29	0.945
Bus 30	0.961
Bus31	1.00

Table 2.6 Power flow results of modified 30 bus system with DFIG

Real power generation	325.22 MW
Reactive power generation	121.83 MVAR
Real power load	311.5 MW
Reactive power load	100.63 MVAR
Real power loss	13.71 MW
Reactive power loss	21.20 MVAR

2.4 MODIFIED IEEE 30 BUS WITH DFIG AND UPFC:

The total real and reactive power loss can be further reduced by integrating DFIG in bus 14 along with placement of Unified Power flow Controller between bus 25 and 26 as shown in Fig 2.2. Because the voltage profile in those buses are much lower when compared to other bus voltages as shown in table 2.5, and also that's the optimal location which gives very real and reactive power losses.

Table 2.7 UPFC Rating

Power, Voltage and Frequency	100 MVA, 33 KV, 50 HZ
Gain Constant (Kr), Time constant(Tr)	50 p.u , 0.1 p.u
Maximum Vp and Minimum Vp	1.1 p.u. , 0.90 p.u.
Maximum Iq and Minimum Iq	1.1 p.u. , 0.9 p.u.

Table 2.8 DFIG rating

Power, Voltage and Frequency	100 MVA, 33 KV, 50 HZ
Stator resistance (Rs) and Reactance (Xs)	0.01 p.u. , 0.10 p.u.
Rotor resistance (Rr) and Reactance(Xr)	0.01 p.u. , 0.08 p.u.
Magnetization Reactance (Xm)	3.00 p.u.
Inertia Constant (Hm)	3 (KWs/KVA)
Pitch Control Gain (Kp) Time constant(Tp)	10 p.u. ,3 s
Voltage control gain (Kv)	10 p.u.
Blade length and Number	75 m , 3 int
Number of Poles (p) and Gear box ratio(int)	4 , 1/89

Table 2.9 Voltage profile of Modified IEEE 30 bus with DFIG and UPFC

Bus No	Voltage magnitude
Bus 1	1.06
Bus 2	1.045
Bus 3	1.036
Bus 4	1.030
Bus 5	1.010
Bus 6	1.018
Bus 7	1.009
Bus 8	1.00
Bus 9	1.039
Bus 10	1.030
Bus 11	1.082
Bus 12	1.024
Bus 13	1.071
Bus 14	1.005
Bus 15	0.971
Bus 16	1.002
Bus 17	1.004
Bus 18	0.937
Bus 19	0.941
Bus 20	0.960
Bus 21	0.994
Bus 22	0.998
Bus 23	0.974
Bus 24	0.969
Bus 25	1.010
Bus 26	1.003
Bus 27	0.997
Bus 28	1.008
Bus 29	0.954
Bus 30	0.939
Bus31	1.00

Comparing the power flow results in table 2.10 and table 2.6, shows that the total real power losses reduced from 13.71 MW to 12.20 MW, reactive power losses reduced from 21.20 MVAR to 14.85 MVAR.

