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Power Generation from Batteries and a PV Grid Vehicle Charging Station with Storage Interface

Miriyala. Durga Prasad [1], Arpula. Krishnaiah [2], Maisakshi . Pavan Kumar[3]
[1]Electrical and Electronics Engineering & KLR College Of Engineering and Technology
[2] Electrical and Electronics Engineering & KLR College Of Engineering and Technology
[3] Electrical and Electronics Engineering & KLR College Of Engineering and Technology

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Abstract - This project showcases an improved grid power quality electric vehicle (EV) charging station that incorporates battery energy storage (BES). The evaluation of the unit templates (UTs) and reference grid currents is based on the positive sequence components (PSCs) of the three phase grid voltages. Through a bidirectional buck-boost converter, the dc link between the EV and BES is established. During the day, electric vehicles draw power from solar panels, and when those panels aren't in use, they draw power from the grid. Connecting the system to the grid also causes the point of common connection voltages to synchronise with grid voltages. In order to validate the satisfactory reaction under various dynamic situations, tests are carried out using MATLAB/SIMULINK.

***Key Words*: Battery energy storage (BES), electric vehicle charging station, photovoltaic (PV), power quality, synchronization.**

1.INTRODUCTION

Building EV charging stations is essential given the present global demand for EVs. [1] describes a tiered approach for assessing EV merging, EV trajectory regulation, and the operation controller. In-depth solar photovoltaic (PV) arrays on parking garage roofs and vacant spaces as locations for EV charging stations are covered in [2]. Electric vehicle charging stations that are solely connected to the grid were examined by Lyu et al. [3]. The alternative converter described in [4] uses zero voltage switching and discontinuous pulse width modulation (PWM) to charge EVs from the grid. On the other hand, active authority is not a one-way street.

The two-way active power flow was shown by Son and Lim [5]. Electric vehicle charging consumes a significant amount of grid power. We require an inexpensive, readily available alternative energy source. Varghese et al. proposed renewable energy-based electric vehicle charging stations [6]. There are issues with this charging station on both the load and grid sides. When PV generation is insufficient, the grid might discharge EVs to meet its power need. [7] refers to this function's experimental form as vehicle to grid (V2G). A smart system design for V2G scheduling and allocation is presented in [8]. The energy management in a vehicle-to-grid and vehicle-to-hydro scenario is presented in [9]. An online energy management system for hybrid multi stack fuel cell vehicles based on game theory was presented by the authors in [10]. Energy management for hybrid vehicles could be accomplished with fewer calculations, as demonstrated by Delprat and Riad Boukhari [11]. Establishing EV reference power levels, as covered in [12], is another method of managing the energy needed for EV charging. Action trimming for energy management on fuel cells, batteries, and ultracapacitors is covered by [13], a deep reinforcement learning method for HEVs.

2. SYSTEM DESCRIPTION

In order to lower peak power consumption, battery energy storage (BES) devices are increasingly being placed at electric vehicle charging stations. Nevertheless, a partial power processing converter is used in [14], but the addition of batteries increases the overall cost. Reducing losses is the primary goal of the converter that controls the power flow from the BES to the EV battery. Rafi and Bauman [15] talked about feeding to the grid and fast charging EVs during peak hours. Battery deterioration is the intended function. According to the findings in [16], adding another battery-powered station could increase the grid's and EVs' flexibility. If you like to board or rent one, you can even bring a fully charged battery.

In a similar manner, aggregators can generate or provide smart grid services by integrating batteries into virtual power plants. The concept is demonstrated by numerical calculations, and experts operate the batteries. Balakhontsev. et al. have investigated electronic automobile charging stations, the BES, and related hardware in great detail [17]. Topologies, power levels, and on-board versus off-board chargers. Power factor

correction (PFC) for an on-board charger utilizing dual active-bridge technology was proposed by Park et al. [18]. An onboard charger was created in [19] to replenish the batteries using the grid. An incredibly effective on-board charger was reported by Zinchenko et al. [20]. Compared to the two-stage charger, the one-stage charger is more user-friendly and efficient. To use less power, use the inbuilt charger. Jain et al. [22] and Singh et al. [21] suggested locations for charging facilities for electric vehicles. Here, you can only use grid electricity or photovoltaic (PV) power to charge your electric car [21]. PV arrays and infrastructure are necessary for charging electric vehicle batteries; however, they are insufficient on their own. This limitation is loosened and a BES is included in [22].

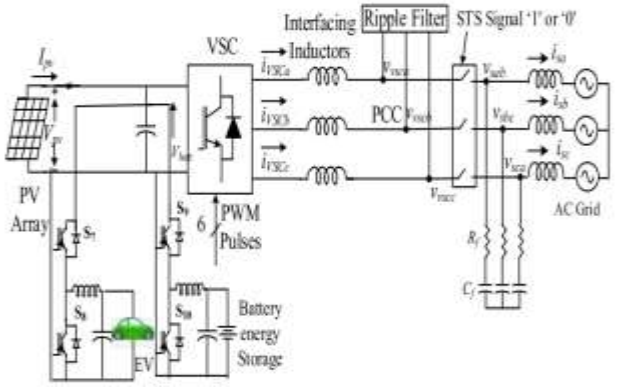


Fig. 1. System Topology

3.PRPOSED SYSTEM

3.1 Recommended Hardware Configuration

Figure 1. depicts the finished EV charging station with BES. Power can be transferred from the grid to the PV array, BES, EV, and vice versa via the VSC. In order to trade with the grid, it transforms DC electricity into AC current. Each of the EV and BES has a bi-directional DC-DC converter that connects them to the common DC link. The BES and EV's charging and discharging are managed by this converter. When VSC is linked to PCC, interface inductors are used to reduce harmonic current. The system is kept in synchronism by a static transfer switch (STS) that is linked to the grid.

