Development of Fast charging system with ZVS integrated with Fuzzy controller-based Hybrid renewable energy source

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Abstract. Climate change is a growing concern due to greenhouse gas emission and transportation has increased the requirement for various energy sources with limiting and less pollution. But with the establishment of more electric vehicles on the road, charging EV's will be difficult if the grid is used. When many numbers of electric vehicles are integrated to the grid, it will inevitably have a huge effect on its function and control. Hence, there is a requirement for an effective charging system for electric vehicles using renewable energy sources. Solar energy is renewable and green, but the volatile nature of energy from the Photo-Voltaic (PV) system and dynamic charging requirement of electric vehicles has added new problems to the effective charging of EV from these sources. The Solar powered charging station with battery storage system is a better solution for this problem. The power is transferred from the AC grid to the DC link when there is a depletion of power from solar. This paper deals with DC level 1 fast charger to charge an electric vehicle with phase shifted full bridge converter as a main charging topology which is able to deliver the load of 50KW to charge the electric vehicle. To maintain a constant voltage at the output of the boost converter connected to the solar panel, a fuzzy controller is also developed in the proposed system.

1. Introduction

Artificial Intelligence (AI) is currently the hottest spot in Information technology (IT). Since the early an electric vehicle functions on an electric motor instead of flaming of fossil to generate required power through an IC engine. Thus, an EV is seen as a replacement for the current generation automobile, in order to acknowledge the problem of global warming, rising pollution, and decreasing natural resources. As the electric vehicle has been for a long time, it has drawn attention in the past decade amid rising carbon footprints, and environmental effects on fuel vehicles. EVs increase our energy independence and contribute to healthier air and lower carbon emissions. There are various reasons why the public want to switch to EV’s over integrated combustion engine like

- EV’s are exciting and comfortable in driving as they are smooth and fast.
- The emissions from burning fossil fuel such as gasoline are proven to produce harmful greenhouse gases from few studies. Compared to this EV’s produce no smelly fumes or harmful greenhouse gas.
- EV’s just cost’s $360 approximately when compared to $3600 for gasoline.
- EV’s are innovative, convenient, smart and cool choices.
The 1st question, people question is how long an EV can travel before it needs to be re-charged? Firstly, when would one have the last time, ran out of gas in a vehicle?? Most of the people's answer would be never, as many of them check the fuel meter and fill up the tank when it is getting empty. Well, It’s the same with an EV, one can pull into one of the charging stations to “top up” a car each night at home just like a cell phone and always leave home with a full battery. The renewable energy sources and plug-in hybrid electric vehicle (PHEV) are becoming very popular because of high fuel costs and concerns about emission issues.

2. Literature review

Nowadays, a lot of researchers are working on development of highly efficient electrical vehicles. As EV’s are gaining much popularity there is an increase in the requirement of the charging infrastructure for electric vehicles charging. The adequate acceptance of electric vehicles, there needs to be development of an efficient charging method that can be easily integrated with ongoing distribution systems. A literature review is carried out to understand the fundamental concepts of fast charger converter topologies and applications and challenges faced by it, and to develop a system model for analysis purpose. For the wide acceptance of electric vehicles on the road, wide range of charging networks need to be available for the consumers. This kind of sudden increment of the charging network may affect the existing grid network as mentioned in the literature [1-5]. The expansion of EV more than 20% of the total vehicle population, may affect the present grid network [1]. The penetration of EV also affects the distribution transformers and their lifetime [2-3]. There are different levels of charging stations for charging the EVs [4]. Level 2 charging is around 6% efficient than level 1. In low temperature range such as less than 50°F as well as high temperature ranges such as greater than 70°F, the charging efficiency of level 2 is better than level 1 [5-7]. Compared to AC level charging method, DC level 1 charging is faster as well as efficient [8]. Introducing renewable energy sources also for charging the electric vehicles other than depending only on the grid is suggested by many researchers considering the fact that grid power generation from traditional schemes are depleting. Solar energy source is integrated with the grid power to charge the electrical vehicle is suggested in [9]. While using the solar arrays to charge the EV’s, the power transfer should happen from source to the load. The phase shift full bridge converter is employed as a fast-charging topology with zero voltage switching is suggested in [10]. Because of the overlapping between voltage and current during switching transition, switching loss is generated. The PSFB operating in ZVS condition to avoid switching loss is implemented in [11, 12]. Different soft computing techniques are deployed in control applications [14, 15]. Fuzzy based controller has the advantages like they cover wide range of operating conditions, customizable in natural language terms and no requirement of mathematical modelling etc [16,17]. In the work focus is also given to develop fuzzy controller so that irrespective of the load change constant voltage can be maintained at the boost converter output. It will work for even if there is a change in irradiance also.

