

‘All-Vehicle Electrification by 2030 Project’ in India – Impacts and Solutions

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Abstract: *As a developing country, India is about to commence the most enthusiastic electric-car transformation in the transportation sector. India is planning to be the first all-electric vehicle country by 2030. Compared to previous years, a booming in electric vehicle sale is clearly visible in the vehicle markets. However, the question is whether India is equipped to welcome this transformation. The purpose of electrification of a vehicle is to ensure a pollution-free transportation. As per the latest reports, out of the 300 GW of electricity produced in India, 80% is from thermal power plants. The pollution contribution by thermal power plants is unquestionable. So the cause of vehicle electrification is violated at this point. Apart from that, the grid effects of plugged in hybrid vehicles is another major issue. As India lies in a geographical condition of high solar energy exposure, integration of renewable energy to the charging stations, grid and facilitating the V2G implementation will support this endeavor as well as help to establish a sustainable transport system. This paper presents a case study of impacts and challenges of vehicle electrification venture in India. In the proposed renewable energy powered wireless charger system according to the Indian model, efficiency of 94% achieved, which can replace the present grid based wired charger used in India. The findings and statements are validated with PSIM simulations and data published from Govt. of India.*

Keywords: *Electric vehicle; Renewable energy; Vehicle to grid integration; Solar power; Wireless charger; Power quality*

1. Introduction

Electric vehicles (EV) are becoming the fundamental solution for pollution-free transportation and energy conservation. Every country has contributed towards this cause in their own way. Electric vehicles are replacing gasoline vehicles. However, India is leaping towards another mesmerizing goal by ‘All vehicle electrification by 2030’ project [1]. By 2030, India is planning to replace/modify every gasoline vehicles with electric vehicles. However, the infrastructure and power utilization scenario are not all promising towards this venture [2], [3]. Out of 300 GW electricity produced in India, only 16% is from renewable energy resources. This low renewable energy consumption will adversely affect this initiation both technically and economically. For grid-connected EVs have several impacts on grid performance including overloading, demand variations, power quality etc. [4] – [9]. However, according to the geographical scenario of India, integration of EVs with abundantly available solar or other renewable energies will solve both pollution problems [2] and grid-related issues [10] – [19]. With the proper energy extraction mechanisms with

vehicle grid integration (V2G) [13] – [18] techniques, we can achieve sustainability in transportation sector along with the power quality enhancement of grid.

The detailed analysis is given in following sections. Section II describes the present energy scenario of India. While section III discusses the impact of EVs on the grid. The renewable energy powered EV systems are explained in section IV. Section V deals with the advanced V2G technique for grid interconnection.

2. Energy Scenario in India

India is becoming the fastest growing countries in the aspect of infrastructure, economy, and technology. If we consider the power generation sector in a period of 2009 to 2017, an uninterrupted growth can be seen. The contribution of various power generation sources like thermal, hydro, nuclear and renewable energy sources should be considered during this period.

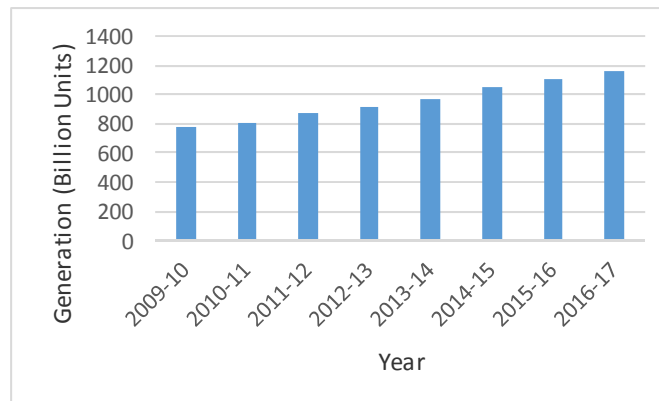


Figure. 1 Power generation (Billion units) [2]

Figure. 1 shows the graphical representation of power generation in billion units during a period from 2009 to 2017. For a sustainable development, the growth rate should be higher than the previous year. Nevertheless, in the period under consideration, a fluctuation is clearly visible.

