Energy Management and Power Quality Improvement in HRES Grid-Connected System

B. Srikanth Goud
Department of Electrical and Electronics Engineering, Koneru Lakshmaiah Education Foundation, India 522502
srikanth.b@anuraghyd.ac.in

R. Rekha
Department of Electrical and Electronics Engineering, Anurag College of Engineering, Ghatkesar, India 501301
rrekha122@gmail.com

M. R. L. Jyostna
Department of Electrical and Electronics Engineering, Anurag College of Engineering, Ghatkesar, India 501301
jyostna_muktevi@yahoo.co.in

S. Sarala
Department of Electrical and Electronics Engineering, Anurag College of Engineering, Ghatkesar, India 501301
saralajcyp@yahoo.com

B. Loveswara Rao
Department of Electrical and Electronics Engineering, Koneru Lakshmaiah Education Foundation, India 522502
loveswararao@kluniversity.in

Ch. Rami Reddy
Department of Electrical and Electronics Engineering, Koneru Lakshmaiah Education Foundation, India. 522502
crreddy229@gmail.com

***Abstract*— Nowadays the Power Quality issues are the major concerns in the grid integrated system. Hybrid Renewable Energy Sources (HRES) plays a vital role in the distributed generation for supplying the world energy consumption demand. This paper presents control, modelling and design of grid integrated inverter for power quality improvement in the HRES system. Extended Search Algorithm (ESA) is used to stabilize the voltage, reducing the power loss, and energy management. The simulated results will indicate the better performance of the proposed converter over the conventional PI controller. The simulations are carried on the MATLAB/ SIMULINK platform**.

Keywords –HRES, Power Quality improvement, ESA, PV, Wind, Battery, Harmonic Compensation, Reactive power compensation

I. Introduction

Renewable Energy Source (RES) based distributed generators are predominantly gaining a lot of importance due to the advancement in technology, environmental concerns and the huge demand for power to the utility grid. Many optimization techniques have been developed to control various power electronics and control technology with better flexibility while integrating various alternative sources like solar, wind battery etc., which are playing an important role to meet the huge power demands [1-3]. Due to the limitation of generating power from conventional energy sources Distribution Generation (DG) has a lot of importance because it gives more productive, best quality and dependable power to the commercial loads which require continuous administration [4].

Nowadays, generation of power became a challenging issue due to the increase in population as well as an increase in demand, so conventional sources alone cannot meet these requirements. Hence, alternative sources like solar, wind, battery is widely used in DG [5-6]. In the proposed paper DG system contains a source connected to the DC link of grid interconnected inverter controlled with ESA technique, which is strongly guarded in such a way it feeds real power to the grid. The proposed approach compensates the harmonics and unbalances even under distorted supply voltage conditions if the load is associated at the Point of Common Coupling (PCC), which is non-linear or unbalanced and both. In accession to real power injection from RES to the grid and grid-interfacing inverters, we desired to take care of the load reactive power and current harmonics [7-9].

II. Extended Search Optimization proposed to HRES

The developed system circuit is as shown in Fig.1. Which consists of DG comprising PV-Wind connected to Current Controlled Voltage Source Inverter (CC-VSI) for interfacing to the grid via-an energy-storing DC-link capacitor. By using the ESA, from the PV and Wind more power is extracted. From ESA a mentioned DC link voltage is created. The reference DC link voltage is set to its default value when the solar energy is missing. An inductive filter is connected to the AC-Side of the VSI. To increase the voltage level, a step-up transformer is used before the system is connected to the PCC. An uncontrolled rectifier non-linear load is associated at the PCC. To minimize the load current harmonics and power factor and regulate the DG power flow to the PCC an inverter control is used [10].

III. Design and analysis of controller for Grid-Interface unit

Elimination of zero steady-state error of the output currents a double-loop current controller which is an outer loop with proportional resonant is used and the proportional controller is used to improve the stability along with the inner capacitor current control loop. Fig. 2 depicts the controller arrangement of the grid-connected inverter from which the reference current required for its operation can be evaluated for the proper functioning of CC-VSI and reducing current harmonics [10-12]. A set of harmonic n, n= {1,2,3…. N}, components are present at the common point whose Voltage $V_s(t)$ and current $I_L(t)$ can be written as (1-2).

