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Ultra-Fast Charging E-Vehicle Batteries from PV using DC-DC Converter

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***Abstract*— The article discusses the PV nursed energy effective, ultra-fast, high power, high gain DC-DC converter for EV charging with MPPT through the Hybrid Simplified Firefly and Neighborhood Attraction firefly (HSFNA) algorithm. The Single-Ended Primary Inductor Converter (SEPIC) is used because of its efficient MPPT operation with ultra-high gain with high efficiency and easy control system. The continuous input current, high current handling capability, and DC voltage with good quality power are required for charging the EV battery. Though there are numerous isolated dual bridge unidirectional converters available for EV charging, the high current demand for EV batteries cannot be met. The proposed converter provides higher current charging for the battery on demand by looking into the various control parameters. An ideal PV module is assumed to study the operation of the proposed converter, and an additional HSFNA algorithm supports the global maximum power point under various operating conditions like partial shading. The simulation of the proposed converter is carried out and the results are discussed.**

***Keywords*— Electric vehicle, Charging, Ultra-Fast, High Power, High Current.**

I. INTRODUCTION

Despite the research studies on the performance and energy density of the lithium-ion batteries, the cost and size of the battery is a huge problem for limiting the driving range [1]. This paves the path for the high-powered high gain DC charging infrastructure for rapid/ ultra-fast charging similar to that of the IC engine refuelling. The problems of the existing EV such as limited distance covered, battery charging station's unavailability, and only home charging availability, makes the huge population not adopt the EV [2].

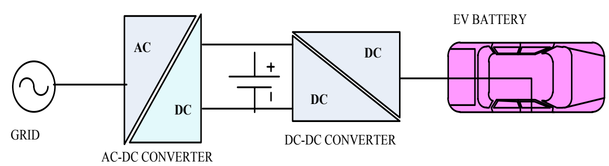

Figure 1. Off-board DC fast charging

So, the fast-charging stations are to be installed around the globe at an implausible pace. Due to size, weight and cost, the onboard charger has limited power ranges in the order of 3-20Kw [3]. The off-board chargers are capable of delivering high DC power directly to EV batteries, thereby the charging time is reduced considerably by providing the galvanic isolation between the grid and EV battery [4]. Figure 1 shows the off-board charging. These off-board charges are available at various ranges of 50-150kW, such as the offboard ultra-fast charger [5]. The large-scale discontinued loads may increase the peak load demand of the utility, which in turn causes the transformer to overload which causes quicker aging, and the power loss also increases [6]. The power system instability and poor quality of power are the consequences of the discontinued load on the electrical circuit.

The initial and operating cost can be reduced by proper design of the charging station by considering the exact storage unit which reduces the peak power demand of the station and the size of the protecting equipment will also come down [7-9]. The key indicators are the reason behind the interesting research by the industrial and academic researchers on the synchronous grid i.e., constant frequency, voltage constant, sinusoidal with low harmonics, and protection of the system in case of the faulty condition [10-12]. Various Maximum Power Point Tracking (MPPT) algorithms are available like hill climbing, perturb & observe incremental conductance and so on. The soft switching techniques like fuzzy logic controller, artificial intelligence, bee colony, ant colony, grey wolf, swarm particle, and neural network are the optimization techniques available for MPPT algorithms [13].

The proper application of renewable energy is growing because of the demand for renewable energy, and the charging of EV batteries [14]. The medium voltage application uses non-isolated converter topologies. The boost and Cuk converters provide less voltage gain [15-17]. Therefore, the SEPIC transformer less converter provides a very high gain and can be employed for EV battery charging which provides noninverting and steady-state output [18–19].

Figure 2 shows unidirectional charging without energy storage for EV fast charging. EV usage has increased in recent days, the charging the EV battery is a tedious task, and currently charging can be done only at home and commercialized charging stations are not available due to lack of infrastructure. The planned SEPIC converter, incessant input current, condensed ripple, even MPPT, ultra-high gain, onward control, and high efficacy deprived of coupled / transformer ultra-fast circuit can charge the EV. Battery fed from PV integrated with grid can perform EV charging in ultrafast pace [20]. The HSFNA algorithms minimize perturbation of PV tracking with the varying weather conditions. The same can be monitored by IoT devices and wireless sensor networks [21].