3. System and Specification.

3.1 Block diagram of proposed system

This section is an overview of the system and overall block diagram of the system description and component specification of the proposed work. In order to make more sustainable and efficient production it uses both solar and grid integrated energy conversion systems.

The proposed system shown in Fig.1., consists of a grid system and a model of PV (photovoltaic) panel. The output of the PV is in the form of DC and therefore DC-DC (Boost) converter is being used to increase the voltage which is connected to DC link.
The grid voltage is rectified and connected to DC link.

3.2 Grid and solar circuit.
A three-phase AC source used as grid which is connected to a three-phase rectifier with filter. The output is 700V DC [18]. The block diagram of PV solar array with irradiance and temperature as input is shown in Fig.2. The number of series and parallel cells are chosen according to the load rating required. The output of solar panel is connected to boost converter to boost to the required voltage.

3.3 Boost converter
The boost converter is a circuit which step-up the given input terminal voltage to higher levels. The boost converter mainly consists of inductor, capacitor and a high frequency switching device. In series fashion the inductor coil is connected in with the DC voltage source and a high frequency switching device is connected in parallel to the capacitor and to the DC input voltage which need to be step up. The secondary switch in the circuit is diode. The diode will not allow the reverse currents to the source and inductor. It was connected to the capacitor end and to the load. Due to the presence of an inductor at input side, it allows constant current into the circuit and it allows constant voltage to the load due to the presence of capacitor as shown in Fig.3.

\[
Duty\ ratio(D) = \frac{T_{on}}{T_{on}+T_{off}} \quad (1)
\]
\[
V = \frac{V_{in}}{1-D} \quad (2)
\]

From the source, the entire current is driven into the inductor, this builds up the magnetic field across the inductor. Assume the capacitor is charged from the previous cycle and there is no way to discharge through a reverse biased diode and the input power source won’t be short circuited as the inductor doesn’t allow sudden change in current and reduces the current ramp relatively slower. The voltage across the output side capacitor is equivalent to input source voltage minus the diode drop. The capacitor is charged to the input voltage when the switch is in off state, as the input voltage is appeared across the capacitor. When the MOSFET is turned off, current through the inductor is interrupted. It is not desirable to change the current through the inductor. The nature of the inductor is to maintain the constant uninterrupted current flow. The inductor doesn’t allow the sudden change in current through it. When
the current through the inductor is turned off it generates a large voltage spike which is opposite to the polarity of the voltage, supplied at source with the help of magnet field energy stored across the inductor to maintain the current flow constant. The capacitor and inductor need to be designed by considering switching frequency of the semiconductor switching device ($f_s$) and current ripple and voltage ripple [19].

The current ripple in the circuit is need to be taken as

$$\Delta I_L = 20\% \times I_{out} \times \frac{V_{out}}{V_{in}} \quad (3)$$

The value of the capacitor

$$C = \frac{I_{out} \cdot \Delta V_{out}}{f_s \cdot \Delta V_{in}} \quad (4)$$

The value of the voltage ripple ($\Delta V_{out}$) is considered as a 10% of output voltage value.

The value of the inductor

$$L = \frac{V_{in} \cdot (V_{out} - V_{in})}{\Delta I_L \cdot \frac{f_s \cdot V_{out}}{V_{in}}} \quad (5)$$

Let neglect the remaining circuit elements for a while and notice the polarity of the sign across the inductor, the inductor remains like a voltage source in series with the terminal supply voltage. This indicates the anode has higher voltage than the cathode of the diode and the diode will get forward biased. The capacitor is charged to the supply voltage. This indicates that the capacitor is charged to a higher level than before and higher voltage appears across the load than the source voltage level.

