Obstacles to Electric Vehicle Adoption in India and Proposed Remedies

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Funding: No specific funding was received for this work.

Potential competing interests: No potential competing interests to declare.

Abstract

The inductive approach focuses on analyzing the factors influencing Electric Vehicle (EV) adoption in India, while the deductive approach centers on understanding how these factors play out in developed nations and their applicability to developing countries. By iteratively applying the inductive-deductive approach, a taxonomy is developed categorizing these factors into micro-, macro-, and meso-level antecedents. This taxonomy serves as a framework for systematically organizing cohesive initiatives to promote EV adoption in developing nations, stressing the importance of tailoring these factors to the unique infrastructural, economic, and market conditions of such countries. One significant challenge hindering the adoption of EVs is the concern over their limited driving range. Recent proposals suggest the implementation of dynamic wireless charging, enabling power exchange between vehicles and the grid while in motion. This paper highlights the importance of optimizing EV routes requiring charging to maximize the utilization of Mobile Energy Disseminators (MEDs) functioning as mobile charging stations. The growing popularity of EVs has brought about a corresponding increase in challenges. Lengthy waiting times at charging stations present a major hurdle to widespread EV adoption. To address this, battery swapping stations (BSSs) offer an efficient solution, reducing wait times and promoting healthy recharging cycles for batteries. Additionally, these swapping stations create opportunities not only for EVs but also for power systems, providing regulation services to the grid, particularly beneficial for smaller networks like microgrid (MG) systems. This study delves into determining the optimal location and size of swap stations to maximize revenue within an MG system.

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I. Introduction

The transition to electric vehicles (EVs) plays a crucial role in tackling climate change and establishing sustainable transportation systems. In countries like India, where rapid economic growth is accompanied by a substantial transportation sector, embracing EVs holds significant importance [1]. Despite facing more acute pollution challenges, especially concerning urban air quality, many developing nations trail behind developed ones in promoting EVs, with China standing out as an exception. This disparity underscores the need for global collaboration to address environmental issues effectively. While problems like urban air pollution are primarily local, greenhouse gas (GHG) emissions affect the climate universally, regardless of their source. Therefore, involving developing countries in pollution reduction efforts, including EV adoption, is essential [2]. A key initial step toward advancing EVs in developing regions entails understanding the factors influencing EV adoption in those specific contexts.

However, numerous barriers and challenges hinder the widespread deployment of EVs in the country. Additionally, the integration of vehicle-to-grid (V2G) technology presents optimization opportunities to enhance the energy ecosystem [2]. This paper provides a comprehensive review of the barriers and challenges faced by EVs in India, while also exploring the potential of V2G optimization. By examining the infrastructure limitations, range anxiety, high initial costs, battery technology, and consumer awareness, as well as the benefits of grid integration, energy management, demand response, and renewable energy integration, this paper seeks to shed light on the current state of EVs in India and propose strategies for their successful integration [3]. India faces several barriers and challenges when it comes to the adoption of electric vehicles (EVs). An efficient approach to achieving high-speed DC fast charging at a reduced cost involves integrated EV charging. Integrated chargers utilize the EV's drivetrain components, such as power electronics, passive elements, and cooling systems, during parking for charging purposes. As these components are originally designed for high-power drive operations, they can be adapted for integrated AC level 1 charging, AC level 2 charging, or fast charging [4]. This integration has the potential to significantly decrease the costs associated with both on-board chargers and off-board charging stations by eliminating redundancy between the driving and charging systems. Intelligent vehicles are anticipated to play a role in a Vehicular Ad hoc NETwork (VANET), a mobile ad hoc network of cars designed to improve traffic safety and offer comfort applications to drivers. VANETs possess distinctive characteristics, including the high mobility of nodes, adherence to predefined routes by cars, messages from various applications with different priority levels, and operation in a high-interference, noisy environment [5]. Through on-board units, vehicles can communicate with each other and with roadside units (RSUs), enabling smart application solutions and contributing to enhanced road safety and traffic management. As outlined in various studies, such as, smart vehicles typically demonstrate five features: self-driving, safety driving, social driving, electric vehicles, and mobile applications.