In the later section of this paper, the descriptions of the proposed topology are discussed. In section III, the simulation of the topology along with the results are discussed and section IV represents the conclusion. Figure 2 shows the multi-port unidirectional charging of the EV battery. The grid is connected to AC - DC converter, and through DC-link the DC-DC converter charges the EV battery. The DC-DC converter regulates the EV battery charging voltage and ensures continuous power flow. Number of ports can be connected in the same fashion, but power quality and reactive power components need to be addressed.

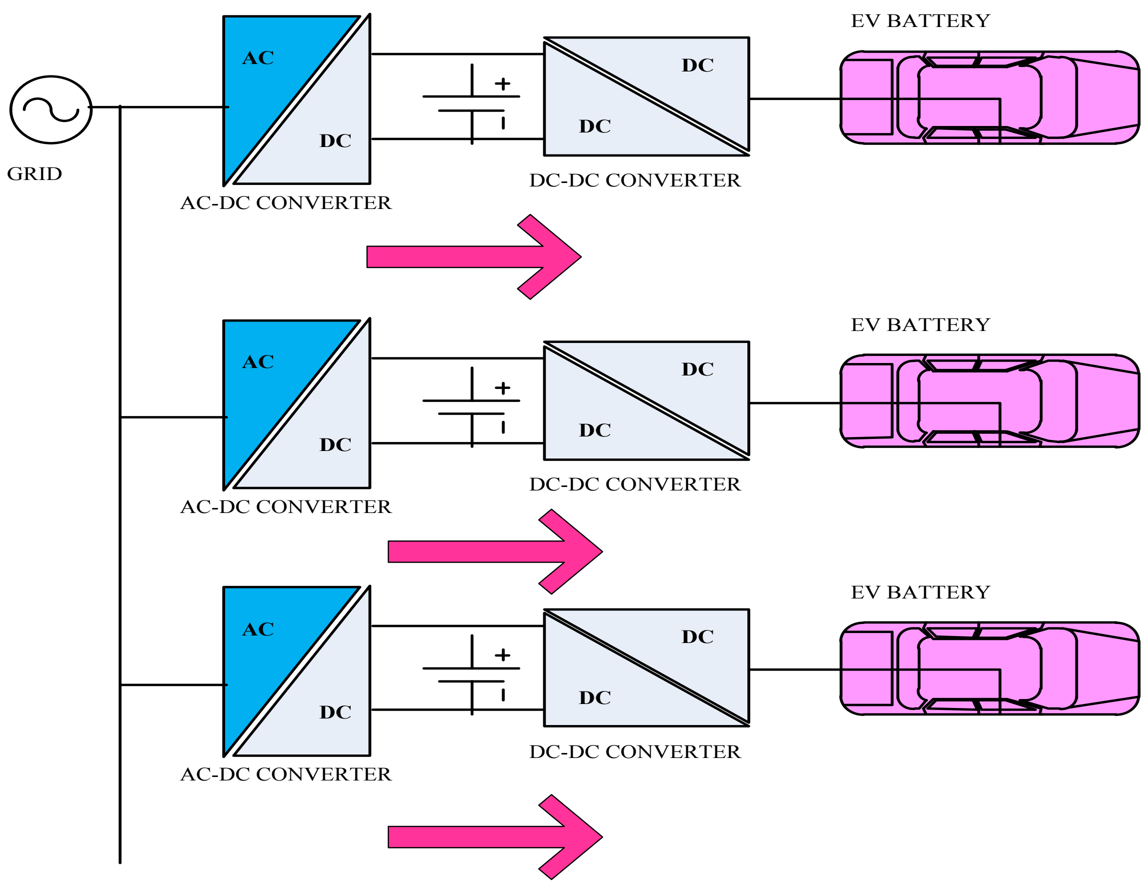

Figure 2. Unidirectional charging without Energy Storage for EV Fast Charging

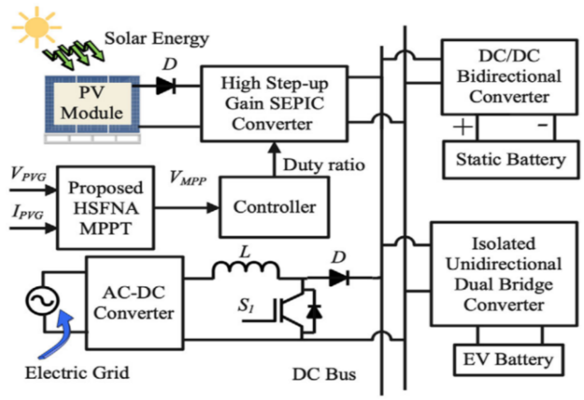

Figure 3. Block plan of PV nursed EV Battery Charging

Figure 3 shows the block diagram of the proposed EV charging system. The PV module with a high gain SEPIC converter is controlled by the HSFNA algorithm used for MPPT. The other way of power supply to the DC link/ DC bus is through a regular AC source with a controlled AC-DC converter with filters for ripple-free DC. The bidirectional converter enables the charging of the static battery and discharging the same as per the need. The vehicle battery is charged using the isolated unidirectional dual active bridge converter. It is well known that the PV cannot