$$V_s(t)=\begin{bmatrix} V_{s1} \\ V_{s2} \\ V_{s3} \end{bmatrix}=\begin{bmatrix} \sum_{n=1}^{N} V_{sn1}\sin(n(\omega t)) \\ \sum_{n=1}^{N} V_{sn2}\sin(n(\omega t-120^\circ)) \\ \sum_{n=1}^{N} V_{sn3}\sin(n(\omega t-240^\circ)) \end{bmatrix} \quad (1)$$

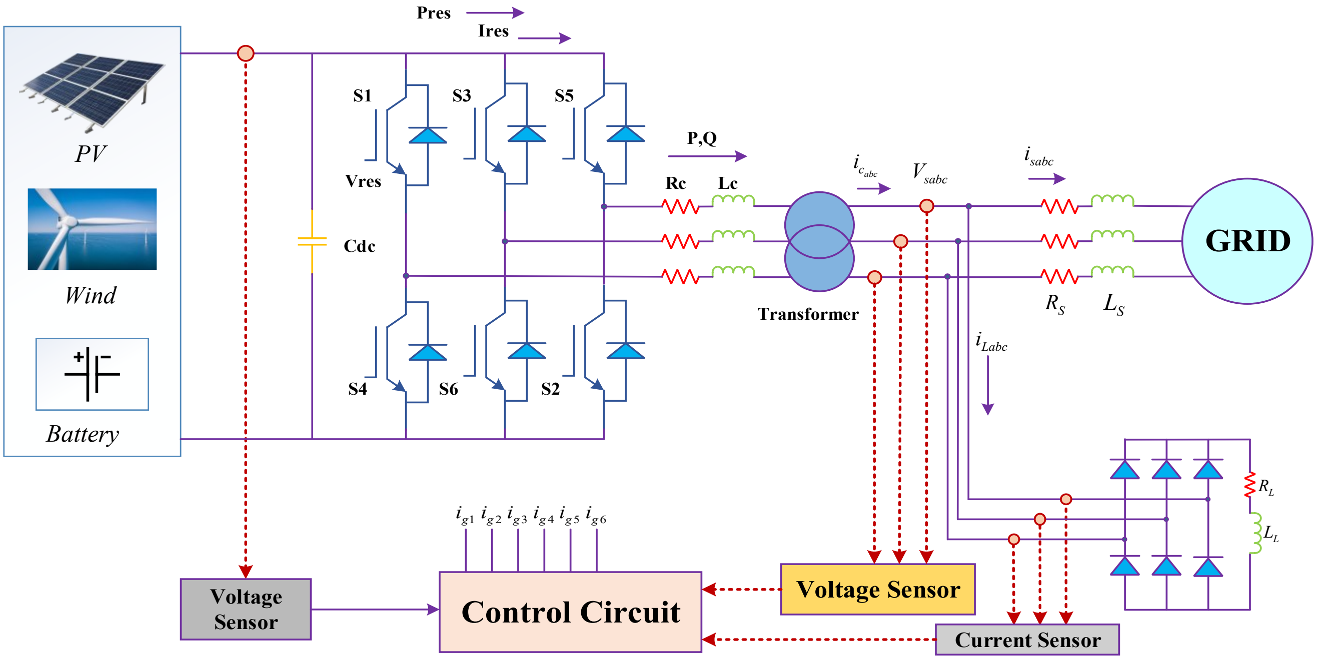

Fig. 1: Proposed Block Diagram

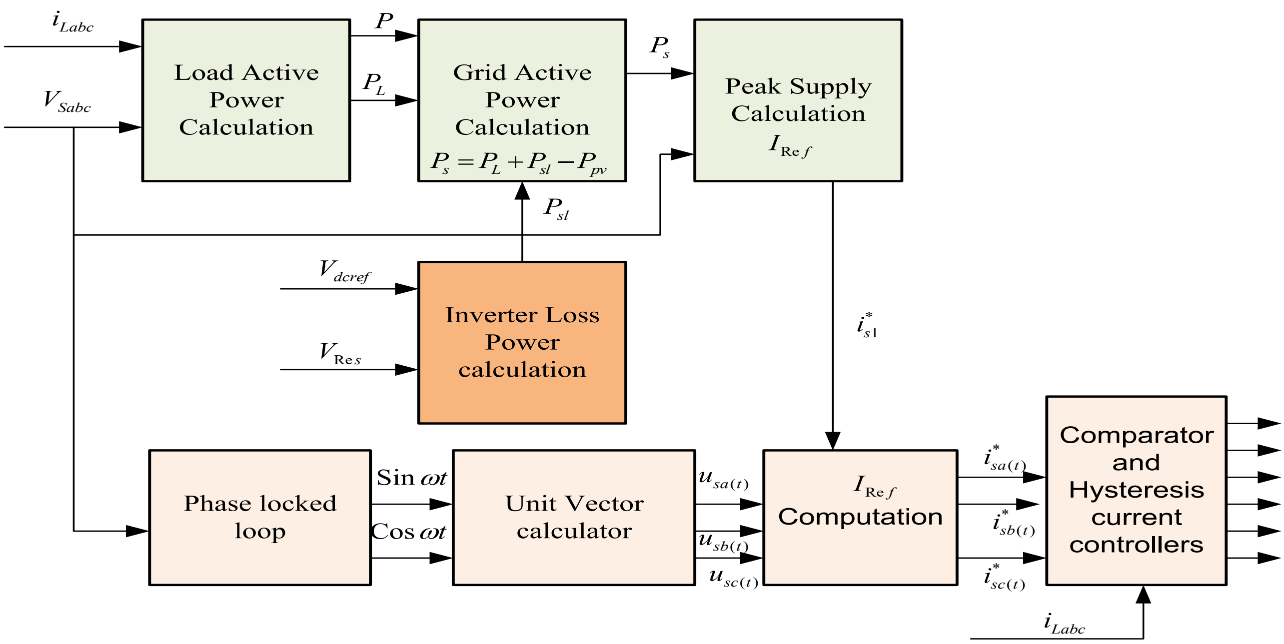

Fig. 2: Control Diagram

$$I_L(t)=\begin{bmatrix}I_{l1}\\ I_{l2}\\ I_{l3}\end{bmatrix}=\begin{bmatrix}\sum_{n=1}^{N} I_{Ln1}\sin(n\omega t-\phi_{n1})) \\ \sum_{n=1}^{N} I_{Ln2}\sin(n(\omega t-120^{\circ})-\phi_{n2}) \\ \sum_{n=1}^{N} I_{ln3}\sin(n(\omega t+120^{\circ})-\phi_{n3})\end{bmatrix} \quad (2)$$

(V_{s1}, V_{s2}, V_{s3}) PCC Voltages peak values (I_{Ln1}, I_{Ln2}, I_{Ln3}) Load current peak values $\emptyset_{n1}$, $\emptyset_{n2}$, $\emptyset_{n3}$ nth order harmonic component phase angles. Real and reactive power which is flowing against the output of the inverter to the common point can be written as (3-4) [10-11].

$$P=\frac{V_sV_c}{X_c}\sin\delta_c=\frac{m_aV_{fc}V}{X_c}\sin\delta_c \quad (3)$$

$$Q=\frac{V_s}{X_c}(V_c\cos\delta_c-V_s)=\frac{V_s}{X_c(m_aV_{fc}\cos\delta_c-V_c)} \quad (4)$$

