

# Impacts of EV Charging on Distribution Grid with Solutions

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**Abstract**— Due to the rise in fuel prices, the depletion of fossil resources, and environmental concerns, electrical vehicles are a technology that shows the most promise and offer an alternative to internal combustion engines. The analysis of the effects of grid charging for electric vehicles and its method of mitigation is the primary focus of this paper. The effects of electrical vehicle grid charging are complete in the MATLAB Simulink environment. In order to stabilize the grid against the penetration of electric vehicles, a hybrid control approach is created, with the outer controller being a fuzzy controller and the inner controllers being vector control technique-based proportional integral controllers. Results for charging vehicle batteries using hybrid and PI control techniques are compared, demonstrating the usefulness of the suggested model and the capacity of the control system for quick dc charging. At last, the solutions to EV Penetration in grid for upcoming years are given.

**Index Terms**—hybrid control, Drivers for EV Penetration, Solutions to EV Penetration, Charging Methodologies.

## 1. Introduction

Hydrocarbons, nitrogen dioxide, lead, carbon monoxide, sulphur dioxide, and particulate matter are the main pollutants that vehicle emits. India's has a massive automobile industry, the fourth largest in the world, accounts for a significant portion of vehicular pollution. The population of electric vehicles is growing in India at a pace of 37.5%, according to [1]. Additionally, the government is giving electric vehicles [2] and charging facilities [3] more attention. According to reference [4], the positioning of charging stations has been suggested to maximize their effectiveness and supply the necessary amount of power. Electric vehicles are also gaining worldwide attention and acceptance as a promising potential long-term solution for sustainable personal mobility [5]. In order to sell demand response services by electrifying the grid or lowering charging rates, it describes a system in which plug-in electric vehicles, such as vehicle-to-grid (V2G), electric cars (BEVs), and plug-in hybrids (PHEVs), connect with the power grid. Four broad categories can be used to categorize the active power markets for V2G. Base load, shaving, spinning reserves, and regulation are these four categories [6]. V2G is rarely utilized for base load power because it consumes a lot of battery charge. Peak shaving takes place when the demand for predictable power is at its maximum. To comply with contract requirements, thread reserves must be incorporated into the system power design. They are typically called 20 times annually on average. To maintain a consistent voltage and frequency, active regulation is used. When the car battery is charged from the mains, it operates in

G2V mode. Grid stability will be seriously impacted by on-grid vehicle charging as EV penetration rises as a result of uncoordinated grid-to-vehicle (G2V) charging. Power quality issues, transformer losses, line losses, line heating issues, and higher reactive power consumption can all be brought on by these charging effects. These problems may result in general power system and voltage stability problems, as well as system network crashes [7],[8]. The researchers constructed a model in which the EV effect on the load curve could be analyzed to determine peak load periods for charging and peak load times for discharging the car, or they worked on the best placement of automobiles in the distribution network using the genetic algorithm as a Smart control. Charge-related disadvantages are lessened.[9],[10],[11]. A group of control techniques known as intelligent control makes use of artificial intelligence (AI) computing techniques such neural networks, Bayesian probability, fuzzy logic, and machine learning. Genetic algorithms and evolutionary computation [12]. The integration of vehicles with the grid is the main concern of this article. The electric vehicle charging station design that has been suggested is appropriate for quick dc charging of electric automobiles.

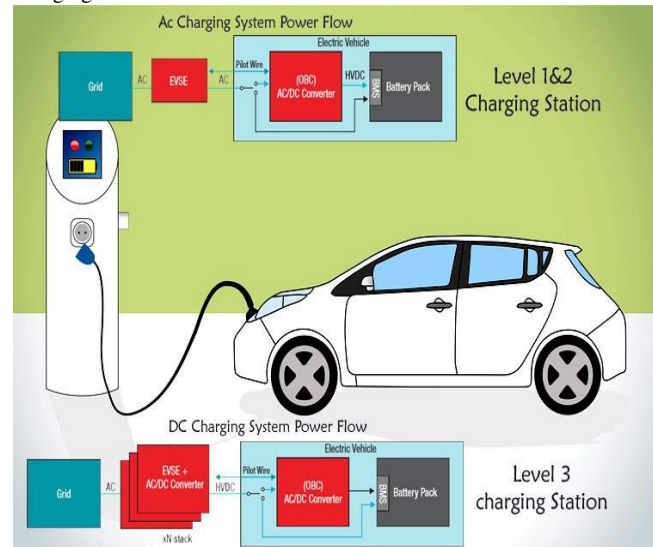


Fig. 1 EV charging Methodologies [13]

For EV charging, various technologies are available. Wired systems employing conductive technologies are by far the most widely used because they can easily ensure the requisite power level, safety, and interoperability with the majority of cars.5; nonwired methods (based on inductivity principles) are being investigated for highway applications. Battery swap is intended for high-speed applications (car racing), but it may also be ideal for fleets, sharing, and/or heavy-duty applications. Alternating Current (AC) infrastructures rely on car on-board chargers and are power limited due to vehicle size and expense. Off-board power electronics installed at the charging station are used in DC infrastructures. This enables

larger / bulkier / more expensive components, resulting in charging power of up to 350 kW in today's best performing devices. Although the trend in the early years of E-mobility was to increase AC charging power (up to 43 kW in some models), the current approach is to limit AC charging to less than 22 kW (typically 7 kW single phase or 11 kW three-phase). Fast charging will, in reality, be achieved by a DC charger, which is becoming standard equipment for all EVs[14].