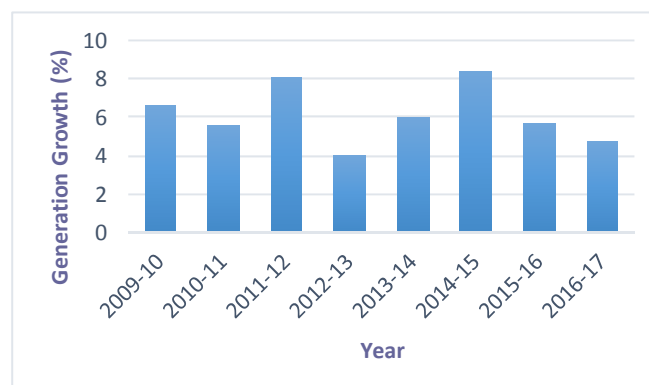


Figure. 2. Generation growth (%) [2]

Figure. 2 shows the generation growth in a period from 2009 to 2017. Even though the generation is growing in each year, the growth rate is not at all uniform. Compared to the maximum growth rate in the 2014-15 period, in 2016-17, a reduction of 3.72% is visible. Now we should consider the contribution by different sources towards this generation.

Region	Thermal	Nuclear	Hydro	RES	Total
Northern	52305.76	1620.00	18382.78	10246.98	82555.52
Western	83796.42	1840.00	7447.50	16861.14	109945.05
Southern	46227.74	2320.00	11739.03	21721.42	82008.19
Eastern	30167.87	0.00	5378.12	896.63	36442.62
North-East	2117.05	0.00	1242.00	280.44	3639.49
Islands	40.05	0.00	0.00	1.40	51.45
ALL INDIA	214654.89	5780.00	44189.43	50018.00	314642.32

TABLE I. All India installed capacity (MW) [3]

Table 1 shows the Electricity was generated from thermal, nuclear, hydro and renewable energy sources in this period. 70% of the total installed capacity belongs to thermal power plants, depend on the conventional fuels. Thermal power plants use coal, gas, and diesel for the generation of thermal power. The burning of these fuels will enhance the air pollution. Another fact is that these kind of conventional fuels are rapidly reducing from earth. The combustion of fuel enhances the evaporation of water in thermal power plants. In 2016, the percentage of thermal power plants was 80%. Even though, there is a reduction of thermal power plants by 10%, the renewable energy resources (RES) increased just by a 3%. In 2016, the contribution of renewable energy sources was 12% and in 2017, it increased to 15%.

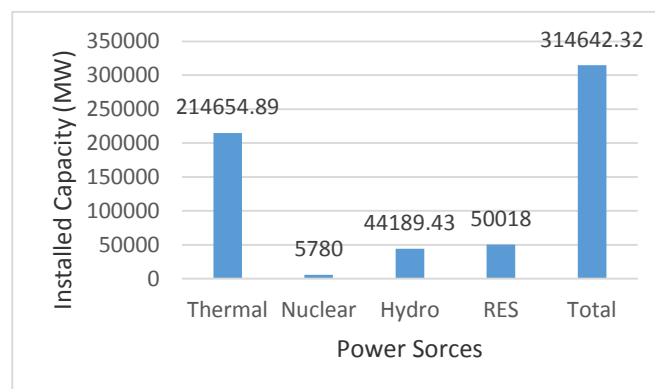


Figure. 3. All India installed capacity (MW) [3]

Figure. 3 shows the graphical representation of installed capacity in MW in 2017. The total power generation by renewable energy sources during this period was just 15%. Even though India lies in a geographical region, where plenty of solar energy is available, we are not utilizing this abundant resource of free energy.

As per the ‘All-Vehicle Electrification by 2030 Project’ action plan, the sale of EV has already been boosted up. The ultimate aim of this mission is to ensure a pollution-free transportation. By observing the present energy generation pattern, this aim is far behind. Because this 70% of thermal power plants will constitute an almost similar order of pollution as the fuel based vehicles.

