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DESIGN AND CONTROL OF MICRO-GRID FED BY RENEWABLE ENERGY GENERATING SOURCES

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Abstract— This paper presents a micro-grid at an isolated location fed from solar and wind energy sources. DFIG (Double Fed Induction Generator) equipped with MPPT (Maximum Power Point Tracking Technology) is used to harness wind energy. A crystalline solar photovoltaic (PV) system is used to convert solar power which is evacuated at the common DC bus of DFIG. The solar power is fed through DC-DC boost converter which is also equipped with MPPT algorithm to extract maximum solar energy. A battery bank is connected at the common DC bus of the DFIG which acts as buffer storage for exchange of energy. The system is designed for complete automatic operation taking consideration of all the practical conditions. The system is also provided with a provision of external power support for battery charging. The voltage and frequency are controlled through a modified indirect vector control of the load side converter which is incorporated with droop characteristics. It alters the frequency set point based on the energy level of the battery. The system is modeled in Sim-Power System tool box of MATLAB and its performance is simulated under varying conditions e.g. unavailibity of wind or solar energy, unbalanced and nonlinear loads has been presented.

Keywords— Renewable Energy System; Solar PV Energy; Wind Energy; Hybrid System; DFIG; Micro-grid; Vector Control; Battery Energy Storage System; Power Quality.

1.NOMENCLATURE

CERTS = Consortium for electric reliability techno- logy solutions
FC = Fuel cell
HGU = Hydro generation unit
MG = Micro-grid
MCFC = Molten carbonate fuel cell
NEDO = New energy and industrial technology development organization
NPEP = Newfoundland power energy plan
PV = Photovoltaic
PCC = Point of common coupling
PAFC = Phosphoric acid fuel cell
SOFC = Solid oxide fuel cell
WT = Wind turbine WPGS = Wind power generation system

2. INTRODUCTION

The demand for more power combined with interest in clean technologies has driven researchers to develop distributed power generation systems using renewable energy sources [1-3]. On the other hand, the integration of a large number of distributed generations into distribution network is restricted due to the capacity limitation of the distribution networks and their unidirectional power flow behaviour [2, 4, 5]. Such barriers have motivated researchers to find an alternative conceptual solution to enhance the distributed generation integration into the distribution networks. An alternative approach called “Micro-grid” was proposed in 2001 as a means of integrating more distributed generations into the distribution networks [5].

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Distributed generation in micro-grid operation provides benefits to the utility operators, distributed generation owners and consumers in terms of reliable power supply, transmission loss compensation, reduction in transmission system expansion and enhancement of renewable power penetration. A review of the existing literature reveals that the first micro-grid architecture was proposed by R. H. Lasseter [5, 6], and called CERTS micro-grid. The CERTS micro grid generally assumes converter-interfaced distributed generation units based on both renewable and non-renewable power sources. Barnes et al [8] also proposed a micro-grid system under the frame of the European project "Micro-grids". The European micro-grid architecture consists of two PV generators, one wind turbine, battery storage, controllable loads and a controlled interconnection for the local low voltage grid. The NEDO in Japan proposed three micro-grid projects in 2003 [9, 10]. The first NEDO micro-grid (1.7MW) system comprises different kinds of fuel cells such as MCFC, PAFC, SOFC, and photovoltaic (PV) system and battery storage. The second NEDO micro-grid (610kW) configuration consists of PV, WT, biomass and battery storage. The third NEDO micro- grid (750kW) system consists of PV, WT, MCFC, biogas and battery bank, which has very low percentage (13 percent) of renewable energy generation. Micro-grid research in Canada has started in universities with the cooperation of the CANMET energy technology center at Varennes [9]. This research group has identified industry cases, such as the isolated Ramea wind diesel micro- grid system, and the Fortis Alberta grid-tied micro grid system for investigation. Canada's micro-grid research and development also evolved to develop a test bed for industrial grade prototype testing and performance evaluation [9]. A study of micro-grid dynamic behavior, along with the control of the micro-generation units is performed by F. Kateraie [7]. This micro-grid system is based on the benchmark system of the IEEE Standard 399-1997 [11], which consists of three generation units comprising a diesel generator or a gas turbine generator, an electronically interfaced distributed generation and a fixed speed wind power generator. Research on micro-grid systems is also found in literature, where the generation units and loads combination are arbitrarily assumed [12-16].