## 2. System Configuration

To observe the impacts of electric vehicle penetration on several electrical parameters, such as DC bus voltage, current, active power, reactive power, harmonics, and power factor, simulations of the impact of this penetration are run in the MATLAB environment. In order to deliver continuous dc bus voltage with unity power factor in rapid charging mode for electric vehicles, hybrid control technology offers quick adjustments. The control architecture for decoupling uses alignment with PI regulators to a dq synchronous reference frame orientation. In the voltage source converter, a synchronously rotating dq reference frame is employed. Grid synchronization is a crucial and essential component of upstream converter control, and PLL (Phase locked loop) is employed for this purpose [15]. Internal and external control loops are the foundation of the hybrid control technique used here [16]. While the outer loop regulates the dc voltage of the load, the inner loop controls the power flowing between the dc connection and the grid. Utilizing the vector technique, proportional integral controllers are employed as internal controllers and the fuzzy controller is built as an external controller. The PI control approach is used with fuzzy logic control. Given that it doesn't require accurate, noiseless inputs, fuzzy logic is naturally robust. Fuzzy logic can be adjusted. Any system can be easily managed and expanded upon without the need to start from scratch. Since FLC executes the user-defined rules that control the system, it is simple to add to, enhance, or alter system functionality. Here, the internal vector control technique is combined with an external fuzzy control technique and PI controllers to provide quick dynamic response, lower harmonic generation, and enhance power factor while maintaining a constant dc bus voltage. For quick dc charging of electric vehicle batteries, the notion presented here might be quite helpful. There are several parts that describe the studies that were done.

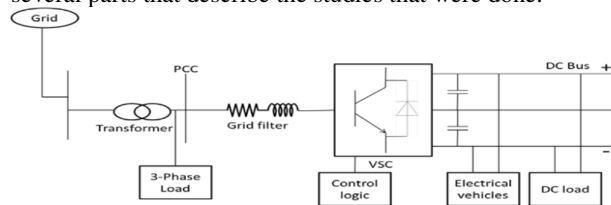


Fig. 2 System configuration for proposed work [17]

The system configuration for examining the effects of car charging is shown in Figure 2. A transformer and grid filter are used to link a 30 MVA generator to a 3-phase, 3-level voltage source converter. The reduction of harmonics is a filter's function. By carefully choosing a dc capacitor, ripples and harmonics on the dc side of the voltage source converter can be effectively managed. Transformers are used to link voltage source converters to the ac system, as seen in Figure 1. The transformer's job is to convert ac voltage to the necessary level of ac voltage for car DC charging. By managing the currents that pass through them, phase reactors are used to regulate the flow of active and reactive power.

Reactors lower the high frequency harmonic contents of the ac currents that are brought on by the switching operation of the IGBTs by acting as filters as well. There are two capacitors of the same size on the DC side. The needed dc voltage determines the size of these capacitors. The dc capacitor's main purpose is to offer a low inductive path for the turn-off current. It also functions as an energy storage device to regulate the power flow. Additionally, a capacitor lowers dc side voltage ripple. The energy storage device for voltage source converters on the ac side is an inductor since they function as continuous current sources. The voltage source converter functions as a constant voltage source on the DC side, and it needs a capacitor as an energy storage device. In order to evaluate the effects of battery charging, loads are applied to both the ac and dc sides, as is standard procedure. Table 1 displays the model definition for the system setup.

TABLE 1 MODEL SPECIFICATIONS [17]

Descriptions	Value
Voltage source converter rating	500 Volts DC, 500 kW
AC Supply: three-phase	500 V, 30 MVA, 50 Hz system
Load	Ac side 1MW&500KVAR, DC side 400kw including electric vehicle batteries
DcLink:2 capacitors	25000 mF
Switching Frequency	1620 Hz

The MATLAB Simulink battery model is used for analysis.

## 3. Control Strategy

Many VSC control approaches, including voltage mode control, current mode control, and vector control technique, have been created by the researchers with various techniques, algorithms and battery modelling [18]-[20]. It is possible to use random modulation, fixed frequency modulation, or both. Linear (or Ramp Comparison) Control, Hysteresis Control, and Predictive Control are the three main categories that can be taken into consideration while discussing the fundamental control methods. However, new and novel approaches to current regulation have been introduced, including fuzzy logic controls, neural networks, and delta and sigma delta modulation[21],[22].Numerous variations and enhancements of the fundamental ideas have been produced for each of these categories as a result of the vast research on these converters. Voltage source converters are used in every application nowadays because they have fast response times, high accuracy levels, and high performance requirements. As these attributes become more and more important, there is a growing demand for low-cost, dependable, and high-quality methods. There is a need to compare and summaries the qualities of the available solutions because there are so many different ways [21]. There are also several authoritative books detailing the state of the art for PWM approaches generally [21] and for VSI current regulation [22]. The most widely utilized type of control for VSC is vector control. By establishing a control approach based on the energy stored in the DC-link capacitor, DC-link voltage management is accomplished. The control algorithm uses PI regulators to align to a dq synchronous reference frame orientation in order to decouple. Active and reactive power can be independently controlled using a synchronously rotating dq reference frame in voltage source converters. Grid synchronization is an essential component of grid side converter control. A PLL (phase locked loop) is employed for this reason

The inner and outer control loops are the foundation of the vector control technique used here. While the outer loop regulates the load's DC voltage, the inner loop controls power between the DC link and the grid. With constant DC bus voltage, vector control technology provides quick dynamic response, lowers harmonics, and boosts power factor. The concept presented here will be very helpful for quickly DC charging the batteries of electric vehicles. In Figure 3, a vector control technique is displayed. Figure 4 depicts every element required for the vector control technique. The grid-connected AC/DC converter for battery charging is configured as shown in Figure 4. Analysis of the effects of vehicle battery charging on the grid will be greatly aided by a thorough understanding of the control function of the voltage source converter. Understanding this will facilitate the creation of an appropriate fast or slow charger for electrical vehicles.

