An-Najah National University

Faculty of Graduate Studies

Optimal Sizing of a Standalone Photovoltaic Based Electrical Vehicle Charging Systems: A Case Study of Electrical Buses for Nablus-Ramallah Road

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وأيضاً لجدي الحاج عمر (أبو هاني) وجدتي الحاجة آية (أم هاني)

إلى اصحاب الفضل الكبير الذي لا ينسى خالي الحبيب راجي (أبو فارس)

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الإقرار

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List of Abbreviations

PV	Photovoltaic
V2G	Vehicle to Grid
EVs	Electric Vehicles
P	Power
SOC	State of Charge
E	Energy
PEVs	Plug in Electric Vehicle
Km	Kilo Meter
DOD	Depth of Discharge
LLP	Loss of Load Probability
Eff	Efficiency
SAPV	Standalone PV
ED	Energy Deficit
V	Volt
A	Ampere
LPSP	Loss of Power Supply Probability
LOLE	Loss of Load Expected
TEL	Total Energy Loss
LA	Level of Autonomy
SPBP	Simple Payback Period
BV	Battery Vehicles
CS	Combined Collector
RES	Renewable Energy Source
Ah	Ampere hour capacity
Wh	Watt hour capacity
D	Duty cycle of converter

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Abstract

In this research, a novel design and operation of solar based charging system for battery vehicles for a 50 km run is proposed. The proposal aims to replace 110 existing diesel vehicles with 39 electric buses. Several operation scenarios for the charging stations are proposed and analyzed. Scenarios include two different battery charging methodologies and one hybrid option between electric busses and diesel vehicles. An energy model of the adapted electric buses is developed first. After that, load demand and needs including number of daily trips, number passengers per hour and hourly energy consumption are determined based on the developed model and gathered information. Results show that a 5. 7 MWp photovoltaic system is required to power this transportation line with a loss of load probability of 5% and a trip cost per passenger of 2.05 USD. The simple payback period of the system is found to be 10 years, which is 40% of the system's lifetime. The amount of 〖CO〗_2 mitigated by the proposed system is estimated as 1,629,387 (kg/year). The social impact of the proposed project is found acceptable whereas most of the current employees will keep their jobs with higher salaries by about 145% and less working hours by 50%. Moreover, it is expected that the proposed project will significantly increase the reliability, convince and sustainability of the transportation process.

Keywords: solar chargers; electrical buses; photovoltaic system; green transportation.

Chapter One

Introduction

Electric vehicles (EVs) have been the focus of considerable attention in recent years because of the large amount of carbon dioxide gases released from conventional vehicles [1]. Moreover, the dependency on imported crude oil and the depletion of fossil fuels led to the search for alternative transportation systems such as EVs that are more economical and environment-friendly [2].

The electric vehicle (EV) is classified as a vehicle, which has a battery and operates using electricity supplied from an external power source. One of the EVs is the battery vehicles (BV), which is recharged by a charging station that is either connected to the grid or powered by a standalone renewable energy source [3].

EV charging stations should be optimally sized, planned and allocated considering the type and the location of the charging stations. In case of grid connected charging stations, the impact of the charging station on the electricity distribution grid should be considered during the planning and sizing phase. Moreover, the geographical location of the charging stations should also be considered [4].

Grid connected charging stations are optimally planned by considering power loss and voltage stability in distribution networks [5]. Moreover, driver's behavior is also considered when optimally planning charging stations [6]. Furthermore, charging schedule and demand nature are also being considered in such an optimization problem [7] as well as driving habits, road nature and transportation demand [8]. In [8] for example, charging stations for BV are optimally planned and sized. It is recommended in [9] that city traffic networks as well as electrical distribution network should be considered for optimal planning and sizing of the charging stations. Moreover, land price and its adoptability as well as convenience of BV's drivers are considered in this research to optimally allocate the charging stations [9].

On the other hand, in case of charging stations that are powered by a standalone renewable energy system, accurate system sizing for the power source as well as the storage unit is required beside all the aforementioned aspects [10]. Recently photovoltaic (PV) systems are being utilized as chargers for BV charging stations [10]. In [11] the authors have proposed a PV based charging station for BV. The cost function of the system is optimized by considering stopping rate, establishment cost and expense discount. Similarly, in [12] the authors have introduced PV based/grid charging stations without storage.

