Electric Vehicle DC Charging Stations Design, Floating Solar Photovoltaics, and HVDC Power Transmission and Distribution

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***Abstract:** The purpose of this study is to evaluate a semi-urban area in India—Hassan, Karnataka, for its transition to electrified roadway transportation with electric vehicles (EVs) for all EV variants in light, medium, and heavy-duty. The potential of solar photovoltaics with floating provisions was applied to meet the power needs for electric vehicle charging stations. The untapped potential of HVDC power transmission and distribution was leveraged to increase the efficiency of the power system. A 545 MW floating solar photovoltaics (FPV) system was simulated using NREL SAM, which becomes suitable for meeting the annual energy demand from EVs in Hassan. Since DC power transmission and distribution were chosen, a new DC charging equipment concept with DC-DC buck converters was simulated in MATLAB Simulink. The absence of AC-DC conversion (rectification) in DC fast chargers, as proposed in this system, maintains consistent power at DC from generation to transmission and distribution, ultimately serving the EV charging loads through a set of DC-DC converters throughout the proposed power system. The practices in sustainability for commercial buildings are enhanced with the proposition of including provisions for efficient EV chargers, as proposed in this paper.*

***Keywords:** Clean Energy, DC-DC Converter, Electric Vehicle Charging Station, Floating Solar Photovoltaic System, High Voltage Direct Current Transmission and Distribution*

Abbreviations:
EVs: Electric Vehicles
SAM: System Advisory Model

I. INTRODUCTION

The Gorur Hemavathi dam, situated in the Hassan district of Karnataka, India, was constructed in 1979 with an operational storage capacity of 1,050.63 million cubic meters [1]. The hydroelectric power plant at the Gorur Hemavathi dam has an approximate capacity of 25 MW and an asset value of around Rs 150 crore [2]. The electrification of electric vehicles for small cities in India is a pressing agenda for central city planners and government agencies, as the depletion of fossil fuels is evident [3] and renewable energy transition becomes a resource in reducing reliance on fossil fuels for energy generation. One such application of renewable energy is solar energy, which harnesses energy from solar irradiance throughout the year through the photoelectric effect, generating electricity for the power grid using solar panels.

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Past research on renewable energy as a clean energy resource has identified several limitations, including the lack of steady power generation due to uneven solar irradiance throughout the year. Additionally, wind power has a lack of consistent wind. Thus, a need exists for the combined use of fossil-fueled power generation and renewable energy to meet customer demands. However, when renewable energy is added to the system, there is a significant drop in dependence on thermal power generation (fueled by fossil fuels). Some crucial challenges with ground-mounted solar photovoltaic systems in urbanised areas include a lack of available space and disturbances from sunlight reflection on neighbouring properties. Located in areas rich in annual rainfall, winds, and sunlight throughout the year, all major types of renewable energy power generation are feasible at Hassan.

The vehicle-to-grid (V-2-G) concept allows bi-directional power flow [4]. The concept of integrating the power grid and EV charging stations is a growing trend. This enables power resilience and improved utilisation of the stored energy potential available from EVs. Similarly, stored energy from battery storage systems available in renewable energy applications allows for bi-directional power flow. Given that the grids are prepared for AC power flow, a DC power flow problem, using known methods in power system studies, allows for simplifying the intricacies. For example, the Newton-Raphson method enables the accurate determination of voltages at buses and phase angles for AC systems.

Commercial buildings make a significant contribution to both energy consumption and resultant carbon emissions. Motivations to include clean energy and reduce carbon footprint from both site development, selection of construction materials, and choice of energy sources lie in the foundation of certification of these buildings by many organizations, such as the US Green Building Council, which requires a contained carbon footprint within each of the categories specified for the certification process [5]. Allocation of parking spaces for electric vehicle charging stations, whether in covered parking garages or open spaces, allows business owners to evaluate the needs of building occupants who are motivated to ride electrified fleet vehicles.

