A HYBRID DIESEL-WIND-PV-FC BASED POWER MANAGEMENT SCHEME THROUGH BRUSHLESS GENERATORS

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Abstract

This paper presents associate implementation of a standalone micro grid topology supported one voltage supply device (VSC) and brushless generators .The micro grid system is energized with completely different renewable energy sources specifically wind, cell and star PV array. However, a diesel generator (DG) set and electric battery energy storage system (BESS) are wont to maintain the reliableness of the system. The planned topology has the advantage of reduced shift devices and easy management. The enforced topology has DGset as associate ac supply. The generator, cell and therefore the star PV array ar dc sources that ar connected to the dc link of the VSC. The BESS is additionally used at the dc link to facilitate the fast power balance beneath dynamic conditions. at the side of the system integration, the VSC additionally has the potential to mitigate the ability quality issues like harmonic currents, load equalization, and voltage regulation. a good sort of check results ar bestowed to demonstrate all the options of the planned system.

Index:-Terms—Brushless generator, composite observer, power quality, Standalone micro grid, voltage regulation, voltage source converter (VSC).

I.INTRODUCTION

Electrical power systems face several challenges in development and growth. These aren't any longer restricted in technical, economic, or monetary in nature however square measure environmental and social. temperature change and property development square measure major challenges of the twenty first century, with extraordinary implications for energy and environmental security. the employment of ancient energy sources like gas, coal and oil causes the rise of current generation value besides their waste product effects to surroundings. A zoom of the energy demand effects on} the surroundings and deed an extended lasting harmful effect on the surroundings. Renewable energy resources like wind energy, solar PV, recurrent event energy and cell have the potential to beat these difficulties. For different regions and locations, weather conditions together with star irradiance, temperature and wind speed square measure unendingly dynamical. it's going to cause the instability defect for electric power generation from star electrical phenomenon and wind turbines. so as to with efficiency and economically utilize the renewable energy resources the thought of Hybrid Energy Systems (HES) has been planned. This work focuses on the event of power management systems, management systems for solar-wind-diesel-Fuel cell hybrid energy system, check and validates the algorithms in simulation interface. Mathematical modeling is needed to develop and simulate the model of star electrical phenomenon, wind, diesel energy and cell conversion system.

A modern power network is one that takes advantage of leading technologies to enhance installation potency, dependability and suppleness. variety of technical, economic and social factors square measure coming back along to form micro grids the largest driving modification within the electrical power infrastructure on the horizon. the price of distributed generation is constant to drop and is competitive with grid-supplied power in several regions. for instance, electrical phenomenon (PV) panels and inverters still decline in value and clean gas discharged and diesel generation is cheap thanks to terribly low gas costs. Fuel cells (FCs) square measure rising as a promising supplementary power sources thanks to their deserves of cleanness, high potency, and high dependability. the importance of desegregation renewable energy sources square measure currently thought-about as potential resolution for a propertyfuture. The management of a magnet synchronous generator (PMSG) primarily based wind energy conversion system; connected to associate degree electrical converter with battery acting as a grid is bestowed. The ability generated by WECS is employed to regulate the SOC of battery. In most of the systems, delineate within the literature, variable speed wind energy conversion system operates to extract the most power from the wind. Wind energy is free energy at the operation stage, therefore it's useful to extract the most power and to extend the potency and therefore the utilization of WECS. It wants initial opportunity cost, however the fuel is free. There square measure several topologies and algorithms rumored for MPPT in WECS and star PV system. As in [19]–[21], totally different strategies for MPPT in WECS square measure planned like formula just like hill ascension, the mechanical sensing element less MPPT formula with this controlled electrical converter, and therefore the mechanical sensing element less MPPT formula with a lift device. Basic MPPT algorithms for star PV system square measure delineate in [22] and [23]. These square measure per- turb and observe formula and progressive conductance-based formula. Moreover, a bearing formula is needed to regulate the VSC connected for its operation as voltage and frequency controller, mitigating power quality issues and desegregation the dc sources with ac sources. several basic management algorithms square measure rumored within the literature. Singh and Solanki have rumored SRF, IRPT, and ADALINE {based mostly| primarily based} management formulas and Icos alphabetic character based algorithm for DSTATCOM. a sophisticated management formula supported composite observer is rumored. Composite observers square measure wants to extract harmonic parts from any signal then the extracted elementary is additional utilized in this management formula. This paper deals with associate degree implementation of a reduced device topology of a diesel-wind-solar PV-based standalone small grid system with the BESS. These generators square measure synchronous reluctance generator (SyRG) and magnet brushless dc generator (PMBLDCG). each these generators square measure brushless in construction. The wind and star PV systems square measure perpetually operated at their most electric receptacle exploitation boost converters and therefore the decigram is operated at intervals a fixed power vary to optimize the potency of the decigram. A VSC is employed to integrate the DC sources with the AC sources with the bifacial power flow capability and therefore the power quality improvement capability. A mechanical sensing element less MPPT formula is employed for WECS associate degreed an progressive electrical phenomenon primarily based MPPT formula is employed for star PV system.