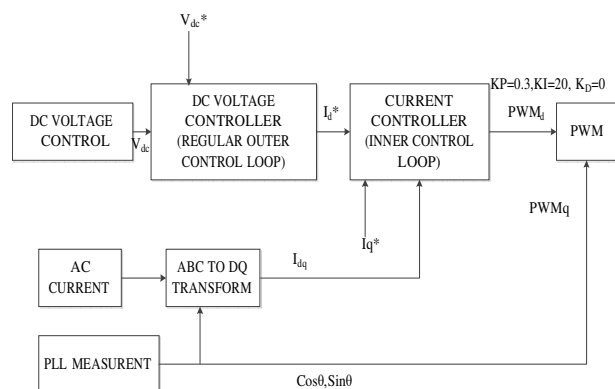


Fig. 3 Control strategy [17],[28]

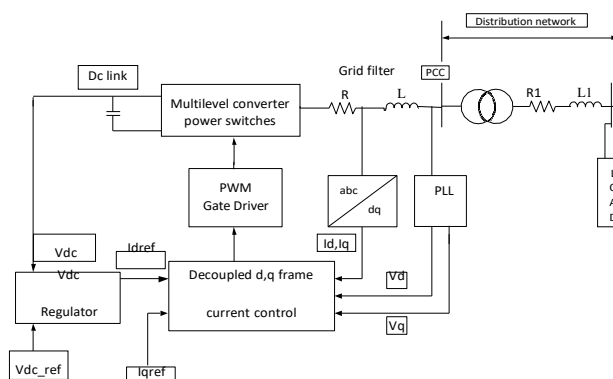


Fig. 4 Configuration of grid connected AC/DC Converter for battery charging

The suggested control strategy makes use of active and reactive power calculations, direct-quadrature-zero transformation equations, and a phase-locked loop (PLL) algorithm to synchronize with the utility grid voltage. The phase currents  $i_a$ ,  $i_b$ , and  $i_c$ , as well as the utility voltages  $v_{sa}$ ,  $v_{sb}$ , and  $v_{sc}$ , are transformed from a-b-c coordinates to a d-q frame using the Park transformation and  $\theta$  generated by the PLL. The following equations can be used to characterize the d-q

$$\begin{bmatrix} v_r \\ v_d \\ v_q \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \sin(\omega t) & \sin(\omega t - \frac{2\Pi}{3}) & \sin(\omega t + \frac{2\Pi}{3}) \\ \cos(\omega t) & \cos(\omega t - \frac{2\Pi}{3}) & \cos(\omega t + \frac{2\Pi}{3}) \end{bmatrix} \begin{bmatrix} v_{sa} \\ v_{sb} \\ v_{sc} \end{bmatrix}$$

$$\begin{bmatrix} i \\ d \\ q \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \sin(\omega t) & \sin(\omega t - \frac{2\pi}{3}) & \sin(\omega t + \frac{2\pi}{3}) \\ \cos(\omega t) & \cos(\omega t - \frac{2\pi}{3}) & \cos(\omega t + \frac{2\pi}{3}) \end{bmatrix} \times \begin{bmatrix} i_{sa} \\ i_{sb} \\ i_{sc} \end{bmatrix} \quad (2)$$

Following the aforementioned transformation, the three-phase instantaneous active power and reactive power in the d-q frame are determined using the three-phase grid voltages and currents as given in the following two equations.

$$\vec{p} = -\frac{\hbar}{2}((\vec{v}_d \times \vec{i}_d) + (\vec{v}_q \times \vec{i}_q)) \quad (3)$$

$$\mathbf{q}^3 = \frac{1}{\gamma} ((\mathbf{v}_q \times \mathbf{i}_d) - (\mathbf{v}_d \times \mathbf{i}_q)) \quad (4)$$

The computed instantaneous active and reactive powers include oscillation and average components. The outer PI control loop is applied to track the difference between reference and actual DC bus voltage. PI controller generates active current reference  $i^*_d$  and reactive current reference  $i^*_q$ , as shown in the following equations:

$$i_q^* = k_{pp} \left( \frac{d_{ref}}{Q} - \frac{d_c}{Q} \right) + k_{ip} \int \left( \frac{d_{ref}}{Q} - \frac{d_c}{Q} \right) dt$$

$$i_q^* = k_{pq} \left( Q_{ref}^{dref} - Q_{ref}^{dc} \right) + k_{iq} \int \left( Q_{ref}^{dref} - Q_{ref}^{dc} \right) dt \quad (6)$$

