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CONTROL STRATEGY OF HYBRID SYSTEM BY USING KALMAN FILTER

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ABSTRACT

This paper presents the design of a micro grid. The proposed micro grid consists of a micro-turbine and a photo voltaic array which represents the main generation units in the hybrid system and proton exchange membrane fuel cell is supplement the variable power generated by the photovoltaic array. a lithium ion battery is included in the hybrid system for reduce the burden of the power generated by the hybrid system during the peak period. The all those different dg's units is coordinate to operate the energy management systems during the grid connected operation and islanded mode of operation. The overall system improves the power quality and reliability of the power distribution system that the hybrid system is connected to. The control design employs the output regulation (OR) theory. Kalman filters used to extract the harmonic component of the load current, and estimate the state observer gain and frequency tracking .The simulation studies verified through different test case.

Key Words— Distributed generation (DG), hybrid system, output based controller (ORC), kalman filter

I. INTRODUCTION

Over the last decade, efficient and reliable communication and control technologies, coupled with an increase in smarter electrical facilities, such as electric vehicles and smart meters, have resulted in an increasing number of consumers participating in demand response management (DRM). The current research is also focused on achieving a smarter grid through demand-side management (DSM), increasing energy reserves and improving the power quality of the distribution system, such as harmonic compensation for nonlinear loads [1]–[4][14][15]. These new trends enable higher levels of penetration of renewable generation, such as wind and solar power into the grid. The integration of renewable sources can supplement the generation from the distribution grid. However, these renewable sources are intermittent in their generation and might compromise the reliability and stability of the distribution network. As a result, energy-storage devices, such as batteries and ultra-capacitors,
are required to compensate for the variability in the renewable sources. The incorporation of energy-storage devices is also critical for managing peak demands and variations in the load demand.

This paper represents the micro source devices are connected to the utility grid through dc to dc converters and voltage source inverters at the point of common coupling (PCC). At point of common coupling different electrical loads are connected to. The proposed hybrid system consists of a micro-turbine, photovoltaic array, proton exchange membrane fuel cell and lithium ion storage battery. The micro-turbine and photovoltaic array operates main generation units of the hybrid system. During the sunless hours proton exchange membrane fuel cell operates this case micro-turbine and proton exchange membrane fuel cell is acts as a main generation units. The lithium ion storage battery is implemented to operate the peak shaving during the grid connected operation and islanded operation. As such modern control theories are used to implement the system. Such controllers' presents in this paper as output regulation based controller (ORC), this controller regulates the dc link voltage of the system.

II. SYSTEM DESCRIPTION AND MODELLING

A. System Description

The figure shows the configuration of hybrid system presented in this paper that is operated to operate grid connected and islanded mode of operation. The proposed hybrid system consists of 15KVA micro turbine, 6.5kW_p photovoltaic array. The PV array is connected to grid through dc to dc converter and voltage source inverter (VSI). [14,15] The micro-turbine and PV array operates as primary generation units. 5Ah of lithium ion storage battery (SB) and 5kW proton exchange membrane fuel cell (PEMFC). The SB is connected to grid through buck boost converter and VSI. The PEMFC and SB are back up protection of the PV array and will supply the power for any shortage in the generated power to ensure the stable operation of the overall system.

When the fault occurs on the upstream of the distribution network the circuit breaker is disconnect the hybrid system from utility grid. Then the generation of the main DG's units are able to meet the load demand the system must be stable otherwise PEMFC and SB are supply the power unless it cannot meet the load demand shutdown the system completely.