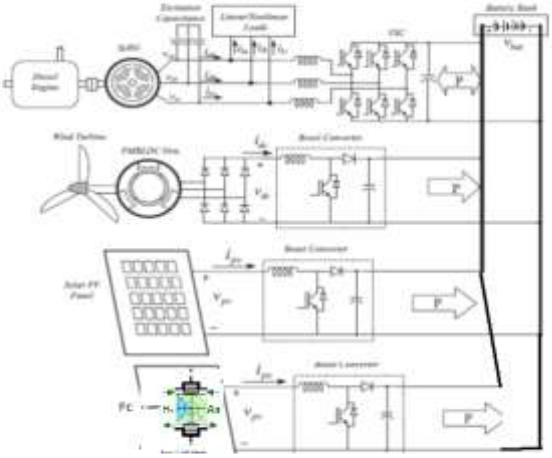

Fig.1.Proposed single VSC and the brushless generation-based standalone micro grid system.

II.STANDALONEMICROGRID TOPOLOGY

The proposed system is a diesel-wind-solar PV and Fuel cell based standalone micro grid with the battery energy storage to feed the local loads. The complete system topology is shown in Fig. 1. A SyRG is used as a DG and a PMBLDCG as a wind generator. These generators are selected purposefully due to the following reasons. Both these generators are brushless generators that reduce the maintenance cost relative to the brushed ones. For a DG, SyRG is used rather than a conventional synchronous generator, so the need of a speed governor and AVR is eliminated yet the voltage andfrequency of the system are regulated using VSC. The PMBLDC generator is driven by a wind turbine. As shown in Fig. 1, the WECS is connected at the dc link of the VSC through a diode rectifier and a boost converter. PMBLDCG is best suited for an uncontrolled rectification due to trapezoidal back EMF. If the winding currents are also made quasi-square wave, then a low-ripple torque is produced and the machine operates smoothly. This feature is not there with PMSG as the EMF generated is sinusoidal, so the quasi-square wave cur- rents produce a fluctuating torque. Moreover, the energy density of the PMBLDC machine is high which makes it small in size, hence good option for pole mounting application. The proposed topology also includes solar PV system, which is also connected to the dc link of the VSC for power transfer to the ac side where loads are present.

