POET Structured energy management and efficiency improvement of a grid-integrated electric vehicle energy Charging Stations

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Abstract. Sustainable energy supply plays a pivotal role in the successful deployment of electric vehicle charging station (EVCS). The EVCS’s daily operation is governed by the availability of resources to meet the energy requirements without any load rejection. Developing countries have now turned to renewable energy powered vehicles to reduce their dependency on fossil fuels. They have been successful in their attempts to deploy EVCS in their respective countries whilst constantly working on the improvement of this infrastructure. However, the same cannot be uttered in South Africa. The county has limited power-generating capacity, which limits its capability of fully sustaining the existing load. An additional burden on the already ailing grid could have dire consequences on the local grid. Load shedding is imposed on customers as a temporary solution in order to avoid imminent blackouts. Conversely the ever increasing fossil fuel prices threatens the livelihood of an ordinary citizen. As an increase in this resources leads to an increase in transportation cost and food prices. To combat this problems, an efficient, sustainable and cost effective electric vehicle charging station that will be beneficial to the grid as well as the environment is necessary. POET (performance, operation, equipment and technology) energy efficiency improvement and management framework is utilized as an effort to analyse and initiate a feasibility and sustainability of the system to be implemented, by holistically looking at the performance, operation, equipment as well as technology. The afore mention POET energy efficiency improvement and management will look into the two of the three processes, namely targeting and planning in fourth level: An engineering level as an attempt to improve the efficiency and economical nobility of the system. A review in to the impact of technological advancement, of the proposed grid-integrated hybrid peer to peer electric vehicle energy sharing at a Charging Station in South Africa will be conducted.

1. Introduction

The energy crisis in South Africa requires urgent reliable, sustainable and cost effective solutions with minimal impact to the local grid as well as the environment. The country’s economic development relies heavily on availability of electrical energy and affordable transportation of goods and people. Contrarily power outages as well as increments on the fuel prices affects the economic stability of the country. Electric vehicles could very well be a viable option for the country’s economic emancipation. The EV’s popularity is on the rise around the globe, and this present trend suggest the likelihood of their dominance in the near future [1-4]. Their introduction was aimed at reducing the world’s dependency on fossil fuel and decrease external costs of road transport. However, their charging strategies as well as charging options restrict their popularity in South Africa [5-6]. EVCS could play a significant role in the popularization, reduction of carbon emission and the country’s reliance on the imported fossil fuels. The afore mentioned paradigm highly depends upon various factors such as energy security, resource availability, infrastructural design, energy management, charging schemes, charging cost as well as reasonable profit margins of running the station [7]. The high volume of EV penetration as well as un-
coordinated charging could threaten the stability of the local grid. This can lead to a disruptive impact on the current power distribution systems and in particular, its substantial impacts in building power energy systems [8-9]. Attempts to eliminate the use of the grid was presented in numerous research studies. Stand-alone renewable energy charging stations became a popular choice amongst fellow researchers. However, the variability of the resources offered limited solution such as coordinated charging schemes and which constituted limited activities at the stations. The next attempt was an introduction of battery energy storage system (BESS), although the BESS offered a quick response time for re-charging and were well suited for renewables application [1,8], they increase the overall system and operating costs. Furthermore, constant charging and discharging of these battery banks reduced their life expectancy in the station [7, 10-11]. Grid integrated renewable energy charging station presented new possibilities in the charging station, they are seen as a practice of developing efficient and cost effective solutions to variable renewable energy sources and the burden previously placed on the battery banks [12]. A proper energy management is necessary to improve the efficiency of the charging station without compromising the stability of the local grid as well the quality of power supply. The energy management and overall system efficiency improvement will be formulated according to POET structured framework. POET framework has been used previously with great success to diagnose the most energy management activities and identify further energy improvement opportunities in numerous system such as buildings, haul train, conveyer belts etc. [13-15]. Xia and Zhang defined each acronym in POET according to their intended function in the system. They used deterministic indicators to measure the performance efficiency of a system, such as the cost, energy resources and environmental aspects. The physical aspects such as time and human coordination is utilized as a measure to evaluate the proper coordination of different system components in operation efficiency whilst the equipment efficiency is said to be the measure and evaluation of energy output of the individual technologically advanced equipment in a system. The last acronym in POET was defined as a measure of energy efficiency governed by conservation laws, this part evaluates the feasibility and life span of the system. In this study the same framework will be employed to manage the systems energy and also improve the overall efficiency of the charging station.