The diverse micro-generation units in a micro-grid system and the desire to integrate more clean power in future power network has led to a focus on a micro-grid system based on renewable power generation units in this research. As a whole, the characteristics of a micro-grid system depend on the size and nature of the micro- generation units in the micro-grid, as well as the site, and the availability of the primary energy resources on the site, especially for renewable power sources. Therefore, taking an existing real system is the better approach to investigate the micro-grid system issues rather than assuming or taking a hypothetical system. The objective of this research is to investigate the system behavior and technical issues of a micro-grid system contains renewable power generation units in Newfoundland. Considering these reasons, the technical challenges and methods for addressing them for the system shown in Figure 1 have not been investigated yet.

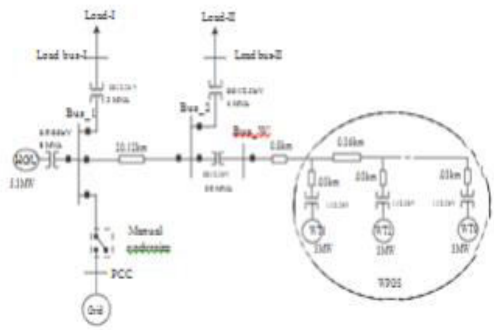

Fig. 1 The micro-grid system currently under investigation

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3. SYSTEM COMPONENTS AND DESIGN PRINCIPL

A single line diagram of the proposed REGS fed micro-grid is shown in Fig.2. The same has been designed for a remote hamlet having projected peak demand and average demand of 15 kW and 5 kW respectively. The capacity of both wind turbine (Pwmrated) and solar panel (Psmrated) in the proposed system is taken as 15 kW each. The capacity utilization factor of 20% is considered for the system which is enough to provide full day energy requirement of the hamlet

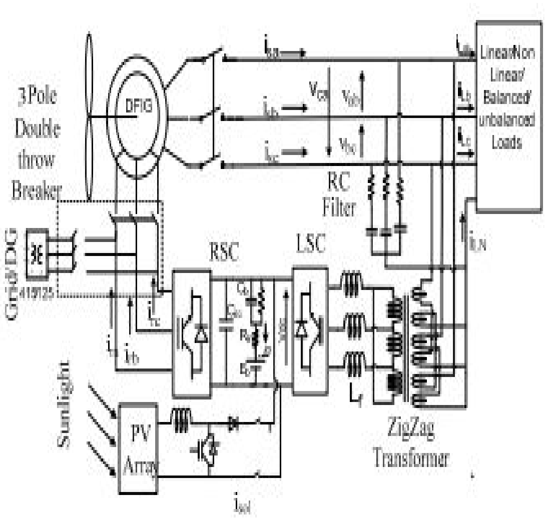

Fig. 2. Schematics of isolated micro-grid network fed by renewable energy source using Battery Storage.

As shown in the schematic diagram, the wind energy source can be isolated with the help of a 3-pole breaker from the network in case of insufficient wind speed. The DC side of both RSC and LSC along with HV side of DC-DC converter are connected at battery bank. RSC helps the wind energy system to run at the optimum rotation speed as required by WMPPT algorithm. The LSC controls the network voltage and frequency. The energy flow diagram of the complete system is shown in Fig. 3. Following sub-sections illustrate the procedure for determination of parameters of each component of REGS.

A.Wind Turbine and Gear

The mechanical energy captured by wind turbine depends on wind speed Vw, radius r and coefficient of performance Cp and related as,

$$P_m = 0.5 c_p \pi r^2 \rho V w^3 \quad (1)$$

C_p is a function λ and angle β [9] and expressed as,

$$c_p(\lambda,\beta) = 0.73\left(\frac{151}{\lambda_i} - 0.002*\beta - 13.2\right)e^{-(18.4/\lambda_i)} \quad (2)$$

where,

$$\frac{1}{\lambda_i} = \frac{1}{(\lambda+0.08\beta)} - \frac{0.035}{\beta^3+1} \quad (3)$$