III.CONTROL STRATEGY FOR PROPOSED STANDALONEMICROGRID SYSTEM

The projected system topology has several sources, thus associate operational strategy is developed to optimize the fuel potency and to maximize the extraction of free energy offered. The decigram is that the solely ac supply within the system, therefore the system and therefore the load finish frequency is expounded to the operation of the decigram solely. a continuing frequency of the system suggests that the constant speed of the generator (as the generator is SyRG). it's expressed in [29] that with fastened speed operation of the diesel motor, the fuel consumption doesn't vary a lot of from its price at full load, therefore creating the diesel motor fuel potency poor at lighter hundreds. The diesel engines operate at cheap sensible potency between 80–100% loading. Here, the management strategy is developed for the decigram to work it continually among a such loading vary as shown in Fig. 2. The decigram with rating as full load rating isn't needed as their square measure renewable energy resources and therefore the battery energy device is accessible. The WECS consists of a PMBLDC generator, three-phase diode bridge rectifier (DBR) and a lift convertor. associate inductance is employed once the DBR to form the dc current virtually constant that reflects as quasi-square wave form of current on the ac aspect that is helpful for the operation of PMBLDCG as mentioned earlier. The operation of the WECS is simplified by eliminating the necessity of any mechanical detector for MPPT. associate MPPT rule is employed which needs solely sensing of vdc and idc. This MPPT rule is that the same as perturb and observe, that is employed for max power extraction in star PV system.

IV. CONTROL STRATEGY FOR PROPOSED STANDALONE MICROGRID SYSTEM

The proposed system topology has many sources, so an operational strategy is developed to optimize the fuel efficiency and to maximize the extraction of free energy available. The DG is the only ac source in the system, so the system and the load end frequency is related operation of the DG only.

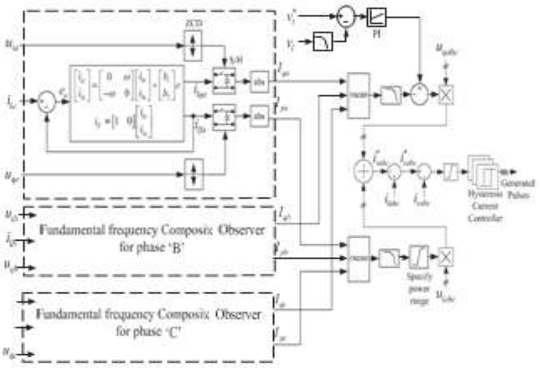

Fig. 2. Control strategy for VSC.

A constant frequency of the system means the constant speed of the generator (as the generator is SyRG). It is stated in [29] that with fixed speed operation of the diesel engine, the fuel consumption does not vary much from its value at full load, thus making the diesel engine fuel efficiency poor at lighter loads. The diesel engines operate at reasonable good efficiency between 80–100% loading. Here, the control strategy is developed for the DG to operate it always within a specified loading range as shown in Fig. 2. The DG with rating as full load rating is not required as there are renewable energy resources and the battery energy storage device is available.

The WECS consists of a PMBLDC generator, three-phase diode bridge rectifier (DBR) and a boost converter. An inductor is used after the DBR to make the dc current almost constant which reflects as quasi-square waveform of current on the ac side which is beneficial for the operation of PMBLDCG as discussed earlier. The operation of the WECS is simplified by eliminating the need of any mechanical sensor for MPPT. An MPPT algorithm is used which requires only sensing of *v*dc and *i*dc. This MPPT algorithm is the same as perturb and observe, which is used for maximum power extraction in solar PV system.

A. Voltage and Frequency Control of DG

Any distorted signal like voltage or current can be decomposed in to the dc and different frequencies sinusoidal signals as defined by Fourier series. All these frequency components can be estimated online using composite observers. However, the control algorithm for this system requires only fundamental frequency component estimation. So a composite observer is used to extract the fundamental frequency component of the load currents. The basic structure of a composite observer is described here. It creates a specified frequency in-phase and quadrature-phase components of the input signal. The state space representation of one unit of composite observer is shown as

$X_n= \Omega_n X_n+ B_n e$; $y_n= C_n X_n$;

where n=harmonic order . .

