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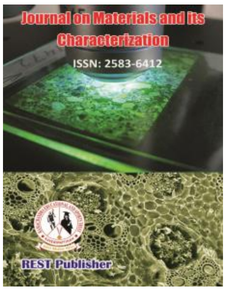

Fractional Order Pi Controller Based Grid Integrated Distributed Energy Resources for EV Charging Infrastructure

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Abstract: *This work presents a novel grid incorporating distributed energy resources (DER) for electric vehicle (EV) charging infrastructure with a fractional order PI controller. A combination of photovoltaic (PV)-solar, fuel cell and battery energy sources are utilized to form a DERs. The integration of DERs not only decreases the impact of environmental issues and enhances power quality and reliability of the grid. The developed grid tied DERs facilitates bidirectional power flow capability, seamless smooth EV charging and significant impact for grid support during peak load demand or grid off conditions. Besides, the proposed common DC bus architecture enables high-power, medium or fast charging at multiple voltage levels, significantly slowing down the EV charging time span. To incorporate DER into EV charger to obtain fast charging application static transfer switches (STS) are employed. The STS switches provide redundancy when power sources affect with intermittent nature for reliable power operation of the load it can provide power from other available power sources. Furthermore, optimize the operation of the DER-based EV fast charging system these STS switches are controlled by an advanced fractional-order PI (FOPI) controller. To analyze the controller performance of proposed work the simulation case study carried out on DER based EV system in both grid integration and grid off conditions. In both the conditions the proposed FOPI control approach provides satisfactory simulation responses.*

Keywords: *FOPI Controller, DER, Static transfer switches*

1. INTRODUCTION

Now a day the adoption of electric vehicles (EVs)is growing rapidly to higher heights in the transportation sector over the internal-combustion engine vehicles. Many Govt encouraging into decarbonizes transportation. EVs decrease the environment issues concern to fossil fuel-driven vehicles. However, widespread usage of EVs providing a feasible and sustainable charging infrastructure is highly prioritized. A few existing grids incorporated DERs for EV charging networks suffers with limitations in terms of grid capacity and potential strain on the electrical network during peak demand periods [1].

To address these problems, [2] presented an EV charging circuit topology with combination of hybrid renewable energy (RE) sources. Integrated solar and fuel cells, with a common DC bus architecture to improve the performance of the EV charger. The hybrid RE sources decreases usage of fossil fuels, on the other hand reduces gas emissions. The DERs can facilitate stabilized grid voltage and frequency, particularly during peak demand or grid disturbances. To form hybrid RE sources or DERs a well operated power converters are essential. These power converters can mitigate power quality issues such as harmonics and voltage fluctuations. Besides, these power converters enable the bidirectional power flow capability during grid-connected and island modes, ensuring uninterrupted charging services even though gridoff conditions also[3].

The common DC bus architecture facilitates high-power, fast charging at elevated voltage levels, significantly reducing charging times for EV users.To attain the environmental and sustainability benefits of EVs, their charging must be powered by RE sources. This aligns with the core objectives of EV adoption: reducing air pollution and diminishing reliance on fossil fuels. While PV arrays offer a promising solution, their performance is significantly impacted by fluctuating solar irradiance. Studies, such as [4], have demonstrated that the effects of these variations are particularly in single mode of scenarios, whether in islanded/grid-connected mode.

Research in [5] explores the integration of EV charging stations into smart grids, focusing on mitigating harmonic distortions and enhancing overall power quality. Furthermore, [6] delves into multiple purposes within the context of smart grids or homes. While literature offers a range of control strategies and converter topologies for these diverse operating modes, existing studies often focus solely on either grid-connected or island mode operation. A significant limitation of this approach is the potential for underutilized solar PV panels during grid disconnections, even when solar isolation is available. To mitigate the impact of fluctuating solar irradiance and ensure continuous operation, the integration of a battery ESS is crucial.

Multiple control algorithm presented in the literature for EV chargers such as SOGI[7], model predictive[8], least mean fourth[9] and adaptive filter[10]. Whereas these control techniques are widely accepted, it affirms poor performance during the weak grid conditions. To solve this shortcoming enhance the synchronization capability of EVs and grid and FOPI based STS switches are proposed in this current work. The STS switches provide redundancy when power sources affect with intermittent nature for sustainable and reliable power operation of EV charging it provide the power from the alternative power source. STS switches well co-ordinate with different energy resources and the energy management among them.

2. SYSTEM TOPOLOGY

Figure 1 describes the layout of grid integrated DER based EV. This EV charging infrastructure comprises the following circuit topologies.