Where V_c<δ_c is the inverter output, m_a is the modulation depth of the inverter, V_s<0is the PCC Voltage and $X_c=R_c+j\omega L_c$ is the impedance of inductive filter impedance. The real power supplied by the grid P_s should be equal to the grid apparent power for compensation at unit power factor is given by (5)

$$P_s = P_L + P_l - P = \frac{3}{2} V_{s1} I^*_{s1} \quad (5)$$

Where the real power of the load is $P_{L, \text{the}}$ real power loss is P_l, real power output by the RES is P, the maximum amount of the principle component of common point voltage is a fundamental component and I^*_{s1} (6) source current component, therefore,

$$I^*_{s1} = \frac{2P_s}{3V_{s1}} \quad (6)$$

Instantaneous currents which are taken as reference (I^*_{s1}, I^*_{s2}, I^*_{s3}) (7) are calculated utilizing the required maximum value and current vectors (us_1, us_2, us_3) calculated from source current from observed source voltages.

$$\begin{aligned} I^*_{s1}(t) &= I^*_{s1} u_1 \\ I^*_{s2}(t) &= I^*_{s1} u_2 \\ I^*_{s3}(t) &= I^*_{s1} u_3 \end{aligned} \quad (7)$$

Instantaneous source voltages generate sine vectors of any phase using a phase-locked loop. The unit sine templates are given as (8) [10-12].