$X_n = [X_{1n}\ X_{2n}]^T$,$X_n= [X_{1n}\ X_{2n}]$

$$\Omega_n = \begin{bmatrix} 0 & n\omega \\ -n\omega & 0 \end{bmatrix}, B_n = \begin{bmatrix} b_{1n} \\ b_{2n} \end{bmatrix}, C_n = \begin{bmatrix} 1 \\ 0 \end{bmatrix}. \qquad (1)$$

As described in (1), with a composite observer having many units present for different harmonics, each unit tends to extract the particular harmonic component for which it is tuned. Thus, combination of all these components converges towards the actual signal. So in this type of system, the error "e" eventually becomes zero. However, with the proposed scheme, only unit corresponding to the fundamental frequency is used, which extracts only fundamental frequency component. The in-phase component of load current is obtained as output of the system and the quadrature-phase is obtained as the internal state of the system.

The characteristic of a unit of the composite observer corresponding to $\omega = 2\pi/50$ rad/s can be derived.

The transfer function of (3b) is similar to a peak filter and with the selected value of $b1$ and $b2$, the quality can be adjusted. Using these in-phase and quadrature-phase components of load currents, the active and reactive power components of the load currents are estimated as shown in Fig. 2. For generation of reference source currents, in-phase and quadrature-phase unit vectors of PCC voltage are required. Their calculation is described in [25].

The control algorithm for the VSC to act as voltage and frequency controller is shown in Fig. 2.VSC maintains the activepower output of the generator thereby regulating the frequency indirectly and it provides reactive power required to maintain
the voltage.

B. Mechanical Sensor less-Based MPPT Algorithm for WECS

The wind energy is free energy as there is no fuel cost, so WECS is operated to extract the maximum available power from the wind. An MPPT algorithm is used to perform this task. To simplify the control and to make it cost effective, an MPPT algorithm is used which does not require measurement of any of wind speed, rotor speed, or turbine speed [21]. Hence, mechanical speed sensor is eliminated by virtue of the proposed system configuration and control algorithm. A perturb and observe-based MPPT algorithm is used to control the boost converter which extracts the maximum power from the wind generator. The mathematical formulation for MPPT algorithm is described as

where $p_{dc} = v_{dc}.i_{dc}$ and δ is a small value. The i_{ref} and i_{dc} are reference and sensed inductor current of the boost converter.

The current is perturbed by a small value (δ) and the power output is observed for the change. In case, the power increases, the next perturbation is kept in the same direction to force the system toward MPP. However, in case the power decreases, the direction of perturbation is changed to pull back the system toward the MPP. The duty cycle is used to generate pulse width modulation pulses as shown in Fig. 3.

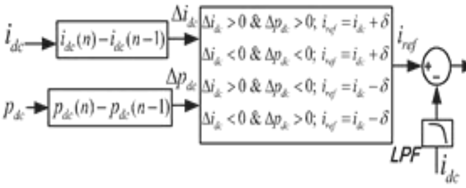

Fig. 3.Control system for WECS.

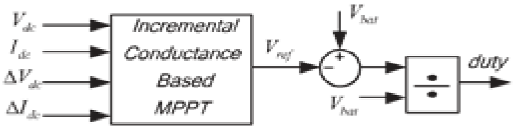

Fig. 4.Control system for solar PV system.

C. Incremental Conductance-Based MPPT Algorithm for Solar PV System

The maximum power available from a solar PV array is extractedusing an incremental conductance-based algorithm [23].This MPPT algorithm gives the reference voltage of the PV array at which it should be operated to provide maximum power output. The reference duty ratio for the boost converter switch is estimated using reference PV array voltage and the known battery voltage. The corresponding gate pulse for the boost converter switch is generated as shown in Fig. 4.