- Solar PV Array: Harvests solar energy, converting it into direct current (DC) power. Increment conductance MPPT approach is utilized to yield more peak power from the solar under various environmental conditions.
- Fuel Cell: Generates electricity through a chemical reaction involving hydrogen and oxygen, providing a reliable and clean power source.
- Energy Storage System (ESS): Acts as an energy buffer, storing excess renewable energy and ensuring a continuous power supply at high demand or low generation.
- DC-DC Converters: Facilitate efficient power flow by adapting DC voltage levels to achieve the desired specifications of both the EV chargers and the grid.
- Grid Interface: Enables seamless bidirectional power exchange between the charging infrastructure and the main electrical grid, allowing for potential grid support functions.

EV Chargers: Deliver charging services to electric vehicles, accommodating various charging needs and speeds.

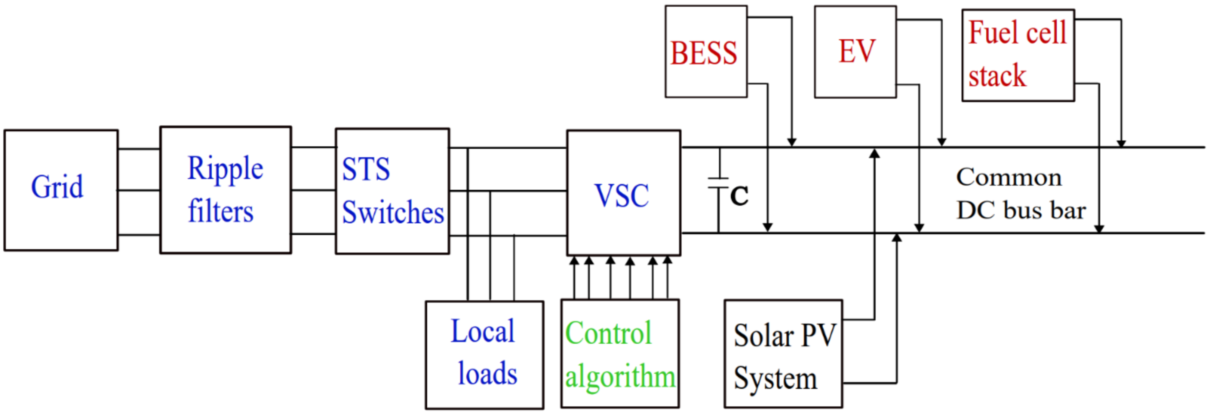


FIGURE 1. Illustrates the system layout of grid integrated DER based EV

3. FOPI CONTROLLER

Advanced control algorithms are essential to ensure optimal operation and stability of the hybrid renewable energy system. These algorithms include manage the flow of power between the various components of the system, including the PV array, fuel cell, ESS, grid, and EV chargers.

FOPI control offers several advantages over traditional PI control:

- **Improved Dynamics:** By incorporating fractional-order elements, FOPI controllers can achieve a more responsive and precise control behavior compared to PI controllers. This translates to faster and more accurate balancing of energy between the batteries.

- **Enhanced Robustness:** FOPI controller's exhibit better robustness to system variations and disturbances, leading to a more stable and reliable charging process.
- **Reduced Grid Strain:** By ensuring a more stable charging process, FOPI control could potentially help minimize unwanted fluctuations in power drawn from the grid.

While the previously discussed control system utilizes a PI controller, research is ongoing to explore the potential benefits of implementing FOPI control in EV chargers. This would involve: Designing a customized FOPI control algorithm specifically tailored for the dynamics of the EV charger system.

Another benefit of this proposed FOPI based EV charger charger is the nature of the current flowing through the motor's leakage inductance. Unlike some other charger designs, this system ensures the current is a clean sinusoid at the grid frequency.

The FOPI control law mathematically defined as

$$C(s) = Kp + \frac{Ki}{S^{\lambda}}$$

λ value numerically varies from [0 to unity]. In other hand, in terms of frequency bounds (ω_b, ω_h) FOPI controller expressed as:

$$K(s) = 〖(1 + bs/d\omega b)/(1 + bs/d\omega h)〗 {}^\wedge\lambda$$

Where s=jw, b>0, d>0, and

In frequency bounds of ωb<ω<ωh Taylor polynomial expansion form as:

$$K(s) = 〖\frac{bs}{d\omega b}]{}^\wedge\lambda(1 + \lambda P(S) + \frac{\lambda(\lambda-1)}{2} p{}^\wedge 2(s)$$

Where $p(s) = \frac{-ds^2+d}{ds^2+b\omega hs}$

It is initiated that

$$s^{\lambda} = \frac{(d\omega b)^{\lambda b-\lambda}}{\left[1 + \lambda P(S) + \frac{\lambda(\lambda-1)}{2} p^{2(s)}\right]} \left(\frac{1 + \frac{bs}{d\omega b}}{1 + \frac{ds}{d\omega h}}\right)^{\lambda}$$

