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STANDALONE MICROGRID USING HYDRO-WIND-PV BASED ENERGY GENERATION SYSTEM FOR POWER MANAGEMENT AND CONTROL

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***Abstract*—** A hybrid renewable energy network provides greater reliability than a single source network. An adaptive sliding mode control (ASMC) with a standalone single-phase microgrid network of enhanced power efficiency. Wind and solar combinations are the most promising source of power mainly because of their complementary benefit. The proposed Microgrid network includes a single-phase, governor-free, two-phase, self-exciting, wind-driven, brushless dc wind-based permanent magnet generator, a solar photovoltaic (PV) array and a battery power storage. Such renewable energy sources are combined with a single-phase VSC converter. In addition to the harmonic current mitigation, the ASMC control algoritm is used to measure the reference source current that controls the single-phase VSC and regulates voltage and frequency of the microgrid. The ASMC proposed estimates the actual and reactive reference power of the device adaptable to fluctuating loads. The sliding mode control is used to estimate the reference real power of the device, which governs the frequency of the standalone micro grid, to maintain energy balance between wind, micro-hydro, solar PV and BESS power. A digital signal processor controller is used to implement the proposed microgrid in real time. MATLAB / Simulink Simulation results from proposed microgrid show that network voltage and frequency are constant as the device meets abrupt load shifts and the wind and solar energy sources intermittently penetrate.

I. INTRODUCTION

The demand for power is ever-increasing. Use of fossil fuels i.e. gas, coal, oil etc. in producing power is also increasing. Still, there are over 1.5 billion people over the world deprived of access of electricity living mostly in remote areas [1]. The source of electricity in those remote islands and villages is diesel generator. This is both costly and hazardous for the environment due to the global warming. Renewable energy resources like wind and solar energy are getting popularity for these reasons. The high cost and limited computational capability have been the two main limiting factors of digital signal processor controllers in previous years, which have reduced their use in implementation of soft computing-based control algorithms for power electronic systems. In order to achieve proper integration of renewable energy sources (RES), the development of effective frequency and voltage control scheme is essentially desired.

The concept of microgrid is most interesting for successful dealing with the challenges in the integration of renewable energy sources. A microgrid is having capability to operate in both standalone and grid tied modes operation depending upon the design of suitable control scheme. The various derived forms of the microgrid such that virtual power plant, cognitive microgrid and active distribution system can be studied as a main constituent of smart grid. In grid tied microgrid, the main grid supplies the deficit power and absorbs the surplus power in a grid tied microgrid in order to maintain power balance which in turn regulates the system frequency. A comprehensive review of control of power electronic converters used in microgrid is presented. The main challenge in control of standalone microgrid includes the balance of powers and control of system voltage.

The adaptive sliding mode control (ASMC) eliminates all possibilities of overshoot and undershoot problem in DC link voltage of the VSC which reduces the required size of DC link capacitor and BESS. The proposed control reduces the size required for DC link capacitor connected across the BESS. The proposed single-phase microgrid integrates the renewable energy sources of low power capacities for their optimum utilization. The capacity of a BESS required to handle surplus generated power is also reduced by integrating various renewable energy sources. The reliability of the system is improved by integrating various low power renewable energy sources, as it is the main limiting factor in utilizing low power renewable energy sources. The reliability is further improved by adding the BESS. The cost of the BESS becomes the main issue while it is used as separately for each individual renewable energy sources like solar PV-array, micro-hydro and wind based generation to improve the reliability of individual system. The total required capacity of the BESS is significantly reduced using proposed standalone single-phase microgrid system.

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The proposed control algorithm regulates the system voltage and frequency, mitigates harmonics current, ensures maximum utilization of BESS capacity and also integrates the various small renewable energy sources. Whenever, the dynamic situation arises (e.g., variation in loads, wind speed or insolation level of solar radiation), the proposed control algorithm maintains the power balance by shifting the load among three generating systems even if it is not possible to achieve power balance, wherein only the BESS comes into action. Thus, the capacity of BESS is optimally utilized. The BESS is used for frequency control instead of speed governor at the small hydro turbine in order to make the system frequency independent of the mechanical inertia of turbine generator. The proposed microgrid is suitable for low power generation using hydro, wind and solar energy to cater to modern nonlinear loads.