generate power at dark/dusk and generates during sunshine. The utility supply is also not trustable. The DC bus/ DC link is supplied by PV, AC source, and static battery, so it ensures continuous charging to the vehicle battery even after the failure of the other two sources.

II. Proposed Converter

The projected HSFNA-built MPPT procedure helps in generating the gate pulse for the ultra-high gain SEPIC converter power electronics switches. The AC utility grid is changed to DC voltage. Figure 4 shows the block illustration of PV-nursed EV charging. The high-frequency DC-DC converter is used to charge the battery in ultra-fast mode. A PV module can be connected in series and parallel to produce the voltage as per the requirements. Due to the photoelectric effect, the cells in the PV panel generate the DC voltage. The entire SEPIC-based high gain converter comprises of three switches, three diodes, three inductors, and three capacitors. It has three modes of operation. The energy storing elements and load are carefully designed.

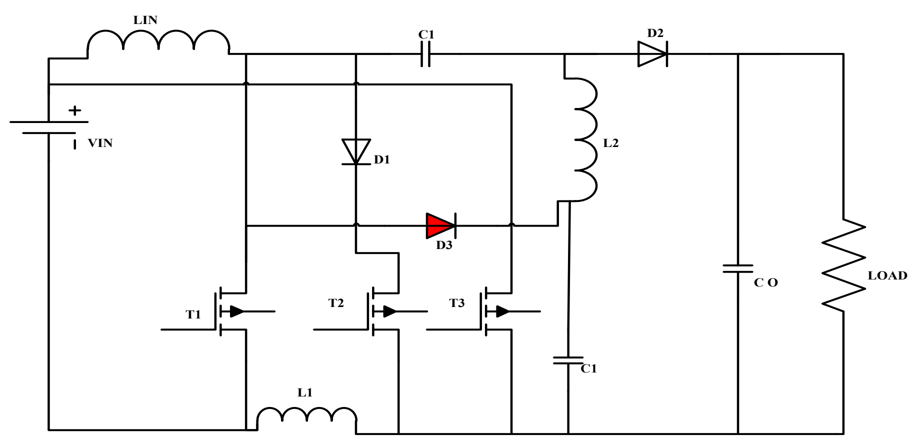

Figure 4. SEPIC-based DC fast charging EV battery

A. Mode A

The switches T1 and T3 conduct, while the T2 switch is OFF. The remaining diodes D1, D2, and D3 remain in reverse bias conditions as in Figure 5. The Lin and L2 are connected directly to the input supply. The capacitor, Cout is continuous to supply the load.

