# Feasibility and Cost/Benefit Analysis of Implementing Electric Vehicle in Iran Smart Distribution System

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**Abstract-** Air pollution has been recognized for years as one of main critical environmental issues in many countries. Using Electric Vehicle (EV) can effectively mitigate air pollution. On the other hand, if EVs are properly integrated to electric network can introduce some advantages in operation and management of power system. However the distribution system must have the required infrastructures to accept and manage charging and discharging lots of EVs. As the Advanced Metering Infrastructure (AMI) is currently implemented in Iran distribution system, the utilization of large number of EVs will be possible in this country. In this paper, a cost/benefit analysis for implementing EVs in Iran distribution system is carried out. Also, the suitable charging and discharging model for EVs that has interoperability with available AMI system is analyzed. For the economical analysis of the integration of EVs or Plug-in Hybrid Electric Vehicles (PHEV) in the distribution operation and market procedure, a case study is conducted on Iran power system with real data. The results show that the integration of EVs reduces the peak load and smooth the load profile. Moreover, the huge uncommitted generation capacity of system in off-peak hours is efficiently utilized.

**Keywords:** Smart Grid, Distribution system, Electric vehicle, AMI

## 1. Introduction

Electric vehicles (EV) have the potential to reduce carbon emissions as well as saving the oil resources. So, many governments around the world have started to support EVs roll-out in these days. However, the uncontrolled and unplanned integration of EVs to current power system may lead to undesirable issues.

Plug-in electric vehicles or PEVs refers to both plug in hybrid electric vehicles (PHEVs) and full electric vehicles (EVs). It is accepted that the future high penetration of EVs and plug-in PHEV in the power network and energy market will introduce an important additional energy demand, and therefore a new stress to the electricity producers, distributers and operators [1], [2].

The effect of EV charging on the distribution system losses has been studied in [3-4]. Also, an optimal EV fleet charging profile has been presented for minimizing the distribution system power losses in [3]. For even smaller sized networks, authors in [5] and [6] emphasized on the integration of EVs at the distribution transformer level serving a few houses and proposed household load control strategies to tackle the transformer overloading problem.

Over 3,000 charge points have been installed in the UK to the end of March 2012. This figure includes publically accessible, domestic and private workplace charge points. 1,673 have been delivered through the Plugged-In Places program, of which sixty per cent are publically accessible [7].

Currently, in Iran, the market of plug-in electric vehicles is not active and consumers have not started to purchase these cars at large scale. So, we are not facing with challenges like control and managing them. However, in the near future, upon this production be commercialized, the power system will experience new loads for which the power system planner should design electrical system based on their characteristics. A study by the Iran Energy Efficiency Organization (IEEO-SABA) found a significant potential

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market for PHEVs, depending on vehicle cost and the future cost of petroleum. Furthermore, several researchers have noted that by adding “vehicle-to-grid” (V2G) capability, where the vehicle can discharge as well as charge, PHEV owners may also receive substantial revenue by using the stored energy in their vehicles to provide high-value electric system services such as regulation, spinning reserve, and peaking capacity.

Transportation sector is one of the major sources of emission in Iran and the share of this sector in urban air pollution in the big cities of Iran especially Tehran (Capital of Iran) is more than 80%. Air pollution in Tehran and other big cities of Iran has been one of the main environmental problems, and health of citizens has faced serious dangers as the air pollution becomes critical. The pollution damages in Tehran are categorized as:

- Harming human health
- Acid rain which damages buildings, monuments, cars, and vegetations surfaces
- Closing schools and shut down the factories which damages economy

As a result, decarbonizes the transportation sector of Iran's cities can effectively mitigate the air pollution and indirectly reduces the damage costs of Air pollution.

The rest of the paper is organized as follows. Section 2 looks at benefit of utilizing EVs. In Section 3, the advanced metering infrastructure system that is projected in Iran is introduced. Section 4 describes the charging strategies of EVs. The case study is analyzed in Section 5 and finally the concluding remarks come in Section 6.