2. POET structured performance and operation in the charging station

There are several operational electric vehicle-charging stations around the globe in use presently. Their performance depends upon various factors such as resource availability, infrastructural design, accessibility, energy management, charging schemes and environmental as well as financial implications. This section of the study will investigate what other researchers have accomplished concerning the performance of EVCS to address the aforementioned factors.

2.1. Resource availability.

The dawn of industrialization and efforts of transforming the world into a global village has seen an increase in the energy requirements. Sustainable development are necessary to meet this future energy requirement without compromising the stability of the power system [16-17]. There are numerous factors known to have popularized the growth of renewable energy technologies, those factors include but not limited to the following: energy security, economic impacts and carbon dioxide emission reduction [18].

2.1.1. Resource variability

The uncertainty and variability of renewable energy resources such as wind and solar generation can pose challenges for grid operators. The fluctuating nature of these resources makes it difficult to sustain a balance between the supply and demand. This variability in the resources impose an implementation of additional measures to balance the system. Knowledge of this variability is important for improving the design of a system (by adding properly sized storage capabilities, for instance) and understanding the performance of a system [19-21].
2.1.2. Energy security
Uninterrupted provision of vital energy services and energy security is a high priority of every nation. Energy supply uncertainties forms a basic part in drafting energy policies. These concerns relates to the integrity of the infrastructure its ability to meet the country’s energy demand without any load rejection, compromising the stability of the grid, energy security as well as its affordability [22]. The continuous provision of reliable, affordable energy has many aspects. Renewable energy eliminates the possibility of grid vulnerability, the use of hazardous substance to the environment as well as the need to Import fossil fuels. Abundances of resources, well-developed infrastructures and cheaper exports translate to energy security [23].

2.1.3. Energy costs
Electricity is the fastest-growing final form of energy, and yet despite its increasing relevance to de-carbonization efforts, the future composition of the power sector remains uncertain. Policy makers work relentlessly to ensure clean, sustainable, reliable and affordable energy. Over the past 10 years in first world countries, the declining renewable energy costs, stringent emissions standards, low-priced natural gas, competitive electricity markets, and a host of technological innovations changed the landscape of an industry that was static for decades [24-25].

In developing countries, the structure of the electricity industry of generation, delivery, and use of electricity over the past century has evolved significantly. Their framework encourages power utilities to use sustainable and technological advancement to generate energy. They have also implemented policies to drive down energy prices. Competitive procurement is vastly encouraged amongst power giants [25-26].

2.2. Infrastructural designs of an EVCS.
Electric vehicle charging station is defined as an infrastcture that houses charging points for electric vehicles. The station is usually equipped with special connectors that conforms to a variety of charging connector standards, which correlates to charging times, modes as well as levels. Some of the advanced station have additional feature such as a light indicator to indicate charging status (initiation, progress and sometimes ending). Whilst some have additional features such as energy meters, electronic payment system, card-controlled access system as well as an Internet access. There are various types of EVCS, which differ based on communication capabilities and how quickly they can charge a vehicle. EVCS can be installed at homes, workplaces, private fleet facilities, and public stations [27-28].

2.2.1 Overview of EVCS.
In stand-alone station resource availability is critical, and a reliable energy storage. Most of the work done on these type of stations focuses on optimization, energy storage, coordinated charging as well as battery swapping [29-34]. In grid-integrated stations, more is achievable as this stations offer a more attractive charging scheme. A proper energy management system as well a control and optimization scheme provides an effective charging. Battery banks retains a longer life span when used in conjunction with the grid at night and during unfavorable weather conditions. Other researchers provided a coordinated charging algorithm, whilst some utilized this station to offer fast charging [35-45].