Approximated the taylor polynomial implies to

$$S^{\lambda} = \frac{d\omega b}{b} \frac{ds^2 + b\omega hs}{d(1-\lambda)s^2 + b\omega hs + d\lambda} \left(\frac{1 + \frac{bs}{d\omega b}}{1 + \frac{ds}{d\omega h}}\right)^{\lambda}$$

The FO is given as

$$S^{\lambda} = \frac{d\omega b}{b} \frac{ds^2 + b\omega hs}{d(1-\lambda)s^2 + b\omega hs + d\lambda} \left(\frac{1 + \frac{bs}{d\omega b}}{1 + \frac{ds}{d\omega h}}\right)^{\lambda}$$

The genuine part's negative poles are in the range of [0 to 1]. Continuous-time coherent simulation is used to approximate equation:

$$K(s) = \lim_{n\to\infty} Kn(s) = \lim_{n\to\infty} = -N \frac{1 + \frac{S}{\omega k}}{1 + \frac{S}{\omega k}}$$

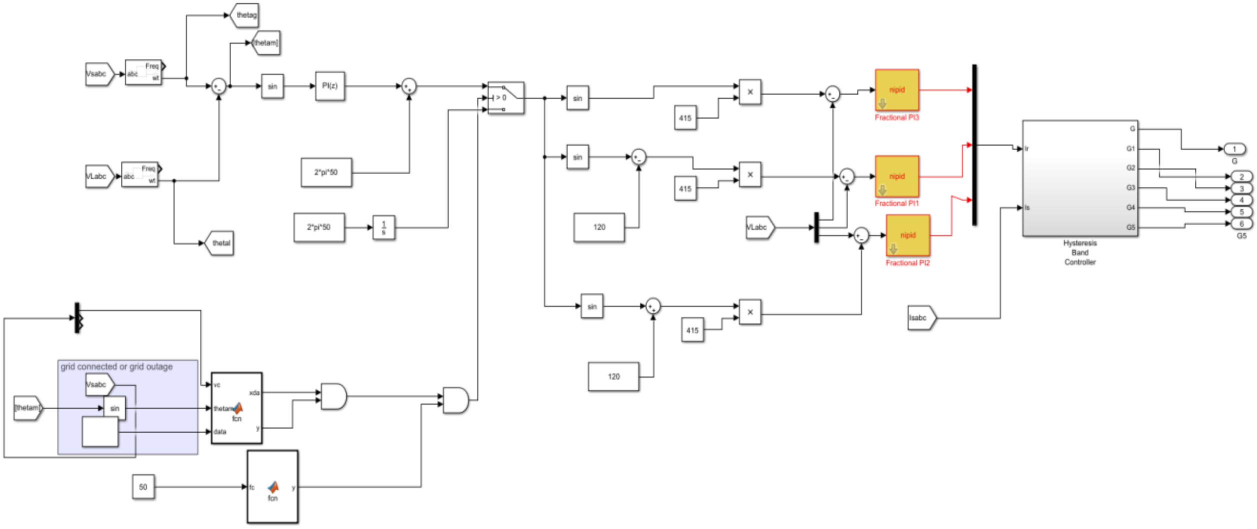


FIGURE 2. FOPI control scheme for operating STS switches

4. RESULTS AND DISCUSSION

The MATLAB circuit diagram of proposed DER based EV with FOPI controller is shown in fig.3. To investigate the performance of the proposed control approach simulations are performed for grid availability to grid outage and grid dis-availability to grid integration.