β is the turbine blade pitch angle and λ is the tip speed ratio (TSR) of the turbine which is a function of generator speed ωr, radius r, wind speed Vw and generator to the turbine shaft gear ratio ηG as,

$$\lambda = \omega_r r/(\eta_G V_w)$$

$$\eta_G = \omega_{rm} r/(\lambda^* V_{wr}) \quad (4)$$

The proposed system consists of 15 kW capacity wind turbine having radius 4.1 m and optimum TSR (λ*) of 5.66. ωrm and Vwr are the maximum allowable generator speed and rated wind speed respectively. The ωrm is chosen as 198 rad/sec which corresponds to the rotational speed of generator as per W-MPPT at Vwr of 9 m/sec. Accordingly the gear ratio ηG as obtained from (4) becomes,

η_G =(198 x 4.1)/(5.66 x 9) = 15.93

B. Rating of DFIG

DFIG should be designed such that it generates 15 kW at rated wind speed. In DFIG, rotor power is slip times the stator power. Neglecting losses, rated rotor power (Prmax), rated stator power (Psmax) and rated input power (Pinrated) are related as,

$$P_{inrated} = P_{smax} + P_{rmax}$$

$$P_{smax} = P_{inrated}/(1+|s_{pmax}|) \quad (5)$$

Spmax is the slip at the rated power of DFIG. The speed range of turbine is 110 rad/sec to 198 rad/sec. Corresponding generator slip range is 30% to -26.7%. Since at rated power, slip is

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spmax=-0.267, hence maximum stator power Psmax corresponding to Pmrated is {15/(1+0.267)} =11.83 kW. As reactive power requirement is met by rotor side converter, 11.83 kW DFIG is sufficient for 15 kW wind turbine. Taking consideration of losses, a 12.5 kW machine is chosen for the system whose detailed parameters are given in Appendix.

C. DC Bus Voltage and Battery Rating

As discussed in sub-section (B), the maximum slip is 0.3 which corresponds to rotor speed of 110 rad/sec. Maximum rotor voltage Vrmax = (415×0.3) ≈ 125 V. For best operation of PWM control, the battery DC voltage (Vb) must satisfy,

$$V_b > \{2\sqrt{(2/3)}V_{L-L}\}m_i \qquad (6)$$

VL-L is the higher of the line voltage of LSC or RSC and is taken 125 V. mi is modulation index which is chosen as unity. Accordingly the DC bus voltage Vb, must be more than 204 V. In the proposed system, Vb is chosen to be 240 V, which is achieved by connecting 20 numbers of 12 V batteries.

The proposed system is so designed that it meets an average load of 5 kW for 12 hours. Taking additional 20% margin for energy losses during exchange of energy, the required battery storage capacity becomes 72 Ampere-Hour (AH). Taking the DC bus voltage to be 240 V, the AH rating of battery becomes 300 AH (72,000/240). This can be achieved using 40 numbers of 12V, 150 AH lead acid batteries divided equally into two parallel circuits is used.

Taking internal resistance of 12V, 150 AH battery as 0.96 mΩ, the total internal resistance of the complete battery bank becomes (0.96 mΩ*20/2) = 9.6 mΩ. The maximum and minimum voltages of a battery are taken 13.2 and 10.8 V respectively. Accordingly maximum battery bank voltage Vbmax becomes 13.2 V*20 = 264 V. Similarly the minimum DC battery bank voltage (Vbmin) becomes 10.8V*20 = 216 V.

A lead acid battery is modeled using a DC source and internal resistance. The voltage change due to charging and discharging can be modeled by connecting the battery to a capacitance (Cb) shown in Fig.2, the value of which is obtained as [10],

$$C_b = kWh \times 3600 \times 1000/\{0.5 \times (V_{bmax}^2 - V_{bmin}^2)\} \qquad (7)$$

A resistance Rb is self discharging of batteries connected in parallel to Cb. Substituting values of Vbmax = 264 V, Vbmin = 216 V and kWh = 72 kWh, the value of Cb obtained is 22500 F.

D. Solar Photovoltaic System

A PV array for this work is based on single diode and 4 parameters [11]. The solar PV array through DC-DC converter is connected to the battery bank. The configuration of solar panels is chosen such that its open circuit voltage should be nearly equal to battery voltage, Vb. The required number of cell (Nc) is a function of open circuit cell voltage Vocc as,

$$N_c = V_b/V_{occ} \qquad (8)$$

Taking Vb and Vocc to be 240 V and 0.606 V respectively, the value of Nc as calculated from (8) comes to be 396 cells which can be arranged in 11 modules having 36 cell each. The ratio of Vocc to cell voltage at maximum power point (MPP), Vmpc for a typical module characteristic is 1.22. Accordingly module voltage at MPP becomes (Vmpc x 36) 17.89 V.