When it comes to achieving whole net-zero emissions from the building's operation, the researchers have focused on increasing the penetration of rooftop solar or covered parking spaces with solar panels. However, when usage is considered, the types of equipment used are energy-efficient—for example, Energy Star-rated illumination lamps and the HVAC system. Apart from using this equipment rated for improved energy savings, EV chargers can be optimised to achieve high energy efficiency. This paper aims to optimise the design of the EV charging equipment. For the certification of buildings by the US Green Building Council, the use of EV charging equipment operating at high performance with lower energy consumption becomes a key driving point towards sustainable practices in the building industry, where the usage of EV charging infrastructure appears to be a feasible solution amid depleting fossil fuel resources. India is the third-largest country by number of LEED Green Building Certifications in 2023 [6]. Although the leading countries were Mainland China and Canada, India continues to make progress toward meeting the UN Sustainable Development Goals as it accomplishes this milestone.

Engineering standards per [7] These are determinants of how safe the equipment is for public use. However, the importance of building codes governs the permitting and inspection processes [8]. Similarly, parking space requirements are governed by several constraints, including accessibility for public use and availability for open use by a broader audience. Across the globe, the total number of electric vehicles varies because of the type of government support and local customer demand. In the United States, the majority of electric cars are owned and operated in California [9].

This paper is primarily focused on the electrification of transportation in Hassan, Karnataka. Karnataka has a significant penetration of renewable energy sources, including solar and wind power. For planning the electrification, floating solar photovoltaics (FPV) [10] becomes a viable option, given that the Gorur Hemavathi dam reservoir is near Hassan, Karnataka (~15 km). The total population is above 248,917, and the number of vehicles in this area is 256,000 as of Dec 2024. The scientific and engineering significance of this research lies in proposing a DC fast charger that eliminates the need for AC to DC converters and utilises a unified approach to DC power, from generation via FPV to HVDC transmission and distribution, and end use for EV charging.

Electric vehicles are characterised by a battery pack that powers the electric motor. These battery packs are rechargeable using an external power source. Depending on the charging technology, two options are available: AC slow charging and DC fast charging. Slow charging utilises an AC source of power and provides an AC output to the electric vehicle. An on-board electric vehicle AC-DC rectifier that allows battery recharging. However, in the case of a DC fast charger, a higher output DC power is converted from an AC input at three-phase power at comparatively high operating voltages. Power flows from EVCS to the electric vehicle via a connector cord. Typically, in a DC fast charger, the power is converted from AC to DC before being supplied to the electric vehicle via a connector cord. However, an alternative topology, where a source DC charges electric cars at the DC output, is possible when a DC power supply is available from utility providers.

The HVDC power transmission allows for purely active power dissipation and reduces any losses associated with AC power, specifically reactive power losses [11]. Corona discharge is higher in the case of AC. Due to reduced losses from corona discharge, conductive materials are required in fewer quantities for an HVDC system. Typically, the cost of installation of HVDC is diminished [12]. from shorter lengths of conductors and lighter supporting structures. The shorter lengths of HVDC lines are attributed to their capability to carry higher current capacities with just two sets of conductors per circuit (positive and negative) as opposed to a three-phase system in AC transmission [13] [14]. These advantages form the basis for selecting a DC transmission and distribution system for the power from the FPV system.

FPV systems consist of a floating set of solar panels secured to allow them to remain at a given position in still water [15]. The inherent cooling effect of the water body enhances the overall efficiency of power generation. Some researchers view this as a solution for reducing evaporation losses from water bodies. Additionally, the reduced environmental impacts of such large-scale FPVs are attributed not only to the clean energy generated from these but also to measures that provide artificial lighting to preserve the local ecosystem [16].

DC-DC power conversion is carried out using buck or boost converters. The buck converter circuit schematic diagram is shown in [17]; and input voltage range, nominal output voltage, and maximum output current per [17] allows for the estimation of the required values for selecting the inductor, rectifier, and filter capacitor. Significant challenges arise with integrating renewable energy during decarbonization initiatives in the transportation sector, necessitating effective demand response strategies to balance energy demand and minimise power grid outages. When considering floating solar photovoltaics, additional aspects related to safe and robust installation come into play. Outages resulting from the failure of the floating structures require a detailed structural analysis and feasibility study of a large-scale floating solar PV system. Although known examples of FPV with a floating mechanism have achieved significant success [10], to ensure nil outages to customers, a design suitable to mechanical stresses from water movement, wind, and any additional environmental factors becomes crucial for this research.