3. Grid Impact of EVs

Grid-connected EVs have a high impact on the performance of grid. To define the impacts, the working of EV charging should be analyzed.

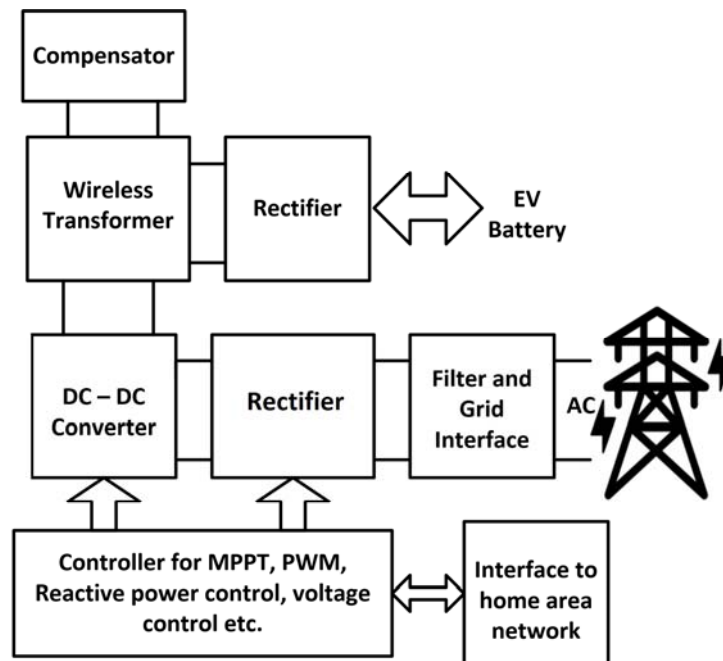


Figure. 4. Grid-connected EV

Figure. 4 shows the block diagram of a grid-connected EV [19]. A wireless charger for EV is considered in this case. The input AC is initially converted to DC by means of a single-phase inverter. Then it is converted to a high-frequency AC by a converter. This high-frequency AC energizes the primary of the wireless transformer. At the secondary side, it is converted to DC by a rectifier and finally fed to EV battery. For reactive power cancellation, compensators are used.

The high input current and power requirement of EV charging make the grid performance vulnerable. The cumulative demand for energy for EV charging at a particular area during a given period is termed as EV charging profile. EV charging profile depends on the geographical location, climate condition and the time under consideration. During charging, the demand over grid will be high even for a single charger. If the number of electric vehicles increased in a geographical region, the time of charging will be approximately same as morning 6 pm – 8 pm and evening 6 pm – 8 pm. The number of vehicle increases, the load over grid will increase as well. Apart from this overload, the ripples from the wireless transformer also affect the power quality of grid supply. The solution is to implement the grid isolated charging stations or precautions for improving power quality by means of an auxiliary supply like renewable power sources.

4. Solutions to Vehicle Electrification Impacts

The main reason behind the adverse impact of vehicle electrification of India is the over-dependence of the power sector on conventional energy sources, as explained in the previous session. So the major solution to be suggested is to reduce the use of conventional energy sources and enhanced & effective use of renewable energy sources. Effective integration of a storage system in the battery with the grid can be considered as another solution. India is gifted with plenty of renewable energy sources due to its geographical importance. By extracting and integrating the renewable energy to the grid can result in a considerable reduction in the effective environmental pollution caused by conventional power plants. It can also be utilized to improve the power quality in the grid. Wind energy and solar energy will hold major importance in this scenario.

Other than the renewable energy integration, another advanced solution to the grid impact of electric vehicles is the V2G facility in charging stations and parking slots. In the V2G concept, a bidirectional power flow mechanism is facilitated in the battery charging mechanism. So if the battery having more than nominal charge, power will flow to the grid. Power flow from multiple battery sources will improve the power quality of the grid as well as a reduction in overloading. Constructing charging stations with a standard separation, following a scheduled charging in normal/ off-peak periods, fixing a message protocol to coordinate the charging, arrange a storage mechanism in the charging station to store the surplus energy etc. can reduce the adverse impacts of mass vehicle-electrification in India.