$$\begin{aligned} u_{s1}(t) &= u_a(t) \\ u_{s2}(t) &= -0.5u_a(t) + 0.866u_b(t) \\ u_{s3}(t) &= -0.5u_a(t) - 0.866u_b(t) \end{aligned} \quad (8)$$

Where $u_a(t) = \sin\omega t$ and $u_b(t) = \cos\omega t$ on computing the dissimilar between instant reference currents and observed load currents the reference inverter currents are (9)

$$\begin{aligned} I^*_{c1}(t) &= I^*_{s1}(t) - I_{L1}(t) \\ I^*_{c2}(t) &= I^*_{s2}(t) - I_{L2}(t) \\ I^*_{c3}(t) &= I^*_{s3}(t) - I_{L3}(t) \end{aligned} \quad (9)$$

Reference inverter current and the existing inverter current error ($\Delta_{ic1}, \Delta_{ic2}, \Delta_{ic3}$) in (10) hysteresis current controller which governs the duty cycle of the PWM inverter.

$$\begin{aligned} \Delta i_{c1} &= I^*_{c1}(t) - i_{c1} \\ \Delta i_{c2} &= I^*_{c2}(t) - i_{c2} \\ \Delta i_{c3} &= I^*_{c3}(t) - i_{c3} \end{aligned} \quad (10)$$

The error produced between the true and measurable current of the inverter the hysteresis controller controls and regulates pulses for the gate drives of the grid-connected inverter. S_1 switch is on when $\Delta_{ic1} > H_b$ and S_4 are off in phase A of inverter and vise-Versa if $\Delta_{ic1} < H_b$. H_b is the width of the hysteresis band. This switching pulses for the other two legs operate on the same frequency.

IV. Extended Search Algorithm

Capacitor currents are computed from response currents and the filter inductor instead of sampling and measures for overcurrent protection. The reference should be zero to eliminate zero-sequence current. PR controller is choosing either of the sequence components which are difficult and time-consuming when we use general PI control. A fundamental frequency a quasi-proportional resonant controller where K_{pis} the proportional gain, Kr the resonant gain, and ω_{br} the correspondent bandwidth of the resonant controller used. The complete architecture for the PR controller has been presented in the literature [10-15].

To keep DC-link voltage like a regular, we used ESA (Fig. 3) with some set of rules. Here reference voltage and regular DC-link voltages are fed as inputs to the set of guidelines used in ESA. Generally, ESA is the advanced optimization technique generally applied to crossover, mutation and genetic operators. The quality factor is strongly used in the considered set of rules to supply a contemporary individual a set of first-rate men or women used to produce in the crossover operation by considering a fantastic individual part of the person. ESA is utilized to keep a DC-Link voltage in the converter by reducing the errors.

V. Results and Discussion

In this case, the proposed hybrid system is developed under a Non-linear load. And also the power management strategy is considered. The test results for this system are shown in the following cases.

