Strategic Renewable Energy Source Integration for Charging Stations in Plug-in Hybrid Electric Vehicle Networks

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Abstract. The optimal allocation of Renewable Energy Sources (RESs) along with Electric Vehicle (EV) charge stations aims to maximize the utilization and efficiency of renewable energy while accommodating the charging requirements of EVs. The EVs in charging stations using RESs could reduce the dependency on the utility grid. However, duty challenges are faced when the number of arrivals and departures of EVs are not managed well, which may be addressed by Energy Management Strategies (EMSs), which improve the deployment of Demand Response (DR). This involves strategically determining the suitable locations and capacities for both renewable energy generation facilities and EV charge stations. The allocation mechanism takes into account aspects such as energy demand, renewable energy availability, infrastructural constraints, and charging patterns by employing complex algorithms and optimization approaches. The goal is to reduce energy waste, gearbox costs, and carbon footprint while guaranteeing a consistent and sustainable energy supply for electric vehicle charging.

Keywords: Optimal Allocation, Renewable Energy Sources, Electric Vehicle, Energy Management Strategies, Demand Response.

1. Introduction

A mathematical model or optimization technique can be used to find the best distribution of renewable energy resources such as photovoltaic (PV), wind turbine (WT), and charge stations for plug-in hybrid electric vehicles (PHEVs) [1]. The model takes into account the anticipated energy demand from PHEVs as well as variables like the cost and capacity of energy sources [2]. It's challenging to integrate sporadic renewable energy sources like solar and wind into the system [3]. Effective scheduling and dispatching procedures are needed to ensure grid stability and reliability, given these energy sources' changing nature [4]. By optimizing a number of

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factors, such as energy dispatch, power flow management, and system reliability, metaheuristic algorithms provide a solution [5].

Additionally, the use of metaheuristic methods in grid-tied systems enables the simultaneous evaluation of numerous objectives [6]. This makes sure that competing goals, such as minimising energy expenditures, cutting greenhouse gas emissions, and maximising the usage of renewable energy sources, are taken into account during the optimization process [7]. Metaheuristic algorithms have shown encouraging outcomes when used in renewable energy systems for grid-tied supports [8]. These methods have been effectively used to address a variety of optimization issues, including system planning [11], power flow management [10], and [9]. They offer solid and effective solutions that change with the conditions and variables of the system [12].

Furthermore, the optimal allocation accounts for geographical and environmental considerations, such as solar irradiance, wind patterns, land availability, and proximity to electrical grids. It also incorporates predictive modeling to anticipate future EV adoption rates, energy demands, and renewable energy generation potential. Ultimately, the optimal allocation of renewable energy sources and EV charge stations promotes the integration of clean energy into the transportation sector, fostering sustainable development and reducing reliance on fossil fuels [13]. Demand response initiatives can be enacted using diverse methods, including time-of-use pricing, critical peak pricing, or direct load control. With direct load control, utilities can remotely modify or reduce specific non-essential loads during periods of peak demand.

This article's unique contribution lies in its focus on North Africa. The remaining sections are structured as follows: Section 2 provides a comprehensive state-of-the-art review of optimal electric vehicles and energy source allocation. Section 3 presents mathematical modeling equations for the relevant components, along with a block diagram of the hybrid system. The concluding remarks and references are covered in Section 4.

2. Optimal Allocation of Electric Vehicles and Energy Sources

Integrating renewable energy sources with the utility grid is a crucial task and could face several challenges, such as increasing the investments in energy-supporting systems, as shown in Figure 1. In order to avoid integration limitations, exploiting optimization methods along with energy management approaches to acquire an optimal system is allowable for optimal component location. Another approach is to use computer modeling and optimization techniques to simulate energy demand and supply scenarios and determine the most efficient allocation of renewable energy sources to meet that demand. This may involve incorporating factors such as energy storage capacity, transmission and distribution infrastructure, and regulatory and policy considerations. Ultimately, the optimal allocation of renewable energy sources will depend on carefully analyzing all the relevant factors and developing a comprehensive plan that considers all of these factors[13].