The grid is assumed to power the charging station when PV array is not able to fulfil the demand. Meanwhile, PV excess power can also be injected to the grid. On the other hand, in [13] the authors have introduced a PV based charging station with regenerative slowing down and battery storage to help the system structure during peak-load. The point of the researchers is to use the greatest measure of renewable energy and lessen the charging cost. Similarly, in [14] a hybrid PV/wind-based charging station with battery storage is proposed to deal with the power generation changes during variable natural condition.

In [15], it is stated that energy storage is important for off-grid charging stations and the system is designed considering a desired reliability. Similarly, in [16] the cost of off-grid charging stations is minimized subject to specific availability of the system. Meanwhile, in [17] the authors have introduced a state of charge (SOC) based control method to deal with deficit cases occurred of the uncertainty nature of renewable energy source.

In general, most of the aforementioned PV based charging stations assume that the BVs can be either charged by PV array directly or by a charging battery in case of having the PV array unable to fulfil the power demand of the BVs. This assumption is very well known however, the focus is always given to the design of the charging station not the load demand assessment as load demand is considered constant in most cases. This actually does fit with battery vehicles research as BV has a very dynamic load demand and the system should be always designed based on that. Moreover, all of these researches assume that the combined collector (CS) will be charging commercial and individual BVs. Meanwhile, none of them have considered transportation lines such as BV buses or small vans.

These transportation lines do have picking and dropping stations with dynamic load demand, whereas PV based CS is really worthwhile as it might be very competitive to the option of using conventional fuels.

In addition to that, all of the aforementioned research utilized conventional designing method for the PV charging system (intuitive or numerical methods) without simulating these charging stations so as to calculate the reliability of these charging stations. Thus, in this research two centralized PV based charging stations are proposed to power the transportation line. These charging stations are used to charge BV buses that will replace the current diesel-based shuttles. The charging stations sizes and locations are optimally designed based on road dynamic demand and system life time cost.

Three main operation scenarios are adapted in this research considering the charging methodology as well as system cost. After that a full simulation of this process is provided so as to estimate the reliability of the proposed systems. The main contribution of this research can be summarized by first the estimation methodology of the BV dynamic load demand. Second, the novel methodology for designing and simulating PV based charging station for a transportation line considering BV dynamic demand. Finally, the proposed operation methodologies and their performance comparison can be considered as contribution for this research.

Finally, this research contains worthwhile information about road demand, road topology, and energy consumption model for a major rural arterial road in Palestine.

1.1 PROBLEM STATEMENT

In general, Ramallah City is currently considered as a trading hub whereas many passengers travel every day to this city from Nablus City. The current transportation system is being managed using seven passengers' shuttles that are operated using diesel which is expensive and emits CO_2. The Palestinian government is recently showing an interest in electric transportation whereas electric buses can address the problem of the conventional transportation between Ramallah and Nablus cities. However, in order to provide an optimal system and optimal sizing of outward and inward charging stations should be done. In the meanwhile, in order to utilize renewable energy which is an interest of the Palestinian government as well, photovoltaic (PV) based charging station is proposed.

1.2 OBJECTIVES

In this research three main objectives are aimed to be fulfilled as below:

1.2.1 To estimate road needs and demands in terms of energy and charging portals.

1.2.2 To optimally size needed solar charging system for charging electrical busses.

1.2.3 To estimate the feasibility of the proposed system.

1.3 RESEARCH METHODOLOGY

WP.1 Literature review

T 1.1 Literature review on standalone PV systems.

T 1.2 Literature review on standalone PV system sizing.

T 1.3 Literature review on EV components and operation.

T 1.4 Literature review on charging station components and operation.

T 1.5 Solar radiation data collection for Palestine.

T 1.5 Collecting civil information about Nablus- Ramallah road.

WP.2 Estimation of Nablus-Ramallah road needs and demand

T 2.1 Study Nablus- Ramallah topography and terrain nature.

