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# OPTIMAL DESIGN AND OPERATION OF FAST CHARGING STATION FOR ELECTRIC VEHICLE VIA RENEWABLE ENERGY IN WADI EL-NATRUN-EL ALAMEIN ROAD, EGYPT

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## ABSTRACT

The cost of Electric Vehicle Charging Station (EVCS) infrastructure is one of the problems which stand as a barrier in the way of widespread Electric Vehicles (EV). In this paper, the optimal design and operation of a renewable-powered EVCS will be introduced with minimizing cost and air pollution. By considering the station located in isolated area and will be supplied by hybrid Energy Sources. Configuration, sizing, economic optimization, operation and its effect on the environment are discussed. The proposed hybrid micro-grid consists of, photovoltaic panels, storage batteries, wind turbines, biogas generator and also a diesel generator. The case study of this work is to satisfy the 1056 KWh/day demand of EVCS for using at the selected site. Five different configurations of energy sources are studied to get the optimum case. HOMER software is used to implement the simulation model; the model is based on economic and environmental factors. Finally, the study introduces a cost-effective, socially and sustainable accepted design that can be useful in specifying the appropriateness of optimal design for other EVCSs.

**Contribution/Originality:** This study is one of very few that investigated an optimal hybrid energy configuring the power system to operate the electric vehicle charging station in Egypt. This study documents that renewable energy sources are effective option to reduce the emissions from burning fossil fuels and also minimize cost of energy.

## 1. INTRODUCTION

The transportation sector is considered one of the major consumers of world oil between different sectors. In 1973, the transportation sector consumed 45% of world oil and this value in 2017 was reached 65.2% according to the International Energy Agency (*IEA*). It represented more than 20% of $Co_2$ (International Energy Agency, 2019).

In Egypt, there are 9.3 million street vehicles and presented 32 % of the emissions. 110bn EGP had been allocated to subsidize petroleum products in 2017, highlighting the substantial financial burden of fuel consumption (El-Dorghamy, 2018). So, the transportation sector in Egypt consumed 60.3% of its oil (International Energy Agency, 2019).

EV with Renewable Energy Sources (*RES*) is a promise solution for green transportation. As Egypt is endowed with a various abundant *RES* for example: the solar radiation intensity annual is 1970-3200 kWh/m2, wind speed varies between 5 and 8 m/s and can reach to 10 m/s in the Gulf of Suez area, so wind energy is suitable for electricity generation moreover the biomass as Egypt has large resources of it from agricultural waste which present 35 million tons annually (IRENA, 2018). Egypt making significant efforts to get benefit from its *RES* by encouraging investment in RES, through the existing Feed-In-Tariff (*FIT*) program.

Egypt's government as the same as the governments in all world moves toward increasing the number of *EVs* and also *EVCS* to ensure the form of the sustainable transportation system in the next few years. If the uncoordinated EVs are supplied from the conventional generation, the emissions from the transportation sector will shift to the generation sector. For that, the *EVCSs* shall be integrated with *RESs*.

This paper checks the creating *EVCS* based on the existing infrastructure of fuel station (*FS*) on highways powered with RES. Using FS infrastructure will encourage EV drivers to take a long trip with more confidence and also help to avoid the initial cost of building new infrastructure for the public charging station. The motivation of this idea is to maximize the use of RES for charging the EVs with minimizing the energy demand from the grid, minimize the cost of energy (*COE*) and also minimize the emissions of $CO_2$.

In this study, HOMER software was used to investigate five different cases to reach the optimum configuration according to economic and environmental views. As a significant contribution is made in this paper as follows:

- A novel real-case design and operation scheme of EVSC using renewable energy sources is presented.
- A complete study from the technical, economical, and technical aspects is introduced.
- A detailed analysis is held to confirm the robustness and effectiveness of the proposed control approach.

This paper is arranged as follows: Part 1 shows the introduction, which includes the background of the study, problem statement, and objectives of this study. Section 2 describes the literature review, while Section 3 discusses the research methodology and defines the whole system parameters. Section 4 discusses the simulation results, whereas the last Section 5 depicts the conclusion, along with future guidelines.