## 2. Achieving full benefit of EVs

The goal of integration of EVs to power grid should be investigated in two main aspects. Firstly, the effect of EVs on emission reduction and fossil fuel conservation should be studied and next, the effect of EVs charging and discharging on electric network control and management should be analyzed. These two aspects are described in this section.

### 2.1 Emission reduction

To estimate the Green House Gas (GHG) impacts of electric vehicle, we should consider emissions that result from fuel combustion at power plants, upstream fuel production and the share of electricity lost in transmission and distribution. As a matter of fact the primary source of electricity in power plant is the key difference between EVs emissions in different countries. For example, in countries with high penetration of renewable generations in their power systems, the electricity which is delivered to electric cars is generated with low carbon emissions. So, in these countries the pertain emissions of EVs is lower than that of conventional cars.

The studies shows that in countries where their power generation is coal dominated, the electric vehicles have the emission equal to average petrol cars. On the other hand, in countries with low carbon power plant and renewable generation the related electric vehicle emission is less than half the emissions of the best petrol cars. Comparing the same electric vehicle in different power systems, the studies shows that EVs’ carbon emissions are four times greater in power systems with coal dominated power plant than in countries with low carbon power generation [8].

Due to the dominant share of coal generation in India, South Africa, Australia, Indonesia and China, grid powered electric cars produce emissions comparable to normal petrol vehicles. With emissions ranging from 370-258 g CO2e/km electric cars generate significant emissions, many multiples of those using low carbon sources. In these countries electric vehicles will have limited climate benefit [8].

As a result, to activate the carbon emission reduction benefit of EVs, the electricity consumed in these loads should be supplied by low carbon power plant as well as renewable generation.

### 2.2 load management and V2G

From power system point of view, the electric vehicles are considered as a load that randomly connect to the network and are energized. So the power system operators should consider these loads in their long and short term operational planning. In long term generation and transmission planning, the system planner predicts the EVs load in future and calculates the extra generation and transmission capacity to be installed to satisfy the predicted load. In a day-ahead generation and consumption scheduling, these loads should also be summed with other electricity loads. Thus, the EVs increase the electricity demand.

However, with emerging new technology that can help the power system to manage their consumption and utilize Demand Response (DR) program, system operators can manage the charging time of EVs to control the demand in peak hours. With charging the EVs in off-peak hours, the power system can easily supply these loads without any generation expansion or transmission or distribution stress. In fact, the main problem of high penetration of EVs is their charging time simultaneity especially in peak hours in which the power system works at their operational levels. Therefore, in order to manage and control the effects of EVs on electric power grid, the demand response programs integrated with EVs charging program are the best solution.

Moreover, EVs can be connected to the grid as a producer and deliver their reserved electricity to grid. This feature is known as Vehicle to Grid (V2G) option. In this case, the operator can manage EVs connection like other energy storage technology to operate the system efficiently.

With a progressively smarter grid, operators get more detailed information about supply and demand as well as state of connected equipment to grid like EVs. These communication and information technologies improve system operators' ability to manage the electricity network and shift EVs charging to off-peak times. Also, when system needs electricity, the operator can offer to EVs owners connecting their cars to grid and buy electricity form them. Consumers are offered far more information about, and control over, their charge and discharge state and benefits, helping reduce overall demand and providing a tool for consumers to reduce cost and carbon emissions.

Another important smart grid development is the “Vehicle to Grid” concept whereby energy from the grid can flow into batteries within PEVs to be stored and then can be extracted and put back into the grid for use at a later time. This could also provide financial incentives for consumers, making an attractive business case for PEV owners.

## 3. Iran AMI system Architecture

Deploying an Advanced Metering Infrastructure (AMI) is an essential early step to grid modernization. AMI is not a single technology but it is an integration of many technologies such as smart meter, communication network and management system that provides an intelligent connection between consumers and system operators. AMI gives system operator and consumers the information they need to make smart decisions, and also the ability to execute those decisions that they are not currently able to do.