3.2 Methods of Control

Its primary purpose is to charge electric vehicles. The BES is charged using the energy that remains when grid power is lost. When necessary, BES, EV, or both can be released into the grid.

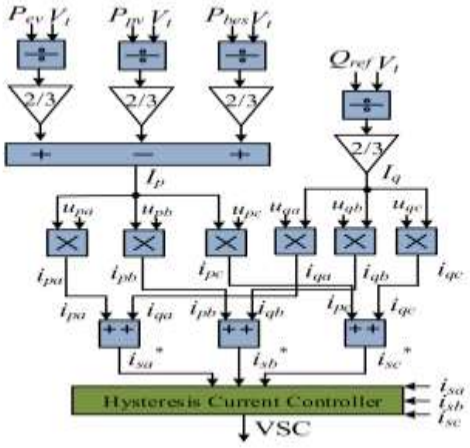


Fig 3.1 GC Control

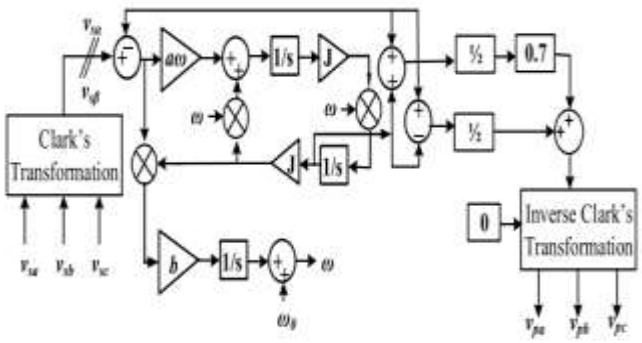


Fig 3.2 PSCs Estimation

They are as follows: MPPT control, GC mode control, SM control (both standalone and synchronization), BES control, and EV control.

1) Control of the GC Mode A.

The VSC switching pulses are generated by the control while it is operating in GC mode, as shown in Figure 3.1.

First, we can see in Figure 3.2 how to calculate the grid voltages' positive sequence components (PSCs) using the unit template (UT) [23]. To transfer the three phase voltages (Vsa, Vsb, and Vsc) into the α-β domain, the Clark transformation is used.

$$\begin{pmatrix} v_{s\alpha} \\ v_{s\beta} \end{pmatrix} = \begin{pmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{pmatrix} \begin{pmatrix} v_{sa} \\ v_{sb} \\ v_{sc} \end{pmatrix}. \quad (1)$$

The overall transfer function from Fig. 3.2 is attained as

$$v_{p\alpha\beta} = \frac{a\omega}{(s+a\omega)^2+\omega^2}\begin{Bmatrix}(s+a\omega) & -\omega\\ \omega & (s+a\omega)\end{Bmatrix}\begin{Bmatrix}v_{s\alpha}\\ v_{s\beta}\end{Bmatrix}. \quad (2)$$

The PSCs are estimated from controller output obtained in (2) by using inverse Clark's transformation

$$\begin{pmatrix}v_{pa}\\ v_{pb}\\ v_{pc}\end{pmatrix} = \frac{3}{2}\begin{pmatrix}\frac{2}{3} & 0\\ -\frac{1}{3} & \frac{\sqrt{3}}{3}\\ -\frac{1}{3} & -\frac{\sqrt{3}}{3}\end{pmatrix} \times \begin{pmatrix}v_{s\alpha}\\ v_{s\beta}\end{pmatrix}. \quad (3)$$

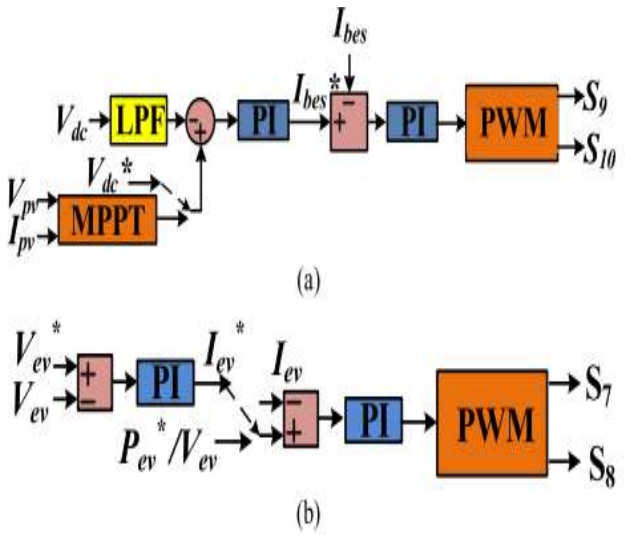


Fig 3.3 Method of control. (a) Control of the BES. (b) Algorithm for controlling the charging and discharging of EV batteries.