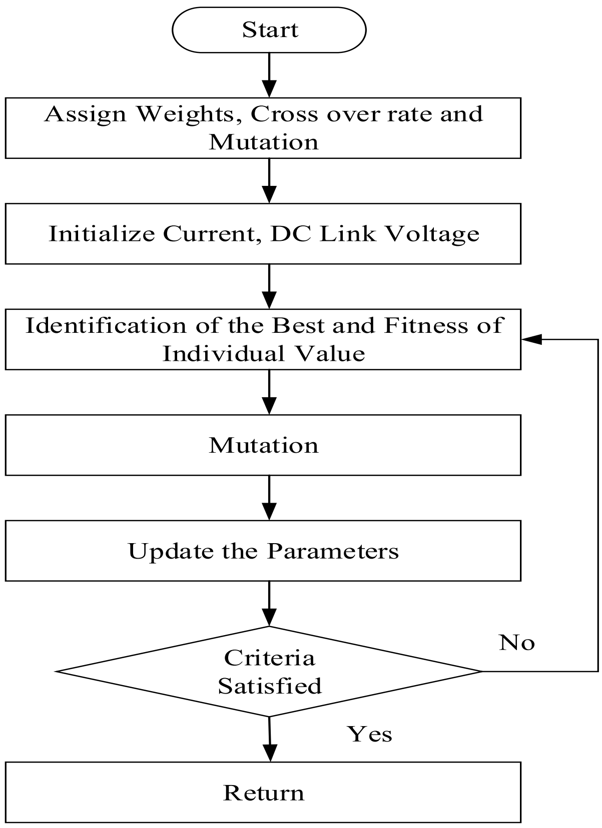

Fig. 3: Flow chart of the ESA algorithm

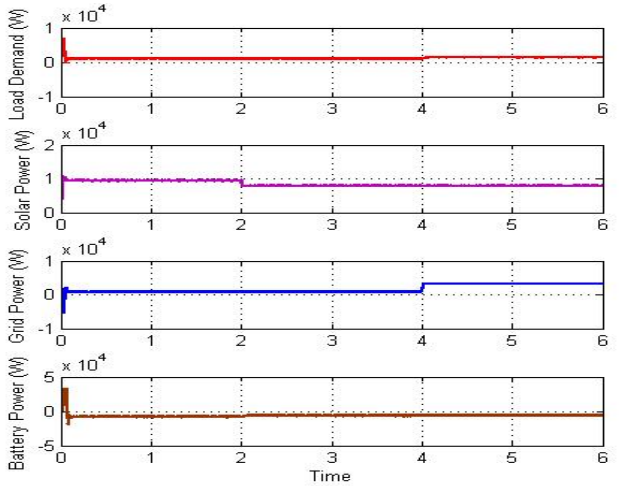

Fig. 4: (a) Load Demand, (b) Solar Power, (c) Grid Power and (d) Battery Power

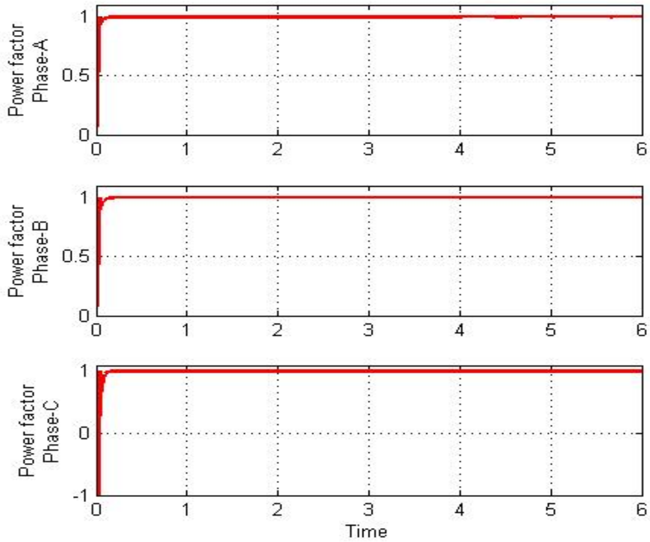

Fig. 5: Power Factors for Inverter Load Current

Fig. 4 depicts the power management strategies for the test system used. Based on the output of each system, the load sharing is selected. In this simulation the variations in the load are considered between 3s to 5s.

Fig. 5 shows the simulation results for the power factors of ABC Phases of load voltage and current. Here, in this case, the load is taken as a linear balanced load, so that the power factor almost reaches unity. And Fig. 8, indicates the simulation output for load voltage and current. In this case, the proposed hybrid system is implemented to operate two loads such as linear and non-linear load. The non-linear load be expressed by a diode rectifier with a series combination of inductor and resistor. The linear balance is connected from start to end while the non-linear load is connected at t= 0.1s. Thus the load current is increased from 80A to 85A. in this case, the system effected by harmonics because of a non-linear load. The proposed inverter eliminates harmonic effects. From t= 0 to t= 0.1 the compensated inverter is in off state condition and at t= 0.1, the inverter is connected to the proposed system and eliminates the harmonic. The simulation result for load, grid and source currents as shown in Fig. 6.

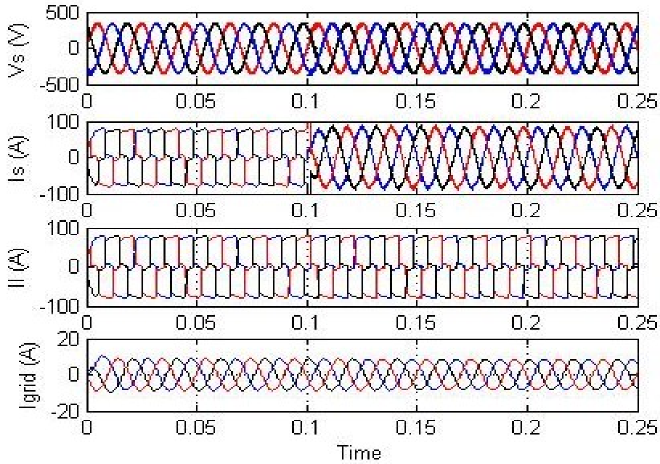

Fig. 6: Grid current(I_{grid}), Load current(I_l), Inverter current(I_c) Voltage (V_s)