5. Renewable Energy Powered EVs

As India lies in a geographical region with higher solar and wind resource availability, the EV charging stations with indigenous free energy harvesting mechanism will prevent all the above-mentioned grid impacts due to charging, as there is no direct connection between the grid. EVs fueled by renewable energy are the driving force of transportation infrastructure in India. Along with undisturbed grid power quality, conservation of

conventional energy sources can be achieved by this integration. If we consider the technical side, the rectifier in the conventional topology can be removed (Figure. 5), as the input is DC already.

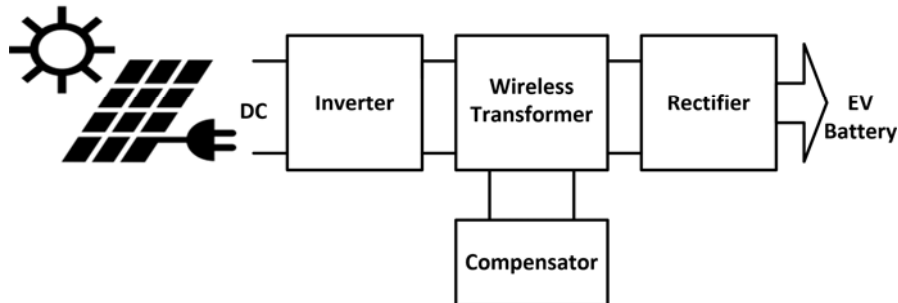


Figure. 5. EV charging by renewable energy

Figure. 5 shows the block diagram of a renewable energy powered EV charging. As the number of blocks reduced, the charging efficiency will increase. The use of a wireless transformer is important for the charging of electric vehicles. As the renewable energy based charging is the prime objective, a wireless transformer is unavoidable. We can charge the vehicle while running (dynamic charging) and we can charge the EV just by parking at a given parking slot without any effort using this technology. The compensator is used to establish the resonance in primary and secondary for maximum transfer efficiency. Performance of the proposed system has to be validated.

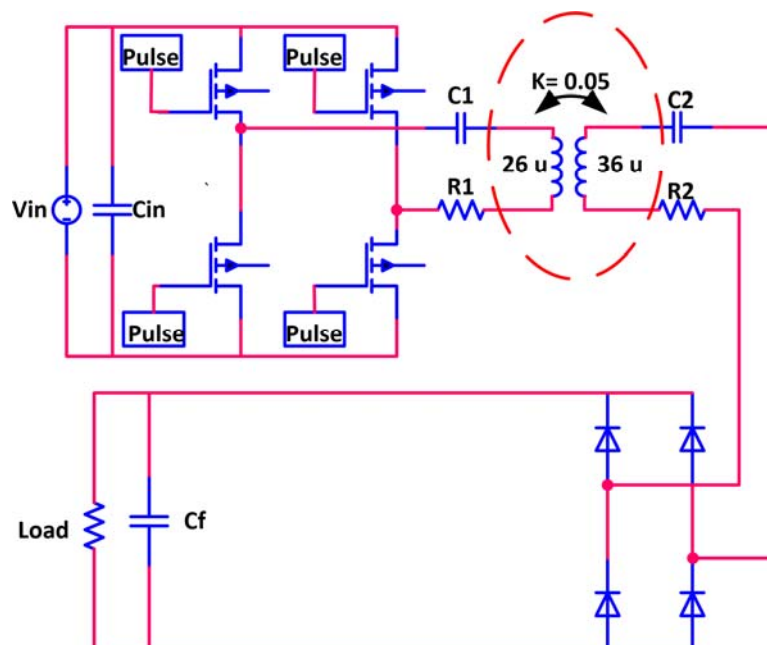


Figure. 6. PSIM simulation of renewable energy powered WPT charger

Figure. 6 shows the PSIM simulation of wireless power charger for EV using renewable energy. The wireless charger is used for integrating vehicle to grid(V2G), vehicle to vehicle(V2V) and dynamic charging facility to EV. This will ensure a sustainable transportation system in India. The wireless charger equation is given as,

$$\begin{aligned} \omega_o &= \frac{1}{\sqrt{LC}} \\ M &= k\sqrt{L_s L_d} \\ Q &= \frac{\omega_o L}{R} \\ \frac{V_2}{V_1} &= k \cdot \sqrt{\frac{L_2}{L_1}} \end{aligned} \tag{1}$$