Power balance equation of the system during grid connected mode is

$$P_{mt}+P_{pv}+P_b+P_{fc}=P_L \qquad (1)$$

Here P_{mt} and P_{pv} are power delivered by the MT and PV array. And P_b is the storage battery power subjected to charging and discharging constraints is

$$P_b \le P_{b,\,max} \qquad (2)$$

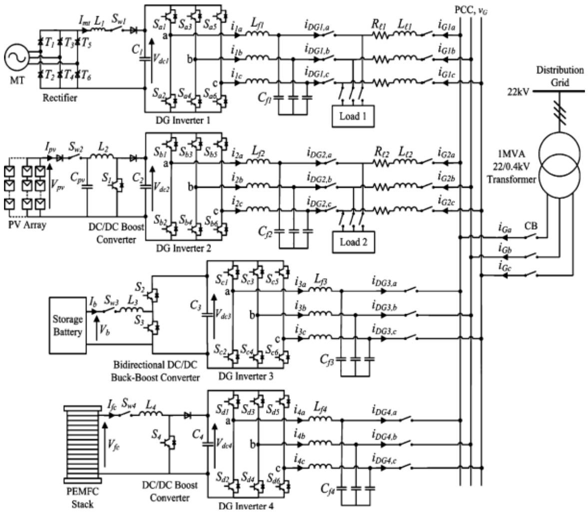

Figure 1. Block diagram of Microgrid

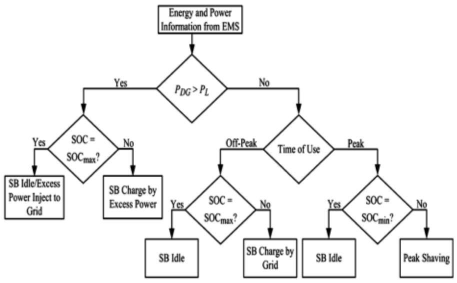

Figure 2: Operation Sb during grid connected operation.

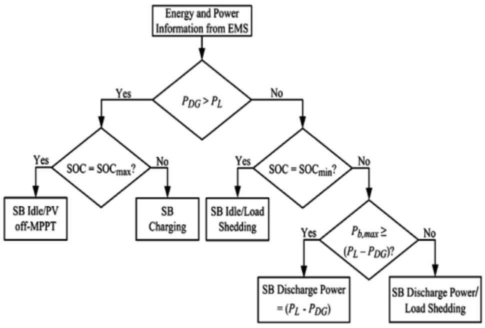

Figure 3. Operation of SB during Islanded mode of operation

Pfc is the power delivered by the PEMFC and PL is the load power .The storage battery energy constraints is given by

$$SOCmin < SOC \le SOCmax \qquad (3)$$

SOC [8-9] of the battery cannot be determined directly, it can be find by different techniques is presented.

B. DG inverter modelling

The figure [4-5] shows the single phase circuit representation of DG inverters during grid connected and islanded operation respectively. [14,15]The output voltage across the DG inverters is U_jV_{dcj}. Where U_j is the control input i.e. j=1,2. And L_f, Cf is the filter which protects from the high switching frequency harmonic. R_f is the resistance loss of the DG inverter.

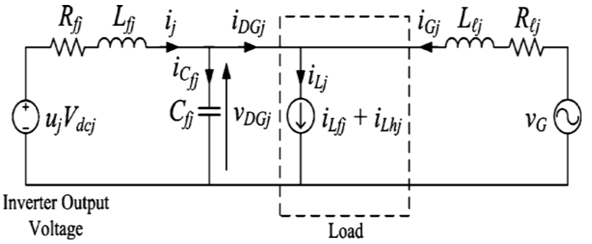

Figure 4. DG inverters during Grid connected operation

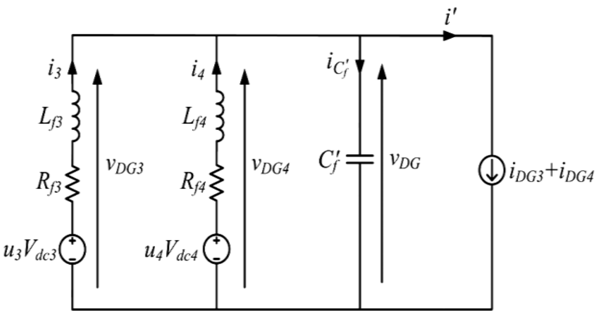

Figure 5. Dg inverters during islanded operation

The load current i_L is the sum of current delivered to the load. i_L includes the fundamental and harmonic component therefore i_L can be written as