Where  $k_{pp}$  and  $k_{pq}$  are proportional constants, and  $k_{ip}$  and  $k_{iq}$  are integral constants for the used PI controllers.  $P_{ref}$  is the reference of the charging power, and  $Q_{ref}$  is the reference value of the reactive power required by the AC grid. The control of the converter is designed by integrating inner loop current and outer voltage loop (DC bus voltage). Comparing the voltage reference with the actual voltage in the outer loop results in the current reference, this is used for the inner loop control. Hence, the inner PI loops are established by comparing actual measured line currents obtained by utilizing the park transformation matrix with the current reference (obtained using Equations (5) and (6)). The results ( $e_d$  and  $e_q$ ) are first added with the decoupling terms and are then normalized by the DC-link voltage (the battery voltage) to get the duty ratios in the d-q coordinate. These calculations are summarized as follows:

$$\begin{bmatrix} \mathbf{d}_d \\ \mathbf{d}_q \end{bmatrix} = \mathbf{V}_{dc} = \begin{bmatrix} \mathbf{e}_d + \mathbf{v}_d + 3\omega_l \mathbf{x}_q \\ \mathbf{e}_q + \mathbf{v}_q - 3\omega_l \mathbf{x}_d \end{bmatrix} \quad (7)$$

$$\begin{bmatrix} D_a \\ D_b \\ D_c \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \sin(\omega t) & \cos(\omega t) \\ \sin(\omega t - \frac{2\pi}{3}) & \cos(\omega t - \frac{2\pi}{3}) \\ \sin(\omega t + \frac{2\pi}{3}) & \cos(\omega t + \frac{2\pi}{3}) \end{bmatrix} \begin{bmatrix} D_d \\ D_q \end{bmatrix} \quad (8)$$

To obtain the duty ratios in the a–b–c frame coordinates, one can use the inverse matrix transformation, as expressed above form.

The phase locked loop measures the system frequency and provides the phase synchronous angle  $\theta$  (more precisely  $[\sin\theta, \cos\theta]$ ) for dq transformation block [23]. Very important and necessary feature of grid side converter control is the grid synchronization. The synchronization algorithm detects the phase angle of grid voltage to synchronize the delivered power. The purpose of this method is to synchronize the converter output current with the grid

implemented in synchronous dq reference frame, where a park transformation is used. The phase-locking of the system is sensed by adjusting the q-axis voltage to zero. A PI controller is used for this purpose. The grid angle is obtained by integration of the angular frequency. The grid angle is introduced in the park transform to calculate the dq voltage components.

The voltage source converter's control strategy consists of a base level and a quick inner current control loop that regulates AC currents. DC voltage control is used as the outside controller. Therefore, the DC voltage controller can provide the reference for active current. While the outer loop regulates the load's DC voltage, the inner loop controls power between the DC link and the grid. Figure 5 displays the overall control scheme.

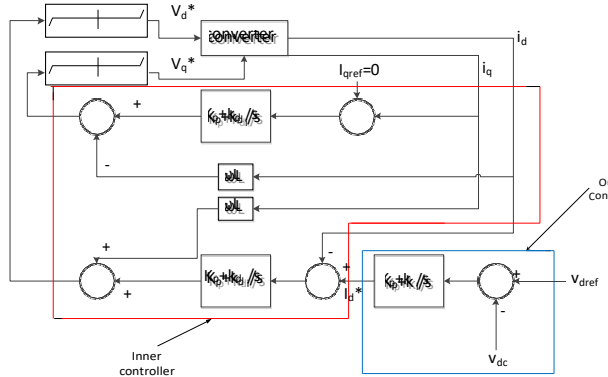


Fig. 5 Overall control strategy [17],[28]

The voltage source converter's overall control method is depicted in Figure 5. Current controller (inner current loop) receives the output of  $I_d^*$  from the output DC voltage regulator block (outside loop). Two PI regulators, one for the q axis and the other for the d axis, make up the inner controller in the figure. Active power flow or DC voltage level are controlled by active current ( $i_d$ ). Reactive power flow into the grid is managed using reactive current ( $i_q$ ), in a similar manner. The difference in inaccuracy between reference current and measured current is fed into the inner controller or current controller.

The PI regulator carries error, and feed-forward compensates for decoupling factors. As a result, the desired converter voltage is obtained in the dq reference frame. The feed-forward is used to mitigate the drawback of cascade control's delayed dynamic response. Because the inner loop variables' reference values are frequently accessible, they are fed forward for faster and safer operation. To achieve unity power factor functioning, the controller within the AC/DC converter manipulates the q axis current. The dq frame is considered to be rotating at a constant speed, and the d axis is oriented along the grid voltage vector. To achieve unity power factor, the value of  $i_q$  reference is set to zero.

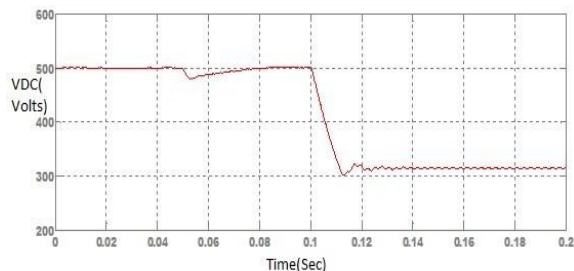


Fig. 6 DC bus voltage of uncontrolled charging

Figure 6 shows dc bus voltage of uncontrolled rectifier. As load increases the dc bus voltage drops considerably in uncontrolled rectifier. Ideally it should remain nearer to 500 volts. So before connecting EV batteries to grid this drop in voltage should be stabilized.

It is critical to stabilize the uncontrolled converter action prior to charging vehicle batteries. The load was kept on the AC bus, and after 150 milliseconds, when an additional load of 200 kW was applied on the DC bus side, the dynamic response of the DC regulator to this rapid load change was found to be satisfactory. Within 1.5 cycles, the DC voltage was restored to 500 V, and the power factor on the AC side remained close to unity. As a result, the system's stability was confirmed.