II. SYSTEM MODELING

The ASMC algorithm provides a robust and adaptive control of system frequency and voltage with good dynamic and steady state response, which is the main requirement of a good standalone microgrid as reported by IEEE-PES Task Force on microgrid control. The reported single-phase SEIG is investigated by many researchers for bio energy and small hydro driven systems but the benefits of this machine are not fully exploited for microgrid system (fearing the complications of nonlinear relationship in frequency, magnetizing reactance and speed of single phase SEIG). SEIGs have many advantages over other generators, like simple, brushless, low unit cost, low maintenance, high power/weight ratio, absence of DC excitation etc. In the proposed system the governor-less control of small hydro uncontrolled turbine driven SEIG and wind driven PMBLDC generators, reduces the overall cost and size of the generators significantly. It also makes the system frequency independent of the mechanical inertia of turbine generator. The block diagram of proposed single-phase microgrid is depicted in Fig. 1. This microgrid consists of an unregulated micro-hydro turbine driven single-phase two winding SEIG (Self-Excited Induction Generator), a wind turbine driven PMBLDC (Permanent Magnet Brushless DC) generator, solar PV (Photovoltaic) array and a BESS. Conceptually, the single-phase SEIG is only the AC generating source in this microgrid, which directly caters the load whereas remaining two generating sources are connected to the load through a voltage source converter (VSC). It converts the DC power generated by PMBLDC generator and solar PV array into AC power when the power generated from SEIG is less than the load. The solar PV-array, wind turbine driven PMBLDC generator and BESS are connected at the DC bus of the VSC.

All these three energy sources supply only the real power to the system. They do not participate in any reactive power transaction with the system. When the total real power generated by the SEIG, PMBLDC generator and solar PV-array is less than the load, then the BESS compensates the additional real power demand of the load. The VSC converts the DC power supplied by the BESS into the AC power to make it suitable for single-phase load connected at AC side of microgrid. In the alternate case, the surplus energy is stored in the BESS to maintain the power balance. Under variable load conditions, single-phase SEIG and the load need adjustable harmonics and reactive power to maintain the microgrid AC voltage at rated value. An adaptive sliding mode control (ASMC) based algorithm is developed to estimate the reference source current and switching pattern for VSC of microgrid. The block diagram of proposed ASMC algorithm is shown in Fig. 2. It is well known that the SEIG system requires an adjustable reactive power under varying load conditions to maintain the PCC voltage at reference value.

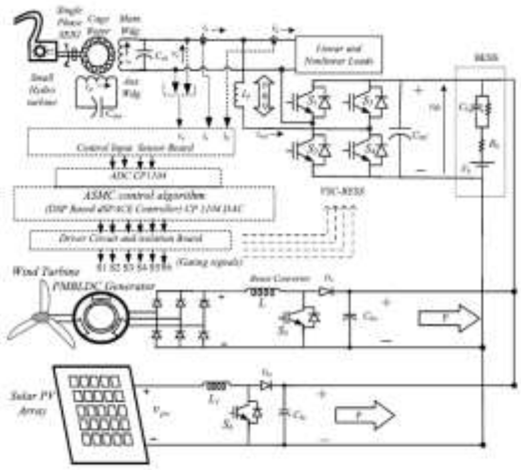

Fig:1. System configuration of the single-phase microgrid.

The quadrature constituent of microgrid AC voltage is estimated and generated using frequency estimation and phase shifting (FEPS) block. The in-phase part of reference source current is responsible for frequency control of the system and power balance among SEIG, PMBLDC generator, solar PV-array, battery and the load. In proposed ASMC control algorithm, an adaptive filter is used to extract the amplitude of fundamental active and reactive power constituents of load current.