$i_L = i_{L1}+i_{L2}$ (4)

$= i_{Lf}+i_{Lh} = i_{Lf}\sin(wt-\theta_{Lf})+\Sigma^{N}_{h=3,5.} i_{Lh}\sin(hwt-\theta_{Lh})$

$= i_{Lf,p}+i_{Lf,q}+i_{Lh}$ (5)

Where θ_{Lf} and θ_{Lh} are the respective phase angles of the fundamental and harmonic component of the load current i_L. The current supplied by the DG inverter is given by

$I_{DGj}=(i_{Lf,p}-i_g)+i_{Lf,q}+i_{Lh}$ (6)

To derive the state space model of the DG inverter during grid connected and islanded operations, is to simply apply the Kirchhoff's voltage and current law to the network is shown in the figure6

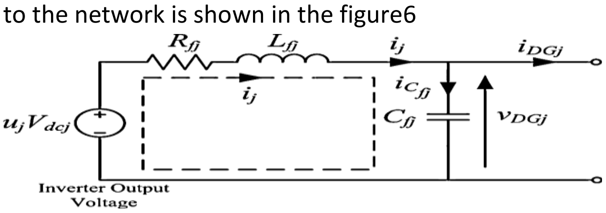

Figure 6. State space representation of hybrid system

$$\frac{di_j}{dt} = -\frac{R}{L_{fj}} i_j - \frac{1}{L_{fj}} v \quad (7)$$

$$\frac{dv_D}{dt} \quad (8)$$

Where i_j is the current flowing through L_{fj}.therefore grid connected DG inverter can be modeled in state space can be written as

$A_{gj}x_{gj}+B_{gj1}v'_j+B_{gj2}u_j$ (9)

$y_{gj}=C_{gj}x_{gj}+D_{gj1}v'_j+D_{gj2}u_j$ (10)

Where g represents the grid connected operation and j represents the operation of the DG inverter (j=1,2)(1=MT,2=PV).

$A_{gj} = -\frac{R_{fj}}{L_{fj}}$; $B_{gj1}=\begin{bmatrix}-\frac{1}{L_{fj}} & 0\end{bmatrix}$ $B_{gj2}=\frac{V_{dcj}}{L_{fj}}$; $C_{gj}=1$

$Dgj1 = \begin{bmatrix}0 & -C_{fj}\end{bmatrix}$; $Dgj2 = 0$

$x_{gj}=i_j$ is the state $Vj' = \begin{bmatrix}v_{DGj} & \frac{dv_{DGj}}{dt}\end{bmatrix}T$ is the exogenous input, u_j is the control input, with $-1 \le u_j \le 1$; and $y_{gj}= i_{DGj}$ is the output.

The islanded operation of SB and PEMFC is derived in state space model is obtained

$=A_{ij}x_{ij}+B_{ij1}i'_j+B_{ij2}u_j$ (11)

$y_{ij}=C_{ij}x_{ij}+D_{ij1}i'_j+D_{ij2}u_j$ (12)

where i denotes model of the DG inverters j during islanded operation. Where j=1,2,3,4 and

$A_{ij}=\begin{bmatrix}-\frac{R_j}{L_{fj}} & -\frac{1}{L_{fj}} \\ \frac{1}{C'_f} & 0\end{bmatrix}$; $Bij1=\begin{bmatrix}0 \\ -\frac{1}{C'_j}\end{bmatrix}$;$B_{ij2}=\begin{bmatrix}\frac{V_{dcj}}{L_{fj}} \\ 0\end{bmatrix}$; $C_{ij}=\begin{bmatrix}0 & 1 \\ 1-\frac{C_{fj}}{C'_j} & 0\end{bmatrix}$

$D_{ij1}=\begin{bmatrix}0 \\ \frac{C_f}{C'_f}\end{bmatrix}$; $Dij2=\begin{bmatrix}0 \\ 0\end{bmatrix}$

