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Challenges, Modeling Simulation and Performance Analysis of Virtual Power Plant in Indian Context

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ABSTRACT:An attempt has been made in this paper to reveal the performance analysis of Virtual Power Plant (VPP) in Smart Grid based on simulation in Matlab/Simulink . Two main Renewable Energy Sources namely PV and Wind generation systems along with controllable load are integrated in VPP for analysis purpose. Matlab/Simulink models of RES are evaluated. Based on the evaluation results are depicted at the end.

KEYWORDS: Virtual Power Plant, Renewable Energy Sources,Photo Voltaic Cell Power Generation System , Wind Power Generation System , Distributed Generation, Distributed Energy Resources

I.FRAMEWORK

A host of issues are confronting India's electrical build out and about the modernization of power grid. Greater electrification will naturally play a significant part in the country's prolonged economic growth, but rising energy demand is outstripping India's available supply. In India at peak usage, demand exceeds supply by seven to eleven percent. Electricity generation in February 2014 was 237.742 gigawatts. By 2032, energy generation in India is expected to be 800 gigawatts.

The supply gaps results into the lack of consistent, comprehensive electric service to citizens as roughly under half of India's rural population is not connected to the grid. Line losses are averaging 26 percent with some states like J&K are having as high as 62 percent. If we consider the country's widespread electrical theft then, transmission line losses average 50 percent. Remarkably, this theft continues despite years of effort by the Indian Government. Thermal efficiency in Indian coal plants also lags at 27 percent compared to 37 percent in the Western countries. Furthermore, the infrastructure is not consistent across the five regional power grids in India which are Northern Region (NR), Eastern Region(ER), Western Region (WR), Southern Region (SR) and North-East Region (NER). Out of all these Regions the NR, ER, WR and NER are synchronized which is known as NEW Grid. Whereas SR is not synchronized with the rest of the regions with AC lines and hence runs on a slightly different Frequency. SR is connected with WR and ER with HVDC links only. Transmission and transportation issues are problematic for moving electricity and fuel needed for power generation due to the geography of hydroelectric and coal resources. Currently there are pockets in India with surplus power that are unable to sell it to those with deficient energy supply, creating an artificial shortage scenario. As a result of these various institutional fractures, each region has developed its own protocols, and a patchwork of generation and transmission solutions. Electrical monitoring across the whole country is very imprecise, making efficient solutions all the more difficult to apply. This all results in frequent power outages, grid failures, heavy line losses, and an increase in overall grid instability.

The government has developed a plan to meet these challenges, and has a huge population and growing expertise in the IT industry to propel it forward. By uniting the complex bureaucracy of the Indian central government with the various states and private expertise, India has laid out an ambitious effort to modernize their grid over the next 10 years.

The Ministry of Power (MoP) has initiated some power sector reforms. Some of main components of it are –

i) The Electricity (amendment) Act 2007

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ii) The Restructured-Accelerated Power Development and Reform Program (R-APDRP)
iii) Distribution Reform, Upgrades and Management (DRUM) program
iv) The Smart Grid Task Force and Smart Grid Forum

The Smart Grid Task Force and Smart Grid Forum coordinates Smart Grid activities in India. Following are the Technologies used in Smart Grid :

a) Smart meters and other sensors
b) Distributed generation
c) Integration of renewable energy resources
d) PHEVs
e) HVDC & FACTs
f) Weather condition Information system
g) Demand control/response
h) Distribution substation SCADA
i) Geographic Information System
j) Micro Grids
k) Virtual Power Plant

After having a background information about Indian scenario of Power system in section - 1 , a brief introduction about Virtual Power Plant is presented in section – 2. Related work is covered in section – 3. The challenges faced while integrating the distributed energy resources in VPP are depicted in section– 4. Section – 5 gives brief introduction about Matlab and Simulink software that has been used in the present work. Section – 6 gives information about modeling and simulation. Section – 7 carries over the results of simulations and discussion. Finally section – 8 concludes the article.