The advantages of HVDC and its integrated use as a bridge between generation from FPV and DC fast chargers (with the absence of AC to DC converters) were driving factors for this study. Still, the disadvantages of this system mainly lie with not only the market availability of such customised EV chargers, which could increase the cost of manufacturing, but also operational limitations with DC-DC converters used at multiple stages along the system. For example, DC-DC converters are characterised by reduced efficiency at higher operating temperatures, ripple effects, poor regulation, poor transient response, and numerous failure points [18].

The paper is organised into sections: Introduction, which includes the background and literature review; Methods, which provide the FPV design; Results, which consist of the results; and Conclusion, which provides the recommended power distribution for Hassan.

II. METHODS

The system is modelled based on the methodology shown in Figure 1. Firstly, the total energy demand was calculated for electrification, and then 500W solar PV floating modules were proposed, with a footprint of 4.12 km² (inclusive of clearances around the panels). A total of

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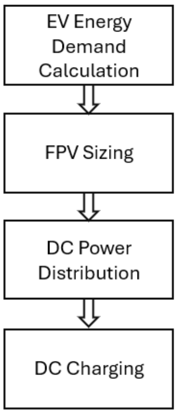
109,1703 modules contributed to a system of size 545 MW. The NREL System Advisory Model (SAM) was used to generate results for the 545 MW FPV at the Gorur Hemavathi dam. Given that the proposed methodology aims to harness DC power distribution for EV charging at both transmission and distribution levels, a MATLAB Simulation was performed to prepare results for a DC-DC converter that regulates the power output to the electric vehicle using a utility input DC supply of 400V DC and an output of 400V DC. This became the basis of a new design development of DC chargers for commercial usage. Figure 9 depicts the location of the EV charging load in the entire generation, transmission, and distribution of the power. HVDC systems are replacing traditional HVAC systems.

A. System Modelling

The total number of registered vehicles in Hassan was obtained, and the annual energy demand was calculated by considering the average annual mileage and the energy required for vehicle charging. The yearly energy necessary to meet the charging needs became the baseline for estimating the size of solar PV systems. Figure 2 shows the layout of the FPV on the Gorur Hemavathi Dam reservoir. The space exactly behind the gates was chosen for the FPV application, given the ease of accessibility to FPV from the dam walls. Additionally, this enables the effective routing of power conductors to the transmission substation. The exact location of the substations was not chosen for this paper. However, the demographic and geographic information available for open-source maps was used to lay out the equipment, namely substations and HVDC transmission lines.

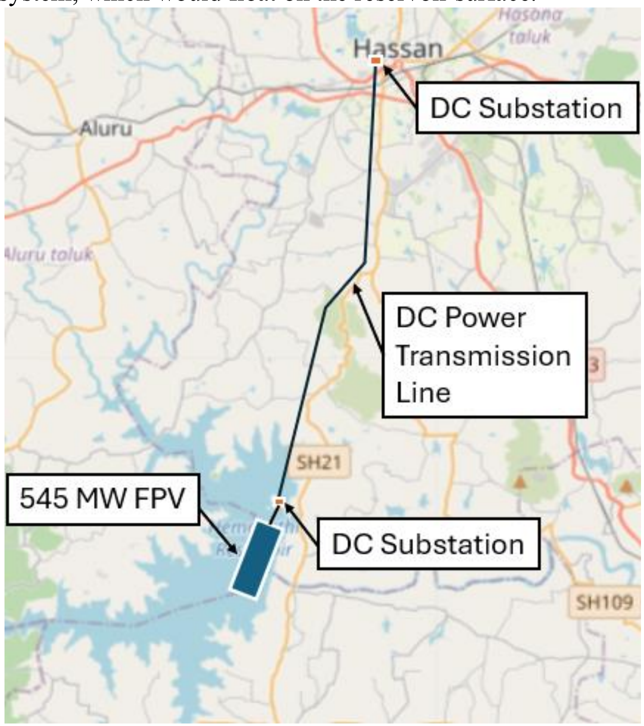


[Fig.1: System Model]

B. FPV Modelling

Using the NREL SAM simulation of a solar PV system with the PV Watts method, a layout of 4.5 km² FPV with an installed capacity of 545 MW was implemented. The effects of cooling were not factored into this calculation, as a detailed analysis is required to estimate the exact efficiency improvement achieved from the cooling effects of the water. The area required for installation is dependent on the safety standards that permit a designated quantity of solar panels within a given area to mitigate fire risks. There are limitations with footprint calculations when evaluating the standards and permissible safety limits. It is safe to install the given system size based on other projects installed around the world, such as those in India, China, and the United States.