Where ω_o is the resonant frequency of wireless transformer, L is the inductance of the coil, C is the resonant capacitance, k is the coupling coefficient, L_s is the primary coil inductance, L_d is the secondary coil inductance and Q is the quality factor of the coil. V_2 and V_1 are the primary and secondary voltages respectively. In Figure. 6, the renewable energy input is replaced by a DC input. A full bridge inverter used for high-frequency AC transmission. High frequency will reduce the magnetic component size of the system. Apart from that, the quality factor as in (1) will improve with higher resonant frequency, which in turn improve the charging efficiency. The selection of coupling coefficient k in (1) depends on the required coupling separation of the renewable energy powered wireless transformer. If we require a higher separation charger means, the value of k should be reduced. In order to maintain the voltage ratio as in (1), either secondary inductance has to be increased or primary resistance has to be reduced by considering the requirement.

Part	Efficiency (%)
Inverter	99.91
Wireless Transformer	93.95
Rectifier	99.72
Overall	93.85

Table II. Performance of PSIM Simulation

With the proper transformer winding design and achieving maximum efficiency condition as in (6), high performance can be attained. Table II shows the measured parameters of the PSIM simulation. The individual efficiency is calculated by finding the ratio between output power and input power of respective blocks. However, the demerit of SS compensation is that, its output voltage will drastically change with the change in coupling. Still with the proper transformer design, we can maintain the efficiency of

transmission. For increasing the operation range, transformers will usually designed for small k values. The variation of performance for different transformer designs are tabulated below.

Coupling factor (k)	Output voltage (V)	Output power (W)	Efficiency (%)
0.3	47.78	475.79	97.22
0.2	69.86	1017.21	94.49
0.1	122.19	3108.74	81.98
0.05	161.66	5445.95	53.59

Table III. Performance of WPT for transformer designed at $k = 0.3$

Coupling factor (k)	Output voltage (V)	Output power (W)	Efficiency (%)
0.3	8.45	14.88	98.54
0.2	12.62	33.20	98.47
0.1	24.97	129.96	97.43
0.05	48.09	481.78	93.84

Table IV. Performance of WPT for transformer designed at $k = 0.05$

Table. III shows the performance of WPT system with varying coupling for transformer design of $k = 0.3$. Since transformer is designed for higher coupling, efficiency is drastically falling for large separation. Table IV shows the performance of WPT system with varying coupling for a transformer designed at $k = 0.05$. We can see a stable efficiency, throughout the operation. And the variation in output voltage can be mitigated by implementing a proper controller [12]-[19]

As the overall efficiency is very promising, this charger topology can be implemented in Indian EV sector for renewable energy based charging. The complete dependency on the grid for EV charging will adversely affect the power quality of the supply. New renewable energy extraction techniques have to be introduced to fulfill the sole purpose of visions like all vehicle electrification. Renewable energy powered wireless charging scheme is a feasible alternative for the grid dependency as proved in the simulation.

For verify the simulated results, a practical system is to be implemented and analyzed. An 80W, 48V WPT charging system is designed with a switching frequency of 200 kHz. A variable input of 9V to 27V is used for the testing. The ultimate aim of hardware implementation is to design a WPT system with higher efficiency for a longer distance. A digital electronic load is connected instead of battery to validate the performance.