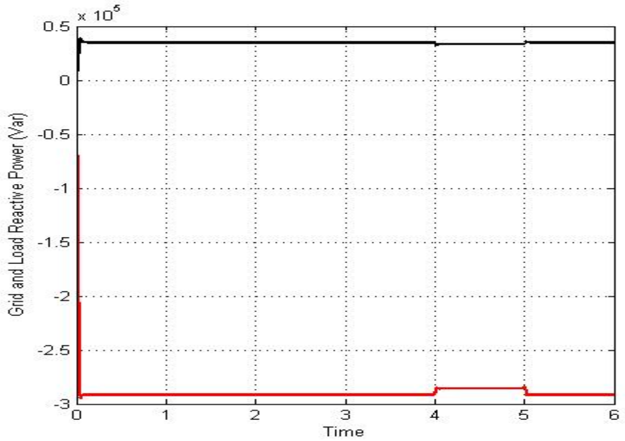

Fig. 7: Active and Reactive Power for Grid load and Source

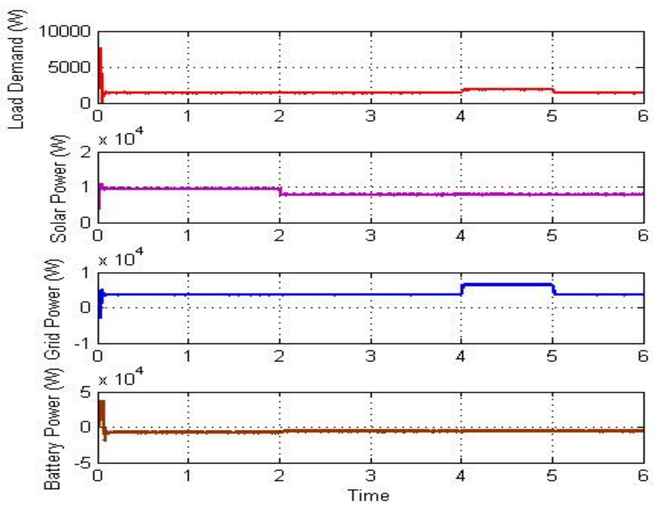

Fig. 8: Load power, Solar power, Grid Power, Battery power

And also the power management strategy between battery, wind and solar systems to meet the load requirement is shown in Fig. 7. Here, the system load is raised from 1.0kW to 1.3kW during t= 4s to 5s. and observe the variation and effective management between the sharing of power between solar, wind and battery to meet the demand shown in Fig. 8.

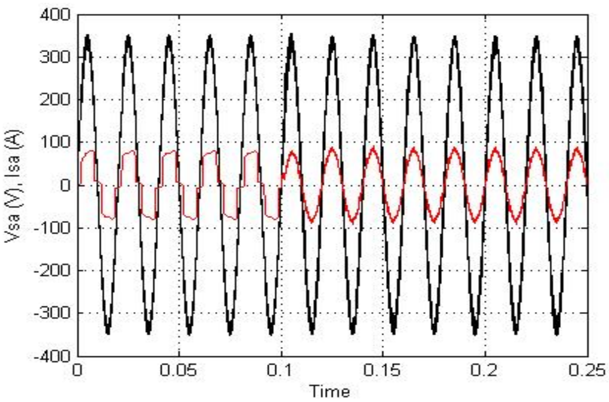

Fig. 9: Load Voltage (V_{sa}) and Current (I_{Sa})

Fig. 9 shows the power factor variation of source load voltage and current during changes of load. During time t= 0.1s the change in current takes place to 85A

VI. Conclusion

This paper presents the grid integrated solar, wind and battery energy storage system with ESA based CC-VSI by injecting real power for power quality improvement. Energy management is also explained during the unavailability of the sources. Optimizations are predominantly playing an important role in grid integrated systems. The corresponding converters were developed and modelled using MATLAB/SIMULINK.

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