Using the simulation software, the geographic information of the reservoir was used to input a weather file with solar irradiance values for the year 2019. More recent data can improve the simulation results; however, for this study, the most recent weather files available (from 2019) enabled us to determine the annual energy generation using the PV Watts method. Although NREL SAM supports many detailed models of solar PV systems for both residential and commercial applications, the purpose of this simulation was to obtain a simplified energy generation profile for the proposed system, which would float on the reservoir surface.



[Fig.2: FPV System]

C. DC Power Transmission and Distribution

A DC power transmission and distribution system, extending from the source to end-users, was proposed. This was achieved by stepping down the DC transmission line's high voltage to the required fast charging voltage of 400V DC, thereby improving the charging infrastructure. Additionally, a conversion process from DC to AC was avoided not only at the power distribution level but also while charging vehicles with market-available equipment. Figure 3 shows the DC power distribution. Figure 9 proposes an HVDC application to enhance transmission efficiency further. HVDC transmission over shorter distances could pose challenges concerning increased costs; however, for this research, the costs were considered less important as a limiting factor when achieving improved energy efficiency through power transmission.

The routing of the power HVDC transmission lines is subject to various other constraints, including environmental disturbances and optimal routing based on the terrain's grade. Due diligence was taken to showcase a schematic diagram, noting the routing along existing roadways, as power transmission and distribution lines are typically routed along the roadways. There is usually a potential access available to these lines from roadway access, which is another motivator for such a routing strategy.

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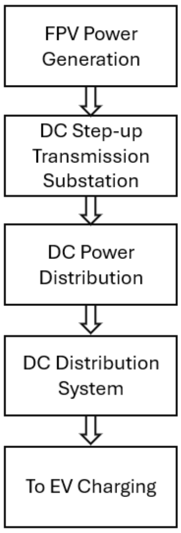
Superconducting materials for transmission and distribution using HVDC are a potential use case when implementing this concept; however, cost and operational factors become key decision-makers in such a selection. Theoretically, with superconducting materials, copper losses can be significantly reduced to 0%. Still, the energy required to cool the conducting material to achieve this reduces the overall efficiency of the system due to power consumption from the supporting cooling system. For example, per Equation (1), the resistance of the conductors increases with temperature. Where RT is the resistance (in Ohms) of the conductor at given temperature T (in Celsius), R0 is the resistance at 0 degrees Celsius (T_0).

$$R_T = R_0 [1 + \alpha(T-T_0)] \quad \ldots \quad (1)$$



[Fig.3: DC Power Distribution]

D. Change in System Configuration

Due to DC power transmission and distribution, copper losses are reduced. The proposed power distribution enables the direct availability of 400V DC power at the user end from the utility company. However, this scheme requires modified DC chargers with in-built components for power regulation, overcurrent protection, and communication links. This reduces the cost of EVCS infrastructure. Table 1 tabulates significant differences between the new charging system and the currently available charging system.

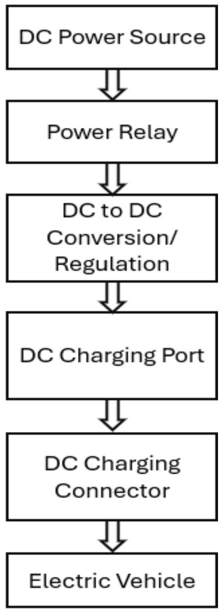
There are no significant modifications required for the electric vehicle model to charge, as it is equipped with charging options that include DC from CHAdeMO, J3400, and CCS connector ports. However, some vehicles that require AC slow charging may have limited application from the proposed system—for example, plug-in hybrids.