II.INTRODUCTION

Virtual power plants – is a term frequently used interchangeably with ‘‘microgrids’’ , depends upon software systems to remotely and automatically dispatch and optimize generation or demand side or storage resources in a single, secure Web-connected system. In short, VPPs can represent an ‘‘Internet of energy,’’ tapping existing grid networks to tailor electricity supply and demand services for a customer, maximizing value for both end user and distribution utility through software innovations.

The VPP, in short, meshes the unique characteristics of all available potential resources into a ‘‘virtual’’ facility that can be organized by program type, supply-side resource category, or location on the distribution network. VPPs are really geared to helping utilities cope with the Smart Grid by aggregating a meaningful number of Distributed Generations (DGs) or distributed RES and/or customers having controllable loads to reap the rewards of economies of scale in a whole new way. Instead of building bigger and bigger physical power plants, software and other controls enable utilities to aggregate resources on a short term basis according to proximity, cost, environmental performance, and/or other criteria.

Distributed generation (DG) is the application of small generators from 10 to 10,000 kW scattered throughout a power system and either interacting with the grid or providing power to isolated sites [1].

The effective integration of distributed energy resources brings following benefits:

a) reduced central generation capacity;
b) increased utilization of transmission and distribution network capacity;
c) enhanced system security; and
d) reduced overall costs
e) reduced CO_2 emissions.

III. **RELATED** WORK

Virtual Power Plant being an active research area is gaining lot of attention from researchers worldwide. Some basic VPP ideas, structures and control methods have been proposed[2]. A direct load control model for controlling VPP has been also proposed [3]. In broader sense VPP can be categorised as Technical VPP and Commercial VPP. If we consider a commercial VPP then that VPP operator has to bid in the open market. The bidding problem faced by VPP is considered in [4]. Market forecasts about VPP are considered in [5]. Integration of small flexible nuclear power plants

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with off shore wind power plants to form VPP has been studied [6]. Weekly self-scheduling of a virtual power plant composed of intermittent renewable sources, storage system and a conventional power plant has been also studied [7]. Economic dispatch of virtual power plants in an event-driven service-oriented framework using standards-based communications has been tried in [8]. In case of commercial VPP the VPP has to participate in auction for sale of electricity. The simultaneous ascending-clock auction format that has been used for virtually allVPP auctions to date is considered in [9].This work discusses the challenges in integrating distributed energy sources and proposes a VPP model where battery is also considered as a one of the distributed source.

IV.CHALLENGES IN INTEGRATING DISTRIBUTED ENERGY SOURCES

Following are the challenges to be faced while integrating the distributed energy sources [10].

a) These sources have to be connected in distribution network at different voltage level.
b) Many types of larger distributed generation plants use directly connected rotating machines which tends to increase the fault level of the network.
c) Distributed generation affects power quality as there is transient voltage deviation and power electronic circuits inject harmonics as well as transients in the network.
d) The protection schemes used in distributed generation needs to be well equipped with variety of aspects apart from conventional graded protection like protection from internal faults, grid voltage loss protection.
e) The integration scheme should be able to provide power supply having tolerable variation in voltage and frequency.[11]

V. MATLAB/SIMULINK SOFTWARE

MATLAB® is a high-level language and interactive environment for numerical computation, visualization, and programming. Using MATLAB, we can analyze data, develop algorithms, and create models and applications. The language, tools, and built-in math functions enable us to explore multiple approaches and reach a solution faster than with spreadsheets or traditional programming languages, such as C/C++ or Java™. We can use MATLAB for a range of applications, including power systems.

Simulink® is a block diagram environment extensively used for multidomain simulation and Model-Based Design. It supports system-level design, simulation, automatic code generation, and continuous test and verification of embedded systems. Simulink provides a graphical editor, customizable block libraries, and solvers for modeling and simulating dynamic systems. It is integrated with MATLAB®, enabling us to incorporate MATLAB algorithms into models and export simulation results to MATLAB for further analysis[12].

VI. MODELING AND SIMULATION

The following section presents the information about the VPP model developed and the different types of models of renewable energy sources used in this work.