## 2. LITERATURE REVIEW

Many studies were discussed the area of integration *RES* with *EVCS*. An economic evaluation for using vehicle-to-grid (*V2G*) services with *PV* by particle swarm optimization (*PSO*) algorithm is presented in Ghofrani, Arabali, and Ghayekhloo (2014). A comparison among different possible system architecture for a *PV-EV* charger is investigated in Chandra, Bauer, and Zeman (2015).

The design *EVCS* integrated with *PV* for workplaces is proposed in Chandra., Bauer, and Zeman (2016). The EV integrated with *PV* under uncontrolled charging with a smart charging application and V2G strategy is studied in Fattori, Anglani, and Muliere (2014). Charging Control strategy for *EVs* with *PV* and grid utility is proposed in Goli and Shireen (2014); Jin, Sheng, and Ghosh (2014). The *EVs* powered by wind energy and *PV* is presented in Capasso and Veneri (2015).

An experimental study of a DC charging station taking into account the integration of *RESs* with stationary energy storage systems and fleets of road *EVs* is proposed in Omar and Bhattacharya (2017). Optimal designs *EVCS* integrated with various energy sources rely on HOMER software to minimize life cycle cost is presented in Aldhanhani, Al-Durra, and El-Saadan (2017); Alghoul, Hammadi, Amin, and Asim (2018).

The use of the infrastructure of a petrol station with solar energy as an *EVCS* is evaluated in Domínguez-Navarro, Dufo-López, Yusta-Loyo, Artal-Sevil, and Bernal-Agustín (2019). Using a genetic algorithm (*GA*) to optimize the operation and installation of a fast-charging station with hybrid RES and storage systems is presented in Fathabadi (2020). Atallah, Farahat, Lotfy, and Senjyu (2020) Replaced storage battery bank by a s cell (*FC*) with a *PV* system and wind turbines to charge PHEVs. The feasibility of charging alternatives for *PHEVs* from *PV* and the grid is studied in ElNozahy and Salama (2014); Masrur et al. (2020).

## 3. METHODOLOGY

Some stages are taken into account as shown in Figure 2. to obtain the objectives of this paper. The pre-feasibility study of the proposed site was performed including the new estimated demand load on the existing power system of FS to charge EV, metrological input data as monthly average wind speed, global horizontal irradiation (GHI) and ambient temperature obtained from NASA Prediction of Worldwide Energy Resources (*POWER*) database as HOMER software used plus system constrains with economic parameter. Then, optimal design simulation considering technical and economic factors are performed and compared with the basic powered system.

## 4. LOAD, CLIMATE & ENERGY RESOURCES SPECIFICATION OF PROPOSED SITE

*FS* on the highway from New Cairo to Alamein selected as a case study and as a sample in this paper located at Wadi El-Natrun-El Alamein Rd, Alexandria Desert, Egypt to be *EVCS* as Figure 1. The station has an area of nearly 5000 $m^2$ and supplied from diesel generator (*DG*) 50 KW to meet 295 KWh/day which presented the existing load as *FS* is isolated from grid.

For this research, the existing electrical load plus

Electric Vehicle Supply Equipment (*EVSE*) as a new added electric load required for charging *EV*s, were detailed in Table 1. For the charging units *EVSE*s, A 2.5% random variability is considered for both day-to-day and time step analysis to provide more reliability. The daily total energy demand of 1056 kWh/day, a daily average of 44 kW, and a peak load of 110 kW are found.