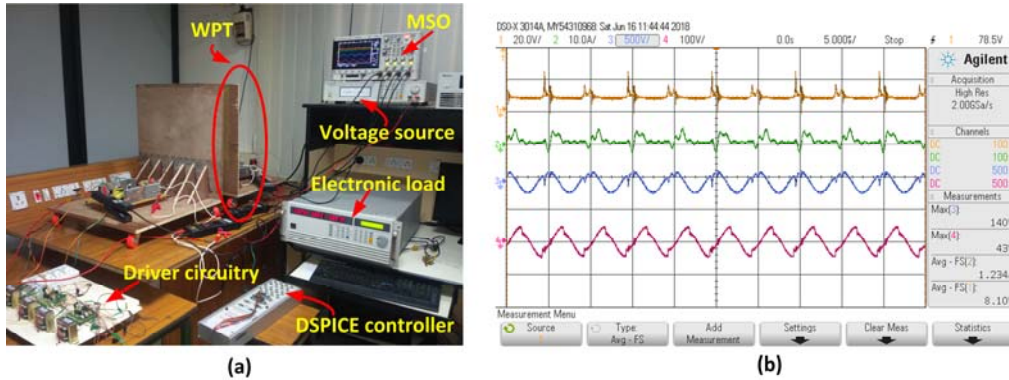


Figure. 7. (a) Implemented WPT system; (b) WPT waveforms at a coupling separation of 20 cm; Colour notation: brown - input voltage; green - input current; blue – primary coil voltage; pink - secondary coil voltage.

Figure. 7(a) shows the implemented WPT system in testing. With each input voltage variation, the coupling separation between the primary and secondary is varied from 0 to 28 cm. Figure. 7(b) shows the output wave forms of the WPT system. As input voltage, input current, output voltage, and output load is known, the system overall efficiency can be calculated by,

$$\eta = \frac{V_{out}^2 / R_{load}}{V_{in} \cdot I_{in}} \tag{2}$$

Using (2), efficiency is calculated for each samples and plotted the efficiency curve.

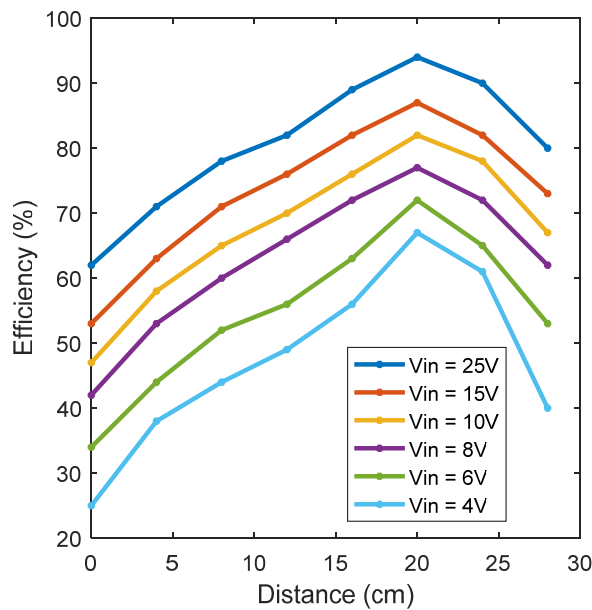


Figure.8. Efficiency Vs coupling separation with the input voltage variation

Figure.8 shows the detailed analysis of relation between overall efficiency of the system and coupling separation of WPT system with variable input. As the input voltage increases, the efficiency is also seems to be increasing. But a parabolic pattern is visible for efficiency Vs coupling separation. At a coupling separation of 20 cm, maximum efficiency is found for each input voltage conditions.

6. V2G Integration

As per the present EV scenario in India, all vehicles are charged by grid power. In the previous section, as a solution, renewable energy powered charger was mentioned. However, most kinds of renewable energies depend on the weather variations. Sometimes, it produces surplus energy and some time deficit. In order to design a sustainable charging system, the grid integration apart from renewable energy is required. If the charger is bidirectional, then the surplus renewable energy can be fed back to the grid and the process is known as V2G integration.