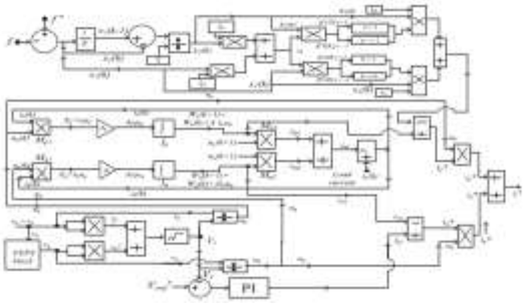

Fig:2. Control algorithm of adaptive sliding mode control (ASMC).

The proposed control algorithm is a combination of two control loops. First loop controls its voltage by injecting an adjustable reactive power and other loop maintains active power balance among various energy elements in the microgrid. The perturb and observe (P & O) control algorithm is used for sensorless control for MPPT of PMBLDC generator based wind energy conversion system. A boost converter is connected at the output of diode bridge rectifier. This converter is controlled using P & O algorithm to extract maximum power from the wind generating system. An incremental conductance based control algorithm is used to extract maximum power generated from solar PV array.

III. SIMULATION RESULTS

The effect of change in insolation level and step change in wind speed and load are taken into consideration to verify the dynamic performance of the proposed control.

CASE-1: DYNAMIC PERFORMANCE OF PROPOSED MICROGRID AT A STEP CHANGE IN SOLAR INSOLATION LEVEL

The response of microgrid following a step increase in solar insolation level is demonstrated in Figs. 3(a) and 3(b). The response of the system following a step decrease in solar insolation level is shown in Fig. 3(c). A step increase in solar PV-array output current (channel 3 of result shown in Fig. 3(a)) has been observed while the system is following a step increase in insolation level. Simulation results (Figs. 3(a) to 3(b)) show that in response to this step increase in solar PV-array output current, the controller increases the charging current of the battery to divert the surplus generated power to BESS in order to control the system frequency.

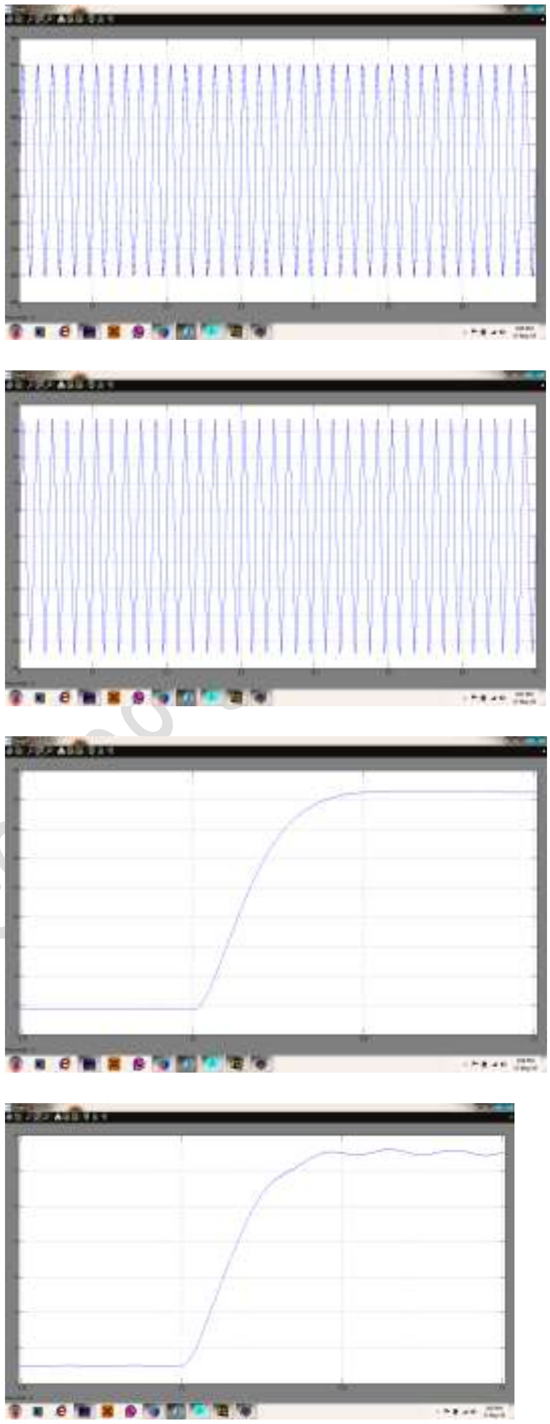

Fig.3(a): Dynamic performance of the *Vs*, *is*, *Ipv* and *Ibattery*, while the system is following a step increase in insolation level.