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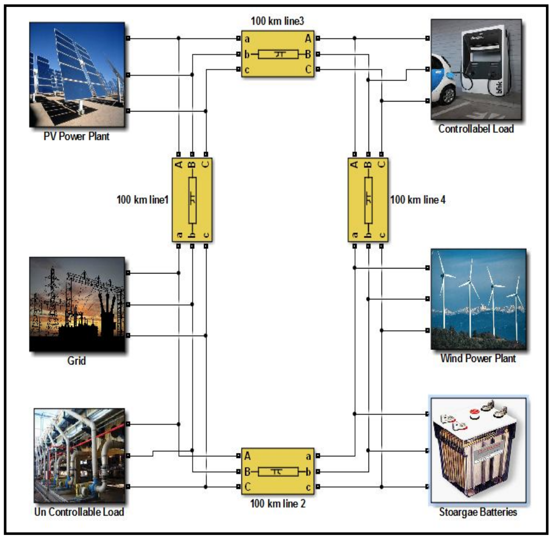

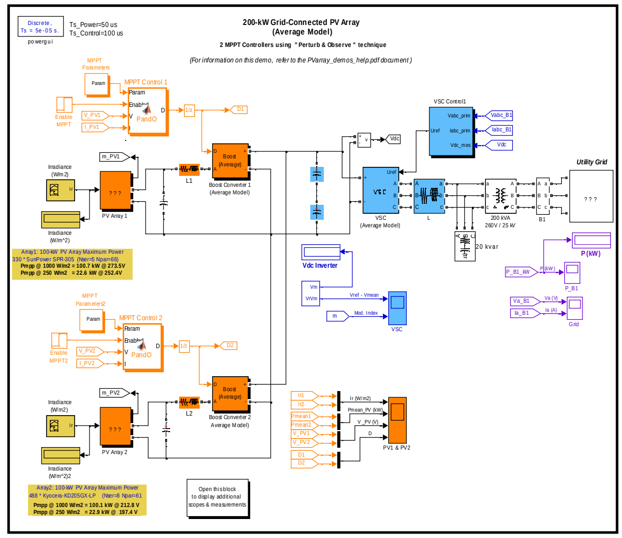

Fig.1 VPP ModelFig.2 PV Model

Fig.1 depicts the VPP model developed in this work. Essentially VPP consists of a centralized energy management system. This system communicates with the different distributed (which may consists of renewable energy sources) energy sources. These distributed energy sources are located at different locations. In the proposed model authors have considered PV power plant, Wind power plant, storage battery, controllable load, uncontrollable load and a utility grid as the components of VPP.

A. PV Array

This is simulated in a model[13] and shown in .This is an average model of a 200-kW array connected to a 25-kV grid via two DC-DC boost converters and a single three-phase VSC. The MPPT controller based on the "Perturb and Observe" technique is implemented by means of a MATLAB Function block that generates embeddable C code.

This model contains

i) Two PV arrays delivering each a maximum of 100 kW at 1000 W/m^2 sun irradiance.
ii) Two average models of boost converter increasing voltage from PV1 and PV2 voltages to 500 V DC. The two MPPT controllers use the "Perturb and Observe" technique.
iii) Average model of VSC. The VSC converts the 500 V DC to 260 V AC and keeps unity power factor.
iv) 20- kVAr capacitor bank filtering harmonics produced by VSC.
v) 200-kVA,260V/25kV three-phase coupling transformer.

The model is shown in Fig.2. Two different modules are used in PV array. One is SunPower SPR-305 WHT and another is Kyocera KD205GX-LP.The characteristics of SunPower-SPR305 PV array are reproduced below in Fig.3.

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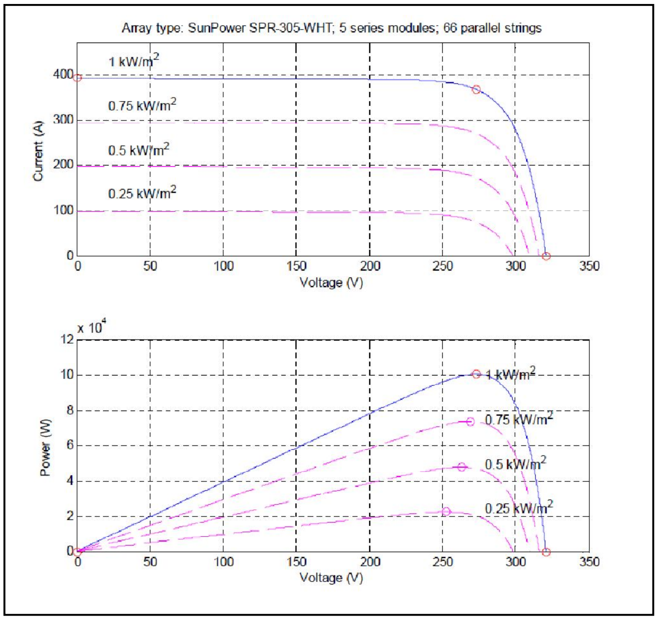