T 2.2 Estimation of number of round trips per day and number of passengers per round trip.

T 2.3 Estimation of road loading profile including peak load, medium load and base load.

T 2.4 Estimation of electrical buses energy consumption per round trip and its correlation with bus loading and road terrain.

WP.3 Formulation of road trip cost function with its constrains

WP.4 Determination of needed charging ports and charging time

T 4.1 Formulation of electrical load profile per bus.

T 4.2 Estimation of number of needed electrical buses.

T 4.3 Estimation of desired charging time and desired buses queue size.

WP. 5 Optimal sizing of PV based charging station

T 5.1 Optimal sizing of battery size.

T 5.2 Optimal sizing of PV array.

T 5.3 Optimal size of required power electronic features.

WP. 6 System simulations

T 6.1 Conduct a numerical simulation of the proposed system using Matlab.

T 6.2 Determination of loss of power supply probability.

WP. 7 Conduct a prefeasibility of the proposed system

T 7.1 Estimation of round-trip cost per passenger.

T 7.2 Conduct a comparison between round trip cost per passenger between the proposed system and the current system, which is based on seven passengers’ shuttles and diesel fuel.

Chapter Two

Literature Review

2.1 Electrical Vehicles

Rising energy independence worries around the world, increasing petroleum costs, global warming impacts and the carbon dioxide (CO2) emissions generated were the motivators for the movement towards Renewable Energy Resources (RES) and growth in the field of transport. The transport industry has the bulk of fuel usage and the latest developments are aimed at reducing the need for oil and by making the cars more fuel-efficient and transitioning to renewable energy sources. [18]

Using RES and researching their implemented programs, it was found that extra resources are required for dispatching. Such as producing thermal power, adjustable pumped storage rates, and storing battery energy. Smart grid technologies are supposed to take advantage of distributed generations and controllable demand-side loads. [19]

Stakeholders such as policy makers, engineers and business leaders agreed that one of those options is re-electrification of vehicle transportation and enhancement of the global infrastructure of power systems. [20]

Electric vehicle (EV) is classified as a vehicle which has a battery and operates using electricity supplied from an external power source. EVs carry zero emissions and low noise.

Many electric vehicle types are known as:

1. Plug-in Hybrid Electric Vehicle PHEVs

PHEV made of two motors, an electric motor and an internal combustion engine. They operate on both petroleum-based and electric power. They plug in the power grid to charge batteries. Depending on the available and margin power sources, the generation mix varies. Most regions are using their technologies for coal and gas and others are increasing their production of renewable electricity. PHEV penetration influences demand, supply, electricity prices and pollution such that if the combined system is not the optimum, it may lead to negative consequences. [20]

PHEVs simply do not have enough onboard battery power to require adequate commitment to the V2 G storage. [21]

2.2 The Battery Vehicles (BV)

The battery is recharged by connecting it to the electrical grid by charging the station which is planned and placed according to different conditions.

The plug-in EVs have the same barriers particularly for all kinds of Electric Vehicles. The high cost of fuel, driving range limitations and efficiency such as speed and aging are still barriers and significant obstacles to taking a large share of the car market [22].

2.3 Vehicle to Grid (V2G) Concept

Energy independence and global warming are two on the rise in the world these days, and a large number of research papers are devoted to trying to solve these two problems with new ideas. Vehicle to grid (V2G) technology is one of the new technologies which involves the assistance of electric vehicles in supplying electricity to the grid during peak times (it aims to reduce the need for fossil fuels by developing electric battery vehicles or BEVs in the form of plug-in vehicles (PEVs) to solve these problems [18]).

By using the bi-directional power transfer, which means that the electric power will flow from the energy grid to the electric vehicle to charge it (storage device), or the other way from the electric vehicle battery to the power grid if the grid needs power (generation resource).

In this case the aggregated BVs will be a generation-storage unit. The whole idea of using the BVs as a distributed resource – load and generation-storage device – is known as the vehicle-to-grid (V2G) by their incorporation into the grid. [18]

Within this principle, the BVs are active participants in grid operations and play a major role in enhancing network operations efficiency, economics and environmental attributes.