To achieve module capacity of 15 kW, the cumulative array current at MPP becomes {15000/(11*17.89)}76.18 A. The number of array is chosen to be 10, accordingly module current at MPP, Imp becomes 7.62 A. The ratio of short circuit current Isc to Imp for a typical module is 1.082 and accordingly Isc is taken as 8.22 A.

The detailed parameters of solar photovoltaic system used for modeling solar photovoltaic system are given in Table-I

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TABLE I
PARAMETERS OF SOLAR PHOTOVOLTAIC SYSTEM

Parameter	Value
Cell Open Circuit Voltage, V_{occ}	0.606 V
Cell voltage at Maximum Voltage, V_{mpc}	0.497 V
μ_{Isc}	0.04 %/ °C
μ_{Voc}	-0.36%/ °C
Module Rating	136 W
Open circuit voltage of a module (V_{oc})	21.82 V
Short Circuit current of module(I_{sc})	8.22 A
Optimum Operating Voltage(V_{mp})	17.89 V
Current at maximum operating point, (I_{mp})	7.62 A
Number of Modules in a string(N_s)	11
Number of Arrays of Solar photovoltaic system(N_p)	10

E. High Pass Filter

To reduce voltage ripples and a high pass filter is used at PCC tuned at half the 2 kHz is used. Accordingly a series RC filter consisting of 4 Ω resistance and 40 µF capacitance is connected at the stator terminal of DFIG. The filter provides less than 4.46 Ω impedance for harmonic voltage more than 2 kHz. F. Transformer The system is designed for a 3-phase, 4-wire system for which a zig-zag transformer is used to provide neutral terminal for single phase loads. As stated in sub-section (D), the DC bus voltage is chosen as 240 V and for efficient functioning of PWM control, the DC voltage must be more than highest line to line voltage. Therefore transformer low voltage winding voltage is chosen equal to Vrmax i.e. 125 V and its transformer ratio 125/415 V. The 415 V side of the transformer is connected to load and stator of DFIG.The kVA rating of transformer should be more than kVA requirement of the connected loads. Accordingly a 20 kVA transformer is chosen which shall be sufficient to transfer rated power along with meeting reactive power requirement of the connected loads at peak demand.

4. THE MICRO -GRID SYSTEM

The schematic of the micro-grid system shown in Figure 1 consists of a HGU, a WPGS, and two load areas represented as Load-I (3.94 MW, .9 MVar) and Load-II (2.82 MW, 0.84 MVar). The two load areas are connected through a 20.12 km transmission line and the two generating systems are connected through a 21 km transmission line. The wind turbines are connected to bus 2 using its own transmission lines and a 12.5/66kV, 30 MVA power transformer. Load bus-II is connected to bus 2 and the power is delivered to the load using a 66/12.5kV, 4 MVA power transformer. Load bus-I is connected to bus 1 and the power is delivered to the load using a 66/12.5kV, 5 MVA power transformer. The HGU is connected to bus 1 using a 6.9/66kV, 8MVA power transformer. A conventional synchronous generator, equipped with IEEE standard excitation and governor system, is used for the HGU. A 66kV,1000 MVA grid is connected to bus 1. Both power generation systems operate in grid connected mode. The automatic isolated operation of the HGU is not the current practice of the utility owner, and the WPGS is not allowed to operate in isolated mode. In the event that the grid power is lost due to faults or scheduled maintenance, a black out would result until the HGU comes in operation. Even with the HGU in operation, some load shedding may be necessary since the HGU would not be able to meet the load demand. Therefore, the consequences of the grid outage are the key drivers which dictate the operational modes of the micro- grid system.

4.1. Operational Modes of the Micro - grid system

Technical issues such as control, power balance strategies, oper- ation, protection and storage techniques differ from one micro-grid to another. The main reasons are the integration of high number of distributed power generation units near to the electrical loads, the nature and size of the micro-generation units, and availability of primary energy sources for renewable power generation units.