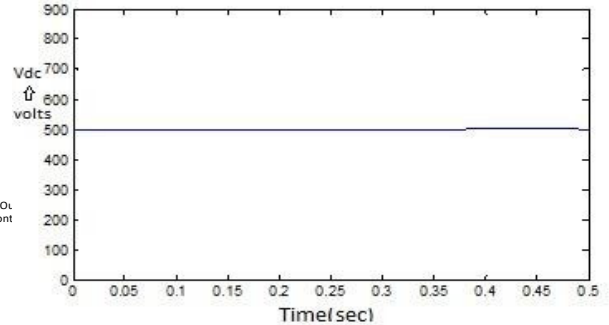


Fig. 7 Stabilised DC bus voltage

The stabilized DC bus voltage is shown in figure 7.

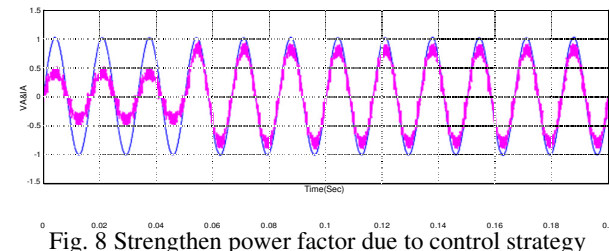


Fig. 8 Strengthen power factor due to control strategy

The figure 8 above depicts the change of source voltage and source current of one phase reading of controlled converter. A healthy power factor of 0.997 was established as a result of controlled converter operation. One of the considerations for considering a modified control technique was the current harmonics and the dc bus stability against disturbance.

Fuzzy control has emerged as one of the most fruitful areas of research in the application of fuzzy set theory in recent years [23]. Lotfi Zadeh (1965) developed the Fuzzy Logic tool, which is a mathematical technique for dealing with uncertainty. It provides a soft computing partnership, which is an important idea in word processing. It provides a method for dealing with imprecision. The fuzzy theory gives a means of encoding linguistic constructs like "many," "low," "medium," "often," and "few." Fuzzy logic, in general, provides an inference structure that supports suitable human reasoning capabilities. Fuzzy logic systems lend themselves well to approximate reasoning. Fuzzy logic systems respond faster and more smoothly than conventional systems, and their complexity is lower. Fuzzy control in water quality management, automatic train operations systems, automatic container crane operating systems, lift control, nuclear reactor control, car gearbox control, fuzzy memory devices, and fuzzy computers are recent applications in fuzzy systems [23].

In general, the input variables in a fuzzy control system are mapped by sets of membership functions similar to this, referred to as "fuzzy sets." Fuzzification is the process of transforming a sharp input value to a fuzzy value. Straight lines are used to create the simplest MFs. The simplest is triangular MF (triMF in fuzzy logic toolbox), which is described by three points forming a triangle. It is easier to apply for controller tuning applications than trapezoidal and other membership functions such as Gaussian and sigmoid. Fuzzy inference systems (FIS) have been used successfully in a wide range of domains, including automatic control, data classification, decision analysis, expert systems, and so on. The technique of mapping a given set of inputs to an output using fuzzy logic described by the fuzzy 'If-Then' rule database is known as fuzzy inference. Mapping serves as a foundation for making decisions. Fuzzy inference involves all factors such as MFs, fuzzy logic operators, and If-then procedures. There are two kinds of FIS that can be used. They are:

- 1 Mamdani-type
- 2 Sugeno-type

The way the outputs of these two types of inference systems differ. The Mamdani model, established by Ebrahim Mamdani in 1975, is the most often utilised methodology today. The output variable is described using fuzzy sets. A procedure known as defuzzification is employed to transform the fuzzy output to crisp form. Mamdani FIS is suitable for both MISO (Multiple Input Single Output) and MIMO (Multiple Input Multiple Output). Mamdani FIS has the advantage of being easier to read, but Sugeno FIS does not have an output membership function. There is no defuzzification; instead, a crisp outcome is generated by taking the weighted average of the rules. Sugeno FIS is applicable to MISO only. In hybrid controller design Mamdani FIS is selected where ease in Interpretability gains preference over Sugeno FIS.

PI controllers are utilized for inner control, and fuzzy logic control is created for the outer control loop. Fuzzy control has emerged as one of the most important and fruitful fields of research in the application of fuzzy set theory in recent years[24]. Lotfi Zadeh (1965) developed the Fuzzy Logic tool, which is a mathematical technique for dealing with uncertainty. Fuzzy logic systems lend themselves well to approximate reasoning. Fuzzy logic systems respond faster and more smoothly than conventional systems, and control complexity is lower [25]-[27]. Fuzzy control is based on fuzzy logic, which is a logical system that is considerably more similar to human thinking and natural language than traditional logical systems [24-26]. Fahid et al. [25] concluded that while proportional integrated derivative (PID) controllers are widely used in control applications, they perform poorly when applied to nonlinear systems because controller tuning is difficult due to a lack of knowledge of the system's parameters.

#### 4. Hybrid Control Algorithm

As an input, the inner controller or current controller takes the difference between the reference current and the measured current. The PI regulator carries the error, and feed-forward compensates for the decoupling terms. As a result, the desired converter voltage is obtained in the dq reference frame. The feed-forward is used to mitigate the drawback of cascade control's delayed dynamic response. As the reference values.

The impact of electrical car penetration on the grid has been observed by replacing the outer controller with fuzzy logic.

The inner controller is the same as in the prior situation, and it is based on the vector control technique idea. When compared to the PI controller, the fuzzy controller performed better. It eliminated the disadvantage of retuning controllers when the system load changed abruptly and dynamically. The fuzzy-based DC voltage controller is depicted in Figure 9. Figure 10 depicts the fuzzy logic controller created in MATLAB Simulink. When working with a fuzzy logic controller, fuzzy rules with fuzzification and defuzzification should be highly precise.