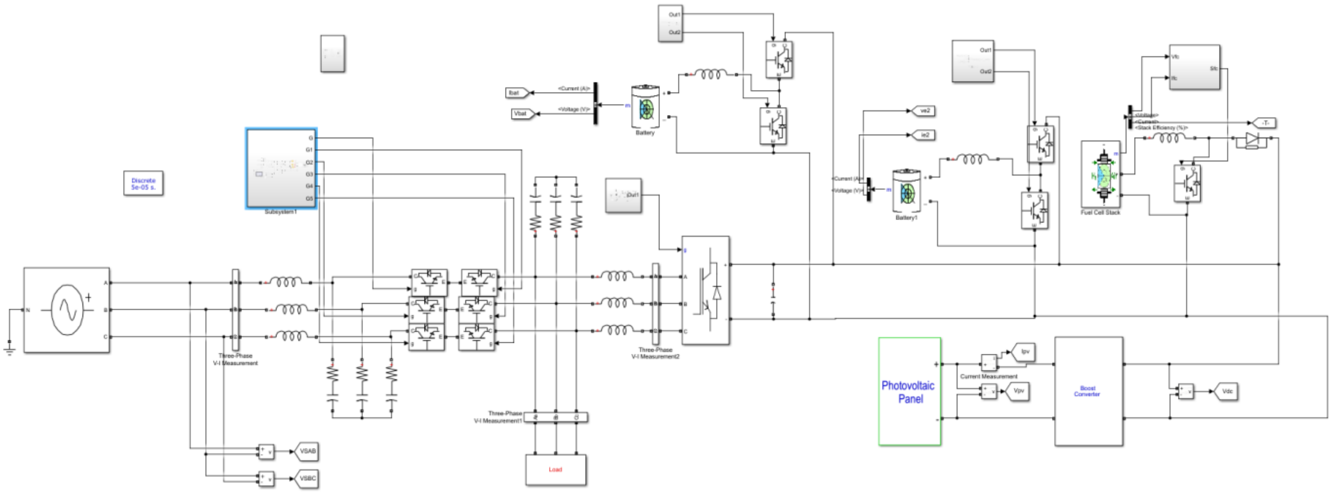


FIGURE 3. MATLAB circuit configuration of grid integrated DER based EV

Mode 1: Performance of DC bus and EV system during grid connection to disconnection:
In this scenario as shown in fig.4a at t=0.4secs the grid disconnected from the distributed system. From fig.4a grid voltage, fig 4b grid current it is ensure that at t=0.4secs the grid volt-amp profiles are reduce to zero and corresponding grid power also zero(see fig.4c).

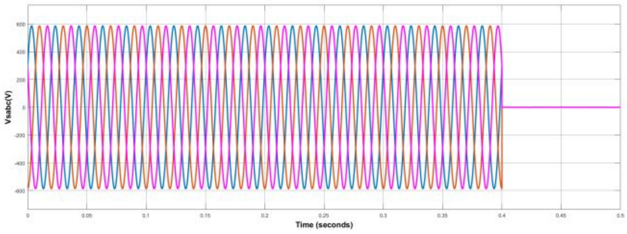


FIGURE 4a. Grid voltage

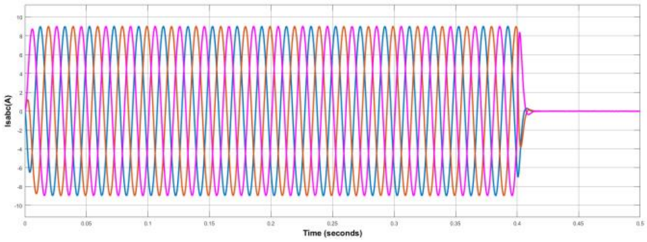


FIGURE 4b. Grid current

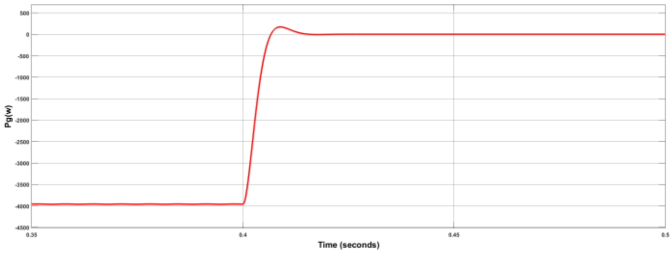


FIGURE 4c. Grid Power

During this grid transition also solar and fuel cell shared the load smoothly. Solar-fuel cell supplied steady state power to the local loads. The output response of load voltage is depicted in fig.4d.

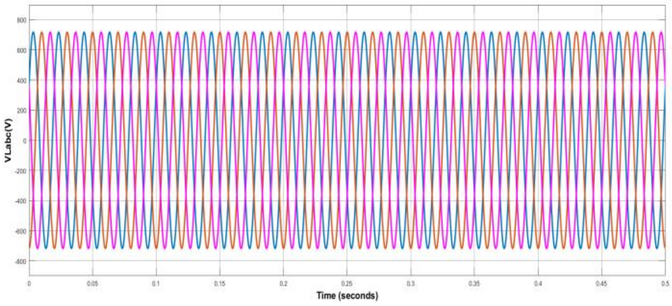


FIGURE. 4d Load voltage

Fig.4e, fig.4f and fig.4g represent the terminal voltages at solar, battery and fuel-cell respectively