5. RESULTS AND DSICUSSION

A simulation model of the proposed system is developed in Sim power system tool box of MATLAB 7.10 with ode3 solver. The wind turbine and solar panels are modeled using Matlab function. Figs. 3(a) and 3(b) show the performance of the system when the wind generator is taken in an out of the system. Fig. 4 shows the performance of the system when solar PV system is taken in taken out of the system. Both the above scenarios also discuss the MPPT on varying wind speed and radiation respectively. Fig.5 and Fig.6 show the results at loss of load and unbalanced nonlinear loads respectively. Fig.7 shows the scenario when the stored energy and the generated power are low and external charging requirement through RSC.

A.Performance of System at Constant Load and Cut-in and Cut-out of Wind Power

As shown in Fig. 3(a) and Fig.3 (b), the system is started with 4 kW and 3 kVAR load without wind or solar energy sources. At t=2.25 s, the wind generator at wind speed of 7 m/sec is taken in service. As a result, a momentary fluctuation in the system voltage is observed. At t=5.5 s, the wind speed is raised to 8 m/sec followed by reduction of the wind speed to its original value at t=9.5 s. The rotor control action maintains the desired rotational speed as per the W-MPPT algorithm. At t=14 s, the wind generator is taken out of service. During cutin and cutout of wind generator, momentary, the voltage surge is observed. The duration and magnitude of the voltage surge are within the requirement of IEEE 1547 standard.

B. Performance of the System at Constant Load and Cut-in and Cut-out of Solar Power

As shown in Fig. 7, the system is started with 10 kW and 6 kVAR load without wind or solar energy. At t=2.25 s, solar system is taken into the service at radiation of 800 W/m2 . At t=4 s, the solar radiation is raised to 900 W/m2 and again it is reduced to 800 W/m2 at t=6 s. The DC-DC converter adjusts the solar PV voltage and operates at S-MPPT. At t=7 s, the solar system is taken out of service. No significant variation of system voltage is observed at any transition point.

C. Performance of System at Loss of Load

The performance of the micro-grid for loss of all loads has been shown in Fig. 7. The system is started with 10 kW load and 6 kVAR reactive load. Neither wind nor solar power is available and the complete load is provided by battery. At t=2 s, the system load is disconnected. It is found that the system voltage and frequency remains unchanged.

D. Performance of System at Unbalanced Nonlinear Load

The performance of the system at unbalanced and nonlinear is shown in Fig. 6. A micro-grid should be suitable to provide requirement of unbalanced as well as nonlinear loads. A worst case scenario is taken when there are no generating sources connected to the network. The connected load consists of 2 kW linear load and 8 kW nonlinear load. At t=3.25 s, the load of R-phase is removed from the network followed by B-phase load at t=3.75 s. It is seen from the results that the system is able to provide quality power to its customer in case of unbalanced as well as nonlinear load.

E. System Running without Generating Source and Battery Charged from the Grid

Fig.7 shows the scenario when there are no generating sources feeding to the network combined with low battery voltage requiring external charging to sustain the load requirement. Charging circuit is enabled as per the logic diagram of Fig. 5. At t=4 s, wind generation is taken out of service and because of lower battery voltage, the charging circuit is initiated. As a result external power is injected through the RSC to cater load requirement in addition to charging the batteries.