**Figure-1.** Satellite view of the proposed location of EVCS.

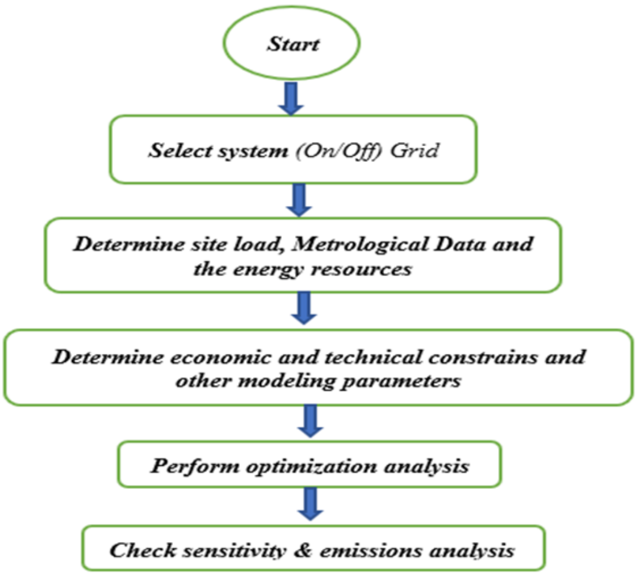


**Figure-2.** Stages of research.

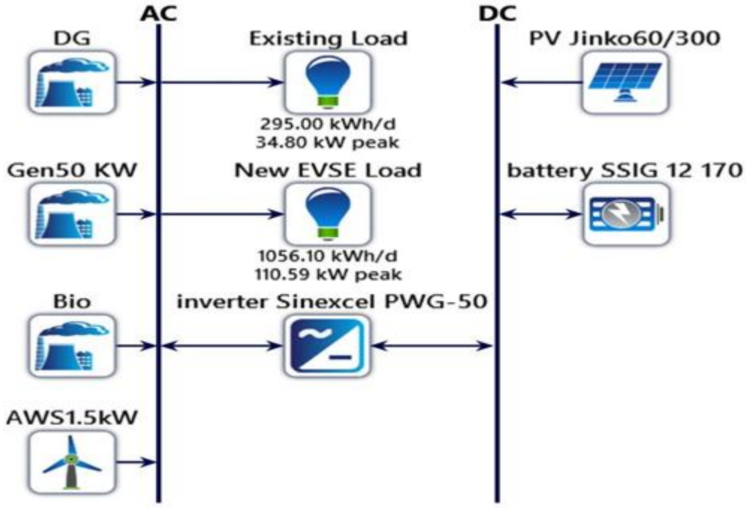


**Figure-3.** Proposed Energy Sources.

**Table-1.** Detailed of existing & new electric load.

| Status of Load | Electric Load | Rated in KW |
|---|---|---|
| Existing | Four of Petrol pumps | 1.5 KW/pump |
| | Twenty of Flood lighting fixtures | 150 W/fixture |
| | Security Room | 2 KW |
| | Supermarket and Coffee (shop) | 24 KW |
| New | Two of EVSEs | 50 KW/unit |

For climate specification and energy resources for the selected site (30˚36.9`N latitude 29˚48.8`E longitude) as the annual average wind speed is 5 m/s at 50 m above the surface of the earth, the annual average *GHI* is 5.5 KWh/m$^2$/day and the annual average temperature is 20.5˚c. The annual average for biomass can be provided per day is nearly 50 tons.

## 5. SYSTEM COMPONENT SPECIFICATION OF PROPOSED CONFIGURATIONS

The proposed configurations with different schemes are composed of a wind turbine, *PV* with batteries, *DG*, biogas generator and converter to meet the electrical load as Figure 3. For capacity, the HOMER software optimizer finds the optimal sizing of each component. The technical specifications of each component are shown in Table 2.

## 6. MATHEMATICAL MODEL OF PROPOSED CONFIGURATIONS

Economics plays a vital role to have an optimal combination of the RES components which based on net present cost (*NPC*) for EVCS. *NPC* is the present value of all the costs of installing and operating the component over the *EVCS* lifetime, minus the present value of all the revenues that it includes salvage value and grid sales revenue over the *EVCS* lifetime. Costs include capital costs, replacement costs, operation, maintenance costs, fuel costs and emission penalties. So, *NPC* is considered one of the most significant methods for the economic evaluation of the project over the entire operating life. The formula of the total *NPC* ($) is calculated as follows:

*Equation 1*

$$TNPC = \frac{AC_{Total}}{CRF(i, m)}$$

Where: $AC_{Total}$ is the total annualized cost ($/year) and the capital recovery factor (*CRF*) and the present worth factor (*PWF*) is calculated as follows:

*Equation 2*

$$CRF(r,N) = \frac{r(1+r)^N}{(1+r)^N - 1} = \frac{1}{PWF(r,N)}$$

Where: *r* is the real discount rate (5% in the present study) and *N* is the EVCS lifetime (25 years). The value remaining of each component in EVCS after the project lifetime is called salvage value (*SV*) which depends on replacement cost (*RC*) and the lifetime. *SV* is calculated as follows:

*Equation 3*

$$SV = RC\,\frac{N_r}{N_x}$$

Where: $N_r$ is the component remaining life, and $N_x$ is the life time of the component. The average cost per kWh of producing electricity is *COE* that is calculated as follows:

*Equation 4*

$$COE = \frac{AC_{Total}}{E_{Total}}$$

Where: $E_{Total}$ the total electricity output (kWh/year) which is included the *EVCS* load served and excess electricity sold to the grid if any.

### *6.1. The Following Technical Constraints are Considered in Charging Station Design*

- The maximum annual capacity shortage is set to be 5% which implies that the charging station will meet 95% of annual load.
- The minimum sharing of renewable energy is set to be 0% then the charging station can operate without *RES*.
- The operating reserve is obtained from the sum of four components to ensure the electricity will be supplied even if the renewable energy generation suddenly decreases or the load suddenly increases:
- A 10% hourly load is set to ensure that the *EVCS* can meet the demand load if it suddenly increased by 10%.
- 0% of peak load is set to ensure that the operating reserve is independent of the peak load.
- 25% wind power output is set to ensure that if the wind power output suddenly decreased by 25%, the operating reserve can meet the demand load.
- 25% of solar power output is set to ensure that if the solar power output suddenly decreased by 25%, the operating reserve can meet the demand load.

## 7. RESULTS AND DISCUSSION

Various designs of *EVCS* supplied from different energy sources are presented in this section from the standpoint of economics, operation performance and emissions. HOMER software is used in simulation the *EVCS* for each hour every year. 289,240 solutions were simulated via HOMER with 281,172 were feasible and 8,068 were infeasible due to the capacity shortage constraint. The comparison criteria for the different configurations which are considered as mentioned earlier will be the *COE* produced, total net present cost, operation cost, initial cost as well as emissions. Table 3 is presented the detailed analysis of the optimal *EVCS* design of each case.

**Table-2.** Economic & technical specification of each component.

| Description | Specification | Unit |
|---|---|---|
| **Wind turbine** | | |
| Type | AWS HC | ---- |
| Rated power | 1.5 | kW |
| Rated wind speed | 10.5 | m/s |
| Capital cost | 15000 | $/unit |
| Replacement cost | 15000 | $/unit |
| O&M cost | 150 | $/year |
| Life time | 20 | year |
| **PV modules** | | |
| PV model | Jinko Eagle | ---- |
| Rated power | 300 | W |
| Temp. coefficient | -0.39 | %/℃ |
| Operating temp. | 45 | ℃ |
| Capital cost | 120 | $/module |
| Replacement cost | 120 | $/module |
| O&M cost | 1 | $/year |
| Life time | 25 | year |
| **Diesel Generator** | | |
| Generator model | Generic | --- |
| Rated power | Auto sized | --- |
| Capital cost | 500 | $/kW |
| Replacement cost | 500 | $/kW |
| O&M cost | 0.03 | $/hour |
| Life time | 15000 | hours |
| Fuel curve slope | 0.251 | L/hr./kW |
| Fuel price | 0.431 | $/L |
| **Storage battery** | | |
| Type of battery | Trojan lead acid | --- |
| Nominal voltage | 12 | V |
| Nominal capacity | 2.02 | kWh |
| Capital cost | 300 | $/unit |
| Replacement cost | 300 | $/unit |
| O&M cost | 3 | $/year |
| Lifetime | 4 | year |
| **Converter** | | |
| Converter model | Generic | -- |
| Inverter efficiency | 90 | % |
| Rectifier efficiency | 85 | % |
| Capital cost | 300 | $/kW |
| Replacement cost | 300 | $/kW |
| O&M cost | 1 | $/year |
| Lifetime | 10 | year |
| **Biogas Generator** | | |
| Generator model | Generic biogas fixed capacity | --- |
| Rated power | Auto sized | --- |
| Capital cost | 1000 | $/kW |
| Replacement cost | 800 | $/kW |
| O&M cost | 0.03 | $/hour |
| Lifetime | 20000 | hours |
| Fuel curve slope | 2 | Kg/hr./kW |
| Biomass price | 0.01 | $/t |