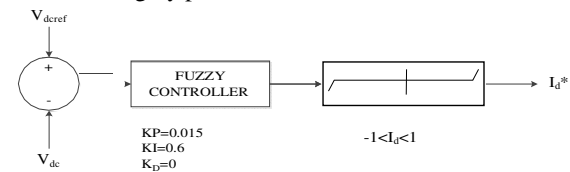


Fig. 9 Outer fuzzy based controller

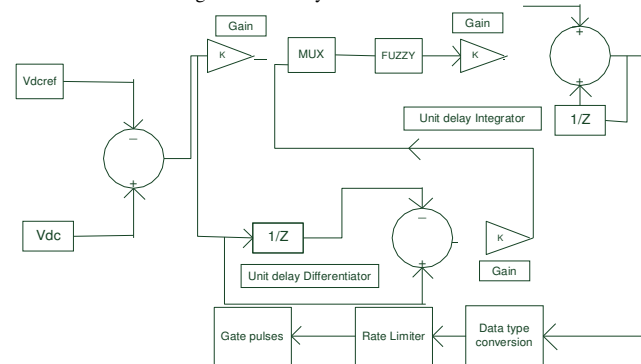


Fig. 10 Outer fuzzy hybrid controller MATLAB Configuration

Fuzzy controller gave a better performance compared to the PID controller. It reduces the drawback of retuning controllers when the system load is abruptly changing and dynamic in nature. Fuzzy surface for proposed fuzzy controller is shown in figure 11 and fuzzy contour in Figure 12.

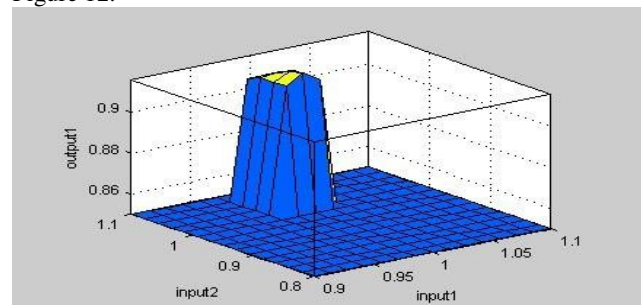


Fig. 11 Fuzzy surface for proposed fuzzy controller

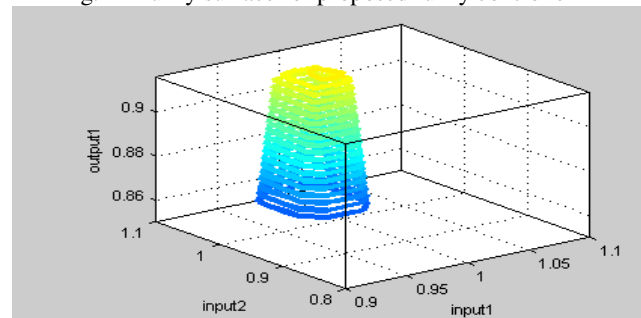


Fig. 12 Figure fuzzy contour for hybrid controller

#### 5. Results

Initially, simulation is performed on an unregulated rectifier. It is discovered that when the load increases, the terminal



voltage lowers and a significant amount of current harmonics is discovered. The same increase in load is simulated with hybrid control technique on 6.5Ah and 30Ah batteries, and constant dc bus voltage with unity power factor at source side is achieved with significant reduction in harmonics, and the results obtained with hybrid control technique are compared with PI control technique. The simulation results are summarized here. The results are given for various loading conditions on the distribution grid. The hybrid control technique eliminates tuning issues associated with the PI controller while also reducing harmonics.

**Table 2 Comparison of PI & Hybrid Control technique**

Parameters	Uncontrolled rectifier	Controlled Rectifier (with 1Mw load on AC side)			
		6.5 AH		30AH	
		PI	Hybrid	PI	Hybrid
Vdc(V)	270	490	490	490	490
Active Power (Watt)	$1.14 \times 10^6$	$1.6 \times 10^6$	$1.1 \times 10^6$	$1.6 \times 10^6$	$1.1 \times 10^6$
Reactive power (Var)	41829	1,58,898	1,10,701	1,56,901	1,04,001
Voltage harmonics	1.48%	0.14%	0.02%	0.14%	0.02%
Current harmonics	43.17%	5.58%	1.96%	3.78%	1.62%
Power factor		0.9976	0.9952	0.9974	0.9957

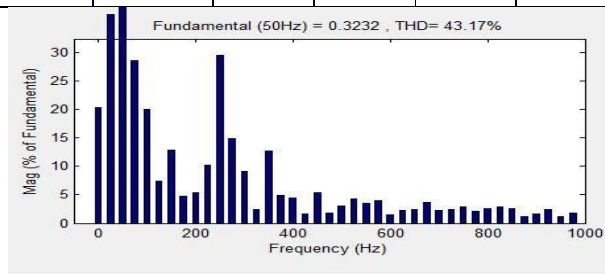


Figure 13 Uncontrolled rectifier with increase in current harmonics  
Fig. 13 shows considerable amount of current harmonics in the supply system due to uncontrolled rectifier.