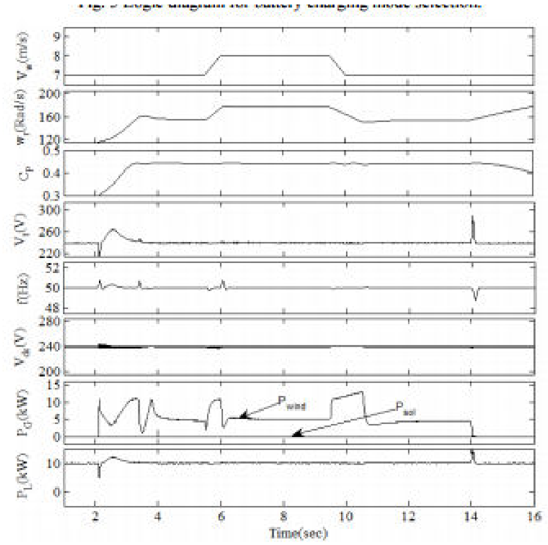

Fig. 3(a) Performance of REGS fed micro grid with wind energy source

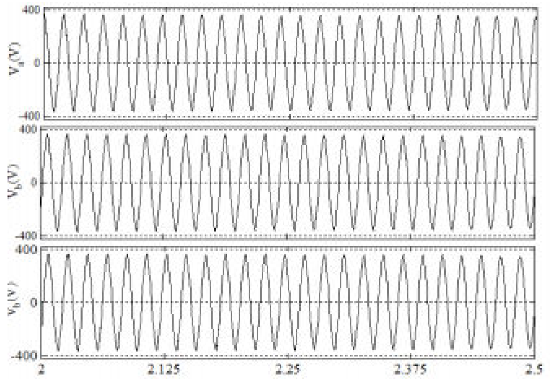

Fig. 3(b) Phase voltage of the system when wind energy source is connected to the network

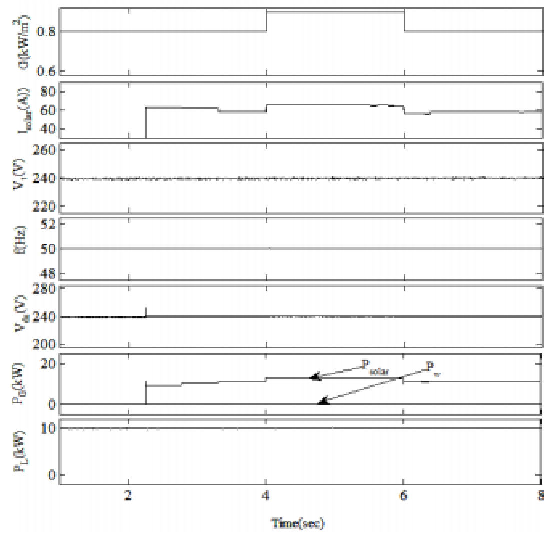

Fig.4 Performance of the system when solar system is taken in and taken out of the service.

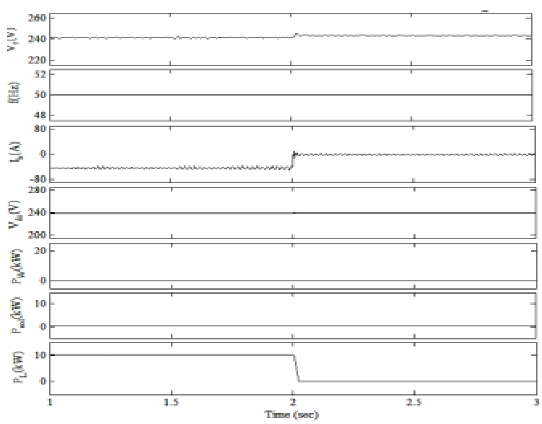

Fig.5 Performance of the system under loss of load at battery power

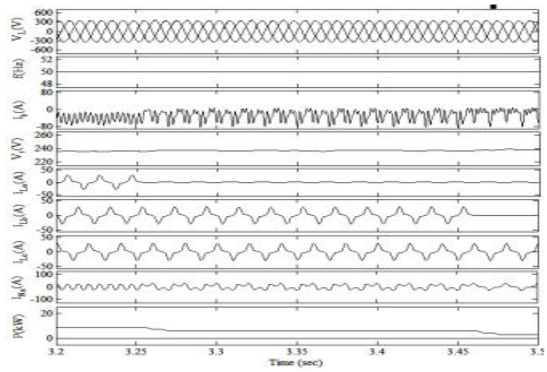

Fig. 6 Performance of the system at unbalanced and nonlinear load

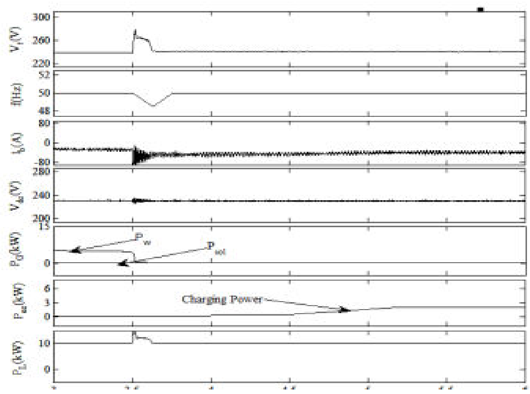

Fig.7.Performance of system through external charging

6. CONCLUTION

The proposed micro-grid system consists of REGS feeding an isolated location. It has used the wind generator with DFIG having MPPT features. The solar photovoltaic system has also been equipped with S-MPPT to extract the maximum solar energy. The system has been designed for complete unmanned operation. The performance of the system under all the practical conditions has been studied and presented. Priority has been given for utilizing the maximum generation form the renewable energy sources. The system has also envisaged the external battery charging by utilizing the rotor side converter and its sensors for achieving rectifier operation with unity power factor.