Several integrated charger configurations have been developed using voltage source converter (VSC)-based AC/DC conversion [6]. Typically, these VSC-based topologies repurpose the EV's motor windings and drive inverter, utilizing them as the charger's input filter and VSC, respectively. While these configurations effectively repurpose drive components for charging, they may pose challenges to the design and operation of the drive system. In [7], dynamic reconfiguration of the drive motor windings is required to transition between charge mode and drive mode. A split winding motor is employed to avoid the need for reconfiguration. It's worth noting that using motor windings as input filters may also generate grid frequency torque in the vehicle during charging.

Firstly, infrastructure limitations pose a significant hurdle. The availability and accessibility of charging stations across the country are crucial for addressing range anxiety and facilitating the smooth operation of EVs [8]. Currently, the charging infrastructure in India is relatively limited, and the lack of standardized charging technologies and protocols creates interoperability issues [9]. The necessity for innovative electric vehicle charging approaches arises due to the lack of supporting infrastructure and challenges in adapting existing civil infrastructure, such as road networks. This adaptation should occur without requiring new, space-consuming, and environmentally unfriendly batteries [10]. Dynamic wireless charging, still in the research and development phase, is actively being explored by various companies. BMW, for instance, has demonstrated wireless charging with its i8 model, while Tesla has produced the Plugless Model S, enabling wireless inductive charging at home. Wireless charging has the potential to be a pivotal factor in surpassing the convenience of traditional gas cars for electric vehicles [11]. Early assessments, as seen in [12], suggest that even seemingly futuristic concepts in wireless charging may become reality sooner than expected.

Qualcomm's Wireless Electric Vehicle Charging (WEVC) technology, as introduced in [13], offers a straightforward solution for EV charging. Utilizing resonant magnetic induction, Qualcomm Halo WEVC facilitates energy transfer between a ground-based pad and a charging pad on the electric vehicle. While this technology suggests installing expensive charging pads on road surfaces, our proposed dynamic charging model utilizes ordinary city buses as mobile energy sources. To overcome this barrier, there is a need to rapidly expand the charging network and establish uniform standards for charging infrastructure, ensuring compatibility and ease of use for EV owners. Secondly, range anxiety is a prominent concern among potential EV buyers in India [14]. The limited driving range of early EV models and the sparse distribution of charging stations contribute to this apprehension. Improving battery technology to increase the driving range of EVs and developing a robust and widespread charging infrastructure are critical steps in alleviating range anxiety [15]. The introduction of fast-charging infrastructure and the implementation of innovative solutions like battery swapping can provide reassurance to EV owners by addressing their concerns about the availability and accessibility of charging options [16]. Educating consumers about the driving range capabilities of EVs and their suitability for various commuting needs can also play a crucial role in overcoming this challenge.

V2G (Vehicle-to-Grid) technology emerges as a promising solution to meet the ancillary service requirements of networks with high renewable energy penetration. However, the distributed and stochastic nature of V2G systems poses challenges in terms of control [17]. The Battery Swapping Station (BSS) streamlines and simplifies the entire V2G organization by eliminating the need for an aggregator to establish communication between electric vehicles and grid operators. Consequently, the BSS enables efficient provision of ancillary services by centrally managing multiple batteries. Furthermore, the significance of a BSS becomes particularly pronounced in small-scale networks relying on renewable energy, such as microgrids (MGs). These systems face difficulties in maintaining voltage stability amid fluctuations from renewable-based generation and ensuring high service quality [18]. In such scenarios, the BSS's contribution to meeting demand proves instrumental in adapting MG systems. The paper articulates an optimization problem incorporating various factors influencing system performance. It encompasses constraints related to both the Battery Swapping Station and battery levels, alongside constraints associated with optimal power flow (OPF). This holistic optimization approach enhances our comprehension of the system's performance.