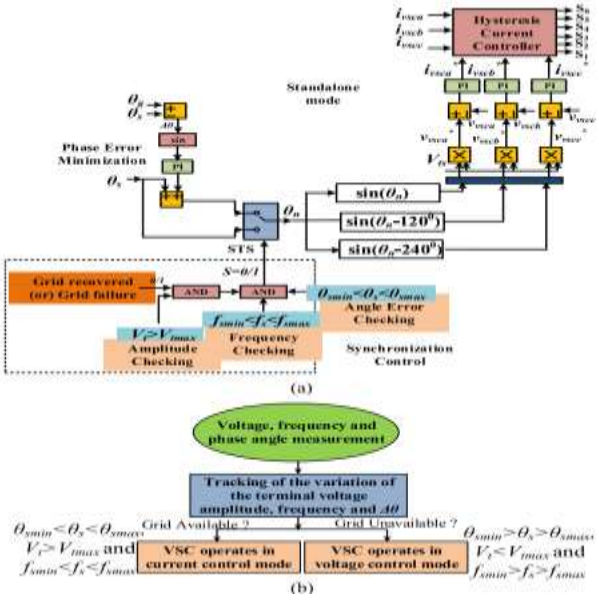


Fig 3.4 (a) Control and synchronization independently. (b) Control at the system level to coordinate switching between GC and SM modes.

The amplitude of terminal voltage (Vt) is computed using phase voltages as

$$V_t = \sqrt{\frac{2}{3}\times\left(v_{pa}^2+v_{pb}^2+v_{pc}^2\right)} \quad (4)$$

where v_{pa}, v_{pb}, and v_{pc} are PSCs. The in-phase UTs are computed from PSCs and terminal voltage as

$$u_{pa} = \frac{v_{pa}}{V_t}, \quad u_{pb} = \frac{v_{pb}}{V_t}, \quad u_{pc} = \frac{v_{pc}}{V_t}. \quad (5)$$

Likewise, quadrature UTs are evaluated as depicted in [16]

4.SIMULATION & RESULTS

During a grid outage, the simulated system performance is shown in Figure 3.6(a). In case of a power outage, the charging station will continue to operate in SM mode. Thereby, grid voltages and currents immediately drop to zero. To compensate for the surplus power, the BES starts charging. Charge methods for electric vehicles have remained unchanged.

Figure 3.6(b) shows the theoretical reaction of the system during grid recovery, which is covered in Section C: System Performance During Grid Reconnection. Upon grid restoration, the VSC synchronizes with the grid and shows currents and voltages as they occur on the grid. As the BES starts to drain, the charging of the EV continues unabated.

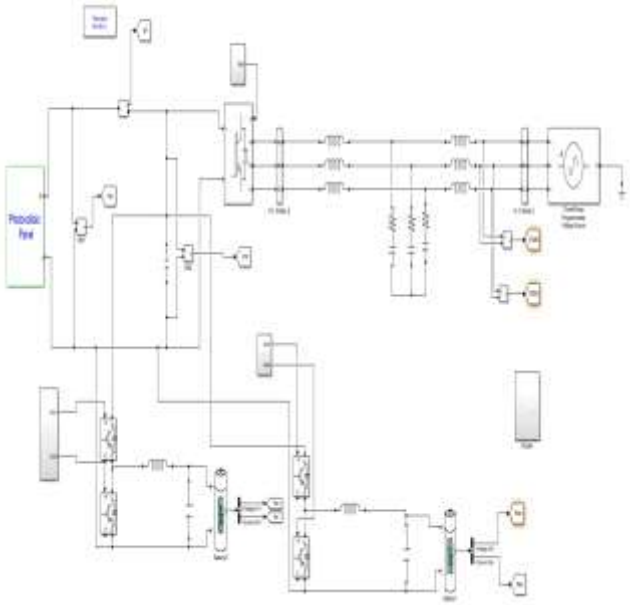


Fig 4.1 Simulation System Model

4. 1. PV Panel Block

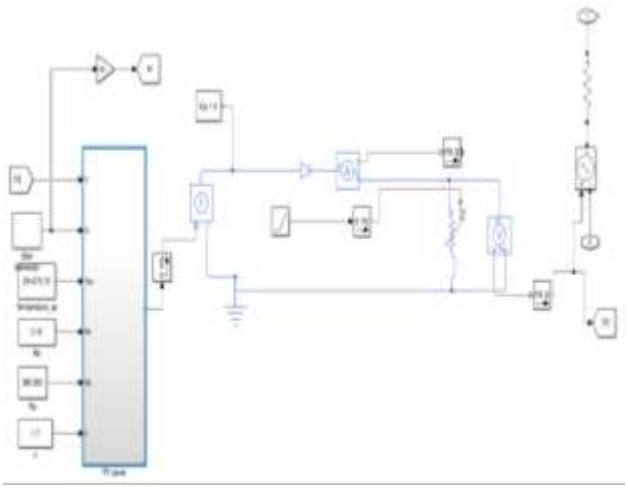


Fig 4.2 PV System

The large block labelled PV panel is the mathematical model of the photovoltaic module.