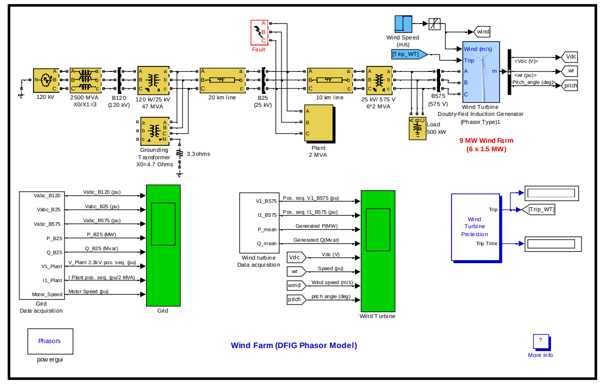


Fig.3 I-V and P-V characteristics of PV arrayFig.4 Wind Farm

B. Wind Farm

This is simulated in model [14]. This illustrates simulation of a 9 MW wind farm using an average model of a Doubly-Fed Induction Generator (DFIG) driven by a wind turbine. In this type of model the Voltage-sourced converters (IGBTs) are represented by equivalent voltage sources generating the AC voltage which is averaged over one cycle of the switching frequency.

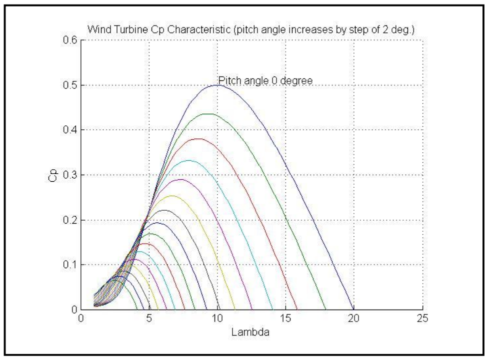
A 9 MW wind farm consisting of six 1.5 MW wind turbines connected to a 25 kV distribution system exports power to a grid .

The model is shown in Fig.4

Wind turbines using a doubly-fed induction generator (DFIG) consist of a wound rotor induction generator and an AC/DC/AC IGBT-based PWM converter modeled by voltage sources. The stator winding is connected directly to the 60 Hz grid. The rotor is fed at variable frequency through the AC/DC/AC converter. The DFIG technology allows extracting maximum energy from the wind for low wind speeds. This is possible by optimizing the turbine speed, while minimizing mechanical stresses on the turbine during gusts of wind.

In this work the wind speed is maintained constant at 15 m/s. The control system uses a torque controller in order to maintain the speed at 1.2 pu. The reactive power produced by the wind turbine is regulated at 0 Mvar.

The turbine Cp curves are displayed in Fig.5.



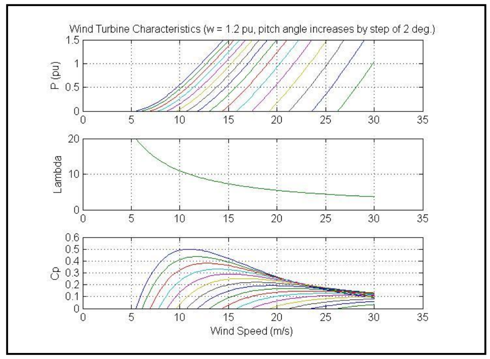


Fig.5 Wind Turbine C_p CharacteristicFig. 6 Wind Turbine Characteristics

The turbine power, the tip speed ratio lambda and the Cp values are displayed in Fig.6 as function of wind speed. For a wind speed of 15 m/s, the turbine output power is 1 pu of its rated power, the pitch angle is 8.7 deg and the generator speed is 1.2 pu.