Some practical cases of poor-quality products in electric vehicle charging limit the potential of DC fast chargers to enhance the user experience. Additionally, continued government support to increase the market penetration of EV chargers becomes vital for major manufacturing companies. Therefore, the concept of eliminating the AC-DC conversion at the proposed fast charger necessitates that manufacturers select high-quality components to minimise failures resulting from electrical and environmental stresses.

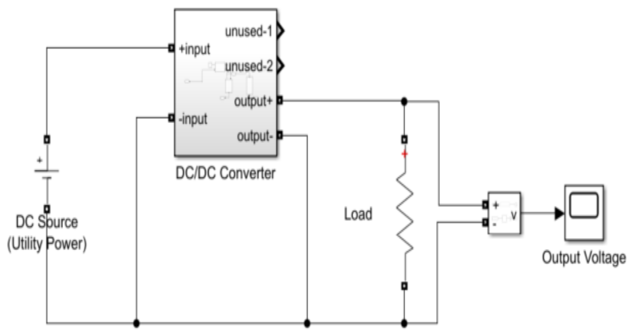
E. Designing New DC Charging Station

The available DC power from the utility company is directly utilized for DC charging purposes. Typically, a DC fast charger consists of several components, including AC to DC and DC to AC conversion, as well as communication protocol equipment, to establish a handshake between the EV and the EVCS. However, the new DC charging station presented in this paper is similar to an AC charging station, but it allows a flow of DC power from the source to the EV through a DC-to-DC conversion/ regulation phase. Additional overcurrent protection devices enhance electrical safety and improve the design. Figure 4 shows a typical layout of equipment inside new DC charging equipment. A basic buck converter circuit was chosen for this new charger, as well as for simulation purposes in MATLAB Simulink. Figure 5 shows the MATLAB Simulink model. Equation (2) governs the output voltage V_{out} relationship with V_{in} (input voltage), η (efficiency), and D (duty-cycle).

$$V_{out} = (DV_{in}) \div \eta \quad \ldots \quad (2)$$



[Fig.4: Conceptual New DC Charger Design]



[Fig.5: MATLAB Simulink Model of DC-DC Converter for Charging]

F. Specifying Building Systems With EV Charging Stations

The idea behind including EV chargers in commercial buildings is not only to support the decarbonization efforts

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underway in several jurisdictions but also to reduce the net carbon emissions associated with their use. Including high-energy-efficient DC fast chargers, as proposed in this paper, located within reasonable distances for ease of commute, is a motivator for this research work. An emphasis on the modification of building standards to incorporate energy-efficient EV charging equipment is proposed. For example, incorporating terminology related to the use of DC-DC converters operating at high power conversion efficiencies, particularly when combined with a DC power source, into building codes would increase the adoption of proposed DC chargers in the practical world.

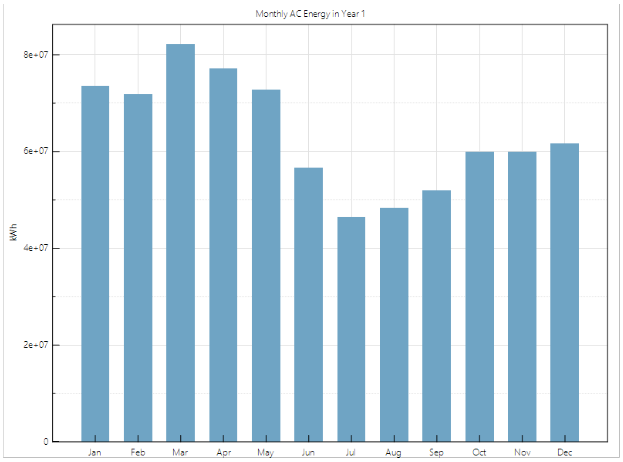
The ideology of using smart devices to monitor charging usage allows utility companies to plan power generation and distribution more effectively. Building innovative energy management systems is an accurate indicator of overall usage and intelligent controls of the demand. Qualification of EV chargers as a distributed generation resource for building operations is not an unheard-of concept when studying the impacts of Vehicle-to-Grid. Vehicle-to-Grid and equivalent bi-directional power flow are constrained by increased costs, complexity, regulation, and diminishing power quality. EV plugin points at the user end to send power back to the power grid, which goes through multiple stages. In these stages, the efficiency of sending power becomes questionable, as power is typically transmitted at high voltages and low current levels to minimise system copper losses.