4.2 Inverter Control

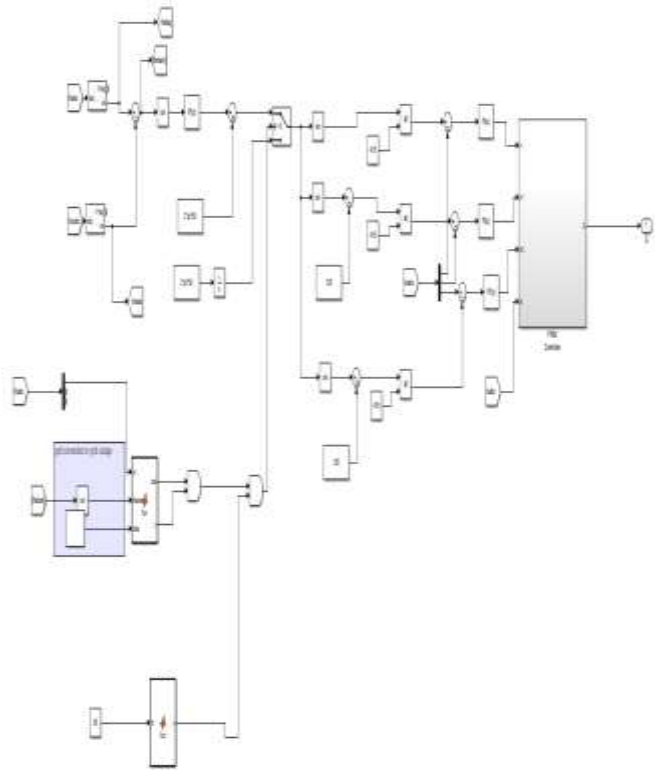


Fig 4.3 Inverter Switching Control

1) Grid Voltage Angle Calculation (PLL)

The blocks labelled **Freq (ω)**, **2π·50**, and the integrator generate the electrical angle

$$\theta = \int \omega \, dt$$

where $\omega = 2\pi f$

$$f = 50Hz$$

Therefore, $\omega = 2\pi \times 50 = 314.16$ rad/s

and $\theta = 314.16t$

2) Three-Phase Reference Signals

The three sine-wave references are generated as

$$V_a = V_m \sin(\theta)$$

$$V_b = V_m \sin(\theta - 120^\circ)$$

$$V_c = V_m \sin(\theta + 120^\circ)$$

In the model the max value is taken as 415, therefore

$$V_a = 415 \sin(\theta)$$

$$V_b = 415 \sin(\theta - 120^\circ)$$

$$V_c = 415 \sin(\theta + 120^\circ)$$

3) Phase Shift Equation

The 120 is taken to create the phase shift

$$\theta_b = \theta - 120^\circ$$

$$\theta_c = \theta + 120^\circ$$

4) PI Controller

The Blocks marked PI(Z) is used for discrete PI control

$$u(t) = K_p e(t) + K_i \int e(t)dt$$

where $e(t) = V_{ref} - V_{measured}$

and $u(t)$ = modulation signal

5) PWM Generation

The modulation signal and carrier wave are compared in PWM controller to generate the gating signals for inverter switches.

$$PWM = \begin{cases} 1, & V_{ref} > V_{carrier} \\ 0, & V_{ref} \leq V_{carrier} \end{cases}$$

$$G = [g_1, g_2, g_3, g_4, g_5, g_6]$$

4.3 MPPT Controller

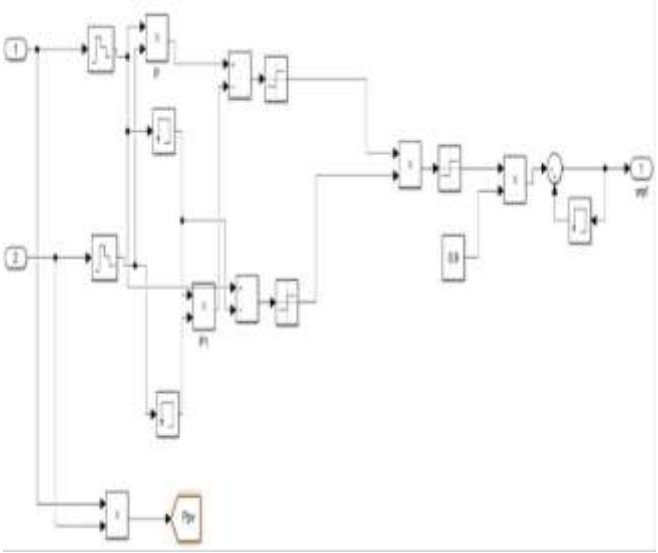


Fig 4.4 Perturb and Observe method MPPT Controller

5.4.1 Case – 1: Grid Disconnection

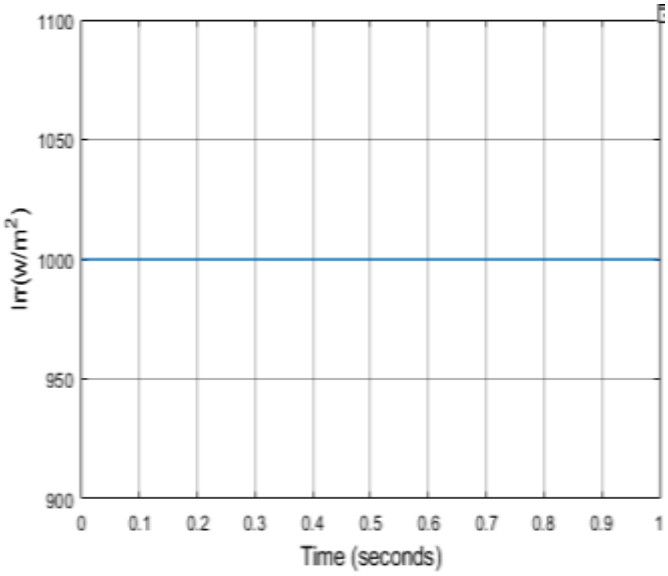


Fig 4.5 Grid Disconnection Mode (a) Solar Power (Irradiance)