With $C'_f = \sum_{j=1}^{4} C_{fj}$;$x_{ij}=\begin{bmatrix}i_j & v_{DGj}\end{bmatrix}^T$ is the stete vector; $i'_j=i_L-\sum_{n\neq j} i_n$ is the exogenous input of the DG inverter j; u_j is the control input , with $-1 \le u_j \le 1$ and $y_{ij}=\begin{bmatrix}v_{DGj} & i_{DGj}\end{bmatrix}^T$ is the output, which will regulated to track the desired reference. i'_j can be derived using a Kalman filter applied to the output $y_{ij}=\begin{bmatrix}v_{DGj} & i_{DGj}\end{bmatrix}^T$.

III. CONTROL PHILOSOPHY

The aim of the controller is to maintain the output of the plant is y= $(v_{mg}\ i_g)^T$ it is to track the reference signal r=(v_{mg}^* $i_g^*)^T$, under a periodic disturbance $(v_{mg}\ i_g)^T$. The reference signals v_{mg}^* and i_g^* both are pure sine waves 50Hz frequency without any harmonic distortions.

A. Model of the exogenous signal

The exogenous signals v_g ,i_L ,v_{mg}^* ,i_g^* are periodic signals all those are represented in state space model. For example v_g can be expressed in state space model is

$\xi_{Vg}=A_{Vg}\ \xi_{Vg}$ (13)

$v_g= C_{Vg}\ \xi_{Vg}$ (14)

$i_{L,\ vmg}^*$, ig^* are modeled into state space form

$= \tilde{A}\ \xi$ (15)

$(v_g\ i_L)^T = \hat{C}_w\ \xi + w$ (16)

$r=(v_{mg}^*\ i_g^*)^T= \hat{C}_d\ \xi$ (17)

Which is called as exogenous system is presented in this paper.

B. Output Based Regulation Controller *(ORC)*

Subtitling the exogenous equations into the state space model of the plant, the following model is obtained

: $= Ax+ B0\xi + B2u$ (18)

$y= Cx + D_0\ \xi + D_2u$ (19)

The control law for the OR is proposed as

$u = U\ \xi + F(x - X\ \xi\ )$ (20)

Where u is the control signal which generated by the controller used for switching scheme for the plant. *x* and ξ are the outputs of the exogenous and plant kalman filter(13).

$X\tilde{A}=AX+Bo+B_2U$ (21)

$=CX+D_o+D_2U$ (22)

$\frac{d}{dt}(x - X\xi)$ =$(A+B_2F)(x-X\ \xi)$ (23)

$e=(C+D_2F)(\ x-X\ \xi)$ (24)

Where 'e' is the error tracking (y-r). F can be find from the $(A+B_2F)$ is Hurwitz and the closed loop system is stable.

IV. SIMULATION RESULTS

The simulation model of the hybrid system is implemented in MATLAB/SIMULINK The hybrid system consists of two types of loads i.e. non liner and linear loads rated of P_{L1}= 15kW, Q_{L1}=9.7KVAr and P_{L2}=5kW, Q_{L2}=3KVAr are respectively.

Test case1: Power Quality Improvement with Load Sharing During Grid-Connected Operation

This case demonstrates the improvement of power quality of the distribution network during grid connected operation and compensate the harmonic injection into the distribution network during grid connected operation.[14,15] In this mode of operation the storage battery is charged and stores the energy for 0≤t≤0.3sec.The total load current is the sum of the hybrid system current and current supplied by the grid current.

The total real and reactive power consumed by the load is 20_KW and 12.7_KVAr during grid connected mode of operation. The DG1 inverter and DG2 inverter shares the power is DG1=7.5kW & 9.7kVAR and DG2 is 3kW & 3kVAR is shown in the figure.[8-9].The remaining power is supplied by the grid is shown in the figure.10. 7.5kW (50% of P_{L1}) and 2kW (20% of P_{L2}). The voltage and current waveform of grid is shown in the figure 11 and voltage across the PCC is shown in the figure 12.