Designing an electricity-charging scheme that takes the parameters of both the charging stations and the EVs into consideration is essential. The four charging schemes documented in numerous research according to their class are uncontrolled, indirectly controlled, as well as smart and bidirectional charging. Uncontrolled charging schemes addresses the random charging and its associated issues to the grid. Indirectly charging responds to challenges associated with uncontrolled by intruding an indirectly controlled, not as a charging restriction mode but as a guidance to the EV users. A smart charging, bi directional and peer-peer charging scheme as a framework that provides the EV user with optimal energy trading solution [46-49].
2.3. Charging modes in the electric vehicle charging station

Level 1 charging dubbed as a private charging is well suited for home and workplace charging as minimal components are required for this application. Level 2 charging is a semi-public well suited for home and workplace charging with an additional component (in cable control box). Level 3 known as smart charging is the most adequate form of charging at the station, whereby the charging capacity is done through communication between the charging station and vehicle. Level 4 charging known as DC fast charging. It utilizes a quick charging point to recharge the vehicle. Inductive charging known as smart charging as the wireless charging at the station. Pantograph, this type of charging delivers high conductive transfer of energy in a very short time, used for heavy-duty vehicles such as busses and trucks [50-54].

| Mode of charging | Types of charging | Charging method | Power provided | Charging times |
|------------------|-------------------|----------------|---------------|---------------|
| Level 1          | Home charging     | Uncontrolled charging, no communication between vehicle and station | 2.3kW 1∅/10A | Up to 10 hours |
| Level 2          | Semi-public charging | In-cable control box and charging point | 7.3kW/ 1∅/10A and 22kW/ 3∅/32A | 2 - 4 hrs 1∅/ |
| Level 3          | Smart charging    | AC-DC converter and power charging source | 11kW up to 44kW | 30min - 3 hrs 3∅/ |
| Level 4          | Fast DC charging  | Electromagnetic induction (Under development) | 50-175kW (Under development) | 20 – 30 min (Under development) |
| Pantograph       | Catenary lines charging | 150kW to 450kW Off-board, 60 -150 Kw with an on board | | 30min -2 hrs |

The table is based on South Africa’s charging capabilities (According to the NERSA energy regulation)
The load requirements are for a 2010 Nissan leaf and a 2019 Mercedes Benz heavy-duty truck.

3. Technology based efficiency at the charging station (POET framework)

3.1. Introduction to PV panel efficiency

The improvement of PV module technologies has been a core focus of many research studies. The efficiency of these modules has a significant contribution to the daily operation of the system. There are numerous types of PV cell technologies to date, for both large scale and small-scale application with different material and efficiency. Their material has great implication on their performance, efficiency as well as cost. Their aforementioned effects have a great potential of increasing the overall efficiency of the system suited to their individual application. For the purpose of this study, a great focus will be on the first and second generation classifications science this two are the types used to generate energy. This type of panels are manufactured utilizing a semiconductor material such as silicon, amorphous silicon, CdTe and CIGS cells. They are made from a single silicon crystal (mono-crystalline), or cut from a block of silicon that is made up of many crystals (multi-crystalline - shown at right). [55-58].

3.1.1 PV panel technology analysis (First Generation).

Numerous studies were conducted with a sole purpose of investigating the efficiency of the first generation PV module. A number of finding were made, concerning their performance due to the variation in the solar irradiation. A study conducted by Gulkowski et al in Poland, indicated that the second generation exhibited high resistance to temperature rise as compared to the first generation. CIGS (second generation) in turn produced more power that polycrystalline (first generation). A similar study
conducted by Serameng et al in South Africa also indicated that the CIGS performed better than c-Si technology in both fixed north facing and east-west tracking configurations. Romero-Fiances concluded that a-Si (silicon crystalline) was better option in Lima due the low irradiation resources. The evidence in the three studies led to one conclusion, that thin film/second generation PV module have a much higher efficiency where the high irradiance were detect, as such they would be a logical choice in South Africa [59-61].

3.2. Introduction to wind turbine efficiency

There are numerous aspects, which contributes to the performance of wind turbines in an energy system. Some of the applications of wind energy includes energy generation, water pumping, boat battery charging etc. Wind turbines utilized in energy generation system are the core focus in this section. The type of wind turbine utilised differs for each application, and are classified according to design, size, configuration and location [62-64]. Since the environment and location tends to be the biggest influencer on the energy generated at each station, aerodynamic design of the wind turbine could be improved and optimized to enhance the wind turbine efficiency [65].

3.2.1 Wind turbine technology analysis (Aerodynamic improvement)

Rahman et al investigated the performance improvement of the horizontal axis wind turbine (HAWT), they noticed an improved efficiency with three blad ed turbine as compared to (2 and 5 blades). Their study also showed that the type of material used in the blades also made a significant difference in the efficiency and performance of the turbine [66]. Mohamed et al also stressed the importance of aerodynamic design to improve the efficiency of the turbine [67]. Beside the technological and design improvement, location/environment as well as turbine placement played a significant role in the overall performance of a wind turbine [68-70].