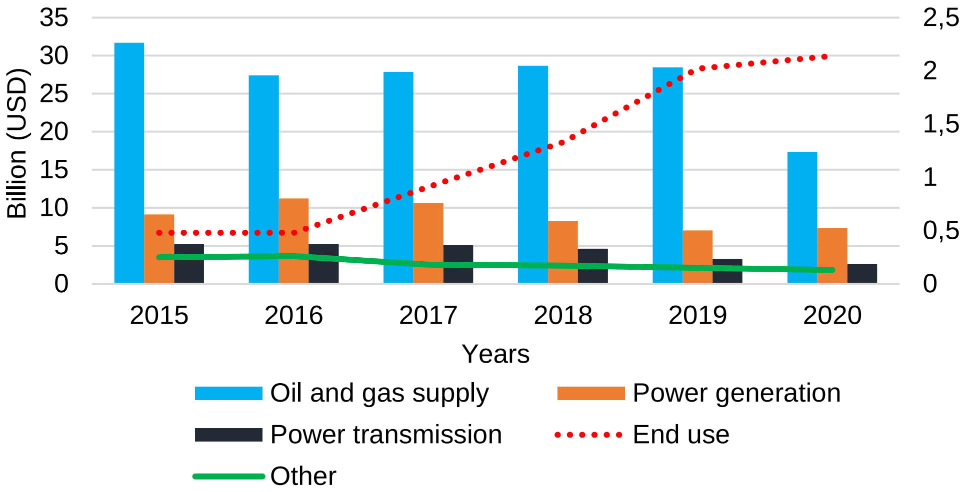

Figure 1 Energy sector investment in North Africa based on IEA.

The optimal allocation for renewable energy sources will depend on various factors, including the availability of different types of renewable energy in a particular location. Besides, the energy demand, consumption patterns in that location, and the economic and environmental considerations of different renewable technologies. The presented steps in Figure 2 can be used to determine the optimal allocation of hybrid configurations in a microgrid system. Additionally, various other approaches can be utilized to determine the allocation. Firstly, one approach to determining optimal allocation is to conduct a feasibility study that takes into account these factors and identifies the most viable renewable energy sources for a given location. This may involve analyzing wind patterns, solar radiation levels, and other meteorological data and assessing the costs and benefits of different renewable technologies. The output of the model will give information on the optimal capacity of PV and WT sources, as well as the capacity of the charging station, which will result in the minimum cost while ensuring that the energy demand of PHEVs is met.

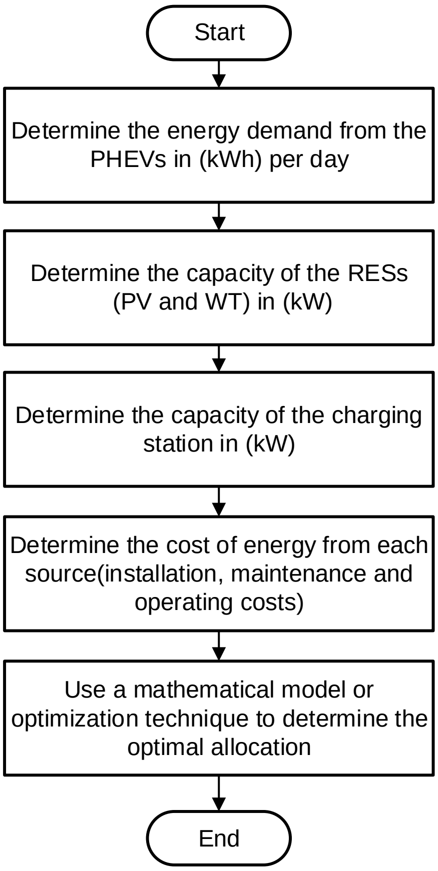

Figure 2 Flowchart of the choosing optimal allocation

3. Mathematical Modelling of System Configurations

The mathematical modeling of the system parameters that are illustrated in Figure 3 are mathematically expressed, starting from Eq. (1) to Eq. (11), respectively. The considered sources in this study are the PV, WT, BT, and EV integrated into the utility grid through a hybrid bus (AC/DC). The main advantage of integrating the aforementioned components with the AC/DC bus is their flexibility in integrating various forms of energy and the availability of energy generation.