Iran Energy Efficiency Organization (IEEO) is responsible for implementation and deployment of Smart Metering project (that is called FAHAM) in Iran [9]. The IEEO follows promoting energy efficiency and load management, improve system reliability, and reduce operational costs by implementing smart metering project. AMI can also be used for EVs management. In this section the architecture of Iran's AMI system is described and its role in EVs integration to distribution system is investigated.

### 3.1 FAHAM system Architecture

In this project the smart meters will be installed for about one million costumers and the communication infrastructures for data exchange will also be implemented. The simple structure of communication system in FAHAM project is shown in Fig. 1 which consists of:

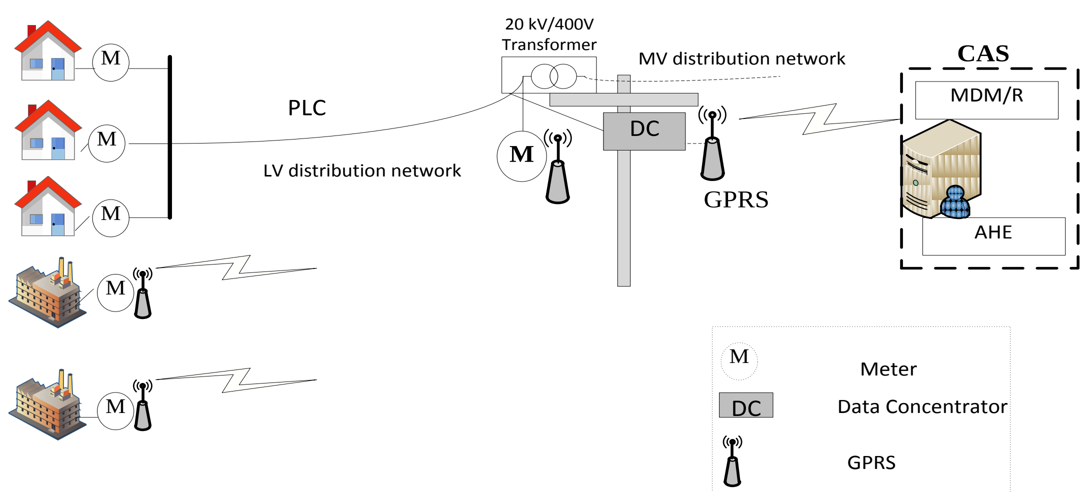


Fig.1 The communication architecture of FAHAM project

- **Smart meters** with PLC communications, installed at the customer premises. They may be single phase or three phase smart meters. Electricity meter provides various information for customers such as amount of consumption (kWh, kVAr), consumption parameters (voltage and current), equipment status and last information of water and gas meters.
- **Communication interface:** Power Line communication (PLC) and General packet radio service (GPRS) are two communication interfaces that connect two different parts of FAHAM subsystem together.

- **Data concentrators** installed in 20kV/400V transformer to manage all smart meters "measured data" from such installations. Data concentrators integrate PLC communications that exchange information with smart meters to communicate with central meter data management systems.
- **Central Access Systems (CAS)**, mainly Meter Data Management systems. CAS is responsible for the management of all information and data related to smart metering, as well as the configuration, control and operation of all system components. The CAS in order to manage the FAHAM network shall have 2 following parts: 1) AMI Head End (AHE) that has the responsibility to manage the configuration, Wide Area Network (WAN) and Local Area Network (LAN) management system, managing the equipments in the network, registration of equipments and operation & maintenance of filed equipments in the network. 2) MDM/R shall manage and archive the acquired data from the AHE.
- **Legacy Systems** are the existing commercial or technical systems that manage the business processes of the utility. Volt/VAr control is one of the legacy systems that include an optimization program to regulate the distribution nodes voltage using the received data from CAS.