II. Advocacy For Electric Vehicles

Literature discusses the diverse roles various entities play in advocating for Electric Vehicles, emphasizing their economic and environmentally friendly aspects, government nudges, and the establishment of charging infrastructure [19]. Initiatives promoting EV adoption can be classified as normative, encouraging people to choose EVs for environmental preservation, and saliency-based, underscoring their long-term cost-effectiveness and improved mileage due to battery technology advancements [20]. Successful nudges, including incentives, subsidies, and favorable policies, have proven effective in countries like China, Norway, and the USA [21]. Crucially, the development of suitable business models is pivotal for EV promotion [22]. Traditionally perceived as a niche product for the affluent and socially conscious segments, aligning EVs with economic models can tailor their market presence in developing countries like India [23].

The existing literature on the factors influencing Electric Vehicle adoption in developing countries is limited and lacks sufficient depth to yield valuable insights. Consequently, for this article, all selected papers, regardless of their focus on developing or developed nations, were utilized to extract insights into EV adoption patterns [24]. The study initially identified antecedents of EV adoption and subsequently examined their application dynamics and potential to drive EV adoption in developing countries. This analysis considered the unique circumstances of developing nations, such as low purchasing power, inefficient value chains, and a lack of technological capabilities [25]. While the identified antecedents may have universal relevance, the article discusses their application from the distinctive perspective of developing countries, encompassing economic, customer characteristics, technological capabilities, and infrastructural perspectives. For example, as detailed later in the article, business models like "economy-specific," "economy-multipurpose," "transportation-as-a-service (TaaS)," "battery leasing," and "battery swapping" are particularly suitable for developing countries where people's purchasing power is relatively low, and customer hesitation is prevalent.

III. Dynamic Charging And Portable Energy Distributors

The dynamic wireless charging system integrates vehicular communications and inductive power transfer (IPT) to facilitate efficient and real-time energy exchange between energy carriers and electric vehicles. This approach allows the vehicles to actively participate in the charging process. Through the IPT wireless method, a 10-minute charge can provide a driver with an energy boost ranging from 3 to 8 kWh of electric energy, equivalent to approximately 9 to 23 miles of travel distance. According to U.S. fuel economy estimates, 35 kWh of energy charging is equivalent to a travel distance of 100 miles. The 3 to 8 kWh energy charging requires a charging rate of 20 to 50 kW from the mobile charging stations [26]. This travel distance represents 30 to 78 percent of the average daily travel distance for drivers. In practical terms, this means that typical urban American drivers could cover 78 percent of their average daily travel of 23 miles with a 10-minute charge at a charging rate of 50 kW. European drivers would fare even better; a 10-minute charge with a charging rate of 50 kW under this wireless scenario would cover nearly two days of a typical European's driving habits, amounting to about 20 kilometers or 12.5 miles per day [27]. One of the primary barriers to EV adoption in India is the inadequate charging infrastructure. The availability and accessibility of charging stations across the country are crucial for addressing the range anxiety of EV owners [28]. Furthermore, the lack of standardized charging technologies and protocols hampers interoperability and creates confusion among consumers and charging infrastructure providers. Infrastructure limitations pose a significant barrier to the widespread adoption of electric vehicles (EVs) in India [29].

IV. Navigating Electric Vehicles Requiring Charging

The routing problem for Electric Vehicles can be represented using a directed weighted graph.

Consider G=(N, A), a weighted graph where N is a set of points (e.g., road intersections or Static Charging Stations (SCS)), and A={(i, j) | i, j ∈ N, i≠j} is a set of arcs connecting two points. Static Charging Stations are denoted as S={s0,…, sv}, and a set of dummy nodes representing possible multiple visits to the same station is denoted as S′={sm+1,…, sm+h}, such that S∪S′ ⊆ N.

Electric Vehicles can also receive energy from Mobile Energy Disseminators (MEDs) that follow a predefined cyclic route of MED points M={m0,…, mu}. Similar to SCS, a set of dummy nodes may represent possible multiple visits to the same MED point, defined as M′, such that M∪M′ ⊆ N. An EV can attach to a MED at any point in its route and start charging. Note that the charging rate of MED is always higher than the consumption rate. Similar to SCS, each MED point i has a waiting time wti, as an EV may need to wait until a MED is available or arrives. MEDs and SCSs intelligently accept/reject demands from EVs to minimize vehicle routes or distribute energy effectively, as defined by the communication system.