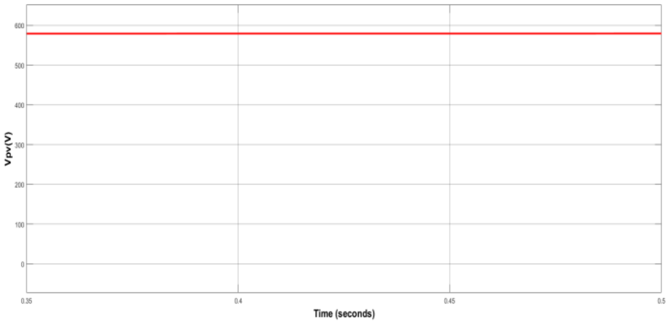


FIGURE 4e. PV Voltage

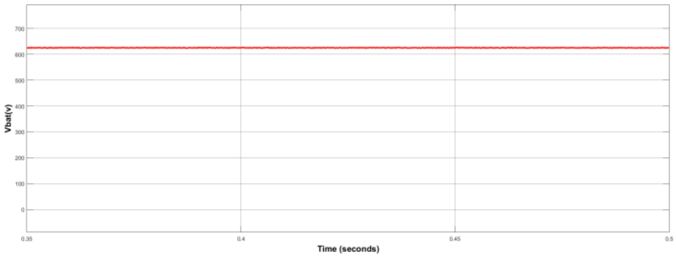


FIGURE 4f. Battery Voltage

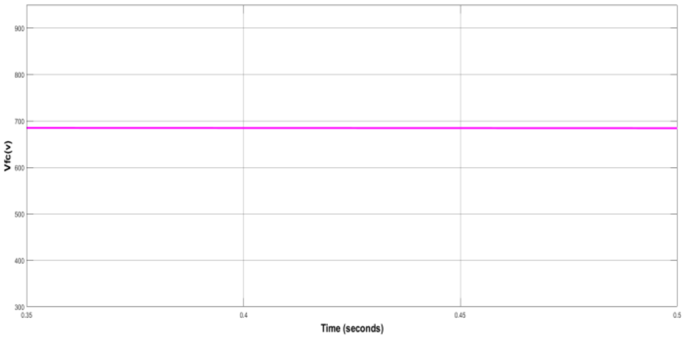


FIGURE 4g. Fuel-Cell Voltage

Even-though grid outage mode, constant voltage and constant power maintained at the DC bus bar and EV respectively with better energy managing between the power converters with proposed FOPI controller. Fig.4h and Fig.4i represents the obtained simulation responses of DC bus bar and EV.

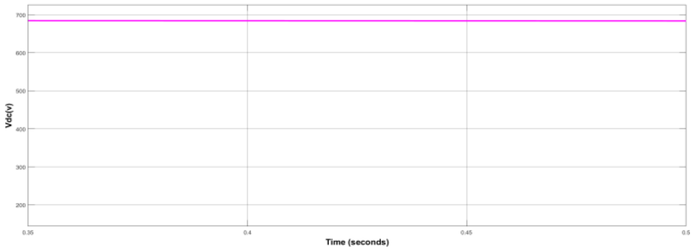


FIGURE 4h. Common DC Bus Voltage

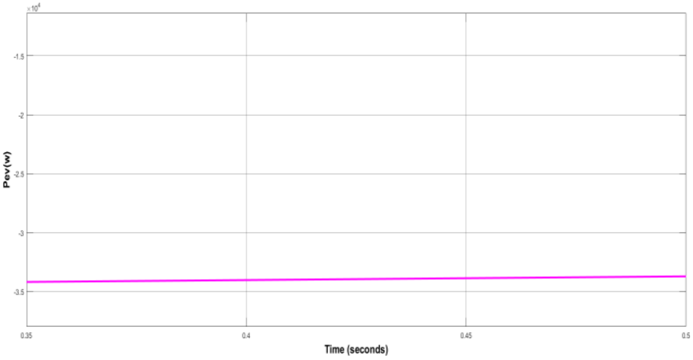


FIGURE 4i. EV Power

Mode 2: Performance of DC bus and EV system during grid disconnection to connection:
In this scenario as shown in the fig.5a at t=0.6secs the grid connected to the distributed system. From fig.5a grid voltage, fig 5b grid current it is ensure that at t=0.6secs the grid volt-amp profiles are reach to its nominal values and corresponding grid power also increases (see fig.5c).