The dynamic performance of SEIG current is shown in Fig. 3(a), while the system is following a step increase in insolation level. Fig. 3(a) shows that the step change in solar insolation level does not cause any change or disturbance in the system voltage and SEIG current. It proves that proposed controller maintains the power balance under a dynamic situation arose due to step increase in solar insolation level which in turn increases the solar PV-array output current. The

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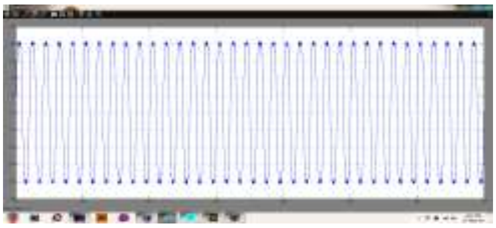
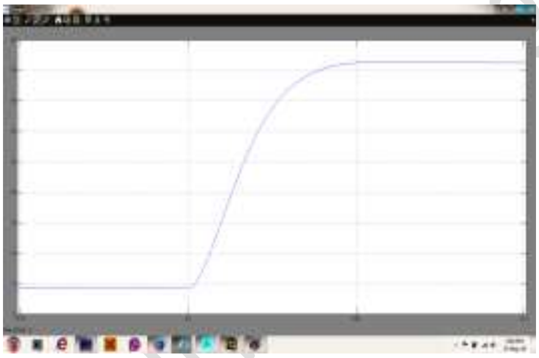
total generated power from all three renewable sources (micro-hydro, wind and solar PV array) becomes more than load. Therefore, surplus power is diverted to the battery in order to control the system frequency. Fig. 3(a) demonstrates the directional change of the battery current from discharging to charging mode in response to a step increase in solar PV-array output current. This balance of power among the various energy sources is achieved using frequency control loop of the proposed ASMC algorithm.





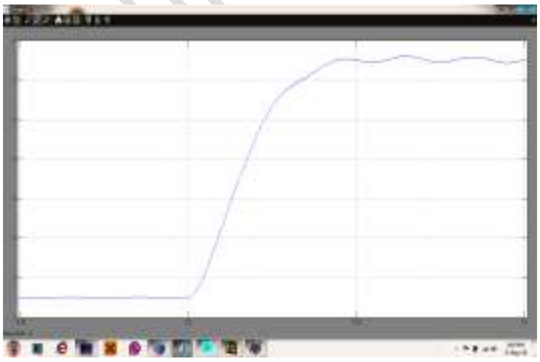
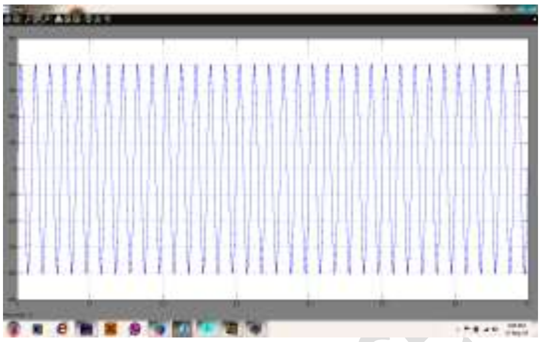
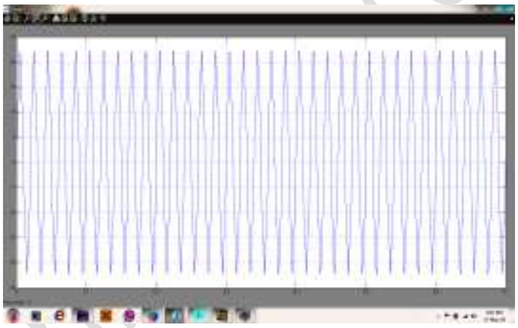
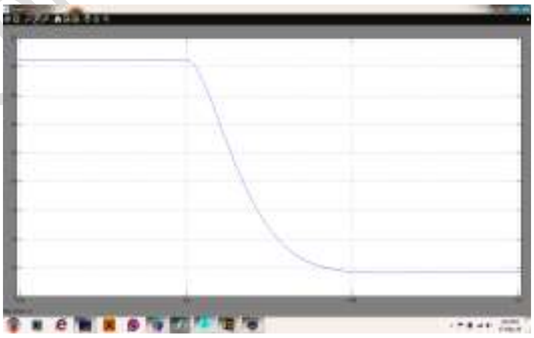