The objective is to route a set of EVs in the most efficient way, minimizing travel time. The problem is formulated as a multiple constrained shortest path problem. The binary decision variables indicating whether EV passed from point i to j and received energy from a MED from point i to j, respectively. The binary decision variables indicating the SCS where EV received energy and the MED point where EV attached to a MED, respectively. As the problem is a shortest path problem, it can be efficiently solved using several existing optimization algorithms (i.e., in polynomial time). In this study, we employ the well-known Dijkstra's algorithm to determine the shortest route, minimizing the travel time. However, the problem encompasses various constraints that require consideration. Simply applying Dijkstra's algorithm may lead to an infeasible route, where condition does not hold.

The proposed solution method revolves around the core concept of initially verifying whether the route computed by Dijkstra's algorithm satisfies, ensuring it has sufficient energy to reach the destination. If the route is deemed feasible, the EV should commence its journey without considering energy recharging. Otherwise, the EV must identify a point, either static or mobile, to recharge its battery, ensuring it has enough energy to reach the destination.

This concept presents various revenue opportunities. Electric utilities, for instance, might contemplate subsidizing the transformation of trucks and buses into Mobile Energy Disseminators (MEDs), establishing a scenario where the utility becomes a revenue-sharing partner with the MED owner. Governments at different levels, including state, local, and national, play crucial roles in formulating policies related to environmental impact mitigation, often utilizing analytical tools. In this context, governments may explore offering tax incentives to encourage the modification of trucks and buses into MEDs, thereby further promoting the popularity and adoption of Electric Vehicles.

Moreover, there are entrepreneurial advantages. The development and refinement of specialized software for the physical platooning of MEDs and EVs, along with managing appointment and billing logistics, will be essential. Manufacturers will be tasked with designing and constructing the magnetic subsystems that form the basis of the wireless charging systems.

V. Adaptation Of Antecedents For The Indian Context

The categorization of barriers in Electric Vehicle (EV) adoption models in India aligns with the taxonomic framework. An Indian study identified four factors contributing to barriers in EV adoption: 1) market barriers (e.g., vehicle servicing, testing and certification, consumer perceptions, and raw material for batteries), 2) technical barriers (battery efficiency, range, safety, charging time, and environmental impact), 3) policy barriers (taxation, subsidies, and tariff policies), and 4) infrastructural barriers (charging infrastructure, battery recycling, and dedicated lanes for EV). Several barriers in the technical (e.g., battery efficiency, charging time, safety, and environmental impact) and market categories (e.g., raw material for batteries, vehicle servicing, capital cost and financing, and testing) correspond to micro-level antecedents. Policy-related barriers can be seen as analogous to macro-level antecedents, while infrastructural barriers align with meso-level antecedents

Similarly, a study in Pakistan categorized barriers to EV promotion into technical (lack of EV expertise and charging system incompatibility), public acceptability (high-cost and business models), administrative (governance and marketing), regulatory structures (lack of policies), and financial (e.g., lack of subsidies and charging infrastructure development) issues. Once again, these barriers can be mapped to the taxonomic framework: "technical" and "public acceptability" barriers align with micro-level antecedents, "administrative" and "regulatory" barriers align with macro-level antecedents, and "financial" barriers align with meso-level antecedents (Table II). In summary, the taxonomic framework serves as a valuable tool for comprehending the barriers to EV promotion in India. The article introduces a taxonomy that categorizes Electric Vehicle (EV) promotion into micro-, macro-, and meso-levels in the context of India, accompanied by a discussion of the implications for EV value chains in developing countries. The need for this taxonomy arises from the diverse origins of EV antecedents found in various disciplines, such as social sciences (e.g., psychology of EV promotion), business and management (e.g., business models, value chains, and innovation management), technology (e.g., battery and components technologies), and policymaking (e.g., EV infrastructure development). This taxonomy plays a pivotal role in the identification, definition, classification, and organization of EV promotion antecedents, creating meaningful schemas for their systematic implementation. By structuring otherwise disparate antecedents, the taxonomy establishes meaningful connections among them. Without such a taxonomy, knowledge of EV promotion remains fragmented. The taxonomy serves as a framework for organizing the knowledge of antecedents, representing the initial step toward a deeper understanding of EV promotion antecedents, their interrelationships, and the coordination of systematic efforts for EV promotion.