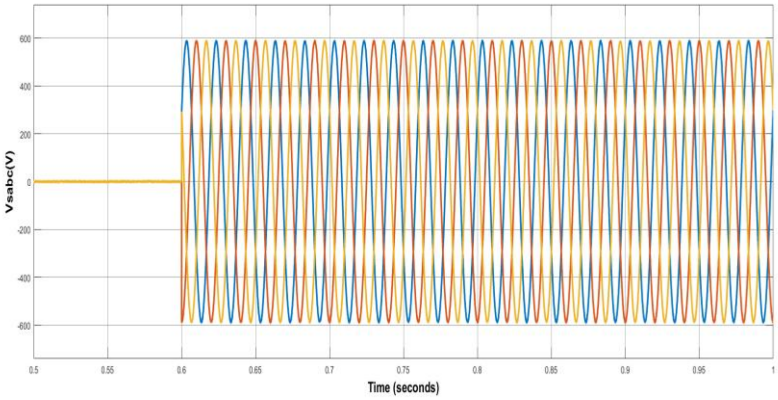


FIGURE 5a. Grid Voltage

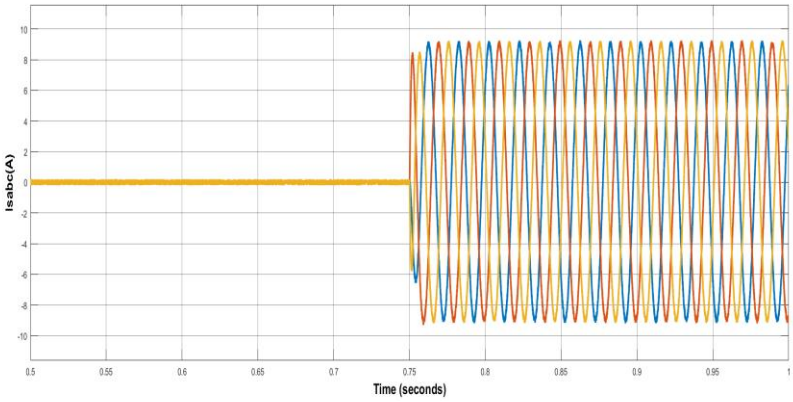


FIGURE 5b. Grid current

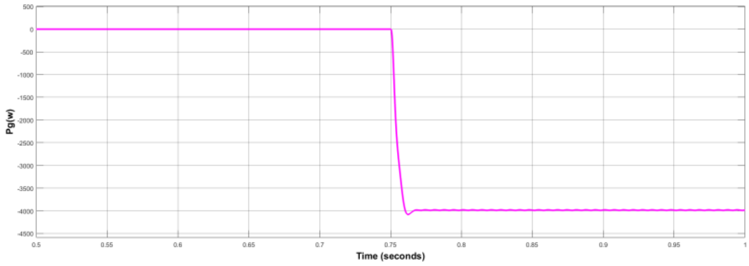


FIGURE 5c. Grid Power

Even this grid transition also solar and fuel cell shared the local-load smoothly. Solar-fuel cell supplied a constant power to the loads. The output response of load voltage is depicted in fig.5d.

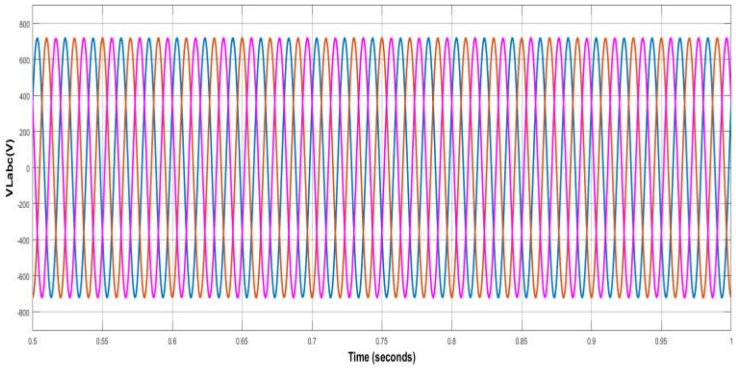


FIGURE 5d. Load voltage

Fig.5e, fig.5f and fig.5g represent the terminal voltages at solar, battery and fuel-cell respectively.