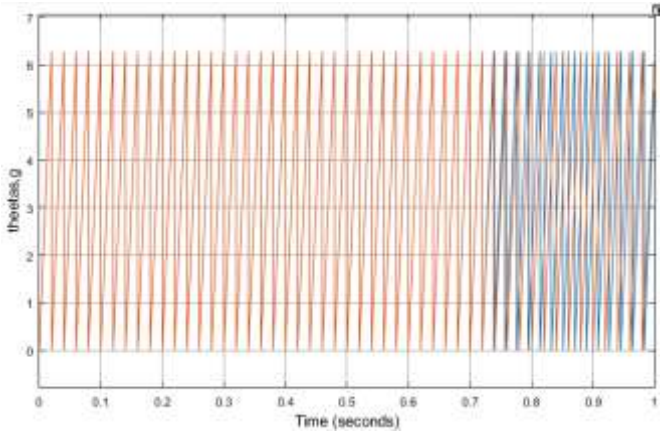


Fig 4.5 (b) Source/Grid Voltage Phase Angle & Grid Synchronization Angle (θ_s & θ_g)

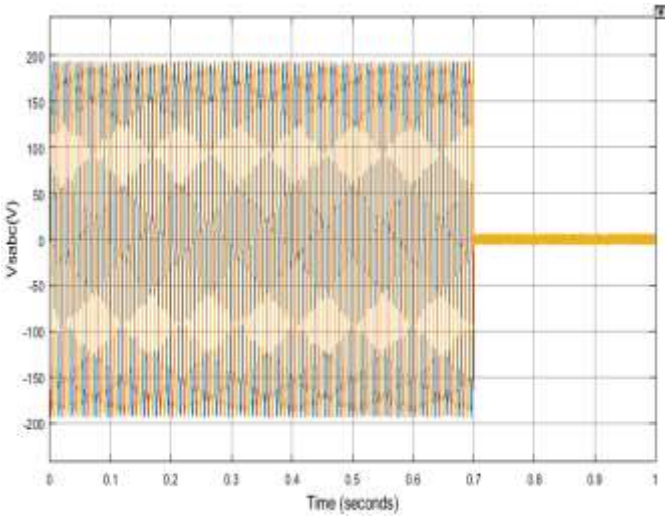


Fig 4.5 (c) Three-phase source (grid) voltages

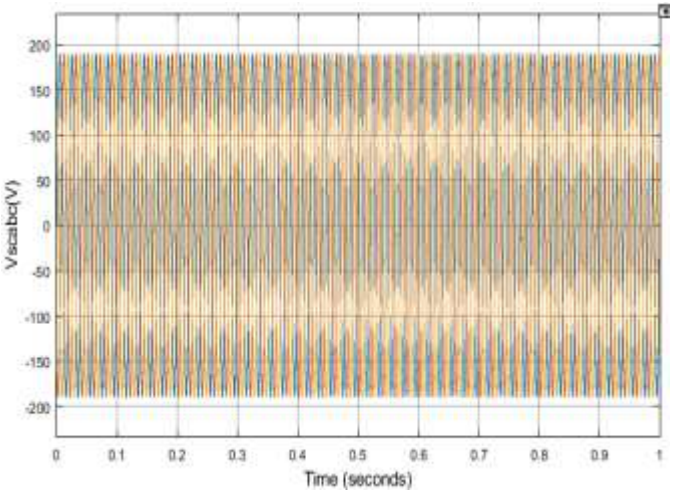


Fig 4.5 (d) Three-phase converter/inverter output voltages

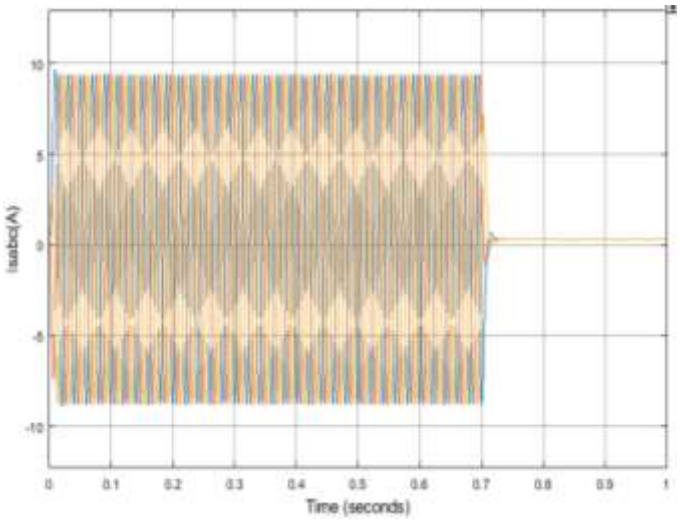


Fig 4.5 (e) Three-phase source/grid currents

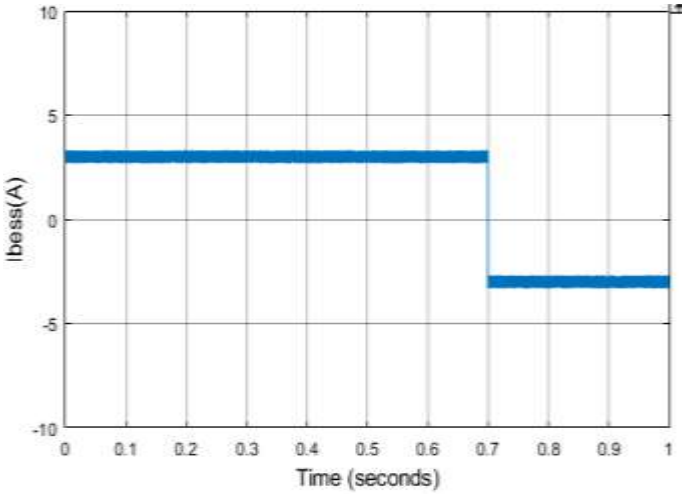


Fig 4.5 (f) Current of the Battery Energy Storage System (BESS)