C. Grid Energy Storage Battery

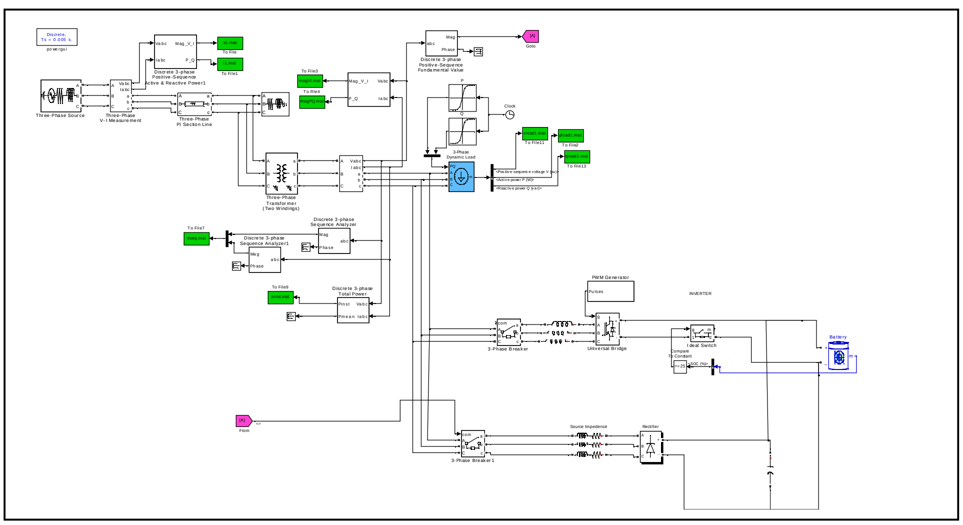


Fig. 7 Grid connected storage battery

Here in the Grid Energy Storage Battery model [15] is suitably modified in Fig.7. In this the grid is simulated by a 3 phase source, and rest of the system by a constant RL load. A 13kV/240V step down transformer supplies a load.The models depicted in [13], [14] and [15] are suitably modified so that they can form a schematic of Virtual Power Plant as shown in Fig.8. The operating conditions of VPP are depicted in Table.1

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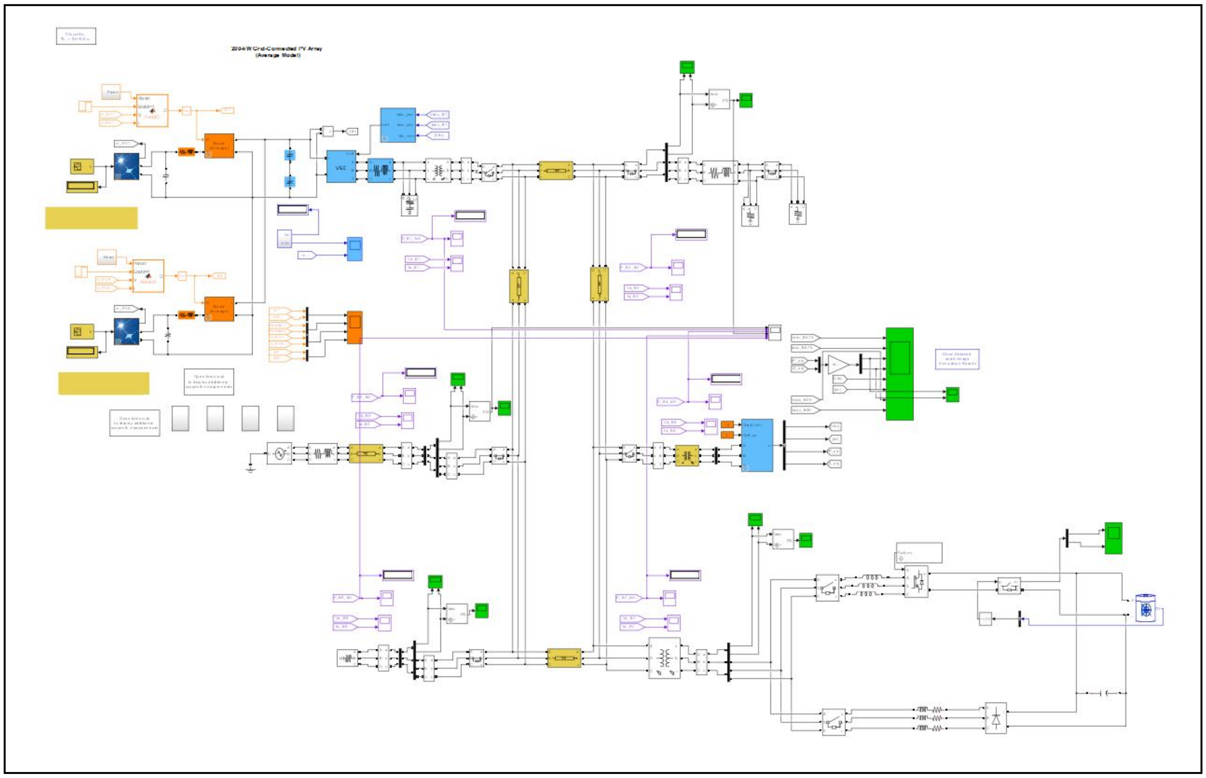