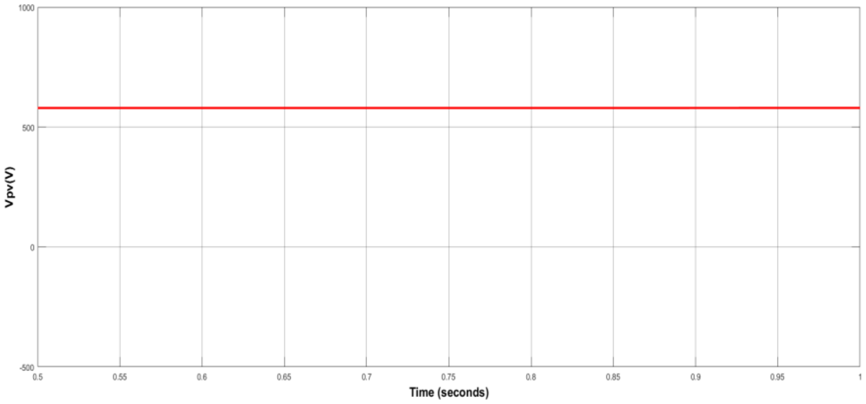


FIGURE 5e. PV Voltage

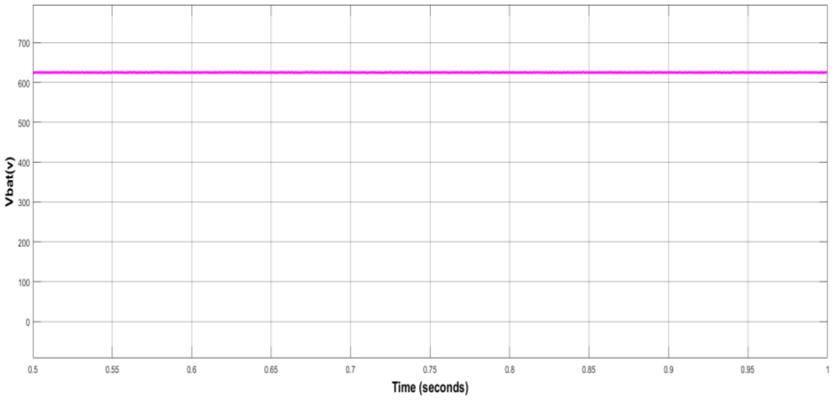


FIGURE 5f. Battery Voltage

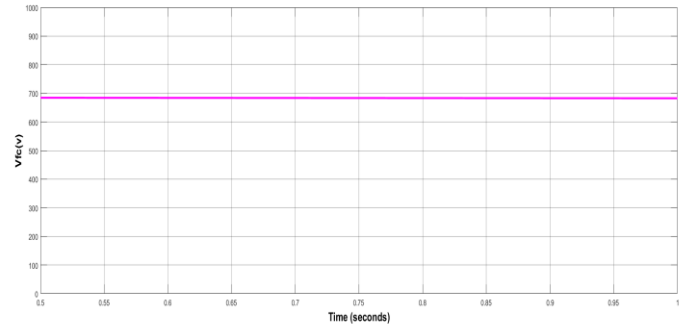


FIGURE 5g. Fuel-Cell Voltage

With sudden grid availability condition also, constant voltage maintained at the DC bus bar and constant power supplied to the EV respectively. In both conditions such grid availability/grid outage, co-ordinate the energy management between the power converters and RE sources well. Fig.5h and Fig.5i represents the obtained simulation responses of DC bus bar and EV.