D. Charge Discharge Control of Battery Storage

As the focus of the paper is on the hybrid generation system, the battery charge discharge control is not considered much. But this section is dedicated to provide some idea behind power flows in the topology and how battery status can be monitored and controlled. On a large scale, the power flow between the various sources can be demonstrated. It can be seen that other than battery, all the other currents/powers are measured. So it would not be difficult to estimate the battery current and take actions accordingly. With the described topology and controls, the battery charge discharge can be controlled usingthe available control of each power source and load. If some situation arises where the charge discharge has to be exactly monitored, a current sensor can be installed in the system to measure the battery current. The battery voltage is already being measured and these can be used to determine the state of charge and other parameters to control charge discharge.

V. EXPERIMENTAL RESULTS AND DISCUSSION

An experimental prototype of the proposed microgrid system described earlier is developed in the laboratory and the control algorithm and the operation strategy are verified on this system. The system information is provided in Appendix. The DG is operated under specified power range. The wind and solar systems are operated always at MPP. The MPPT algorithm for the wind has not been tested on the experimental system due to the unavailability of the wind turbine emulation facility. TheMPPT algorithm is verified using simulation and the experimentation is performed for verifying the control considering that the reference current *i*dcto be tracked is available.

A. Steady State and Dynamic Performance of Simulation-Based Verification of MPPT Algorithm for WECS

As described earlier, the complete system is simulated usingMATLAB/SIMULINK and from simulation results the MPPT of WECS is verified. A basic wind turbine model is considered for this purpose [30]. The power characteristic of the simulated wind turbine. The pitch angle is taken as fixed and the base wind speed as 10 m/s. The corresponding performance of the MPPT algorithm under variable wind operation is shown in Fig. 5. The results with constant wind speed are shown in Fig. 5 until *t*=4 s. The wind speed is changed from 10 to 12 m/s at *t* = 4 s. The dynamic behavior of the system is demonstrated during such variation in wind speed. From these results, it is seen that with an increase in the wind speed, the power output of theWECS increases and also it can be seen that the PMBLDCG current has also increased.

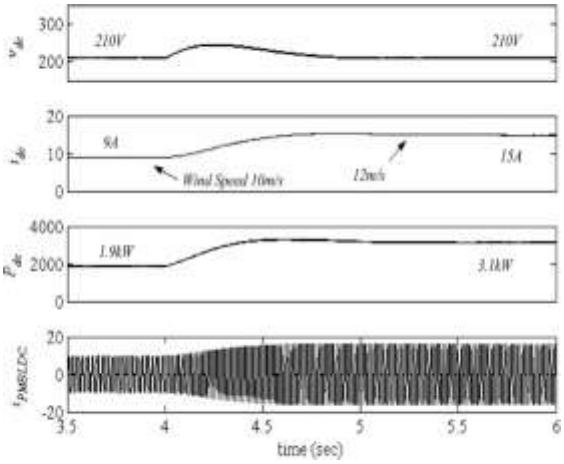

Fig. 5.Performance of WECS under varying wind speed.

B. Steady-State Performance of Standalone System

The proposed system is operated under various loading conditionsto verify the control algorithm. The loading conditions are defined according to the state of the battery whether charging or discharging. Steady-state results of the system in both the conditions are shown in Figs. 6 and 8. Fig. 6(a)–(c) show the three-phase source currents (*i*sabc) and Fig. 6(d)–(f) show the load currents (*i*labc). From here, it can be seen that in addition to voltage and frequency control, the VSC is also performing the task of harmonics elimination, load balancing, and reactive power compensation. All three source currents are almost balanced and sinusoidal. The VSC currents (*i*cabc)shown in Fig. 6(g)–(i) verify this compensation. Fig. 6(j), (k) show the PMBLDC generator current (*i*PMBLDCG) and the dc side current of DBR (*i*dc). The PMBLDCG current (*i*PMBLDCG) is approximately a quasi-square wave current andthe*i*dcconfirms that the WECS system is working well and thepower is extracted from the PMBLDCG.