Table 4 presents the *COE, NPC, REF* and operation and maintenance cost for different configurations with the existing 50 KW *DG*. For case (a), the wind system is added to existing *DG* to meet the modified load with 85% renewable energy. Case (a) ranks the 1$^{st}$ of high net present cost as 52.8 M$ and also cost of energy as 7.88 $/kWh but ranks 2$^{nd}$ of low emissions. For case (b), the biogas generator supported the existing *DG*. It ranks 2$^{nd}$ of high

*NPC* (0.936 M$) and also *COE* (0.135 $). When connected the existing DG with PV panels as the case (c), it ranked 3rd of high *NPC* (0.798M$) and *COE* (0.118 $) and also ranks the 1st of high $CO_2$ emission due to the least of all configurations in Renewable Energy Fraction (*REF*).

When wind energy is added to case (c), the results of case (d) nearly like case (c). The *COE* and *NPC* are decreased by nearly 30% when biogas generator is used with a battery system and added to case (d) to become hybrid renewable energy system with96.2% *REF* so, it ranked as 1st of low emissions and also from point of view cost analysis. So, case (e) is the optimal design for isolated hybrid micro-grid *EVC*S as shown from Table 4, Table 5. The total output power from the diesel system included existing and the new added is 18.9 MWh/year, from biogas generator is 210.8 MWh/year and from the *PV* system is 436.8 MWh/year as shown in Figure 4. The battery system in cases (e) is charged from the excess *PV* power generation, biogas and the diesel system to meet the electrical load, so this optimal case is operated under the Load Following (*LF*) strategy. Other cases are operated under CC strategy.

## 8. CONCLUSION

*EVCS* on highways plays a vital role to achieve the reliability for *EV* owners and help them to travel long distance with full confidence. This paper studied the optimal design for *EVCS*s depended on *FS* infrastructure by adding *EVSE* as a new electric load will be added to the existing load. The power supply system is needed to be modified to meet the new load with minimum *COE* and also minimum $CO_2$ emissions. By facilitating different energy sources such as *PV* modules with a battery system, wind turbines, biomass and diesel system as a stand-alone and hybrid system. Case (e) Hybrid *PV* with a storage battery system, biogas and diesel generators for isolated *EVCS* achieved the economic and environmental factors successfully.

The following points are the major outcomes of the present study and can be applied for all *EVCS*s on the road of Wadi El-Natrun-El Alamein:

- The analysis proved that the optimal tilt angle of the *PV* module is 22° with zero azimuth angle for the selected site.
- For isolated *EVCS*, case (e) Hybrid *PV* with storage battery, biogas generator and added *DG* is the optimal solution with *COE* of 0.0.085 $/kWh and with 96.2% *REF* which consists of 248 kW *PV* panels, 50 KW biogas generator,10kW new *DG*, 44 lead-acid batteries with rated capacity 2.02 kWh and 136 kW converter.
- The simple payback is 2.27 year with 46.1% internal rate of return as shown in Figure 5 obtained from HOMER.