Fig.3(b): Dynamic performance of the *IL*, *iVSC*, *Ipv* and *Ibattery*, while the system is following a step increase in insolation level.

The step increase in insolation level does not cause any disturbance or change in load current, as demonstrated in Fig. 3(b).







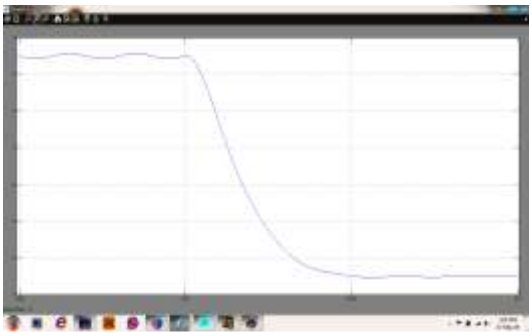


Fig.3(c): Dynamic performance of the *Vs*, *is*, *Ipv* and *Ibattery*, while the system is following a step decrease in insolation level.

The dynamic performance of the system voltage, SEIG current, solar PV-array current and battery current while the system is following a step decrease in insolation level, are demonstrated in Fig. 3(c). It is observed from test results shown in Figs. 3(c) that the step decrease in insolation level causes a decrease the solar PV-array current with

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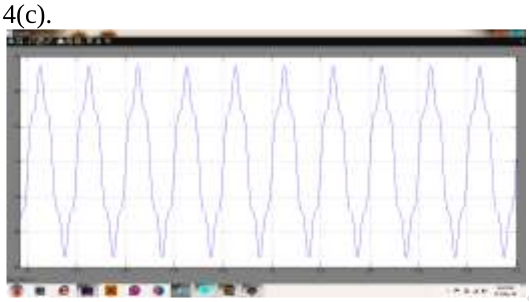
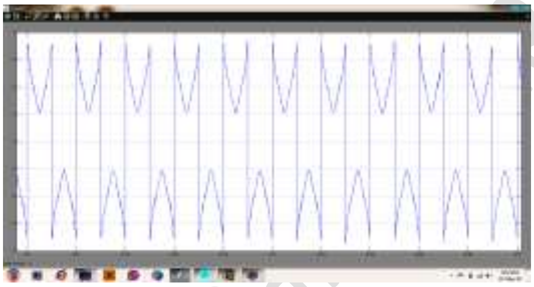
the same slope and it subsequently decreases the battery current but it does not disturb the system AC voltage, load current or system frequency. The battery current goes from charging to discharging mode in order to regain the power balance in the system as shown in Fig. 3(c). Simulation results show that the system frequency and voltage are maintained constant during this dynamic condition.

CASE-2: DYNAMIC PERFORMANCE OF MICROGRID, UNDER A STEP CHANGE IN WIND SPEED

The effect of a step change in the wind speed and consumer load on various other power quality parameters like system voltage, frequency, VSC current and load current, is considered to evaluate the dynamic performance of proposed microgrid. The response of the system following a step increase in wind speed is demonstrated in Figs. 4(a) and 4(b).The response of the system following a step decrease in wind speed is depicted in Fig. 4(c).