3.3. Charging point technologies in the EVCS

There are numerous electric vehicle chargers for different charging requirement. Figure 1 describes the acceptable charging units, which conforms to the standard developed by the society of automotive engineers (SAE) International as well as international electrotechnical commission (IEC). Level 1 and 2 standard chargers are compatible with most EV’s and PEV’s. The CHAdeMO DC fast charger is a
preferable fast charging option due its efficiency and reliability. Other fast chargers include the combined charging system (CCS) and Tesla super charger [1].

3.4. Battery bank technologies in the EVCS

The battery selection process depends upon what the designer intends to accomplish in his design. There are different types of batteries to date which possesses different behavior and performance criteria. These performance criteria include specific power, typical voltage, amp hour efficiency, energy efficiency, commercial availability, cost, operating temperatures, self-discharge rates, number of life cycles and recharge rates [11]. BESS’s use electro-chemical solutions and include some of the following types of batteries [72-75]:

- Lithium ion batteries- are a popular choice in EV’s as well as EVCS due to their exceptional storage capacity and capability. Constant charging and discharging does not limit their performance as well life span.
- Lead-acid batteries – Have been a reliable form of storage in most engineering applications such as back storage in utility grids, microgrids and control system. There are cheaper than the newly developed types such as Lithium ion.
- Sodium Sulphur batteries- have been widely used as battery banks in renewable energy systems such as wind and solar.
- Zinc bromine batteries- have been widely used for the same application as the sodium sulphur batteries; however, they hold more promise in large-scale energy storage.
- Flow – flow batteries are quite large and are generally used to store energy from renewable sources.

3.5. Energy management system technologies in the EVCS

Energy management system acts as smart control strategy to employ apt functionality in the EVCS, through a proper communication between the resources, battery bank, charging point, the grid whilst considering the vehicle’s charging requirements. This effective communication within the station has proven to be a game changer in the station, as more activity in the EVCS could be achieved without compromising the energy supply, grid stability and CBB state of charge whilst minimizing the charging cost for EV’s [5]. The section below will deal the EMS’s applicable technologies that addresses the issue of the EVCS dynamic pricing, whilst it constantly monitors the energy level in EVCS and the EV’s charging/discharging requirements. However, the EMS requires a control system to successfully manage the energy form the RE resource to different components of the system [75].

Mao et al presented a study that proposed algorithms, which was suitable to schedule EV charging in many occasions, such as home charging, EV aggregations (stations), at power companies, etc. They designed a comprehensive intelligent scatter search (ISS) algorithm within the frame of a basic scatter search with both unidirectional and bidirectional charging considered. They presented a detailed design of the ISS with the objectives of smoothing the daily load profile and minimizing the charging cost [76].

proposed an energy management scheme to govern the operation of a smart EV charger. Their proposed technique was compared with another battery-capacity-based power allocation method. The results showed that the larger EV battery was less vulnerable to battery degradation according to the proposed approach. Furthermore, the scheme contributed to the satisfaction of all EV customers, enabling the participation of all EVs. Furthermore, during V2G/G2V scenarios, to support the grid during renewables; transients, a 100% utilization factor showed the aggregation of EVs at the charger level. The V2G/G2V operation reduced the grid congestion and increased the load factor [77].

4. Discussion and conclusion of the reviewed framework

The POET energy management framework has been successfully used in the past to evaluate and improve the efficiency of large scale energy system with various load. It is known for its energy savings and improvements based on the four levels, conceptual, active, technical and further improvement. In this research study a review was based on a holistic approach in the further improvement of the charging
station. Technological advancements of the major components as well as an effective energy management system for effective charging were reviewed with an intention to analyze and propose a viable charging option. This advancement as well as the type of material used in the manufacturing process of various components could be beneficial to the overall performance of the station. However, careful consideration needs to be made during the selection of these components. Literature suggested that climate, location and environmental aspects plays a pivotal role in the energy generation and efficiency improvement of the system. Energy management schemes, controllers and energy storage system are necessary components in the station. Their purpose is to ensure uninterrupted energy supply, effective communication, system optimization and to maximize profit without compromising the integrity of the station. Through reviewing the major components of the station, it can be concluded that a measurable amount of efficiency improvement in the station is achievable. Further studies need to be conducted, to assess the POET framework in the other three levels namely; the conceptual level, active level, as well technical to investigate their level of energy improvement capability.

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