Fig. 6(l) shows the battery current. As the load is almost fedby the DG, the energies coming from the solar PV array andthe WECS are stored in the battery. 6ig. 6(m), (n) show the PV voltage and current and the battery voltage and boost converteroutput current. Fig. 8(o) shows the power extracted from the PV system. Fig. 6(p), (q) show the harmonic content of the source and load currents. The power quality improvement capability of the VSC along with the voltage and frequency control is demonstrated. The THD of source current is only 4.9%, thereby negligible harmonic currents are entering the machine windings, hence no extra losses and thus no derating of the machine is required. The voltage THD is shown in Fig. 8(r). This shows the quality of supply given to the customer loads.

The performance of the microgrid system under heavilyloaded condition is shown in Fig. 7. Fig. 7(a) shows the source current (*i*sa)and Fig. 7(b) shows the load current (*i*la),which are significantly more than the source currents. Even the system is heavily loaded, the DG is still supplying the load with in the specified power range. Fig. 7(c) shows the VSC current (*i*ca).PMBLDC generator current (*i*PMBLDCG) is shown in Fig. 7(d). The power output from the WECS is kept the same for the comparison purpose. With the same power from the wind turbine and solar PVarray, if the system loading is increased, theDG hits its upper power limit and the load is then fed from the battery.

This is seen from Fig. 7(e) where the battery current is negative and hence the battery is discharging. This confirms the functioning of the control strategy for the complete system. Fig. 7(f) shows the battery voltage and the output current of the boost converter after solar array, *i*pvo..In this case also, the solar PV current and voltage which are the same as previous case of light load. It can be seen from Fig. 7(f), *i*pvo,that the power obtained from solar PV array is kept the same as in previous case.

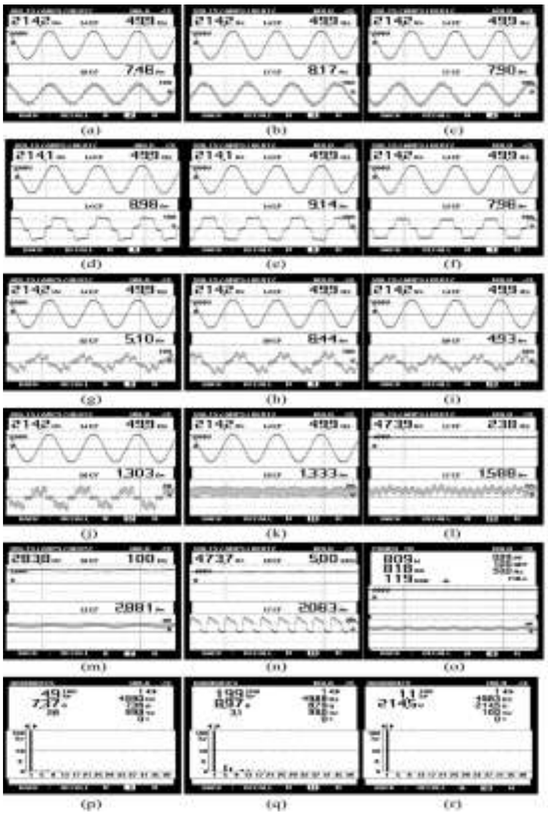

Fig. 6.Steady-state performance under light load condition, (a)–(c) vab, isabc ; (d)–(f) vab, ilabc ; (g)–(i) vab, icabc ; (j) vab,iPMBLDCG ; (k) vab, idc; (l) vbat, ibat ; (m) vpv, ipv ; (n) vbat, ipvo; (o)Ppv ; (p) harmonic content of isa ; (q) harmonic content of ila; and (r) harmonic content of vab.