3.4 Fuzzy controller

Fuzzy models, expert systems, rule-based all these are generally known as Fuzzy Inference systems. (FIS) Fuzzy Inference system is the most key unit of a fuzzy system. This system's primary work is decision making. In the field of machine intelligence there are many ways to present knowledge. Language expression type is the most frequent path to represent human knowledge. As humans uses antecedents and consequents as linguistic variables, fuzzy rule based system which uses similar concepts is more effective in solving complex systems. Rule based system usually have more than one rule. Input for FIS may be fuzzy or crisp, output will be a fuzzy set. Since FIS is utilized as a controller then the output should be in crisp value. Therefore, there must be a Defuzzification unit for the fuzzy variable to be converted as crisp variables with FIS.

FIS is of five functional blocks:

- Rule base contains numerous fuzzy rules.
- The database that defines the membership functions of fuzzy sets are used in fuzzy rules.
- Operations on the rules are performed by Decision-making.
- The crisp units are converted to fuzzy quantities by fuzzification interface units.
- Fuzzy units are converted into crisp units by the Defuzzification interface unit.

Defuzzification is the methodology for a fuzzy set to represent as a crisp value. Representation of data internally in a fuzzy system are usually fuzzy sets. Defuzzification methods to calculate crisp outputs are (1) Maxima Methods like Height Method, First of Maxima (FoM), Last of Maxima (LoM) and Mean of Maxima (MoM) (2) Centroid Methods like Centre of Gravity Method (CoG) and Center of Sum Method (CoS) (3) Weighted average method. In this work, the Centroid of Gravity (CoG) method is implemented to get the crisp i.e., duty ratio values. According to center of gravity to provide a crisp
value for the fuzzy set Centroid of Area (CoA) Method is used. Fuzzification’s inverse process is called as Defuzzification, it basically transforms fuzzy output into crisp value

3.5 Phase shifted full bridge converter.
Lot of researchers are working on development of highly efficient electrical vehicle charging stations. There is no proper charging station available to charge the electric vehicle with various input sources. Phase shifted full bridge converter is chosen as a fast-charging topology after been analysed from different charging topologies due to its high-power dealing capability of delivering load greater than 50KW with 420V and 120A current. It will be able to provide good isolation to the load. Fig.4 depicts the outlook of the (PSFB) Phase shifted ZVS full bridge converter. The advantage of this converter is having minimal switching losses. Due to the presence of ZVS, this method can be employed for high frequency applications and at high power applications. Functioning principle of a full bridge converter is given as follows: $T_1$ and $T_4$ are turned on parallel, applying a +ve terminal voltage to the primary winding. $T_2$ and $T_3$ are turned on by complementary pulses, applying opposite terminal voltage to the primary side of high frequency transformer. As a resultant of dealing with high frequency switching is that it converts the available DC to high frequency AC. By creating dead time during switching, it promotes the circuit to work under ZVS.

![Phase shift full bridge converter](image)

3.6 Zero voltage switching
For achieving the ZVS and for eliminating the switching losses, the PWM switching control technique is employed. It allows the MOSFET devices to achieve ZVS operation and smooth working of circuit even in presence of circulating currents by creating the delay time between switching. Improved dynamic performance and Smooth operation of PS-FB ZVS DC-DC converter require the proper choice of components The component selection for PSFB converter with ZVS is far different from the conventional PWM converter in order to achieve precise operation and accurate working. Because of the overlapping in between voltage and current during switching transition, switching loss is generated. The PSFB is operating in ZVS condition to avoid switching loss. To achieve the soft switching action, required time delay is created between switching devices to avoid the overlapping between the voltage and current pulses.