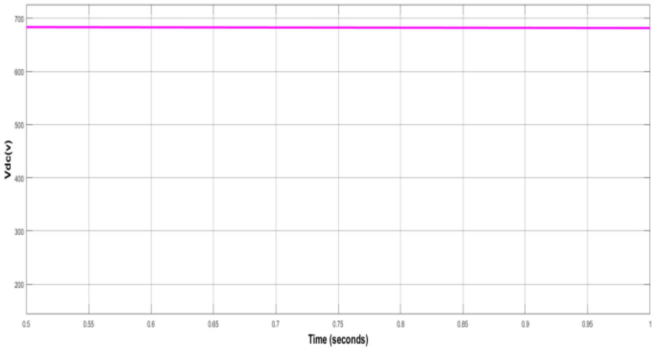


FIGURE 5h. Common DC Bus Voltage

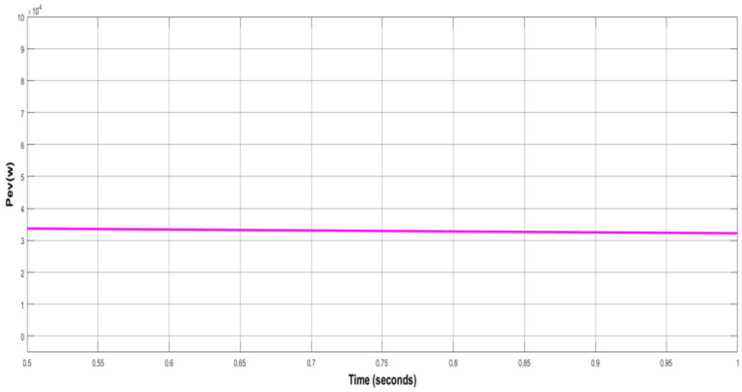


FIGURE 5i. EV Power

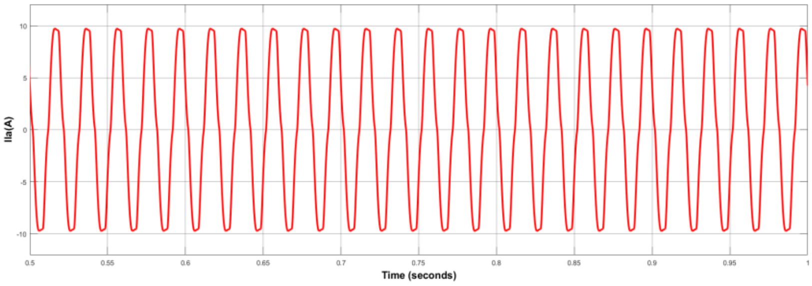


FIGURE 5j. Phase-a load current

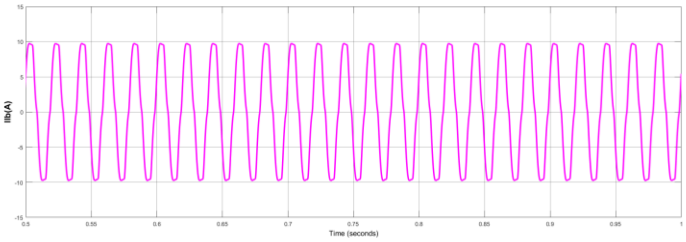


FIGURE 5k. Phase-b load current

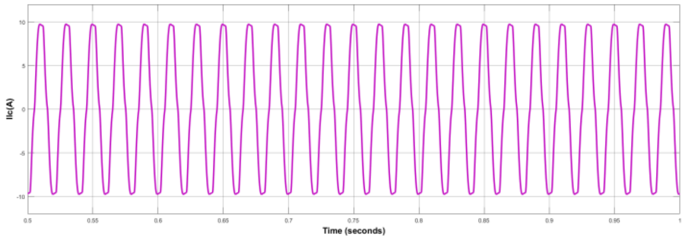
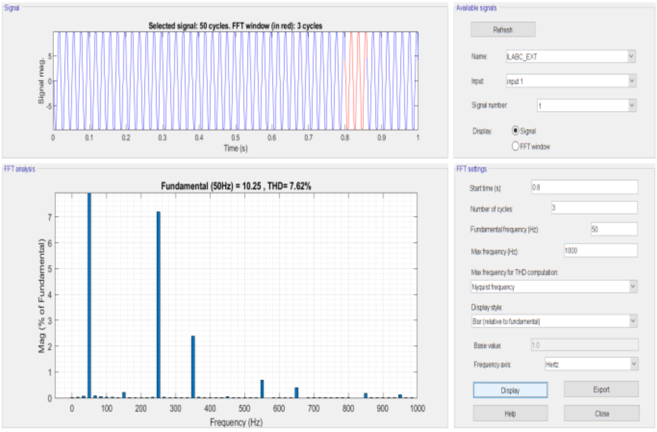


FIGURE 5l. Phase-c load current

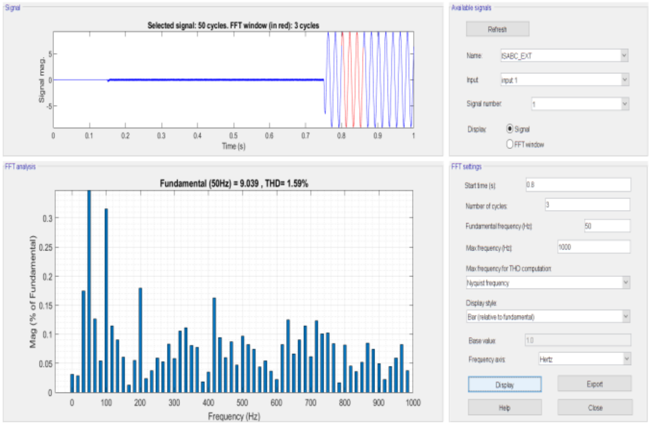
The simulation results of load current in each phase configured in fig.5j to fig.5l respectively. The harmonic presence in the load current during case-II is 7.62 corresponding THD plot is depicted in fig.6a.



Name: ILABC_EXT
Input: input 1
Signal number: 1
Display: ● Signal ○ FFT window
Start time (s): 0.8
Number of cycles: 3
Fundamental frequency (Hz): 50
Max frequency (Hz): 1000
Max frequency for THD computation: Nyquist frequency
Display style: Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Hertz

FIGURE 6a. THD plot corresponding to load current

The harmonic presence in the source current during case-II is 1.59 corresponding THD plot is shown in fig.6b.



Name: ISABC_EXT
Input: input 1
Signal number: 1
Display: ● Signal ○ FFT window
Start time (s): 0.8
Number of cycles: 3
Fundamental frequency (Hz): 50
Max frequency (Hz): 1000
Max frequency for THD computation: Nyquist frequency
Display style: Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Hertz

FIGURE 6b. THD plot corresponding to source current

From fig.6a and fig.6b it is revealed that the harmonic contents in load current and source currents are within the IEEE standard power quality acceptable limits.

5. CONCLUSION

The proposed EV charging infrastructure powered by a distributed renewable energy system and employing a common DC bus architecture, offers a promising solution for sustainable and efficient EV charging. By integrating REs sources, enhancing grid resilience, and facilitating fast charging, this approach can significantly contribute to the widespread utilization of EVs and the adaptation to a decarbonized transportation sector. From the simulation results it is observed that the proposed FOPI controller operates the STS switches well and co-ordinates energy management among the various power sources well. Common DC bus bar voltage maintained at constant, and a steady power supplied to the EV. Development of more sophisticated control algorithms for improved system performance and stability and analyzed the impact of modern controllers' deployment of such systems on grid stability and reliability is the requisite in the future direction of this paper.

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