In a Vehicle-to-Grid system, sending power from a low voltage to the system, which eventually steps up the power to a higher voltage, is less efficient when considering the distances over which power is transmitted from a given customer, due to copper losses and voltage drops. For example, longer lengths of conductors result in higher copper loss and voltage drops when the source and loads are farther apart. The dissipation of energy due to these reasons allows for the proposed concept of utilising FPV, HVDC, and EV chargers as a comprehensive system. System complexity is mitigated by avoiding multiple stages of power conversion between DC and AC, or vice versa. When combining the commercial building with Vehicle-to-Grid [19] the energy management system becomes capable of allocating the appropriate use of the energy (either from the grid or distributed generation resources on building systems). Building codes that allow this integration within permissible limits of power quality motivate the building certification processes for improved energy efficiency.

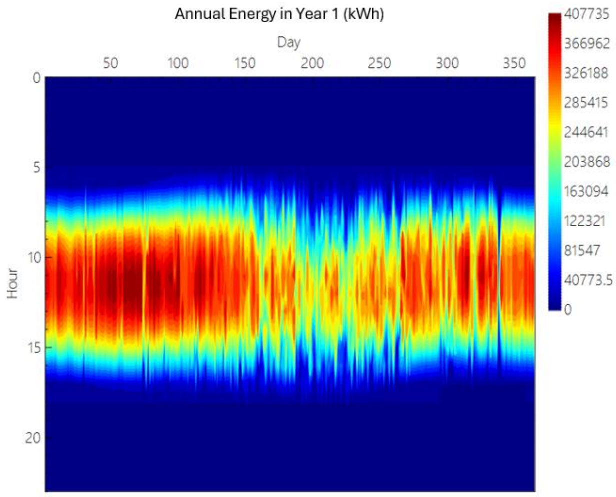
III. RESULTS

The NREL SAM simulation results for the annual energy generation profile are shown in Figures 6-7. A total of 762,575,552 kWh (or 0.76 TWh) of energy generation was offered by a 545 MW FPV system. This doesn't account for the inherent cooling effects of the water. Figure 8 shows the simulation results from MATLAB Simulink for the output voltage from the new DC charger. The output voltage remains at 400V DC, which suits the requirements for an electric vehicle battery charging.

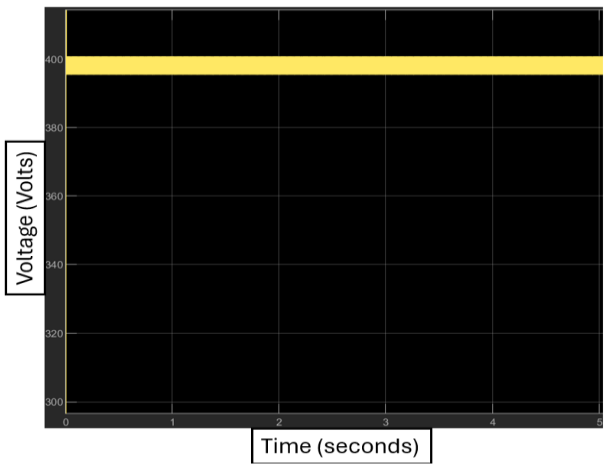
The simulation results were based on AC energy generation, which accounts for the inversion of power using an inverter to convert DC to AC. However, the assumption here is that the DC power output will be similar to the AC power output, as simulated using the NREL SAM software.