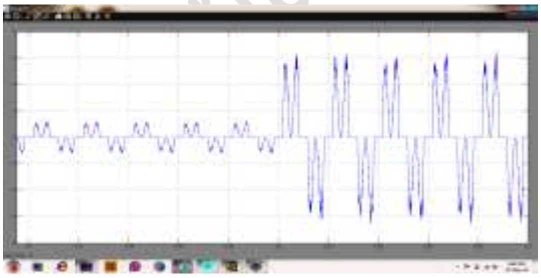
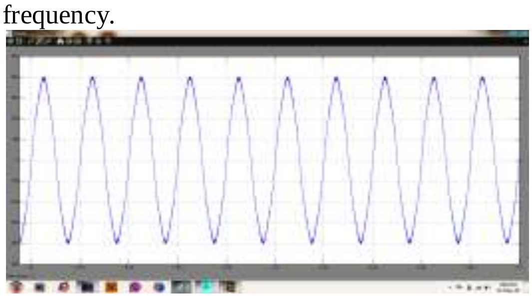


Fig.4(a): Dynamic response of *IL*, *iVSC*, *Ipmbldc* and *Ibattery*, while the system is following a step increase in wind speed.

The dynamic response of load current, VSC current, PMBLDC generator current and battery charging current are shown in Fig. 4(a) while the system is following a step change in wind speed. A step increase in PMBLDC generator current is observed in Fig. 4(a) while microgrid is following a step increase in wind speed. Test results shown in Fig. 4(a) to Fig. 4(b) show the system response to step increase in wind speed. The controller increases the battery charging current to divert the surplus generated power to the battery in order to control the system frequency. The dynamic response of system AC voltage, SEIG current, PMBLDC generator current and battery current while the system following a step decrease in wind speed, is demonstrated in Fig. 4(c). A step decrease in PMBLDC generator current (in response to the step decrease in wind speed) does not cause any disturbance in the SEIG current and system AC voltage as shown in Fig. 4(c).Test results shown in Figs. 4(a) and 4(b) show that total generated power from all three renewable sources (micro-hydro, wind and solar PV array) becomes more than that of load, while the system is following a step increase in wind speed**.** Therefore, battery charging current increases to divert surplus power to the battery in order to control the system frequency.



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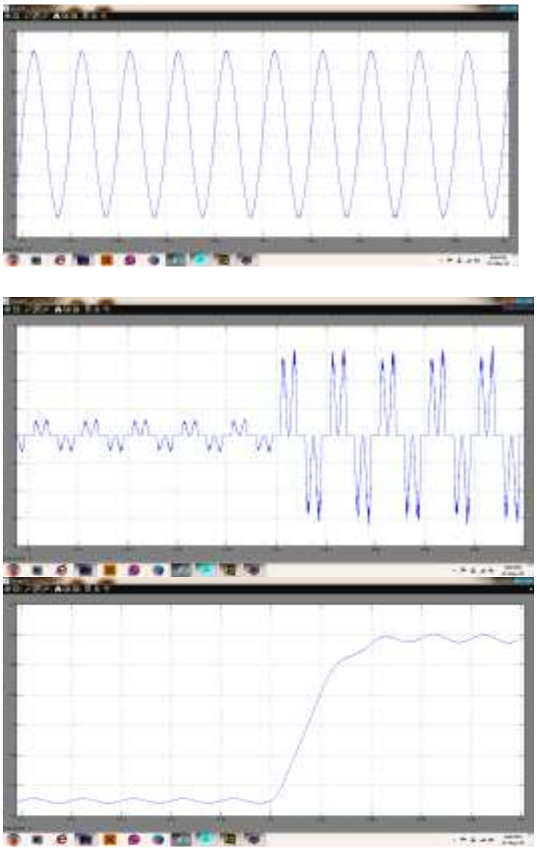

Fig.4(b): Dynamic response of *Vs, is, iPMBLDC* and *ibattery,* while the system is following a step increase in wind speed.

Fig. 4(b) demonstrates the directional change of battery current from discharging to charging mode in response to a step increase in PMBLDC generator current. This balance of power among the various energy sources is achieved using frequency loop of the control algorithm. The step increase in wind speed and PMBLDC generator current does not cause any disturbance or change in load current, as demonstrated in Fig. 4(a). It can be observed from test results shown in Fig. 4(c) that a step decrease in wind speed causes a decrease in the PMBLDC output current with the same slope and it subsequently decreases the battery current.