### 3.2 Integration EVs to FAHAM

Iran's AMI system has been designed for multiple purposes such as automated reading meter and billing system, demand response programs, and managing customers' distributed generations. So, for the purpose of integration of EVs to distribution systems, This AMI system can help in the following cases:

- Read the electric vehicle energy consumption data and send it to central access system
- Transfer commands and real time price of electricity to home or charging station
- Display the information about low cost time for charge and good time for discharging in some customers' gadgets like cell phone, computer or In Home Display (IHD).
- Consider EVs management software within legacy systems and keep coordination between this software and other information system such as demand side management, voltage control optimization, Geographical Information System (GIS) and Customer Information System (CIS).
- Deliver the EVs State of Charge (SOC) data to EVs management software and send the output scheduling results of this software to customers.

It is worth noting that in order to fully manage and control all EVs, some equipment like special sensor or meter for measuring charge and discharge state of each EV are necessary to be added to FAHAM AMI system.

## 4. EV charge and discharge measuring and control approaches

In this section the charging strategies in a conventional and modern powers system are investigated in 3 cases:

Case I: charging without any infrastructures and measurement

In this case, the electric vehicles can connect to every electricity plug for charging. But some problems can occur in this case. First, the EVs electricity consumption cannot be measured, and EVs owner cannot use other people or organization electricity for charging. On the other hand, the system operator cannot predict the EVs demand and their randomly charging procedure may lead to some operational problem through the system. Moreover, the V2G option is not activate in this case due to uncontrolled and unmeasured features of this method.

Case II: charging with credit card

Similar to banking procedure in which a customer can use the automated teller machines (ATMs) of any bank, the EVs owners could use multiple charging points regardless of the supplier. In this case, each EV has an electronic credit card that can use in every electricity available plugs equipped with cart reader machine. Fig. 2 shows a credit card capable electric vehicle charging station with monitoring and reporting features [10].


Fig. 2 charging station with credit card [10]

The charging stations will be located near the rear of the plaza parking lots – generally behind the service-plaza buildings. Customers will pay at the charging station with a credit card. In this case, the system operator can use the data of EVs charging to mange and schedule for this load.

Case III: Using an Identification chip

Surveys have shown that about 80% of charging would need to be done at home, since most drivers could not take the time to fill their batteries at a station. So the home's wiring should be checked out. In this case, we propose an identification chip to install in EVs while an EV connects to an electricity plug, this chip sends a signal to smart meter. As soon as smart meter recognizes an EV connection, sends its charging and discharging data to central access system.

For advanced features, the identification of the vehicle itself at the charging spot is required, which is typically realized via Power Line Communication (PLC). In these cases, a variety of data, including vehicle identification, current battery status, maximum allowed charge current and number of phases, charging times (e.g. delayed charging start), and overall 'charged' electricity amount with associated costs are exchanged. The identification of the car in the network opens up a cross utility provider usage of the electricity, similar like roaming in a mobile phone network. However, this brings up one of the most important requirements: every car has to work with every charging spot. So, the standardization does not only apply to the used plug standard, but also to the method of communication of the car with the charging infrastructure. The PLC is a well suited choice as the connection cable is needed anyway for charging.

## 5. Case Study

We developed three future vehicle-charging scenarios for cost benefit analysis. This analysis used data from a variety of public sources; along with proprietary system data from IEEO. The planning horizon is considered to be up to 2025 when vehicles were predicted as being 10% of total available cars. The electric vehicles electricity demand in 2025 is predicted as 6000 MW. The total peak demand of Iran's power system without EVs load is considered 75000 MW. The required installation of establishing electrical network to deliver 1kW electricity to consumer in distribution end node is given in Table 1. According to this data, the cost of this installation to prepare 1 kW electricity in distribution is estimated 1500 $/kW.

The three scenarios and their analysis results are given as follows:

**Scenario 1: Just generation capacity planning**

In this scenario, it is supposed that the EVs will be integrated to power system without any scheduling. It means the power system planner will just plan to install new capacity to supply EVs demand in 2025. So the power system needs to install 6000MW new generation capacity only for EVs. As shown in Table 1, the related capital installation cost of delivering this amount of electricity to EVs owner should be considered. The capital cost of required installation for supply 6000MW EVs demand is $9 billion.