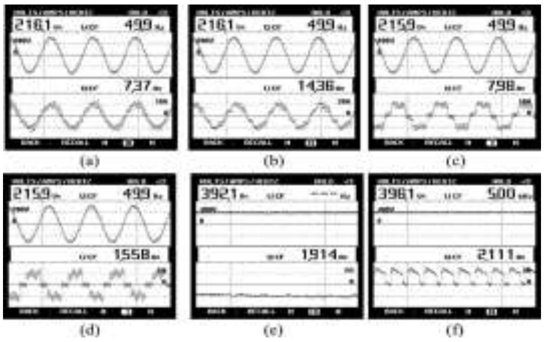

Fig. 7.Steady-state performance under heavy load condition(a) Vab, Isa ; (b) Vab, ila ; (c) Vab, Ica ; (d) Vab, iPMBLDCG ; (e) Vbat, Ibat ; and (f)Vbat, ipvo

C. Dynamic Performance of the Proposed Microgrid System

The proposed system topology along with the associated control algorithm is tested for the performance of the controllers under various disturbances and the randomness of the renewable energy resources. The response of the system is verified for sudden load changes like removing load on one phase. Fig. 8(a) shows that even after removing the load of phase a, the source current remains unchanged and the voltage of the system is also constant. This drastically reduces the load on the system and also creates a large unbalanced load. The performance is checked in terms of the capability of the system to survive with this sudden load rejection and injection. Moreover, the controller is designed to maintain the balanced source currents.

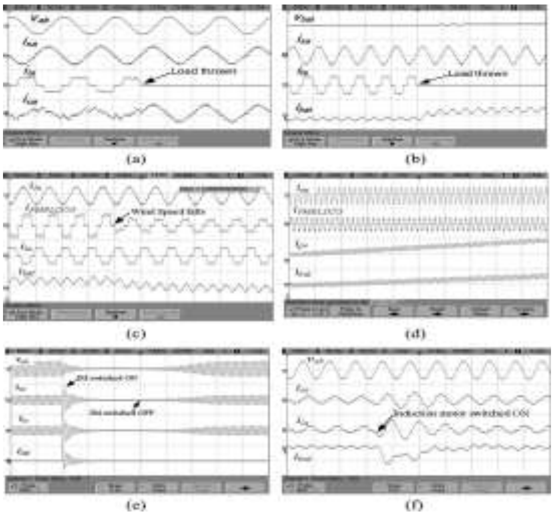

Fig. 8.Dynamic performance (a) vab, isa, ilaandica; (b) vbat, isa,ilaandibat; (c) isa, iPMBLDCG, ilaandibat; (d) isa, iPMBLDCG, ipvandibat; (e) vab, isa, ilaandiIM; and (f) vab, isa, iLaandibat.

The system is stable under load variations and also thesource currents are balanced and maintained as per the control. Fig. 8(b) shows that with load removal, the extra power goes to the battery, so the battery is going from discharging mode to charging mode. The WECS is also tested for variable speed or change in power reference. It is shown in Fig. 8(c) that keeping the load unchanged, with a decrease in wind speed, the battery starts discharging to feed the load. So the deficiency created due to wind speed fall is fulfilled by the battery as it can be seen that the battery current is becoming negative (discharging mode).

Other renewable source is solar PV energy, so it is also uncertainin nature. So with change of the insolation level, the power output of the solar PV array changes. The effect of this change is shown in Fig. 8(d). Maintaining the power from WECS constant, with an increase in solar insolation, the battery starts charging by the extra power.

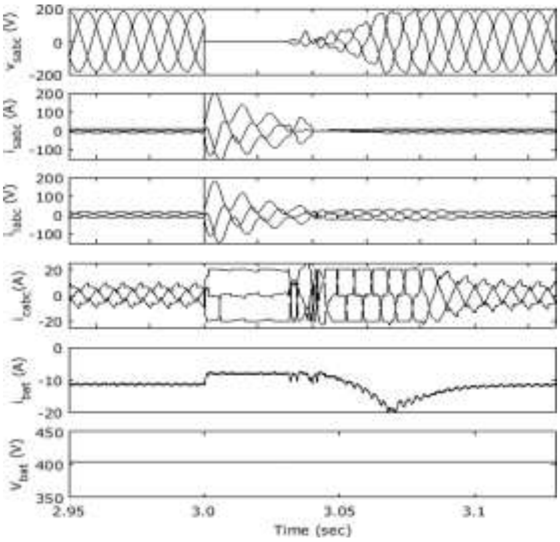

Fig. 9System performance under faulted condition.