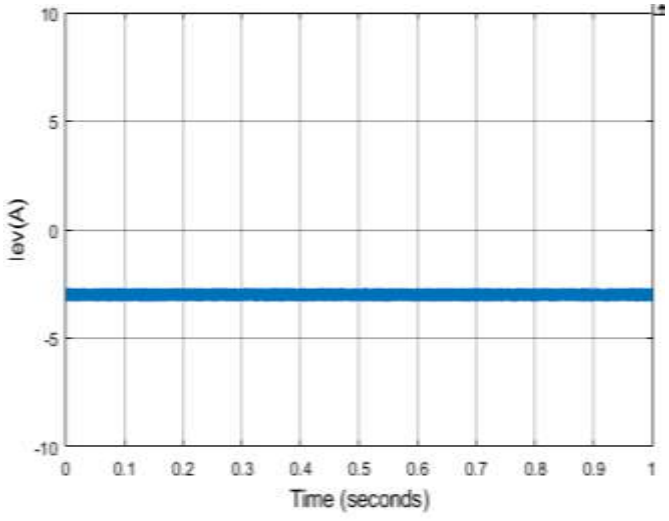


Fig 4.5 (g) EV battery charging current

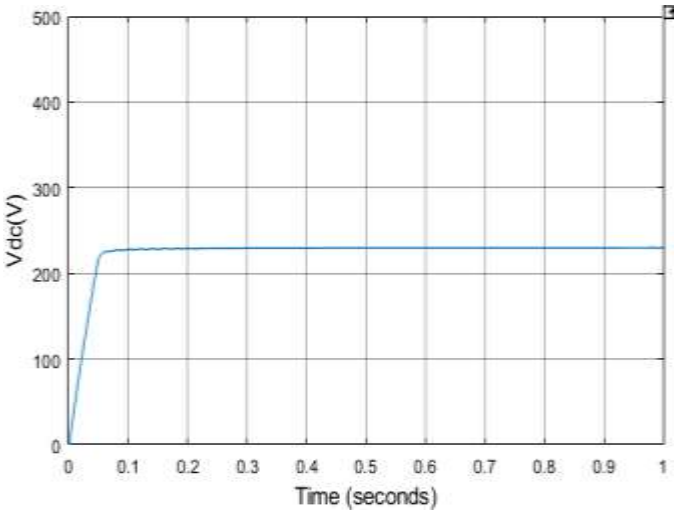


Fig 4.5 (h) DC-link voltage

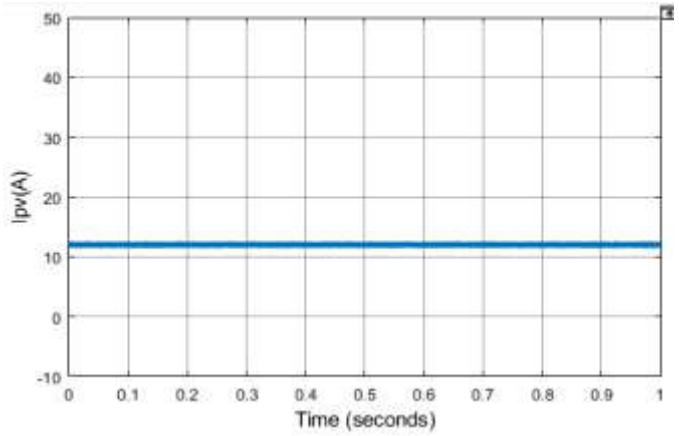


Fig 4.5 (i) photovoltaic (PV) array output current

5.4.2 Case – 2: Grid Reconnection

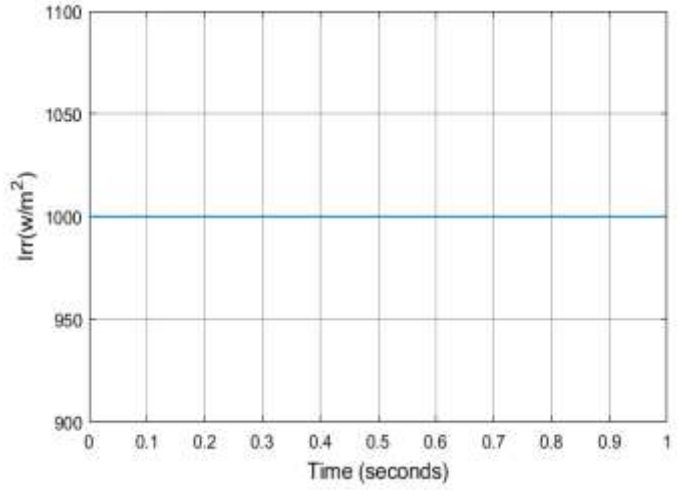


Fig 4.6 Grid Reconnection Mode (a) Solar Power (Irradiance)