[Fig.6: Energy Generation Results]



[Fig.7: Annual Energy Profile]



[Fig.8: Output Voltage of New DC Charger]

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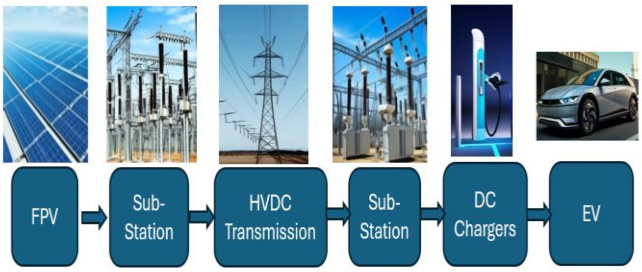

[Fig.9: Use of HVDC for Transmission [20]]

IV. CONCLUSION

An EV plan to power all electrified vehicles in Hassan, Karnataka, was materialised by providing power from an FPV System. A 545 MW FPV installation at the Gorur Hemavathi dam reservoir was proposed to supply power to EV loads in Hassan, with a total annual energy generation of 0.76 TWh. A scheme of using DC power transmission and distribution to the end customer was prepared by laying out a sketch of the power distribution. A simple buck converter application for a new EV charging station powered from DC and supplying DC loads was prepared and simulated in MATLAB Simulink. The output voltage can be easily controlled to maintain a desired 400V DC using DC-DC converters. Additional safety devices for overcurrent protection further improve the design. This design is straightforward and cost-effective when compared to existing DC fast charging stations. Accounting for the energy efficiency improvements from the cooling nature of the water for FPV becomes a topic of detailed discussion and research. With the shift to DC power transmission and distribution, there is no significant impact on the existing EVs in the market, as they support DC charging. However, an improved design of DC chargers, as recommended in this research paper, offers a solution that is both simplistic and cost-effective. Practices in commercial buildings to achieve clean energy certifications must be emphasised, particularly with the chosen equipment for EV chargers, which should prioritise high energy efficiency and low energy losses. Additionally, building codes must permit the incorporation of DC power systems to enable the direct charging of EV chargers from DC power sources.

Nonetheless, technology continues to advance in the electrification sector, particularly in the transportation industry, with EV chargers. Renewable energy offers a solution not only for decarbonising the market but also for reducing greenhouse gas emissions from power generation and other conventional fossil fuel sources. DC-DC converters commercially available are designed to withstand electrical and environmental stresses; however, some known limitations, including failure points, become a key concern when using them, particularly for applications such as DC-DC step-up between generation from FPV to HVDC transmission and distribution, or for step-down from HVDC to supply electric vehicles.

Table-I: Comparison of DC Fast Chargers

Component Name	DC Fast Chargers	
	Traditional DC Fast Charger	New DC Fast Charger
AC Power Quality Components (Transformer & Filters)	Yes	No
Energy Measurement	Yes	Yes
Electrical Overcurrent Protection	Yes	Yes
Electrical Disconnects	Yes	Yes
DC Current Devices for GFCI	Yes	Yes
Current Measurement	Yes	Yes
AC to DC Power Converters	Yes	No
Terminal Blocks	Yes	Yes
Cable Sealants	Yes	Yes
Thermal Management System	Yes	Yes
Harmonic Filters	Yes	Yes

DECLARATION STATEMENT

I must verify the accuracy of the following information as the article's author.

- **Conflicts of Interest/ Competing Interests:** Based on my understanding, this article has no conflicts of interest.
- **Funding Support:** This article has not been funded by any organizations or agencies. This independence ensures that the research is conducted with objectivity and without any external influence.
- **Ethical Approval and Consent to Participate:** The content of this article does not necessitate ethical approval or consent to participate with supporting documentation.
- **Data Access Statement and Material Availability:** The adequate resources of this article are publicly accessible.
- **Author's Contributions:** The authorship of this article is contributed solely by the author.

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AUTHOR'S PROFILE

Pravin Sankhwar, "With a passion for environmental stewardship and a commitment to sustainable practices in the electrical engineering industry, Pravin Sankhwar brings an extensive amount of experience in engineering design and research. Holding a master's degree in electrical engineering from Michigan Tech, a bachelor's degree in electrical engineering from Malviya National Institute of Technology, and a PhD candidate, he combines academic knowledge with practical expertise to drive meaningful change in the electrical engineering and renewable energy industry. Throughout his career, Pravin Sankhwar has successfully led projects that promote sustainable initiatives, reduce carbon footprints, and engage communities in eco-friendly practices. He believes in the power of collaboration and innovative thinking to address today's environmental challenges. Pravin Sankhwar is a licensed Professional Engineer."