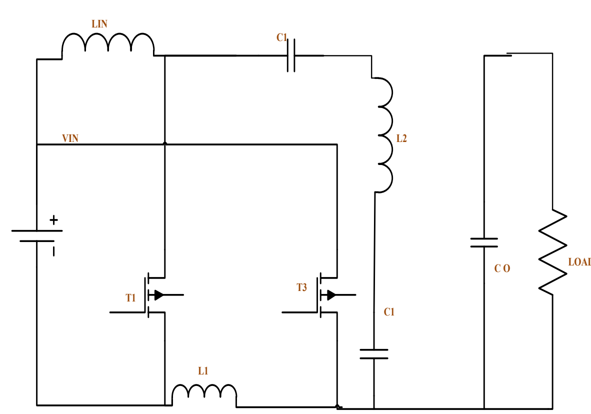

Figure 5. Mode A

B. Mode B

This mode starts when T2 starts conducting while T1 and T3 are OFF. Diodes D2 and D3 do not conduct, and D1 is in forward bias as in Figure 6. Lin is connected to the supply voltage. The capacitor keeps supplying the load and mode b ends when the capacitor is completely discharged.

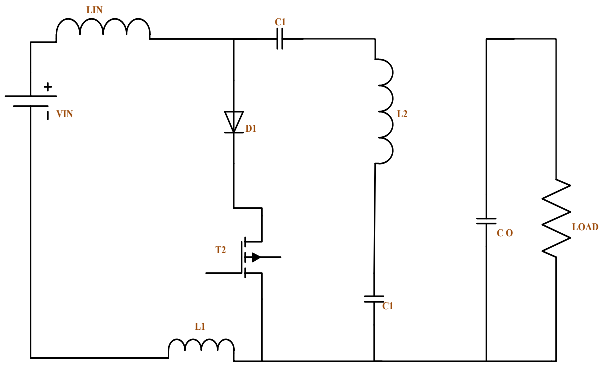

Figure 6. Mode B

C. Mode C

The power electronics switches T1, T2, and T3 are turned OFF. The diode D2 and D3 conduct, and the diode D1 stops conducting as in Figure 7. The stored energy in the inductors is discharged to the capacitors. Mode C ends when the capacitor is charged completely to the Vmax.

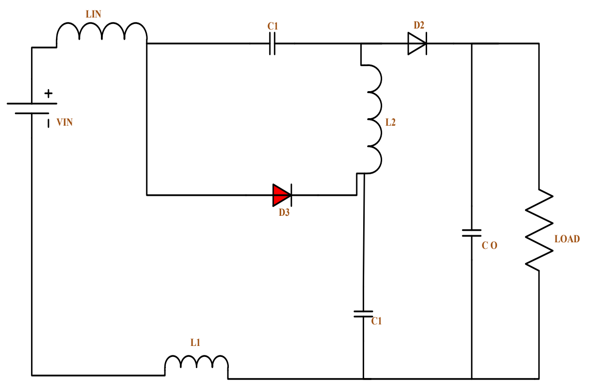

Figure 7. Mode C

D. HSFNA

The Hybrid Simplified firefly and Neighbourhood Firefly algorithm used, is depicted as a flowchart in figure 8. The algorithm starts with initializing the values and evaluating a few more values like Dji, a0, and Di. It checks whether the convergence is obtained or not. If yes, then it proceeds with a few steps; if not, then it repeats the process.