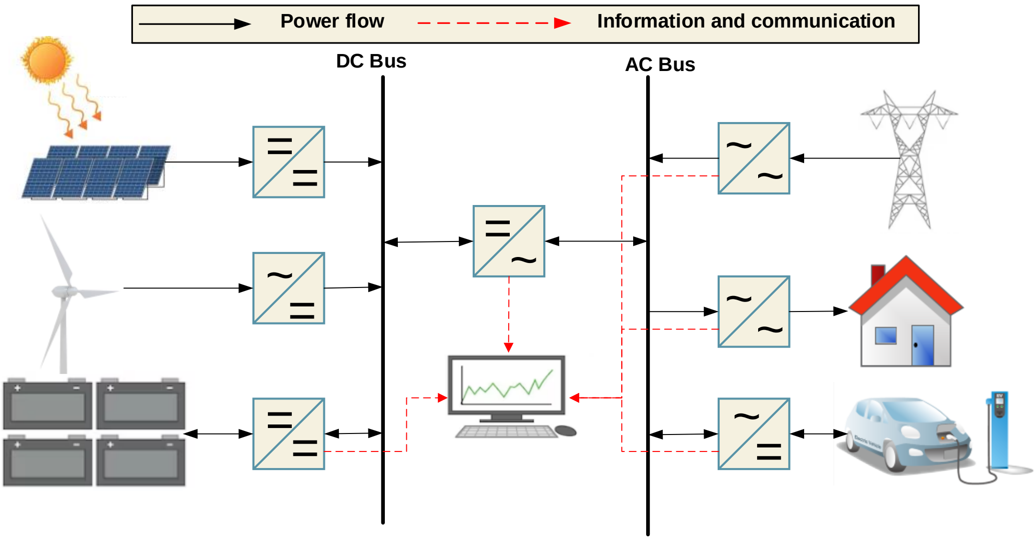

Figure 3. Block diagram of the hybrid proposed system

3.1 PV

The produced hourly output from the PV (P_{PV}) mathematically can be acquired by employing Eq. (1) with the help of Eq. (2) to determine the area of the PV module (A_{PV}) in m^2. Besides, the estimated energy demand to determine the number of PV ($N_{pv\_modules}$) mathematically can be expressed in Eq. (3)

$$P_{PV} = A_{PV} \times H_{t(AV)} \times \eta_{PV} \tag{1}$$

$$A_{PV} = \frac{E_L}{H_{t(av)} \times \eta_{PV} \times \eta_{BT} \times \eta_{inv} \times A_{Tcf}} \tag{2}$$

$$N_{pv\_modules} = \frac{P_{PV}}{S_{Peak-power}} \tag{3}$$

Where the assessed power from the PV obtained in Eq. (1), while the ($H_{t(AV)}$) represent the average solar radiation of the considered case study in (W/m^2), η_{PV}. η_{BT}, and η_{inv} are the efficiency of the PV, BT, and the inverter models, respectively. Additionally, Eq. (2) mathematically exploited to measure the area of PV modules in order to meet the required demand and the A_{Tcf} is the temperature correction factor. Moreover, Eq. (3) represented the number of PVs needed to generate the required amount of solar energy ($N_{pv\_modules}$) and the maximum power of the chosen PV ($S_{Peak-power}$).

3.2 WT

The second renewable energy source mostly applied to generate green energy is WT; the output power from the WT (P_{WT}) can be expressed in Eq. (4), including the wind speed data (V) of the site and rated power (P_r) and rated wind speed (V_r^3) that is provided in the wind turbine datasheet.

$$P_{WT} = \begin{cases} 0 & V < V_{ci} \\ p_r(\frac{V^3 - V_{ci}^3}{V_r^3 - V_{ci}^3}) & V_{ci} < V < V_r \\ P_r & V > V_{co} \end{cases} \quad (4)$$

$$P_{wind\_out} = P_{WT} \times A_{WT} \times \eta_g \quad (5)$$

$$N_{turbines} = \frac{P_L \times SF}{P_{wind\_out}} \quad (6)$$

Additionally, Eq. (5) utilized for the output power (P_{wind_out}) with the conservation of area (A_{WT}) and efficiency of ….. (η_g) and Eq. (6) denoted for the number of turbines ($N_{turbines}$), respectively.