The operation of system is validated under an inductionmotorload. As the starting current of an induction motor is high, so a system has to be reasonably stable and well controlled to feed such type of dynamic loads. Fig. 8(e) shows the response of the system without any control or no voltage and frequency regulation. It can be seen that with the induction motor starting, the voltage of the system collapses and on removing the motor the voltage regains. So this system cannot survive without a proper controller. On incorporating the complete system with voltage and frequency controller, the performance can be seen in Fig. 8(f). The system voltage is effectively maintained constant and the starting transient is taken care by the battery.

D. System Performance Under Faulted Condition

The fault situations are created and analyzed by using simulation tool. First case is taken where the fault is created at the ac bus. Current through the converter is controlled within the control algorithm. As the currentsare non-sinusoidal, a hard current limit is used to protect the devices and the system. If the switching devices have their own protection system (like desaturation for IGBTs), then an indirect current control can be used, which requires only source currents. But those protections are latch able (shutdown the system), so it is better to limit the current without disrupting the operation.

That is why a direct current control incorporating compensator currents is used. The results are shown in Fig. 9. As shown in Fig. 9, the reactive power support to the generator is mostly provided by the converter and with the fault on the ac line, the reactive power diverts to the low-impedance fault path and the generator's voltage collapses. But as soon as the fault is cleared, the generator picks up again. Another advantage of this system is that it is a machine-based system and hence the generator majorly contributes to the fault current, which has a large short circuit rating compared to the semiconductor devices. Moreover, the fault current in such cases is large, which makes the protection system design easier. Other case could be fault at the dc bus, which is catastrophic in every case of energy storage. In that case, the battery will be protected by the fuse or MCB and the system has to shut down. Or in some cases, the storage can be isolated and the load can be fed by generator, butthat can be achieved only by observing the load conditions and maintaining power balance, e.g., shedding load in case of overload. In that case, the converter can act as a shunt compensator to provide reactive power support.

VI. CONCLUSION

Hybrid energy systems (HES) will offer surroundings friendly and value effective energy solutions with higher irresponsibleness and power quality. Rather than standard energy, complete solar-wind-diesel and electric cell based mostly HES will offer good provide of electricity in remote locations. In lately, HES is AN economic reality to scale back the dependency on a fuel for off-grid communities. A diesel driven power generator is usually provided in remote HES just in case of inaccessibility of electric power from renewable energy sources. Moreover, HES will well cut back a fuel consumption and emission compared to the standard power systems. However, a fancy power management strategy is needed to confirm correct power sharing between multiple sources and optimize the facility quality. a short study through simulation is concentrated during this analysis with AN objective to develop an influence management strategy and management systems for complete solar-wind-diesel and electric cell hybrid energy systems (SWDHES). The projected micro grid topology with one voltage supply convertor and brushless generators has been enforced beneath numerous operative conditions. AN integrated operation of management algorithms is additionally tested for system's voltage and frequency management, mitigation of power quality problems, power balance within the whole system beneath numerous disturbances starting from giant load variation to renewable energy provide uncertainty. Some plan of battery charge discharge management and fault analysis is additionally mentioned. Matlab/simulink results have confirmed the quality of this topology for rural/isolated areas because the topology is straightforward and value effective.

APPENDIX

A. SyRG Rating: three-phase, 3.7 kW, 230V, 1500 r/min, 22.7A, 50 Hz.

B. PV Array Rating: Open Circuit Voltage = 350 V (at1000 W/m2 and 25 °C), short circuit current = 3 A.

C. Battery Rating: 400 V, 2.8 kWh.

D. Controller: dSPACE 1104 R&D Controller.

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