REFERENCES

[1] R.G. del Valle, M. Cotorogea, B. Rabelo and W. Hofmann, "On the emulation of an isolated wind energy conversion system: experimental results". Proc. IEEE Electronics, Robotics and Automotive Mechanics Conf. CERMA '09, 22–25 September 2009, pp. 462–467

[2] N.A. Orlando, M. Liserre, R.A. Mastromauro and A. Dell'Aquila, " A survey of control issues in PMSG-based small wind turbine system" IEEE transactions on Industrial Informatics, vol.9, no.3, pp 1211-1221, July 2013.

[3] S. Sharma and B. Singh, "Asynchronous generator with battery storage for standalone wind energy conversion system," in Proc. 2011 IEEE Ninth International Conference on Power Electronics and Drive Systems (PEDS), pp.345-350.

[4] I. Penava, S. Galijasevic, A. Muharemovic and M. Penava, "Optimal design and demonstrative application of standalone hybrid renewable energy system" IEEE International Energy Conference (ENERGYCON), pp.960-967, 13-16 May 2014.

[5] N. Adhikari, B. Singh, A.L. Vyas and A. Chandra, "Analysis, design and control of a standalone hybrid renewable energy conversion system" 4th IEEE International Power Electronics for Distributed Generation Systems (PEDG), pp. 1-8, 8-11 July 2013.

[6] Emmanouil A. Bakirtzis and Charis Demoulias "Control of a micro grid supplied by renewable energy sources and storage batteries" XXth International Conference on Electrical Machines (ICEM), pp. 2053- 2059, 2-5 Sept. 2012.

[7] T. Ackermann and V. Knyazkin, "Interaction between distributed generation and the distribution network: Operation aspects", Sec- ond Int. Symp. Distributed Generations: Power System Market Aspects, Stockholm, Sweden, 2002.

[8] C. Abbey, F. Katiraei, C. Brothers, "Integration of distributed generation and wind energy in Canada", Invited paper IEEE Power Engineering Society General Meeting and Conference, Montreal, Canada, June 18-22, 2006.

[9] Frede Blaabjerg, Remus Teodorescu, Marco Liserre, Adrian V.Timbus, "Overview of control and grid synchronization for dis- tributed power generation systems", IEEE Transactions on Indus- trial Electronics, Vol. 53, No. 5,October 2006.

[10] F. Katiraei, C. Abbey, Richard Bahry, "Analysis of voltage reg- ulation problem for 25kV distribution network with distributed generation", IEEE Power Engineering Society General Meeting, Montreal, 2006.

[11] R. H. Lasseter, "Microgrids (distributed power generation)", IEEE Power Engineering Society Winter Meeting, Vol. 01, pp. 146-149, Columbus, Ohio, Feb 2001.

2581-4575

International Journal For Recent Developments in Science & Technology

Crossref

A Peer Reviewed Research Journal

[12] R. H. Lasseter, “Microgrids”, IEEE Power Engineering Society Winter Meeting , Vol. 01, pp. 305-308, New York, NY, 2002.

[13] F. Katiraei, M. R. Iravani, P. W. Lehn, “Small signal dynamic model of a micro-grid including conventional and electronically interfaced distributed resources”, IET Gener. Transm. Distrib., Vol. 01, Issue 3, pp. 369-378, 2007.

[14] M. Barnes, A. Dimeas, A. Engler, C. Fitzer, N. Hatziargyriou, C. Jones, S. Papathanassiou, M. Vandenbergh, “Micro-grid lab- oratory facilities”, International Conference on Future Power System,November 2005.

[15] N. Hatziargyriou, H. Asano, R. Iravani, C. Marnay, “Micro-gridsAnoverview of ongoing research, development and demonstration projects”, IEEE Power and Energy Magazine, pp. 78-94, July/August 2007..

[16] S. Morozumi,, “Overview of micro-grid research and develop- ment activities in Japan”, A Symposium on Micro-grids,Montreal, June 23, 2006.

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