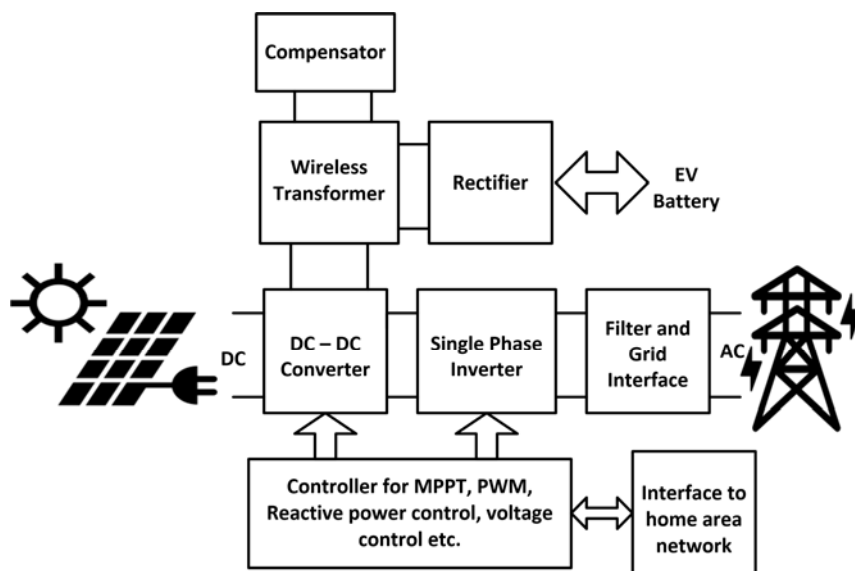


Figure. 9. V2G interface block diagram

Figure. 7 shows the block diagram of a V2G interface. Here both grid and renewable energy are integrated with the charging station, with a bidirectional converter with the grid. As the charging stations act as an uninterrupted supply of clean energy during the sunny daytime, the overcharging will leads supply to the grid. During the overloaded conditions of a grid, it can drop the stored energy in vehicle depend on the state of charge of EV battery and can be returned once demand is met. Likewise, a sustainable transportation along with improved power quality can be ensured using this EV charging system.

7. Conclusion

The announcement of 'All-vehicle electrification by 2030' project started a new technological revolution in India. The sale of EV in 2017 doubled compared to the previous year sales. Although the goal of this project is to establish a clean transportation, the thermal power plant dependent Indian power sector is becoming a hurdle to this achievement. The solution is to bring renewable energy into this picture. The abundantly availing solar and wind energy from the charging stations cannot only energize the car but also able to improve the power quality of grid. A detailed study of power sector in India is done to prove the challenges of clean transportation. Different solutions like renewable energy powered wireless charger and V2G integration is discussed to mitigate the grid effects and for a sustainable transportation. The designed wireless charger exhibits 94% of transfer efficiency even at a coupling coefficient of 0.05.

References:

- [1] Shikha Juyal, Dr. Manoj Singh, Shashvat Singh, and Sarbojit Pal, "India leaps ahead: transformative mobility solutions for all", NITI Aayog and Rocky Mountain Institute article, [Online] Available:URL:https://www.rmi.org/insights/reports/transformative_mobility_solutions_india, 2017.
- [2] Ministry of Power, "Power Sector at a Glance - all India", Government of India article, [Online] Available: URL: <http://powermin.nic.in/en/content/power-sector-glance-all-india>, 2017.
- [3] Ministry of the power sector, "Executive Summary of power sector for the Month of Jan 2017", Annual report – Government of India, pp. 12 – 28, 2017.
- [4] Csaba Farkas, Gergely Szucs and Laszlo Priker, "Grid impacts of twin EV fast-charging stations placed alongside a motorway", IEEE International Youth Conference on Energy, no. 1, pp. 115 – 121, 2013.
- [5] Giuseppe Mauri, Danilo Bertini, Enrico Fasciolo, and Stefano Fratti, "The impact of ev's fast-charging stations on the mv distribution grids of the Milan metropolitan area", IEEE International conference on electricity distribution, no. 5, pp. 1501 – 1505, 2013.
- [6] Theodoros Theodoropoulos, Angelos Amditis, Jesus Sallan, Hans Bludszuweit, Boris Berseneff, Paolo Guglielmi and Francesco Deflorio, "Impact of dynamic EV wireless charging on the grid", IEEE international electric vehicle conference, no. 20, pp.1 – 7, 2014.
- [7] Vito Calderaro, Vincenzo Galdi, Giuseppe Graber, Giovanni Massa and Antonio Piccolo, "Plug-in EV Charging Impact on Grid Based on Vehicles Usage Data", IEEE International electric vehicle conference, no.3, pp. 1 – 7, 2014.
- [8] Bernt A. Bremdal and Stine Sofie Grasto, "Seasonal impacts of EV charging on rural grids - A Case-Study from Hvaler, Norway", IEEE International electric vehicle conference, no.9, pp. 1 – 8, 2014.
- [9] Rajat Dhawan, Shivanshu Gupta, Russell Hensley, Neeraj Huddar, Balaji Iyer and Ramesh Mangaleswaran, "The future of mobility in India: Challenges & opportunities for the auto component industry", Automotive Component Manufacturers Association of India annual conference, no. 3, pp. 1 – 36, 2017.

- [10] Kurt E. Yeager, "Electric Vehicles and Solar Power: Enhancing the Advantages of Electricity", IEEE Power Engineering Review, vol. 3, pp. 13 – 18, 1992.
- [11] Suwendu Samanta and Akshay Kumar Rathore, "Wireless power transfer technology using full bridge current-fed topology for medium power applications", IET Power Electronics, vol. 9, no. 9, pp. 1903 – 1913, 2016.
- [12] Christoph Goebel and Duncan S. Callaway, "Using ICT Controlled Plug-in Electric Vehicles to Supply Grid Regulation in California at Different Renewable Integration Levels", IEEE Transactions on Smart Grid, vol. 4, no. 2, pp. 729 – 740, 2013.
- [13] Changsong Chen and Shanxu Duan, "Optimal Integration of Plug-In Hybrid Electric Vehicles in Microgrids", IEEE Transactions on Industrial Informatics, vol. 10, no. 3, pp. 1917 – 1926, 2014.
- [14] Samantha J. Gunter, Khurram K. Afridi and David J. Perreault, "Optimal Design of Grid-Connected PEV Charging Systems With Integrated Distributed Resources", IEEE Transactions on Smart Grid, vol. 4, no. 2, pp. 956 – 967, 2013.
- [15] Kuljeet Kaur, Amit Dua, Member, Anish Jindal, Neeraj Kumar, Mukesh Singh and Alexey Vinel, "A Novel Resource Reservation Scheme for Mobile PHEVs in V2G Environment Using Game Theoretical Approach", IEEE Transactions On Vehicular Technology, vol. 64, no. 12, pp. 5653 – 5666, 2015.
- [16] Hoang N. T. Nguyen, Cishen Zhang, and Md. Apel Mahmud, "Optimal Coordination of G2V and V2G to Support Power Grids with High Penetration of Renewable Energy", IEEE Transactions on Transportation Electrification, vol. 1, no. 2, pp. 188 – 195, 2015.
- [17] Giuseppe Buja, Manuele Bertoluzzo, and Christian Fontana, "Reactive Power Compensation Capabilities of V2G-Enabled Electric Vehicles", IEEE Transactions on Power Electronics, vol. 32, no. 12, pp. 9447 – 9450, 2017.
- [18] Xiaoqing Bai and Wei Qiao, "Robust Optimization for Bidirectional Dispatch Coordination of Large-Scale V2G", IEEE Transactions on Smart Grid, vol. 6, no. 4, pp. 1944 – 1953, 2015.
- [19] Peter K. Joseph and D. Elangovan, "A Review on Renewable Energy Powered Wireless Power Transmission Techniques for Light Electric Vehicle Charging Applications", Elsevier Journal of Energy Storage, vol. 16, pp. 145 – 155, 2018.

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