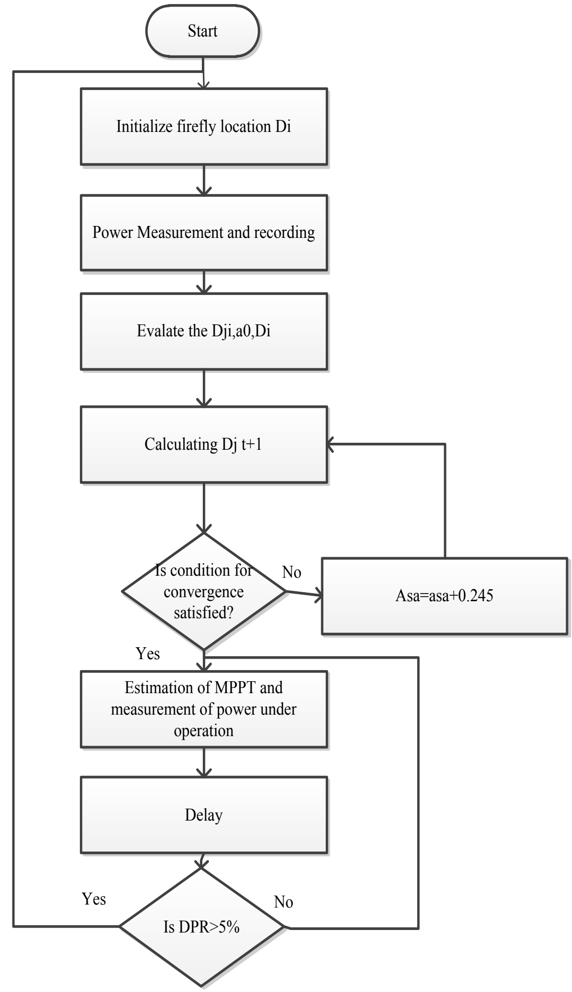

Figure 8. Flow chart of the HSFNA for MPPT

This delivers very fast convergence tracking MPP and reduces the perturbation time by accelerating iterations velocity and bridging the gap between the grid and the PV charging system through SEPIC converter switch control. Figure 9 shows the EV controller flowchart. The duty ratio of the switch in the SEPIC converter is decided by the HSFNA algorithm according to the varying climatic condition. The HSFNA algorithm restarts under transient weather condition.

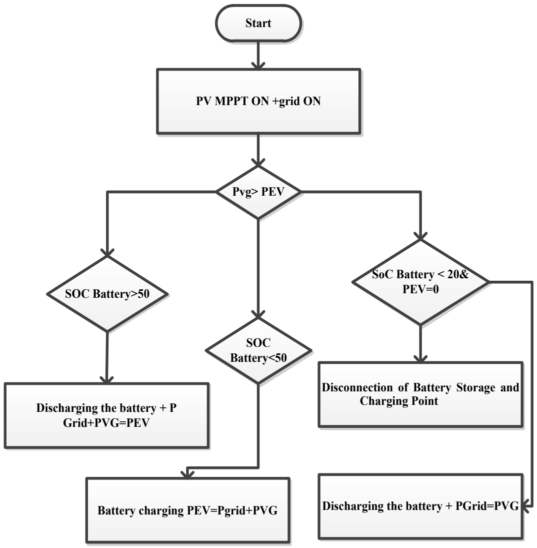

Figure 9. EV controller flowchart

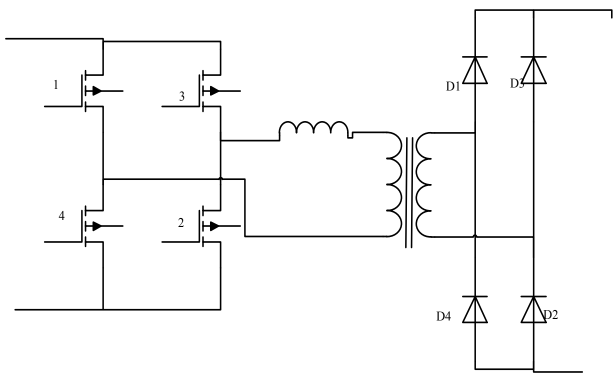

Figure 10. Unidirectional Dual Bridge Converter for Ultra-Fast Charging of EV

Figure 10 shows the dual active bridge unidirectional isolated converter for charging the EV battery. The power from the various source flows through DC link/ DC bus. This unidirectional isolated converter is energized by the DC bus system. The high-frequency AC is attained by the high-frequency inverter, and through wireless inductive charging mode, the primary of the transformer is energized. Due to mutual induction, the vehicle side winding gets energy, then the high-frequency AC is converted to DC by the bridge rectifier of uncontrolled devices and the EV battery is charged.

III. SIMULATION AND DISCUSSION

Simulation of the SEPIC-based high gain ultra-fast charging with the HSFNA algorithm is carried out in the MATLAB/SIMULINK. Figure 10 shows unidirectional dual bridge converter for ultra-fast charging of EV. The default PV panel is set for simulation purposes. The irradiation to the solar panel is 1000 w/m2.