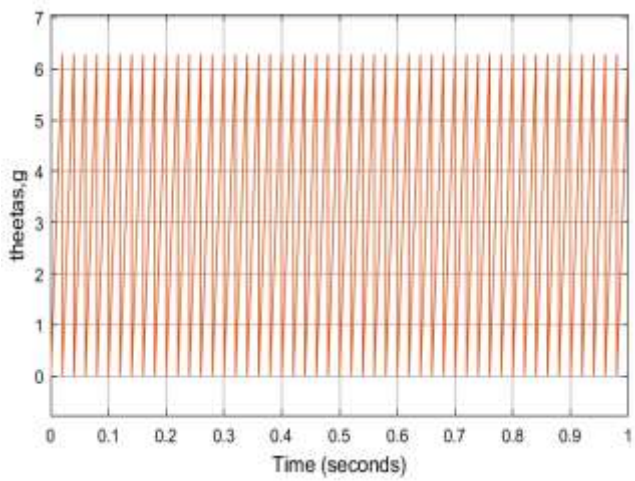


Fig 4.6 (b) Source/Grid Voltage Phase Angle & Grid Synchronization Angle (θ_s & θ_g)

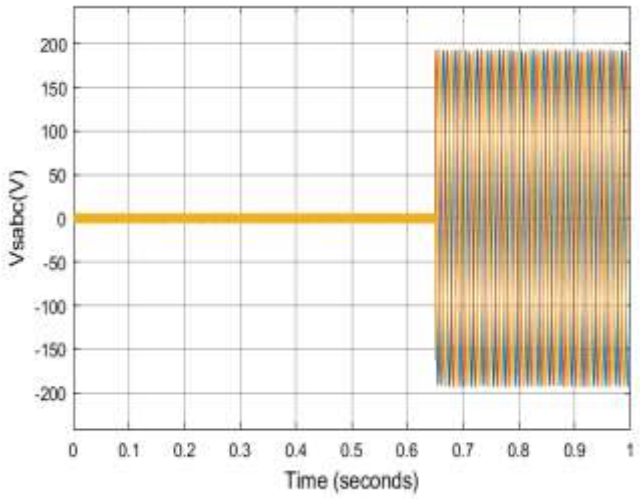


Fig 4.6 (c) Three-phase source (grid) voltages

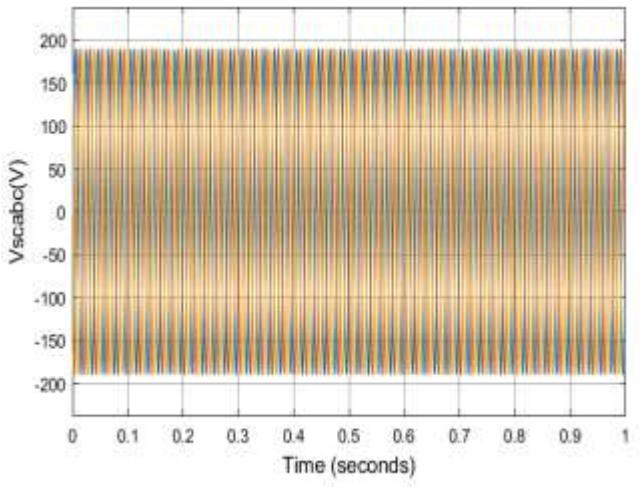


Fig 4.6 (d) Three-phase converter/inverter output voltages

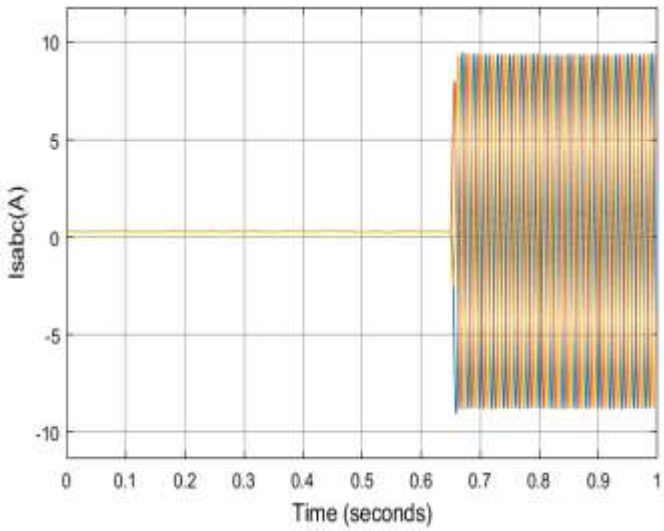


Fig 4.6 (e) Three-phase source/grid currents

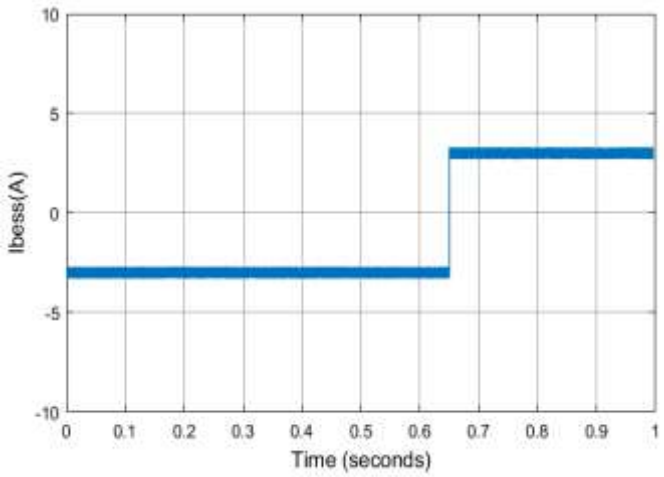


Fig 4.6 (f) Current of the Battery Energy Storage System (BESS)