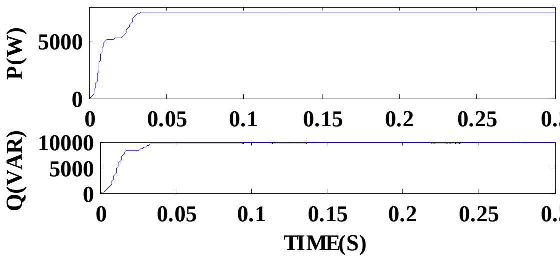

Figure 8. Power delivers by MT

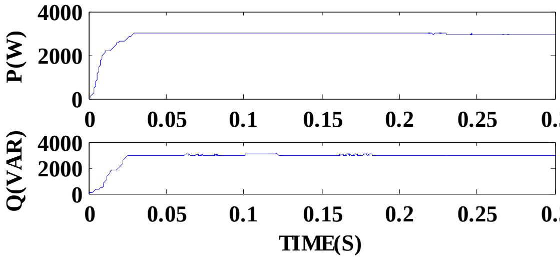

Figure 9. Power delivered by PV array

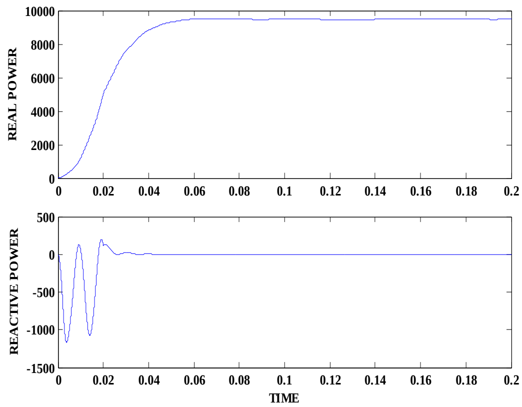

Figure 10. Power delivered by Grid

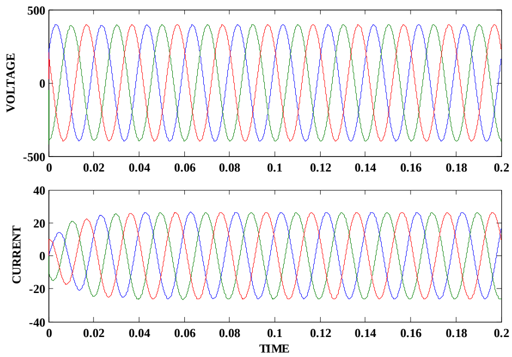

Figure 11. Grid Voltage and Current

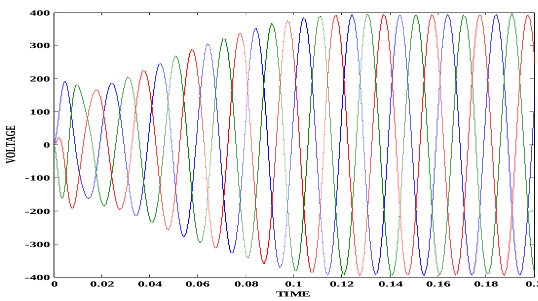

Figure 12. Voltage across the PCC

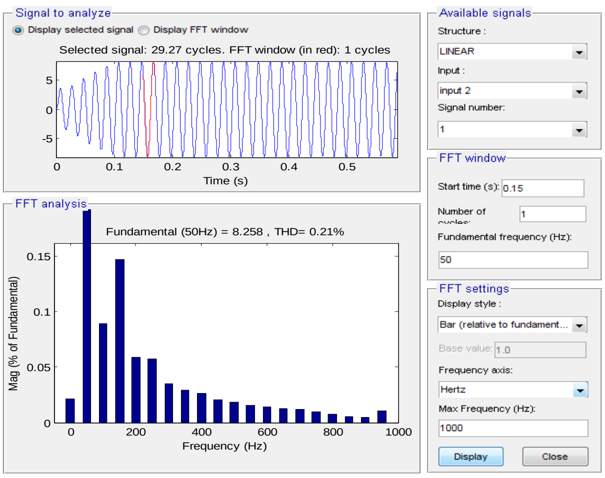

Figure 13. THD analysis of linear load current

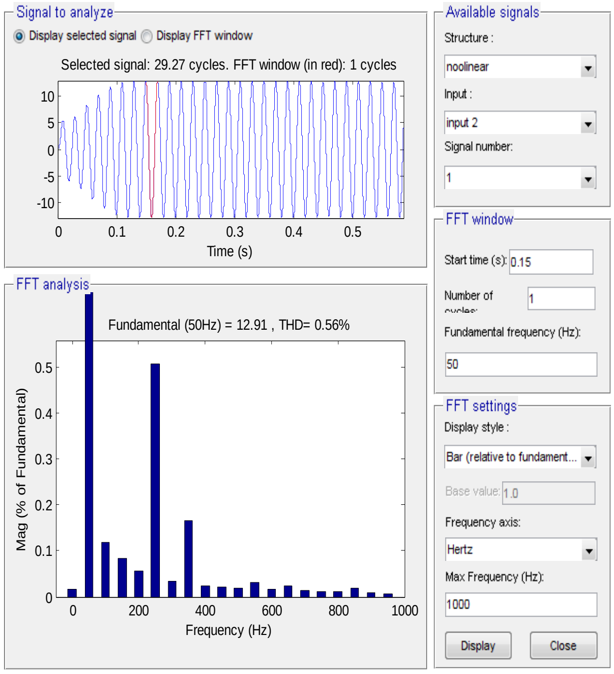

Figure 14. THD analysis of nonlinear load current

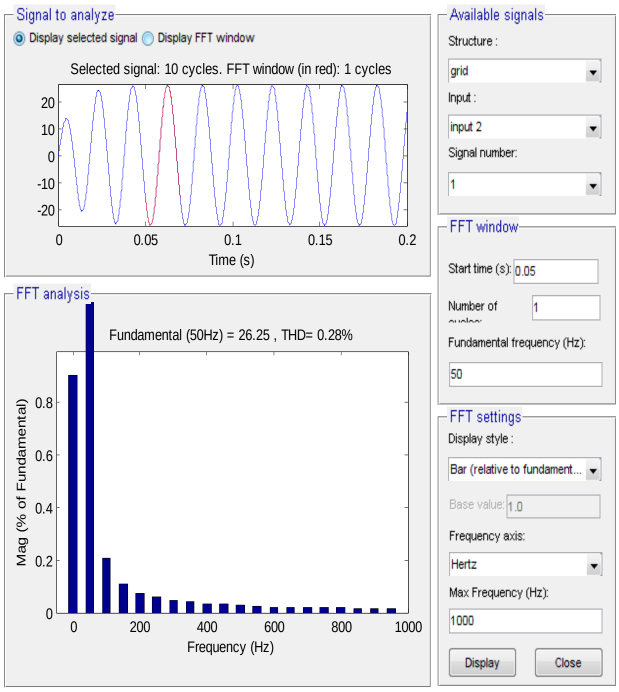

Figure 15. THD analysis Grid current

The calculation of THD analysis is shown in the figures [13 15 16] from that observes that improvement of power quality in the hybrid system system.

Test case 2: load sharing during Islanded operation

This test case demonstrates the islanded mode of operation of hybrid system. The circuit breaker is initially fully isolated, when ever fault occurs on the upstream network, the circuit breaker disconnect the hybrid system from the distribution grid. [14,15]This test is employed to momentarily provide the sharing of real and reactive power of storage battery SB and PEMFC. When the circuit breaker switch opened, the amount of real power delivered by the SB and PEMFC is shown in the figure.[18-19].during this interval the SB is supplies the 3.28KW and PEMFC is supplies the 2.28KW.initially the SB is idle or charge. the real power is supplied by the MT is increases from 7.5kW to 11.4kW and PV array power is remains constant. And voltage across the linear load and nonlinear load is shown in the figure [20,21].