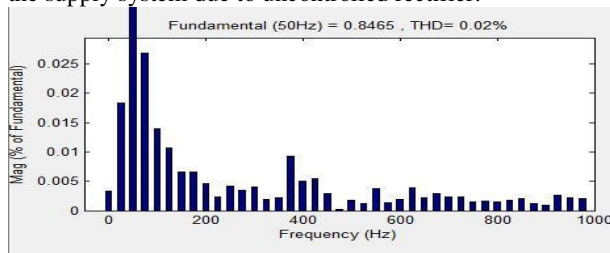


Fig. 14 controlled rectifier voltage harmonics with hybrid controller

Figure 14 shows that with hybrid control technique voltage harmonics are obtained within the standards.

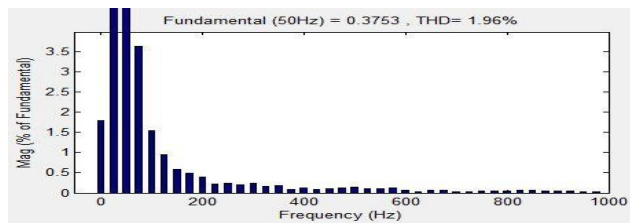


Fig. 15 controlled rectifier current harmonics with hybrid controller

Figure 15 shows that with proper selection of filter, dc bus capacitor and hybrid control technique harmonics are obtained within the standards

## 6. Solutions to EV Penetration

### 1 Under the correct policies, electric vehicles can aid in the integration of renewable energy sources.

At COP26, the Indian government unveiled its ambitious ambitions for the energy transition, promising to deploy 500 GW of renewable electricity generation capacity by 2030 and join the worldwide EV30@30 campaign. The campaign seeks for at least 30% of new vehicle sales to be made up of electric vehicles by 2030, while the renewables plan would treble India's renewable energy capacity. These two lofty goals are linked together. If complemented by a faster decarbonization of India's power sector, switching the nation's vehicle fleet from internal combustion engines to electric motors will reduce emissions even more. The electrification of transportation will also unleash a vast array of distributed energy resources, which, if properly piloted and managed, may help absorb excess solar and wind power, lower prices for consumers and utilities, and further encourage the adoption of EVs. Beyond encouraging EV sales, regulatory support for charging infrastructure and incentives for grid-friendly charging are crucial to realizing this potential. In particular, daytime charging is encouraged to take advantage of the copious solar production during the day.

### 2 The environment in India is favorable for EVs.

Electric vehicle adoption in India increased significantly in 2022, with sales of the vehicles tripling to 48 000 from 12 000 in 2021. The market share of two-wheelers increased to 7%, while the number of new electric three-wheelers sold, at 450 000, increased to 55% ahead from 350 000 in China. In Tamil Nadu, one of the biggest two- and three-wheeler factories is being constructed. The country's pace of EV deployment varies, with the biggest sales shares of EVs occurring in Delhi, Tripura, Assam, and Karnataka, states having pro-EV state policies. For instance, Delhi wants EV sales to account for 25% of all new car sales by 2024. Polluting vehicles are subject to restrictions, whereas EVs are exempt from road taxes and registration fees.

With financing increased to INR 100 billion (USD 1.2 billion), FAME's second phase began in April 2019, with over 85% of the funding going towards EV purchase incentives. Additionally, a component for the deployment of charging infrastructure was introduced as part of the scale up, accounting for 10% of the budget. The plan was extended to 2024 in 2021.

In August 2021, the government think tank NITI Aayog published Version 1 of its Handbook to Guide EV Charging Infrastructure in India, drawing even more attention to this issue. The manual will be updated throughout time with the goal of assisting authorities in the planning and implementation of charging infrastructure. In 2022, the

Indian Ministry of Power also issued updated rules and guidelines for infrastructure used for pricing. The number of publicly accessible chargers has increased dramatically over the past year, going from 900 in 2021 to around 11,000 in 2022.

### **3 Solar and EVs can complement one another.**

Scaling up solar PV and EVs might present electricity systems with both obstacles and opportunity. Large PV capacity might result in daytime excess generation availability, which can cause curtailment. As the sun is setting, the natural propensity for people to recharge their cars can considerably increase evening peak demands, straining grid resources and increasing the need for generating capacity, which may be supplied by fossil fuel generators. On the other hand, if EVs can be charged throughout the day using less expensive, cleaner electricity while also assisting in the integration of solar generation, these two technologies can complement one another.

### **4 Time of Use Tariffs**

One of the key strategies used to encourage EV charging habits that are good for the system right now is time of use pricing. Time of use rates encourage nighttime charging in India today, which lowers peak demand. The goal will be to move charging to the daytime when solar output is greatest as solar generation takes up more and more of the energy mix.

### **5 Dynamic charging is more important when it comes to distribution.**

Optimizing the EV charging pattern lowers operational costs by 29% and CO<sub>2</sub> emissions by 11%. This indicates real-time load adjustment that could be accomplished through dynamic rates. The equivalent operating cost savings between fixed and dynamic daytime charging suggests that the majority of system-level advantages of shifting EV demand into the daytime may still be realized, even if non-dynamic techniques do not take into account daily weather variations [21]. At the distribution level, where it can control regional peaks in demand or renewable energy supplies, dynamic charging may offer greater advantages. Dynamic rates can prevent charging demand from exceeding supply, which can happen with time of use tariffs, for example, during the day on a cloudy day. Locally, this effect might be more noticeable than systemically, where geographical smoothing is applied to both load and renewable energy supply. At the local level, the overlaps between EV and PV are crucial. Co-locating rooftop solar power generating with electric car charging offers the chance to lessen the effects of both technologies on the local grid. Dynamic charging can be used to help prevent grid congestion in areas where solar power and EV demand are physically further apart, and it could be important to take grid strengthening into account.