Table 1 Operating conditions of VPP

Time (Seconds)	Type of Source / Load	Condition of Circuit Breakers
T = 0	Grid ON Controllable Load ON Un Controllable Load ON	CB-2 CLOSED CB-3 CLOSED CB-8 CLOSED
T = 2	PV Plant connected	CB-1 CLOSED
T = 4	Controllable Load put OFF	CB-5 OPEN
T = 5	Wind Power plant connected	CB-4 CLOSED
T = 11	Battery charging started	CB-6 CLOSED

VII. RESULT AND DISCUSSION

For simplicity communication between different distributed generators in not considered here. The VPP model is simulated for 14 seconds and grid power variations are shown in Fig.9

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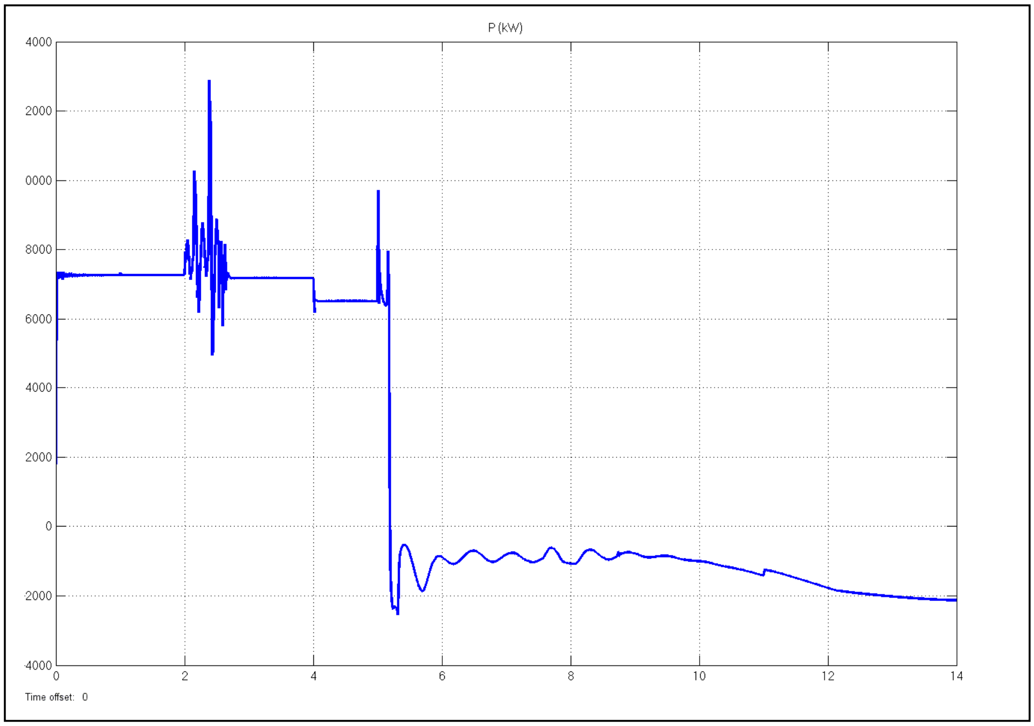