3.3 EV

In the transportation sector, an alternative device to the Internal Combustion Engine Vehicle (ICEV) is an electric vehicle that reduces GHG and is free of exotic gases from the tailpipe. The energy demand for the EV can be presented in Eq. (7) with the help of EV battery capacity (C_{BT}^{EV}) that is presented in the manufacture datasheet considering the period of charging (T) and the maximum (SoC_{max}^{EV}) and minimum (SoC_{min}^{EV}) of SoC, respectively. Where the T can be expected by subtracting the time of arrival from the time of departure as presented in Eq. (8).

$$P_{EV_{DEM}} = \frac{C_{BT}^{EV} \times (SoC_{max}^{EV} - SoC_{min}^{EV})}{T} \quad (7)$$

$$T = Time_{arr}^{EV} - Time_{Dep}^{EV} \quad (8)$$

3.4 Grid

As unlimited energy sources, the average daily load demand for the energy demand $P_L(W)$ in time (t) in hours,

$$E_L = P_L(W) \times t_{(h)} \quad (9)$$

3.5 BT

The chemical device for storing the energy as a backup source in the cases of not meeting the demand by other sources.

$$M_{BT} = \frac{A_d \times E_L}{\eta_{BT} \times \eta_{inv} \times DoD \times V_s} \quad (10)$$

$$\eta_{BT} = \frac{M_{BT}}{M_{sin}} \quad (11)$$

Equation (10) represents the required storage capacity (M_{BT}) of the deep cycle battery in the system, the A_d Represents the autonomy days, DoD refers to the maximum acceptable depth of discharge of the battery, V_s Indicates the system voltage in (V). while the battery efficiency is gained by dividing the required storage capacity (M_{BT}) over the single battery capacity measured in (Ah).

Table 1. Datasheet of the utilized parameters

Configurations	Features	Value	Unit
PV	PV type	SW 315 Mono	

	Maximum power (Wp)	315	W
	Open circuit voltage	45.9	V
	Maximum power point voltage	36.8	V
	Short circuit current	9.16	A
	Maximum power point current	8.63	A
	Model efficiency	16.03	%
	Dimensions (L×B×H)	$78.15 \times 38.98 \times 1.81$	in
	NOCT	46	℃
WT	Wind turbine type	Angel-300	
	Rated power	300	W
	Rated voltage	12/24	V
	Roter dimeter	1.44	m
	Cut in	2	m/s
	Rated wind speed	9	m/s
	Cut out	35	m/s
EV	EV type	Chevrolet Volt 2016	
	Maximum SoC	95	%
	Minimum SoC	20	%
	The capacity of LithionIon battery	18.4	kWh
GRID	Power importing price	0.05	$/kWh
	Power exporting price	0.04	$/kWh
BT	Autonomy days (A_d)	2	Days
	Depth of Discharge	60	%
	System voltage (V_s)	12	V
	Battery efficiency (η_{BT})	0.9	%
	Inverter efficiency (η_{inv})	0.9	%
	Storage capacity ((M_{sin})	250	Ah

4. Factors of RESs Optimal Location And Charge Station

Determining the optimal allocation of renewable energy sources and electric vehicle charging stations hinges on various factors, including location, energy demand, infrastructure availability, and policy framework. Here are some crucial points to take into account

Table 2. Optimal location factors

Optimal location factors	Features
Assessing energy demand	• It is important to analyze the current and projected energy demand in a particular region. • This analysis should include electricity consumption, transportation needs, and future growth estimates.
Identifying renewable energy potential	• Determine the potential of different RESs (solar, wind, hydro, or geothermal power) in the region. • Factors such as available land, sunlight, wind speed, or water resources should be considered.
Developing a charging infrastructure strategy	• Assess the existing electric vehicle (EV) adoption rate and potential future growth. • Identify key locations for EV charging stations based on population density, commuting patterns, and availability of parking spaces.