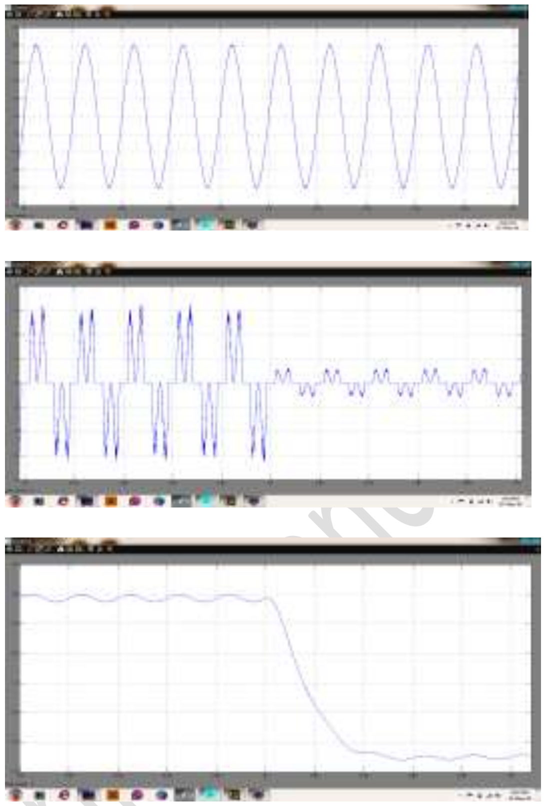

Fig.4(c): Dynamic response of *Vs, is, iPMBLDC* and *ibattery,* while the system is following a step decrease in wind speed.

While system is following a step decrease in wind speed, the battery enters discharging mode from charging mode in order to regain the power balance in the system as shown in Fig. 4(c). A step decrease in wind speed does not disturb the power quality parameters of the microgrid such as system frequency and voltage. It also does not cause any variation in the SEIG output current and load current. It can be clearly observed from Fig. 4(c) that the BESS entering the discharging mode from the charging mode in response to a step decrease in wind speed to control the system frequency and to maintain the balance of power among various generators and BESS. A step decrease in wind speed does not disturb the power quality parameters of the microgrid such as system frequency, voltage and THD. It also does not cause any fluctuation in the SEIG voltage, current and load current. Test results shown in Figs. 4(a) to 4(c) prove the ability of the proposed control algorithm to balance the power among the various sections of the system while the wind speed is fluctuating.

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CASE-3: DYNAMIC PERFORMANCE OF THE MICROGRID, WHILE IT FOLLOWING A STEP CHANGE IN LOAD:

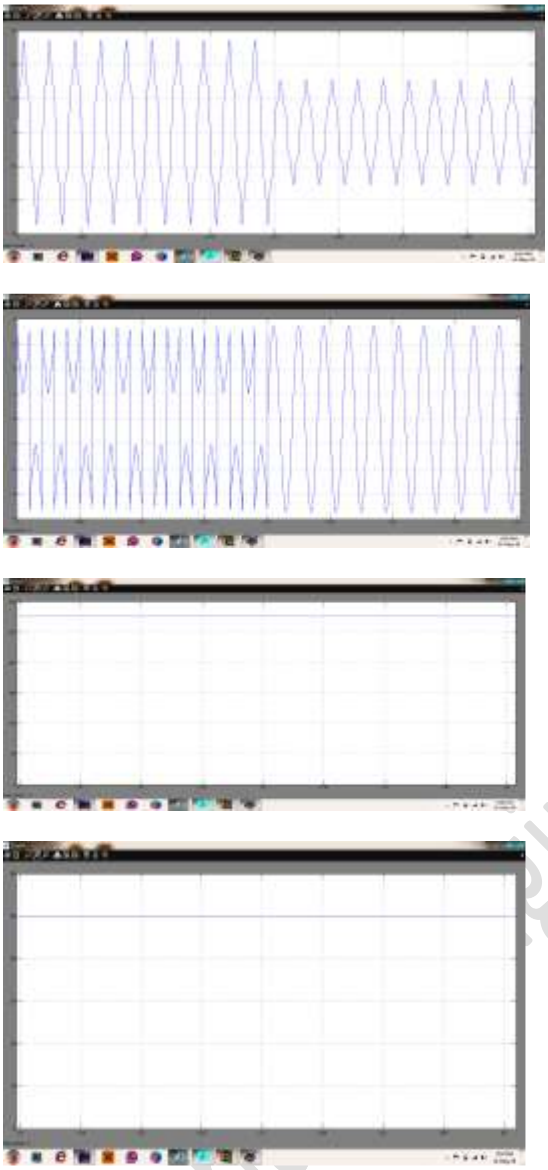

Fig.5: Dynamic response of the proposed system, following a step change in wind speed and load.

The dynamic response of the load current, VSC current, SEIG output voltage and system frequency while system is following a step change in load is demonstrated in Fig. 5. In this dynamic condition, the proposed control re-estimates the revised harmonic and fundamental reactive power need of the SEIG and load as well as active power need of the load with an excellent dynamic response. Here the control revises the switching pattern for VSC to compensate the new reactive and active powers need of the system in order to regulate system voltage and frequency, respectively. Fig. 5 shows that microgrid voltage and frequency are restored to their rated value immediately in response to sudden change in load.

IV. CONCLUSION

A adaptive sliding mode control algorithm has been implemented in real time with the DSP controller for the voltage and frequency regulation of the independent single-phase microgrid. Three key renewable sources including micro-hydro, solar PV, and wind energy were incorporated in the proposed SEIG standalone microgrid. Test results have shown that the ASMC algorithm is efficient and good voltage and frequency control is in place. The proposed control algorithm has also improved the microgrid power efficiency under linear and nonlinear charges and also ensures the efficient use of BESS and renewable energy sources.

REFERENCES

[1] P. Dondi, D. Bayoumi, C. Haederli, D. Julian, and M. Suter, “Network integration of distributed power generation,” *J. Power Sources*, vol. 106, nos. 1–2, pp. 1–9, 2002.

[2] J. P. Lopes, N. Hatziargyriou, J. Mutale, P. Djapic, and N. Jenkins, “Integrating distributed generation into electric power systems: A review of drivers, challenges and opportunities,” *Elect. Power Syst. Res.*, vol. 77, no. 9, pp. 1189–1203, 2007.

[3] N. Hatziargyriou, H. Asano, R. Iravani, and C. Marnay, “Microgrids,” *IEEE Power Energy Mag.*, vol. 5, no. 4, pp. 78–94, Jul./Aug. 2007.

[4] N. Ruiz, I. Cobelo, and J. Oyarzabal, “A direct load control model for virtual power plant management,” *IEEE Trans. Power Syst.*, vol. 24, no. 2, pp. 959–966, May 2009.

[5] H. Morais, P. Kádár, M. Cardoso, Z. A. Vale, and H. Khodr, “VPP operating in the isolated grid,” in *Proc. IEEE Power Energy Soc. Gen. Meetting*, Pittsburgh, PA, USA, 2008, pp. 1–6.

[6] D. Pudjianto, C. Ramsay, and G. Strbac, “Virtual power plant and system integration of distributed energy resources,” *IET Renew. Power Gener.*, vol. 1, no. 1, pp. 10–16, Mar. 2007.

[7] A. Molderink, V. Bakker, M. G. C. Bosman, J. L. Hurink, and G. J. M. Smit, “Management and control of domestic smart grid technology,” *IEEE Trans. Smart Grid*, vol. 1, no. 2, pp. 109–119, Sep. 2010.

[8] D. Pudjianto, C. Ramsay, and G. Starbac, “Microgrids and virtual power plants: Concepts to support the integration of distributed energy resources,” *Proc. Inst. Mech. Eng. A J. Power Energy*, vol. 222, no. 7, pp. 731–741, 2008.

[9] H. Karimi, H. Nikkhajoei, and M. R. Iravani, “Control of an electronically-coupled distributed resource unit subsequent to an islanding event,” *IEEE Trans. Power Del.*, vol. 23, no. 1, pp. 493–501, Jan. 2008.