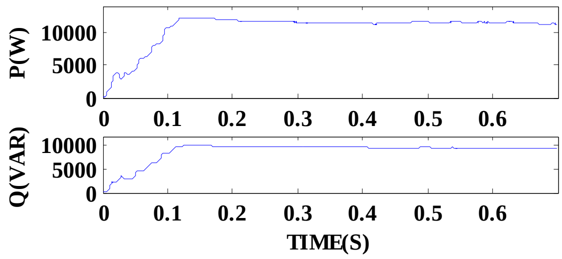

Figure16.Powerdeliversby

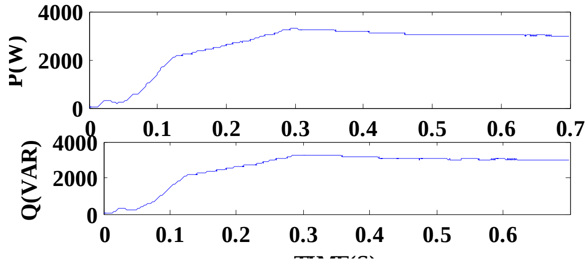

Figure 17. Power delivers by PV array

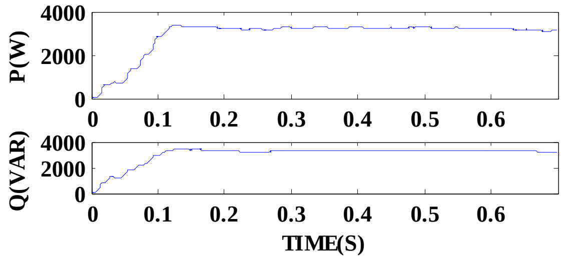

Figure 18. Power delivers by battery

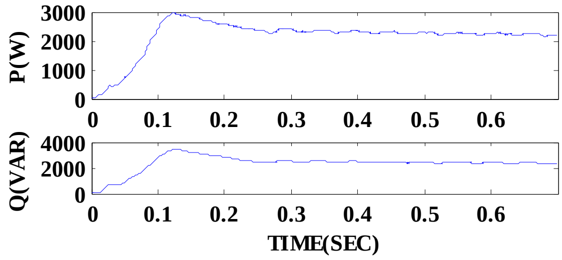

Figure 19. Power delivers by fuel cell

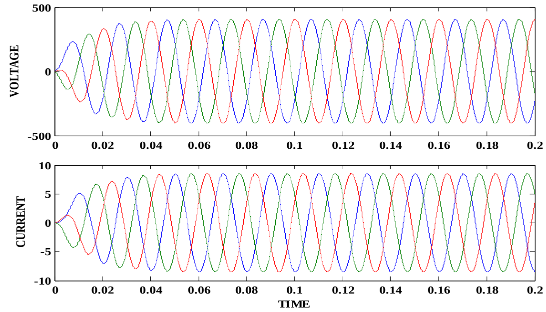

Figure 20. Voltage across the linear load

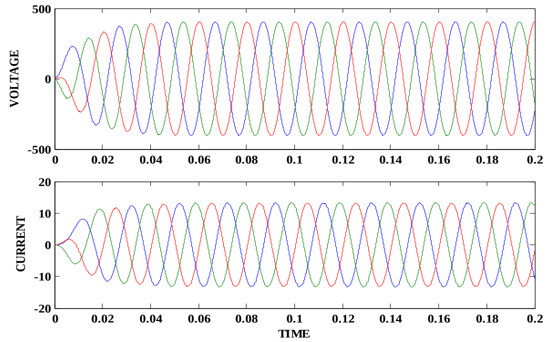

Figure 21. Voltage across the nonlinear load

V. CONCLUSION

This paper presents the design of hybrid system and operation of hybrid system during grid connected and islanded mode of operation has been presented with the help of MATLAB/SIMULINK.[14,15]The proposed system integrates with kalman filter in a control design and it is estimate the state observer gain and extract the harmonic compensation in the load current. The control design Consists of ORC. The system is tested under different test cases and a validate results are presented in this paper. From these test cases the system improves the power quality and reliability.

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