### **6 Peak supply can be effectively contributed by EVs**

Through vehicle-to-grid methods, additional advancements in EV fleet management and assurance of their active involvement in system balance and emissions reduction can be made. Vehicle-to-grid technology enables controlled EV charging and discharging and, with the proper tariff structure, can help to balance the power grid and lower EV owners' charging costs. EVs with vehicle-to-grid functionality have the potential to significantly improve the electricity system. Since each vehicle's battery may be charged and discharged to smooth out changes in demand or supply, they can effectively serve as distributed storage while also being able to meet peak demand and provide improved ancillary services.

Smart charging in India confronts comparable difficulties, but there are even more obstacles to enabling vehicle-to-grid EVs. Complex value chains, the necessity for reliable communication networks and grid-linking protocols, customer acceptability, and the requirement for measures to encourage the provision of ancillary services are a few of these.

### **7 In order for smart charging and the adoption of EVs to occur, policy support is crucial.**

In India, the focus of policy assistance for EVs has so far been on reducing car purchasing costs. Until EV prices reach a point where they can be competitive with conventional vehicles, this will continue to be a key area of focus in the near future. Support for cutting-edge business models, such "energy as a service" methods where battery owners lease rather than buy them, can further speed up adoption.

Future priorities will include further expansions of the infrastructure for charging. The advantages of daytime charging place a strong focus on having charging stations available in places like parking lots or offices where cars are likely to be parked during the day. A workplace pricing manual for corporations in Delhi was published in November 2021 by the Dialogue and Development Commission of Delhi and the World Resources Institute, India, as one example of how this is already gaining attention in some areas. The combined advantages of improving access to charging infrastructure and enabling daytime charging can be achieved by putting more effort into enabling work charging stations across India.

It would also be crucial to have more pricing options that can encourage system-friendly charges. The majority of Indian states offer some time-of-use prices, but they are typically only offered to commercial and industrial users, and given India's current cost-recovery frameworks, they do not encourage distribution corporations to pursue more sophisticated tariff options. In addition, the open access minimum load requirement has been lowered to permit the direct delivery of renewable energy to charging stations with a load of greater than 100 kW, and numerous states have already authorized specific EV charging tariffs across India. A crucial policy step to develop smart charging in India is to enhance the regulatory incentives for distribution businesses, for example through performance-based regulation. Given the quick growth of EV sales in India, it is necessary to design and put into practice these policy measures so that EVs and their capacity become a benefit rather than an additional burden for the country's power industry.

### **7. Drivers & Further Recommendations for Enhanced EV Penetration on Grid.**

1. India has thirteen of the world's top twenty most polluted cities. The low-carbon scenario with the 'highest' EV penetration is expected to result in a 50% reduction in PM 2.5 by 2035 (UNEP, DTU, and IIM-A).
2. Most Indian cities' master plans aim for 60-80 percent public transport ridership by 2025-2030 (Centre for Science and Environment).
3. Large-scale EV adoption will necessitate both demand-side incentives (e.g., tax breaks) and enhanced charging infrastructure, as well as integrated distribution Grid management planning. However, careful planning is required in terms of monitoring and controlling charging infrastructure,

as an unanticipated increase in EV penetration in a region can result in an increase in peak load on an already stressed distribution network.

4. Large-scale EV adoption will necessitate both demand-side incentives (e.g., tax breaks) and enhanced charging infrastructure, as well as integrated distribution Grid management planning.
5. EVs have the potential to act as distributed storage in the urban energy system, which could aid in the integration of intermittent renewables such as wind and solar, as well as feed the grid at peak times if price incentives are designed in the form of dynamic tariffs as part of Smart Grid implementation.
6. EV charging stations should be constructed with rooftop solar generation to reduce reliance on fossil fuels throughout the supply chain and shift towards sustainable energy.
7. Encourage EV manufacturers to create vehicles with swappable batteries, so that an EV owner can just go into a charging station, replace his battery with a fully charged battery, and then continue driving. The charging station may charge the batteries during off-peak hours at a lower electricity rate or directly from rooftop solar power.
8. Area-based integrated public transportation planning, EV promotion, and renewable generation with dynamic power pricing and Smart Grid tools for monitoring and control are all possibilities.
9. The utility will authorize the construction of charging points at houses for EV charging based on the distribution grid's available capacity in that location.
10. Identification of EV charging sites in an existing distribution network without changing the network's voltage profile.
11. Intelligent charging stations include fast chargers, timers, and the ability to convert to conventional charging mode based on real-time grid conditions/parameters.
12. Battery disposal/recycling rules published by the Ministry of Environment, Forest, and Climate Change (Batteries (Management and Handling) Rules, 2001) must be carefully observed to prevent negative environmental impacts of batteries.
13. Investment in research and development for future battery technologies results in batteries with substantially higher specific energy, are more environmentally friendly, and have lower costs. Because batteries account for half of the cost of EVs.
14. Local plans for electric vehicles, subsidies, dedicated parking and related incentives, use of information technology (IT) to find charging stations, partnership with private enterprises, and public car share and lease are other measures that may assist scale up EV in cities.

## 8. CONCLUSION

The paper has pointed out the concerns while charging of Vehicles on Indian distribution grid. It was very necessary to point out the various charging techniques and the distribution grid impacts while EV charging on distribution grid. Vector control technique with hybrid control algorithm can be useful for stability of distribution grid. Concept shown here will be very useful for fast DC charging of electric vehicle batteries. The solutions for massive penetration of EV on Indian power

grid given in the paper will be very useful for EV penetration along with Recommendation's and suggestions given in the paper.

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