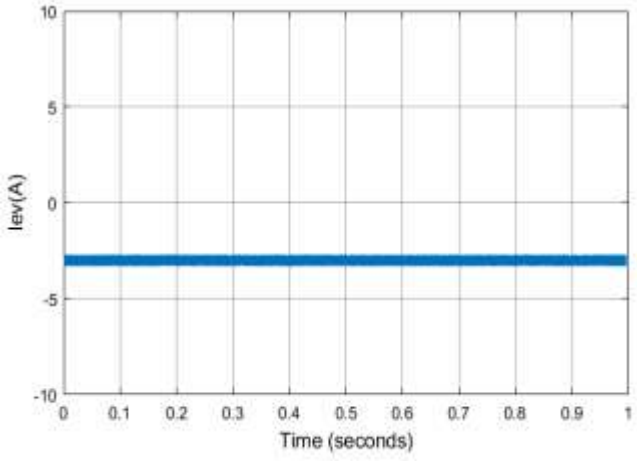


Fig 4.6 (g) EV battery charging current

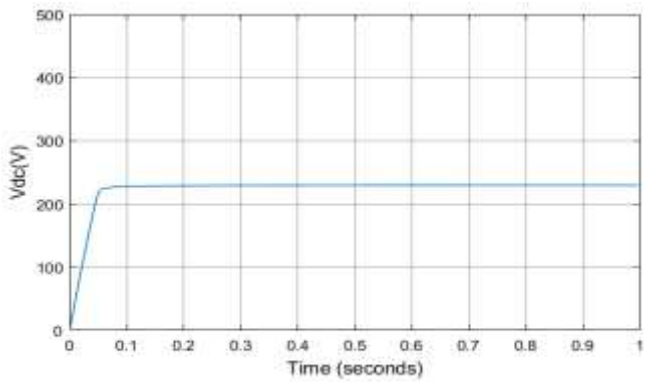


Fig 4.6 (h) DC-link voltage

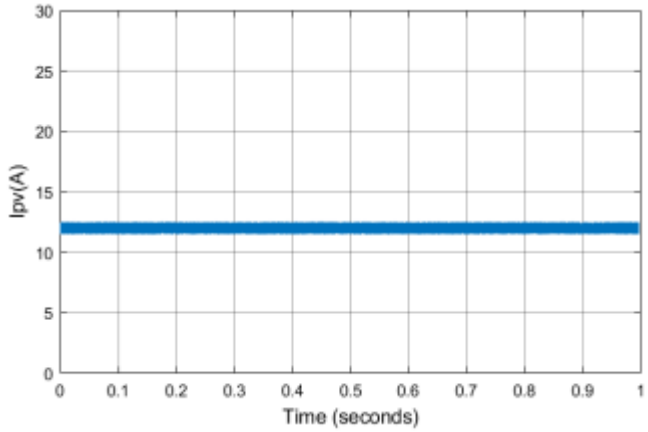


Fig 4.6 (i) photovoltaic (PV) array output current

The performance system is shown in this section.

A. Performance Under Variation of Solar Insolation

During rise in PV array irradiation from 600 to 1000 W/m2 , PV array generation increases, since EV and battery are in floating mode, as shown in Fig 3.5.

B. Performance of System at Outage of Grid

Simulated performance at grid outage is shown in Fig. 3.6(a). When grid outage is observed, charging station operates in SM. Therefore, grid currents and voltages immediately become zero. The BES compensates for surplus power requirement and starts discharging. EV charging remains unchanged.

C. Performance of System at Grid Reconnection

The simulated response of system at grid recovery is presented in Fig. 3.6(b). During grid restoration, the VSC synchronizes to the grid, and the grid voltages and the currents are appeared. The BES starts charging without affecting the EV charging

D. Comparative Analysis of the Proposed Control with Fractional-Order Correntropy Adaptive Filtering Algorithm at DC Offset

A 90-V dc offset is given in grid voltages. The UTs after the use of fractional-order correntropy adaptive filtering algorithm can be seen in Fig 3.7.

3. CONCLUSIONS

This thesis focused on the modelling and simulation of a PV-based electric vehicle charging system with battery energy storage and grid integration. The proposed system was developed to utilize solar energy effectively for EV charging while maintaining a reliable power supply under different operating conditions. A Perturb and Observe (P&O) based MPPT controller was implemented to extract maximum power from the PV array. The DC–DC converter, battery energy storage system, and bidirectional converter were integrated to regulate power flow between the PV source, battery, EV, and grid. The battery storage system helps to overcome the variations in solar power generation by storing excess energy and supplying power when the available PV power is insufficient.

The grid-connected inverter with PLL synchronization and hysteresis controller was implemented to get stable operation and effective power exchange with the power grid. The LCL filter was used to reduce switching harmonics and improve the quality of the grid current. The simulation results confirm that the proposed system can successfully manage energy flow, maintain DC-link voltage stability, and provide continuous EV charging under different conditions. The developed system demonstrates the potential of renewable energy-based EV charging infrastructure and can be further improved by incorporating advanced control techniques, optimized energy management strategies, and experimental validation for practical applications.

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Miriyala Durga Prasad Received B.Tech and from JNTU Hyderabad, pursuing M.Tech in Electrical Power Systems. in KLR College of Engineering and Technology.



Arpula. Krishnaiah received the B.Tech and M.Tech from JNTU Hyderabad, working as Assistant professor and Head of the Electrical and Electronics engineering department in KLR Engineering College, he has Teaching in 17 years of experience in various institutions, published in 25 international publications



Maisakshi. Pavan Kumar received the B.Tech and M.Tech from JNTU Hyderabad, He is currently working as an Assistant Professor in the Department of Electrical and Electronics Engineering at KLR College of Engineering and Technology, where he has been serving for the past five years. He has published in 23 international publications.