Fig. 9 Power deviations in Grid

The result clearly depicts that at T=0 seconds the utility grid is catering the load . At T=2 seconds the VPP operator asks PV power plant to join the grid. This addition of power being small VPP operator tries to reduce the controllable load 10 MW at T=4 seconds. Then also the load being high, Wind power plant is asked to join the grid. With the addition of Wind power plant at T=5 seconds the load on the system reduces drastically and VPP starts supplying power to the grid. So at T=11 seconds the VPP operator starts charging of Battery as there is surplus power with VPP.

VIII. CONCLUSION

In this work, analysis of Virtual Power Plant integrating distributed renewable energy sources was carried out using MATLAB/ Simulink. The critical analysis of simulation shows the various conditions of power transfer in the integrated environment of DG.

REFERENCES

[1] Felix A Farret, M. Godoy Simoes, “Integration of Alternative Sources of Energy”, John Wiley & Sons, Inc., Hoboken, New Jersey , 2006, ISBN-13: 978-0-471-71232-9

[2] ŁukaszNikonowicz_ ,JarosławMilewski, “Virtual Power Plants – general review: structure, application and optimization”, Vol.92(3), pp.135-149,2012.

[3] Nerea Ruiz, IñigoCobelo, and José Oyarzabal, “A Direct Load Control Model for Virtual Power Plant Management”, IEEE Transactions on Power Systems. Vol.24, No.2, pp.959-966,2009

[4] ElahehMashhour, and SeyedMasoudMoghaddas-Tafreshi, “Bidding Strategy of Virtual Power Plant for Participating in Energy and Spinning ReserveMarkets—Part I: Problem Formulation”, IEEE Transactions on Power Systems. Vol.26, No.2, pp.949-956,2011

[5] Peter Asmus, “Microgrids, Virtual Power Plants and Our Distributed Energy Future”, The Electricity Journal, Vol. 23, Issue 10, pp.72-82, 2010

[6] David Shropshire, ArtursPurvins, IouliaPapaioannou and Isabella Maschio, “Benefits and cost implications from integrating small flexible nuclear reactors with off-shore wind farms in a virtual power plant”, Journal Energy Policy, Vol.46, pp.558-573, 2012

[7] HrvojePandzic, Igor Kuzle, TomislavCapuder, “Virtual power plant mid-term dispatch optimization“,Appl Energy (2012), http://dx.doi.org/10.1016/j.apenergy.2012.05.039

[8] StjepanSucic, TomislavDragicevi, TomislavCapuderb and Marko Delimarb ,” Economic dispatch of virtual power plants in an event-driven service-oriented framework using standards-based communications” Electric Power Systems Research , Vol. 81 pp. 2108– 2119, 2011

[9] Lawrence M. Ausubel, Peter Cramton, “Virtual power plant auctions”, Utilities Policy,Vol.18, pp.201-208 , 2010

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 4, April 2014

[10] N. Jenkins, J.B. Ekanayake and G. StrbacMichael, " Distributed Generation", The Institution of Engineering and Technology, London, United Kingdom, 2010, ISBN 978-0-86341-958-4
[11] R.Valarmathi, S.Palaniswami, N.Devrajan, "Simulation and analysis of Wind energy and photo voltaic hybrid system", International Journal of Soft Computing and Engineering (IJSCE) ISSN: 2231-2307,vol-2, no-2, pp-193-200, May 2012
[12] www.mathworks.com
[13] Grid – connected PV array using SimPowerSystems, Pierre Giroux, MATLAB central, www.mathworks.com
[14] Wind Farm – DFIG Average model by Richard Gangnon (Hydro- Quebec), The Mathworks.Inc
[15] Grid Energy Storage Battery – model available at MATLAB central, http://www.mathworks.in/matlabcentral/fileexchange/38105-grid-energy-storage-battery

BIOGRAPHY

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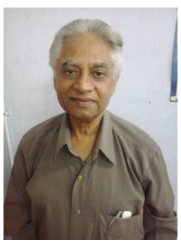

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