Integration of renewable energy and EV charging	• Optimal allocation entails integrating renewable energy sources with EV charging infrastructure. • This involves identifying synergies between renewable energy generation and EV charging patterns to maximize efficiency and minimize grid stress.
Policy and regulatory framework	• Encouraging policies and regulations play a vital role in promoting renewable energy and electric vehicle adoption. Incentives and subsidies can be provided for renewable energy installations and EV charging infrastructure, attracting private investments and promoting clean energy initiatives.
Economic and environmental considerations	• Conduct a cost-benefit analysis to evaluate the economic viability and environmental impact of renewable energy and EV charging projects. • This analysis should consider factors such as investment costs, operational expenses, emission reductions, and potential revenue streams.

5. Energy Management Strategy

The EMS is based on human knowledge that relies on a statement of IF-THEN statement. One energy management strategy to address the optimal allocation of integrating systems considering renewable sources and electric vehicles is called demand response, as demonstrated in the flow chart operation to implement the strategy. Demand response involves adjusting electricity consumption in response to supply and demand variables, including the availability of renewable energy and the charging needs of electric vehicles. By implementing these strategies, energy management can effectively allocate resources, optimize the integration of renewable energy sources, and efficiently and sustainably accommodate electric vehicles' charging needs. Additionally, deploying innovative technologies, such as energy management systems, can further enhance the implementation of demand response.

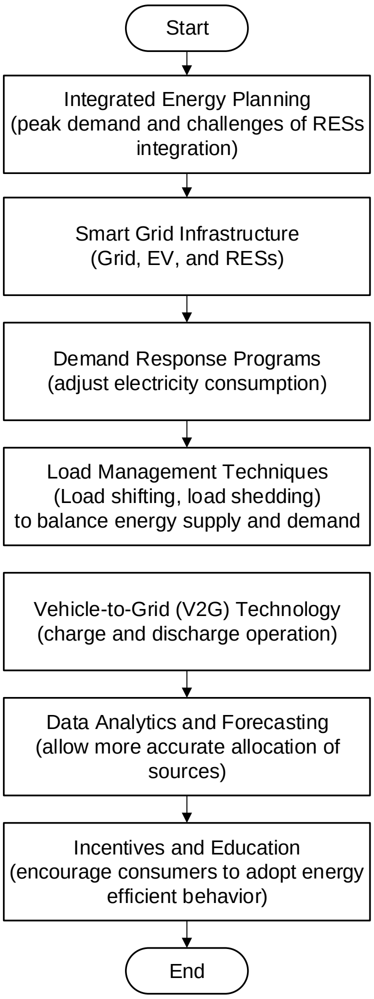

Figure 4. Flowchart EMS based on demand response

6. Results and discussion

The result has been achieved and analyzed based on the modeled hybrid system presented in Figure 3 that ran on MATLAB 2021a. Demand response is crucial for achieving optimal allocation and integration of renewable sources and electric vehicles in the energy system using direct load control. At the same time, DR can accommodate the increased EV and RES integration adoption. By allowing consumers to adjust their electricity usage in response to real-time price signals or grid conditions, demand response enables the efficient management of energy resources and facilitates the integration of intermittent renewable sources like solar and wind. Figure 5 shows the year-round comparison result of the utilized configurations along with the SoC of the deep cycle battery. Integrating renewable sources into the energy grid is essential for decarbonizing the power sector and reducing greenhouse gas emissions. However, renewables have their limitations, such as intermittency and non-synchronous generation, which can impact the stability and reliability of the grid.