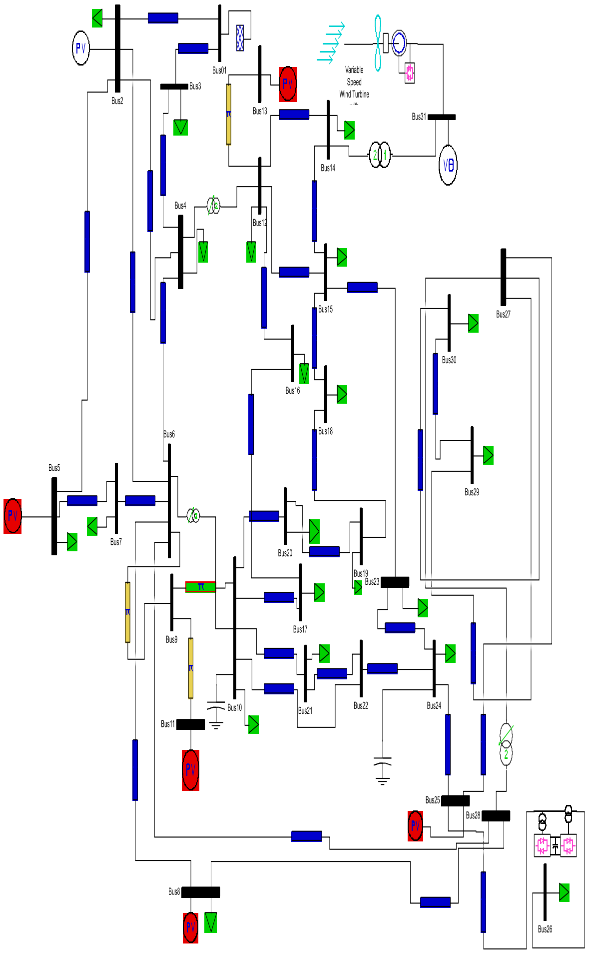

Fig 2.2 Modified 30 bus system with DFIG & UPFC

Table 2.8 Power flow results of modified 30 bus system with DFIG & UPFC

Real power generation	323.71 MW
Reactive power generation	114.78 MVAR
Real power load	311.5 MW
Reactive power load	100 MVAR
Real power loss	12.20 MW
Reactive power loss	14.85 MVAR

3. RESULTS AND DISCUSSION

Graphical representation of fig 3.1, 3.2 and 3.3 clearly shows that voltage profile has been much improved on integration of DFIG and UPFC in the modified IEEE 30 bus system. On analyzing the above results in section 2 a comparative tabulation is shown in table 3.1.