VI. Optimal Placement Of Battery Swapping Stations

This study delves into determining the optimal location for maximizing the revenue of a Battery Swapping Station (BSS). To enhance income, the BSS optimizes its charging–discharging schedule by accounting for the daily variability in electricity costs. For effective optimization, it is imperative to set an upper limit on the charging–discharging power of the BSS. These limits are unique to each Microgrid (MG) bus. The study individually assesses the maximum load that the BSS imposes on each bus—these loads represent the highest values allowing optimal power flow without complications. To streamline the process, the additional load that the BSS can introduce during peak demand is calculated, serving as the maximum charging power of the BSS within a 1-hour timeframe. This is pivotal for the BSS to carry out its charging operations at the lowest cost. Figure 1 illustrates the maximum charging power of the Battery Swapping Station (BSS) for each bus.

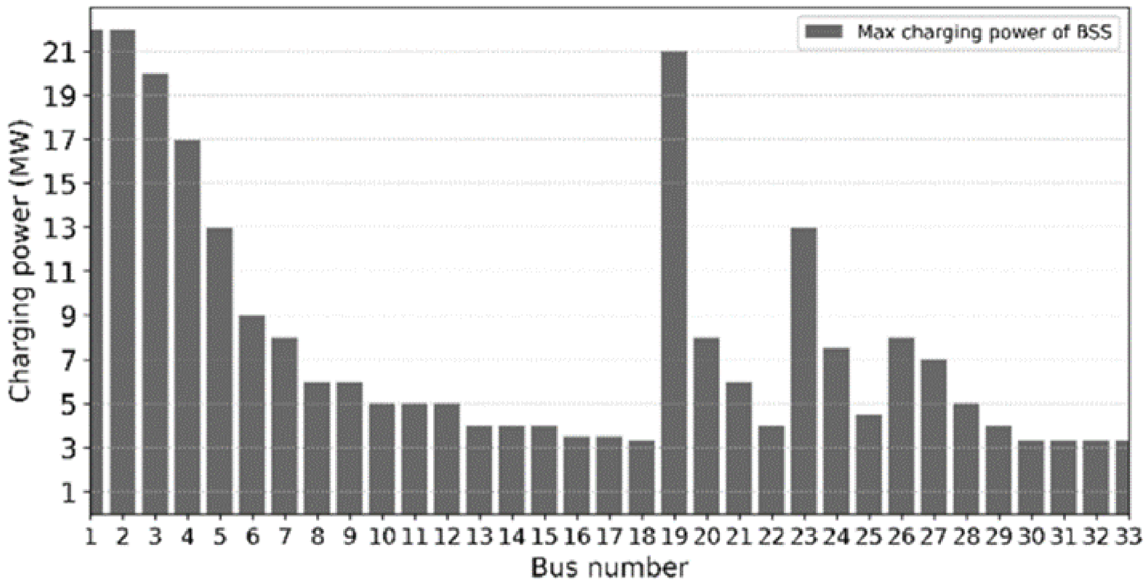

Figure 1. Maximum charging power of BSS

Equal income is assumed from swap operations across all buses, with the Battery Swapping Station mandated to fulfill identical swap demands for each bus. The daily operational cost of the BSS is calculated by deducting the regulatory income from the charging costs. In Figure 9, the daily operational cost of the optimized charging and regulatory operations of the BSS is depicted based on individual buses, without factoring in swap income. The graph clearly indicates that the lowest daily operating cost for the BSS is on bus 23. Despite not having the highest charging power, the BSS on bus 23 can provide more regulation services due to its advantageous location, a crucial factor in cost reduction. The daily operational cost of the BSS on bus 23 stands at 25560 Indian Rupees, making it the most economical. The second-lowest cost is observed on bus 24, totaling 24500 Indian Rupees. In contrast, buses 18, 30, 31, 32, and 33 incur the highest costs as their lower charging power limits their capacity for regulation services, resulting in a daily operational cost of approximately 35,000 Indian Rupees.