Table 1 Required installation of establishing electrical network to deliver 1kW electricity

| **Installation** | **Capacity** |
|---|---|
| Generation capacity | 1.54 kW |
| 400&230 kV transmission line | 1.13 km |
| 132&63 kV sub-transmission network | 1.58 km |
| 400&230 kV transmission substation capacity | 2.7 MVA |
| 132&63/20 kV sub-transmission substation capacity | 2.6 MVA |
| 20/0.4 kV distribution transformer capacity | 2.8 MVA |

**Scenario 2: Charging at off-peak hours**

In this scenario, the power system operator is able to manage and control the charging procedure of EVs. Also it is assumed that the AMI system has completely been implemented. So, the operator can plan to charge some of EVs in off-peak hours. It is supposed, in this case, 30% of EVs charged in peak hours and need generation and transmission expansion capacity and 70% of EVs will charge in off peak hours. In Iran power system, there is considerable uncommitted genration capacity in off peak hours, so use of this capacity for charging EVs will help system to operate efficiently. The required measuring and communicating instruments that should be integrated to AMI system is a PLC modem. The cost of PLC modem for each charging plug is $150. The investment cost for this scenario is calculated as $2.7 billion for generation expansion and $450 million for required controlling and monitoring system. Thus the investment cost of this scenario is $3.15 billion.

**Scenario 3: Demand response and V2G option**

In this scenario, the discharging EVs energy to grid is activated. Also it is supposed that the AMI system has completely been implemented, and the electrical network has the capability of measuring and control of EVs discharging energy. That means the EVs owner can use this option and charge their vehicles in period that the electricity price is low and discharge the EVs battery energy in period in which the electricity price is high. In this scenario, the operator can use the uncommitted generation capacity to supply EVs in off peak hours and use the V2G option to create new generation capacity in peak hours. According to Iran's AMI system architecture and features, this scenario will just require a PLC modem integrated with a plug to have this scenario infrastructure requirement. The PLC model and other related equipment is $150. So, for 3 million electric vehicles which connect to distribution system, the 3 million PLC model are required. The total cost of required infrastructure for this scenario is $450 million. Moreover, in this scenario, the EVs discharging option can increase generation capacity especially in peak hours, and as a result, the generation and transmission expansion will be postponed. With considering one-fourth of EVs capacity for discharge, the 1500 MW generation will be provided which it cause $2.25 billion investment cost saving.

To sum up the above, the results associated with aforementioned three scenarios are given in Table 2.

Table 2 Results of 3 scenarios

| | Scenario description | Investment cost | Benefit |
|---|---|---|---|
| **1** | Uncontrolled EVs charging | $9 billion | - |
| **2** | Controlled EVs Charging and use Off peak hour charge | $3.15 billion | Use uncommitted generation units, improve efficiency |
| **3** | Controlled EVs charging and V2G option | $450 million | Postpone generation expansion, use uncommitted generation units, improve efficiency and reliability |

## 6. Conclusion

The use of EVs would represent a significant potential shift in the use of electricity and the operation of electric power systems. Electrification of the transportation sector could increase generation capacity and transmission and distribution (T&D) requirements, especially if vehicles are charged during periods of high demand. Other concerns include emissions impacts including regulated emissions (NOX and SO2) and currently unregulated greenhouse gas emissions. Utilities are interested in the net costs associated with this potential new load, including possible benefits of improved system utilization enabled by controlled EVs charging. The results show that using conventional technology to ensure that the grid is able to meet future energy needs has been projected to cost $9 billion, but this could be reduced by around $2.7 billion with the use AMI technology options and EVs management programs. Also, with using AMI system and activate smart grid technology like V2G option and demand response, the power system can accept EVs demand without any generation expansion and $450 million investment cost.

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