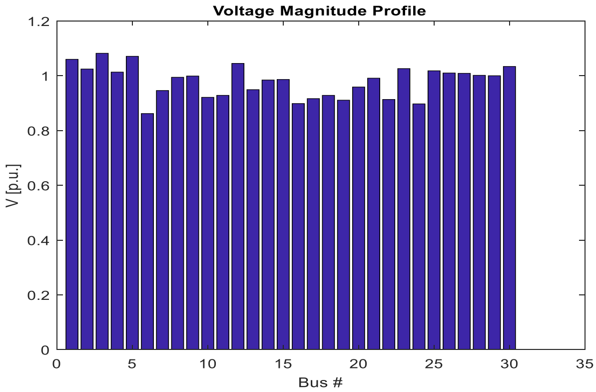

Fig 3.1 Voltage magnitude of IEEE 30 bus system with 12 % load increment

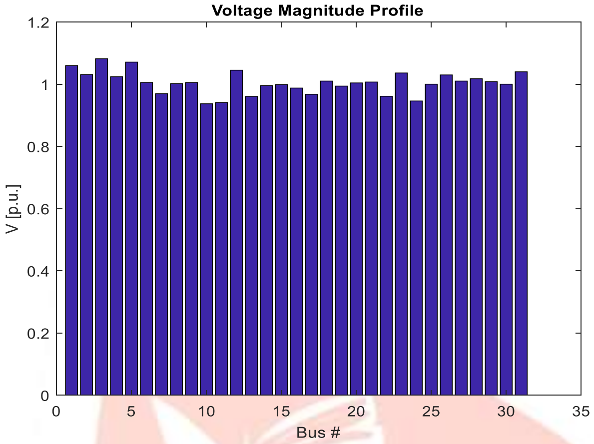

Fig 3.2 Voltage magnitude of Modified IEEE 30 bus system with DFIG

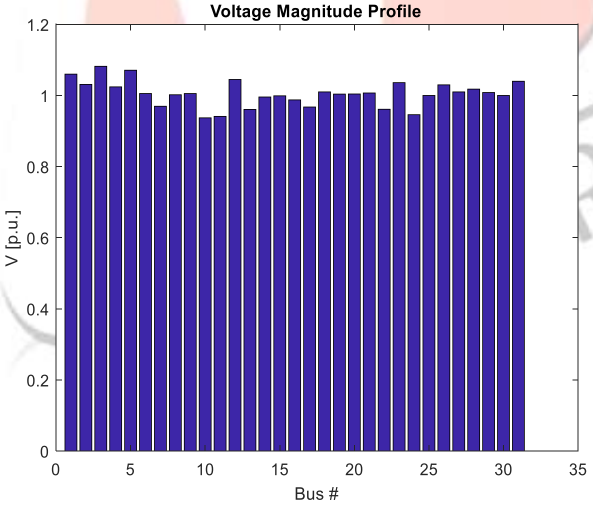

Fig 3.3 Voltage magnitude of Modified IEEE 30 bus system with DFIG and UPFC

Table 3.1 Comparative Analysis

Title	IEEE 30 bus system (base case)	IEEE 30 bus with 12% load increment	Modified IEEE 30 bus with DFIG	Modified IEEE 30 bus with DFIG and UPFC
Total Real Power Generation	291.8 MW	332.06 MW	325.20 MW	323.71 MW
Total Reactive Power Generation	123.17 MVAR	151.39 MVAR	121.8 MVAR	114.7 MVAR
Total Real Power Load	278.9 MW	311.50 MW	311.50 MW	311.5 MW
Total reactive power Load	100.40 MVAR	100.60 MVAR	100.60 MVAR	100 MVAR

Total Real Power Losses(%)	4.42 %	6.19%	4.21%	3.77%
Total Reactive Power Losses(%)	18.48%	33.54%	17.4%	12.81%

4. CONCLUSION

From the above discussion it can be concluded that integration of DFIG and UPFC in a 30 bus system had reduced real and reactive power loss to a significant margin when power demand increases to a considerable extent. The voltage profile also gets stabilized on integration of DFIG and UPFC. Comparative analysis table 3.1 confirms that the real power loss had reduced from 6.19 % to 3.77% (total percentage reduction of 39.09%) and reactive power loss had reduced from 33.54 % to 12.81% (total percentage reduction of 61.80%).Future scope can be given on incorporating various concepts like placement of DFIG and UPFC in a 30 bus system based on locational marginal pricing, power factor along with incorporation of hybrid artificial algorithm’s with it.

5. REFERENCES

[1] Labiba ADJOUDJ, Fatiha LAKDJA and Fatima Zohra GHERBI “Impact of wind turbine based on double feed induction generator and FACTS devices on power systems” Leonardo Journal of Sciences ISSN 1583-0233 Issue 26, January-June 2015 p. 97-112.

[2]Bindeshwar Singh , Bindu Jee Gyanish “Impact assessment of DG in distribution systems from minimization of total real power loss view point by using optimal power flow algorithms” Energy Reports 4 (2018) 407–417.

[3]BindeshwarSingh ,V.Mukherjee , PrabhakarTiwari “A survey on impact assessment of DG and FACTS controllers in power systems” Renewable and Sustainable Energy Reviews 42 (2015) 846–882

[4]M.C. Ramachandran, K. Elango “Improvement of power quality in power system using contingency analsysis” International Journal of Engineering & Technology, 7 (2.21) (2018) 237-241.

[5]John Fletcher and Jin Yang (2010). “Introduction to the Doubly-Fed Induction Generator for Wind Power Applications” Paths to Sustainable Energy, Dr Artie Ng (Ed.), ISBN: 978-953-307-401-6

[6]Nashiren.F. Mailah Senan M. Bashi “Single Phase Unified Power Flow Controller (UPFC): Simulation and Construction” European Journal of Scientific Research ISSN 1450-216X Vol.30 No.4 (2009), pp.677-684.

[7]Yamin HY, Shahidehpour SM. “Transmission congestion and voltage profile management coordination in competitive electricity markets”. Int Journal of Electric Power Energy System 2003;25(10):849–61.

[8] Durga Gautam, Nadarajah Mithulananthan “Optimal DG placement in deregulated electricity market” Electric Power Systems Research 77 (2007) 1627–1636.

.[9] Anusha Pillay, S. Prabhakar Karthikeyan ,D.P. Kothari “Congestion management in power systems – A review”. Electrical Power and Energy Systems 70 (2015) 83–90.

[10] R. Srinivasa Rao , V. Srinivasa Rao “A generalized approach for determination of optimal location and performance analysis of FACTs devices”. Electrical Power and Energy Systems 73 (2015) 711–724.

.