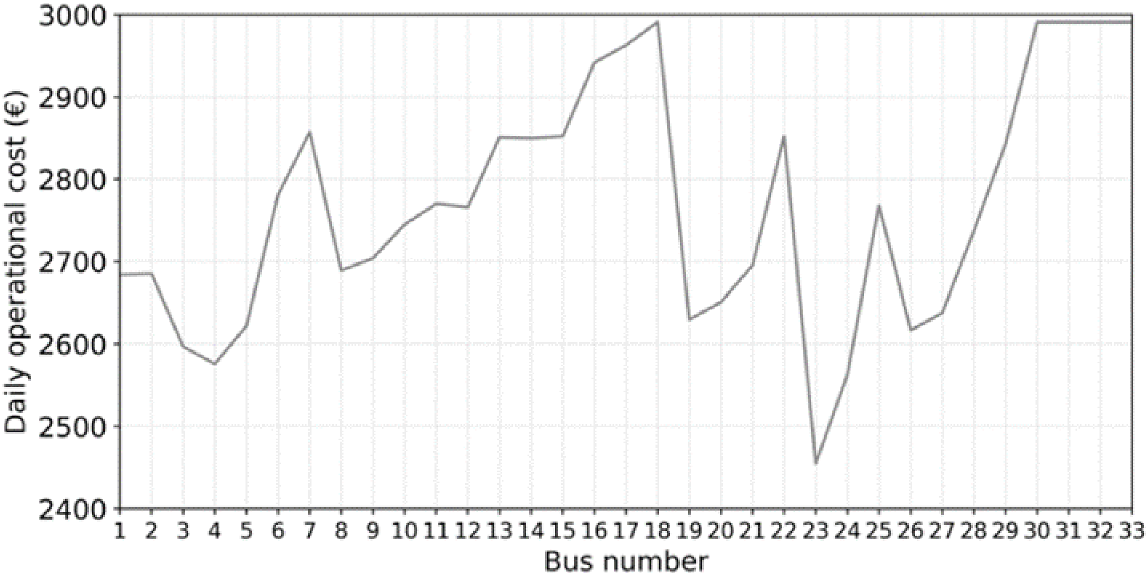

Figure 2. Operational Cost of BSS

VII. Conclusion

The antecedents identified in this article can be considered as "potential" antecedents, requiring empirical testing to enhance their generalizability. Subsequent research endeavors may investigate whether and how these antecedents stimulate Electric Vehicle promotion in India. Cross-sectional studies, such as surveys, may examine the validity of relationships between antecedents and EV promotion in developing countries with diverse economic and socioenvironmental contexts. Longitudinal studies, like case studies, could delve into the unfolding dynamics of these antecedents in resource-constrained settings within developing countries. Significant variations exist among countries categorized within developing economies. Additionally, the list of antecedents and their presented taxonomic levels in this article is not exhaustive, implying the potential existence of other antecedents and taxonomic levels. Utilizing an analytics-based model, the swap demand for a Battery Swapping Station serving Electric Buses operating in the Public Transportation Bus System in India is computed. Subsequently, the optimal charging–discharging schedule for the BSS is determined for various locations and sizes within the 33-bus microgrid. The optimization problem is meticulously formulated, encompassing constraints related to both the BSS and battery level, along with constraints associated with Optimal Power Flow. This formulation ensures a comprehensive optimization approach, considering multiple factors influencing the system's performance. Through the optimized 24-hour operation, the location and size where the BSS achieves maximum profit are identified. Furthermore, Return on Investment values for the investment are provided based on the daily income generated by the BSS from swap operations and regulation services.

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