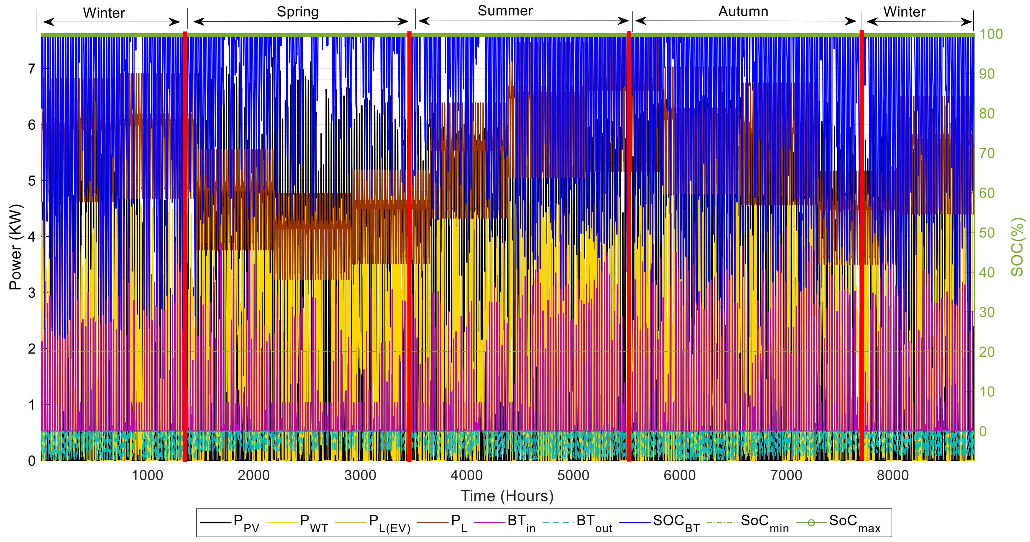

Figure 5. Seasonal comparison output result of the integrated sources.

The achieved optimal allocation for the utilized configuration in the hybrid system is plotted in Figure 6 as the performance of optimal configurations. As it is clearly seen, the bidirectional operation along with the output power from the exploited sources has been considered in the first 24 hours. At a different time, the power differs due to the randomness of the integrated EVs into the charge station with the integration of other home appliances.

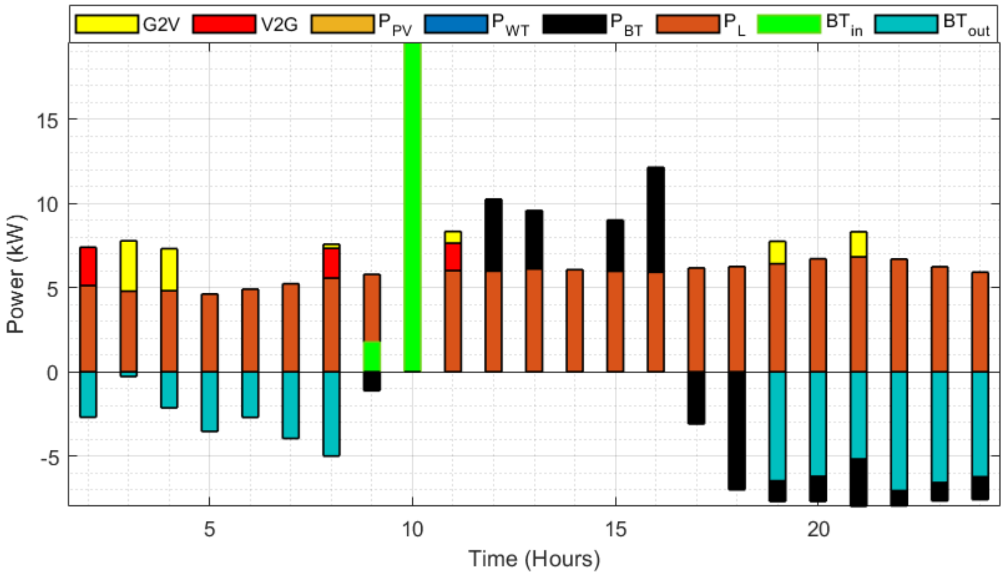

Figure 6. Performance of optimal configurations for first 24 hours.

7. Conclusion

To sum up, a thorough analysis of energy consumption, renewable energy potential, the requirement for charging infrastructure, governmental support, and economic factors is necessary for the best distribution of renewable energy sources and EV charging stations. With control technologies like demand response, collaboration between governmental organizations, energy suppliers, and transportation stakeholders is essential for attaining the most effective and sustainable results. Demand response is a helpful technique for the best distribution and blending of renewable energy sources with electric vehicles. It makes renewable energy more effectively usable, lessens our dependency on fossil fuels, and lessens the strain EV charging places on the system. Investment in smart grid infrastructure, efficient communication networks, and cutting-edge technologies that permit demand response are essential if you want to realize this system's promise fully.

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