4. Simulation Results
The proposed technique for both GRID configuration and Solar configuration is simulated using MATLAB-SIMULINK environment results are discussed in this section. The Fuzzy controller is designed using the Mamdani Fuzzy Inference system shown in Fig.5. The inputs are error in the output voltage and change in error. 20 % change from 700V is considered for analysis. The output is duty cycle.
Fig. 5. Mamdani compared the error with change in error to get the reference value to give crisp output.

This Mamdani system is well suited for human input. It has an output membership function. In the process through defuzzification of rules output crisp value is obtained. The smoothness of the system is decided by membership function antecedent.

Fig. 6. Membership function of error variable i.e., one of the inputs

Fig. 7. Membership function of change in error i.e., input 2
Fig. 8. Output membership function

Fig. 9. Surface view of i/p and o/p.

Fig. 6 and Fig. 7 represent the input membership functions and Fig. 8 represents the output membership function respectively. This surface viewer shown in Fig. 9, is a 3D view of the two inputs i.e the membership function of error and the change in error membership function and output put together.

Fig. 10 Grid simulation

The simulation circuit for the grid system shown in Fig. 10. The Grid voltage is rectified and boosted before connecting to DC link. The final output voltage is shown in Fig. 11.
Fig. 11. Output voltage of grid system

Fig. 12. Solar simulation in MATLAB

Fig. 13. Solar simulation with load variation.

Fig. 12 represents the MATLAB simulation circuit of solar panel connected to boost circuit. Fig. 13 represents the load variation introduced in the circuit shown in Fig. 12. The load change is introduced to check the efficiency of fuzzy controller circuit, where the output of solar panel is given to the boost controller to increase the voltage, where the pulses are given by the fuzzy controller used.
Fig. 14 and Fig. 15 represent the output current and voltage. At 0.25 sec the load change is introduced; it is clear from Fig. 14 and Fig. 15 that the current is changed but the voltage is maintained to 700 V with the help of fuzzy logic controller. For the analysis simple resistive load is connected at boost converter terminals. Table 1 represents values of parameters in PV & Boost converter considered for simulation.

| Photovoltaic (PV) | Boost Converter |
|-------------------|-----------------|
| Temperature       | 25°C            |
| Capacitor         | 100 mF          |
| Irradiance        | 100 W/m²        |
| Inductor          | 0.3 mH          |

To analyse the fast-charging mechanism a load rating of 50 kW is considered for simulation. The input is 700 V (DC link). A Phase shift full bridge converter offers good isolation to the load and provides good efficiency compared to other fast charging topologies. The inverter part of the PSFB converter is driven by the PWM pulses with zero voltage switching. The ZVS provides soft switching to the circuit and eliminates switching losses. The high frequency transformer modulates the input voltage to the required output voltage. Rectifier rectifies the alternative current and delivers the proper DC current to the load after filtering. The simulation circuit of PSFB converter is as shown in Fig. 16.
To overcome the problem of hard switching the zero-voltage switching is employed. To achieve ZVS there should be a dead zone created between pulses so that there should not overlapping between current and voltage as shown in Fig. 18. The gate pulses are designed in a way that there would be a time gap between each switching action and no three conducts at a time as shown in Fig. 17.

The load voltage and current of the DC level-1 fast charger will be in the range of 400-480 volts and current is nearly 120 amps. By using PSFB converter topology the required level of voltage and current is obtained as shown in Fig.19 and Fig.20 to charge the Electric vehicle. Fig.21 represents the output power of the phase shifted full bridge converter which is 50kW.
5. Conclusion

This paper concludes that, with the increase of EVs on roads and for acceptance of EVs by people, charging infrastructure of EVs becomes a crucial issue. To avoid this, issue the charging station with the integration of solar array with grid gives one of the best and adequate solution for efficient charging infrastructure. The proposed scheme uses a fuzzy controller based on Mamdani FIS method. With the help of the fuzzy controller, constant output voltage can be maintained at the boost converter output irrespective of the load variations. To reduce the switching loss, (PSFB) phase shifted full bridge converter is operated in ZVS mode. This converter topology helps in implementing DC level 1 fast charger. This main charging topology will be able to deliver the load of 50KW to charge the electric vehicles.

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