**Table-3.** Optimal design of isolated hybrid micro-grid EVCS with different configurations.

| EQUIPMENT | (a) | (b) | (c) | (d) | (e) |
|---|---|---|---|---|---|
| Wind turbine (Numbers) | 2703 | 0 | 0 | 2 | 0 |
| PV modules (kW) | 0 | 0 | 388 | 383 | 248 |
| DG (kW) | 50 | 50 | 50 | 50 | 60 |
| Converter (kW) | 0 | 0 | 144 | 144 | 136 |
| Storage battery (Numbers) | 0 | 0 | 0 | 0 | 44 |
| Biogas Generator (KW) | 0 | 90 | 0 | 0 | 50 |

**Table-4.** Emissions quantity (Ton/year) comparison of isolated hybrid micro-grid EVCS with different configurations.

| | (a) | (b) | (c) | (d) | (e) |
|---|---|---|---|---|---|
| Carbon dioxide | 60.1 | 89.2 | 165.7 | 164 | 16 |
| Carbon monoxide | 0.375 | 0.558 | 1 | 1 | 0.1 |
| Unburned hydrocarbons | 0.016 | 0.024 | 0.046 | 0.045 | 0.004 |
| Particulate matter | 0.002 | 0.003 | 0.006 | 0.006 | 0 |
| Sulfur dioxide | 0.147 | 0.218 | 0.401 | 0.403 | 0.039 |
| Nitrogen oxides | 0.353 | 0.524 | 0.972 | 0.967 | 0.094 |

**Table-5.** Cost component comparison of isolated hybrid micro-grid EVCS with different configurations.

| | (a) | (b) | (c) | (d) | (e) |
|---|---|---|---|---|---|
| COE ($/kWh) | 7.88 | 0.135 | 0.118 | 0.123 | 0.085 |
| NPC (M$) | 52.8 | 0.936 | 0.798 | 0.833 | 0.589 |
| O&M (M$/yr.) | 0.864 | 0.058 | 0.04 | 0.041 | 0.025 |
| REF (%) | 85 | 80 | 59.5 | 60 | 96.2 |

The excess electricity of case (e) Hybrid *PV* module with storage battery, biogas and diesel generators of isolated *EVCS* can be stored in the battery system as batteries bank depends on the *LF* control strategy that improved the reliability and stability of the system.

The Egyptian government can use this study to expand the use of renewable energy generation to compensate for the shortage in petroleum products. Moreover, practical implementation of this study will contribute in the increasing of *EV*s using in car market in Egypt. The concept of this paper can be used for any location in the World.

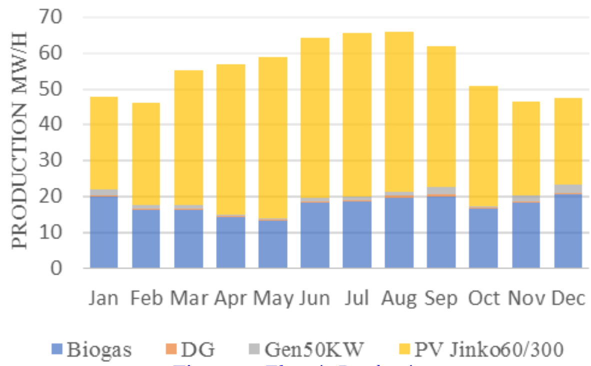


**Figure-4.** Electric Production.

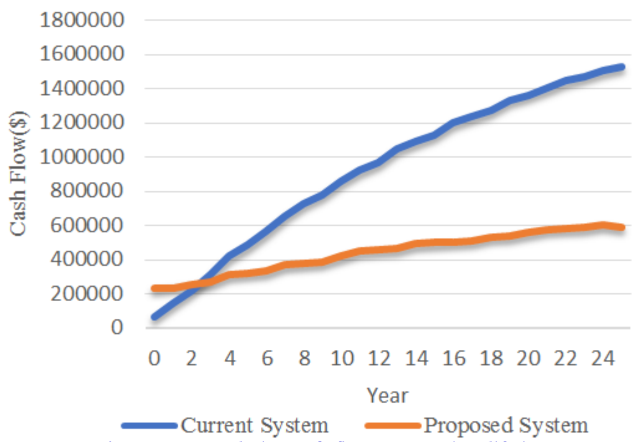


**Figure-5.** Cumulative cash flow over project lifetime.

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