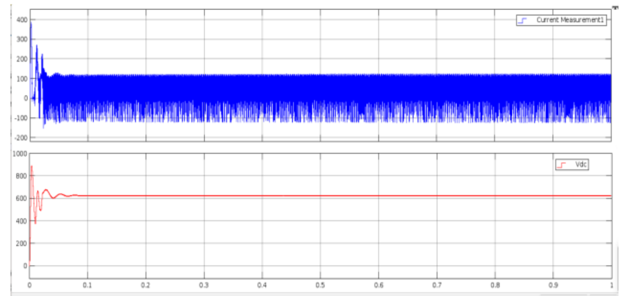

Figure 11. Idc and Vdc of the PV

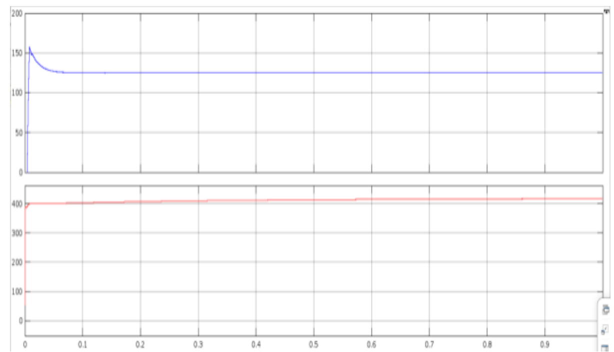

Figure 12. SEPIC converter output current and voltage

Figure 11 shows the Idc and Vdc of the solar PV panel output. The Vdc =600V and the current Idc=100A. Figure 12 shows the output waveform of the SEPIC converter where the current Is=120A, at the voltage of Vs=400V. The SEPIC converter with the high gain and high-power stores energy in the static battery and also in the vehicle battery through the DC bus.

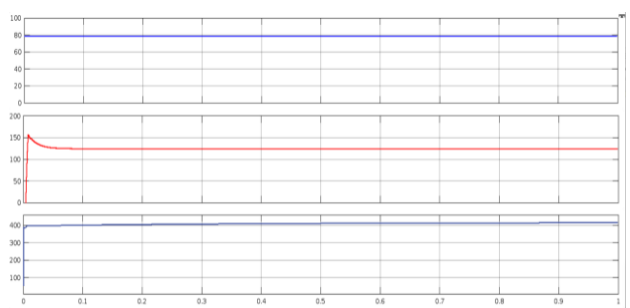

Figure 13. The SoC, current, and voltage of the charger

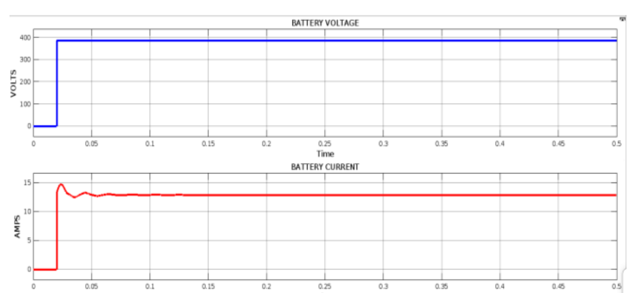

Figure 14. Battery Voltage and Current

Figure 13 shows the SoC, current, and voltage of the charger. The SoC is found to fall by 80%. The current is about 130A at the voltage of 400V. The unidirectional dual active bridge rectifier charges the EV battery at an ultra-fast pace. The voltage is 400V and the current is about 15A. Figure 14 shows the voltage and current of the battery. The current in the battery is 15A at the rated voltage.

IV. CONCLUSION

This article details the PV engaging ultra-fast charging EV through SEPIC converter which is controlled by the HSFNA algorithm. With the topology proposed converter, without the use of a coupled inductor and transformer, continuous input current, condensed ripple, flat MPPT achievement, sophisticated voltage gain, more straightforward control mechanism, and higher efficacy are all possible. The use of the HSFNA algorithm provides a fast response for MPPT, with reduced energy loss, and good efficiency with ultra-fast convergence velocity. The proposed converter allows the EV battery to charge at a very fact/ ultra-fast pace under the situation of the PV and AC utility, failing to supply the DC bus. The energy from the static battery can be utilized for charging the EV battery thereby ensuring the uninterrupted charging at the charging stations. The oscillations are minimized to the minimum possible and the complications are found to be minor. The various conditions of the atmosphere can be tested for the effective efficiency of the HSFNA algorithm and the SEPIC-based ultra-fast charging system for the E-Vehicle.

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