Many parties are provided in the V2G operation:

1) Manufacturer of battery of EV.

2) EV manufacturer.

3) EV owner.

4) Charging stations.

5) Workplace and home.

6) Aggregator

7) Independent system operator (ISO)

8) Local Distributor

9) Regulators

Figure 1 explains the concept of vehicle to Grid [23].

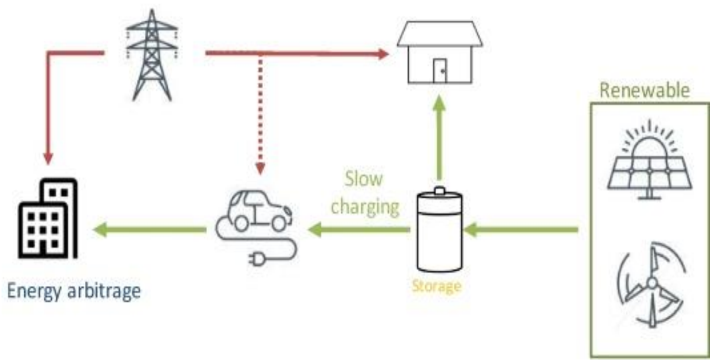


Fig.1: Concept of Vehicle to Grid**.**

2.4 Charging and Discharging Process

Electric vehicles act as machines for storage and generation, which ensures the EV battery must be charged and discharged several times.

The charging / discharging cycle of the battery for electric vehicles will be addressed in this section, based on various parameters, charging rates, charging period, battery consumption index and charging modes.

1. Charging rates: There are many rates of charging power and voltage when the customers choose to charge their electric vehicles.

A. Level 1.

B. Level 2.

C. Level 3.

As shown in Table 1, level 2 is more preferred among those levels. Due to its characteristics such as length of charging period, price and effect on battery life.

Table 1: Charging Levels.

Characteristic	Normal Charger		Rapid Charger
	level 1	Level 2	Level 3
Voltage (V)	110-120	208-240	480
Charge Power (kW)	1.8-1.9	≤ 14.4	30-250
Estimated Charge Time (h)	10-20 h	3-8 h	< 30 *min*
Estimated Price (US$)	~$1000	$500-3000	$17,500-50,000

2. Charging time:

The time the electric vehicle is charged or discharged depends on the time of usage of the electric vehicle and the availability of the power grid there is an intelligent charging method for EV where charging facilities are in response to the TOU price. The aim is to reduce the stress in the power grid under high demand where electric vehicles are discharged during the daytime peak demand times and charged at night when electricity demand is reduced and prices are lower, and to satisfy the demand response requirements in the controlled market [26].

3. Charge modes:

- Constant power charging: charging power at a certain point remains constant and the charging time of the EVs can vary with different SOC values.
- Constant time charging method: charging power will be variable depending on the time set to meet the battery energy requirement. If there is a need to shift the demand of the EVs to low load hours, it is easier to shave peak load demand as EVs charging schedule can be managed with precision.

A favored approach brings these two forms together. The cycle begins with constant charging power until the battery capacity exceeds 70% of the SOC and continues to complete the remaining 30% with a constant time system.

For both cases the time needed for EV charging varies with grid power rates. For example, the lowest charging time for the previous ways is reached at a power rate of 6.6 kW, and the longest at 1.92 kW [26].

4. Index of Battery Utilization (BU):

It is the ratio of the real distance traveled by the energy contained in the battery to the total distance, which can be overcome by the electric range. The BU value depends on the driving mode used, whether it is in road or metropolitan area, freeway area or heavy traffic area. For example, BEV has the lowest BU value, while its electric range value is the highest in the various driving modes. [26].

For example, if the measured BU value is 0.444, it means that only 44.4 percent of the energy contained in the battery is used for car trips and the remaining 55.6 percent of the battery capacity is available for the V2G service.

2.5 Technical Benefits of V2G on the Grid and Ancillary Services

- Regulation up and down

Grid frequency variations arise due to supply-demand imbalances, and erratic production from renewable energy sources. To control these fluctuations in frequency, it is important to regulate Frequency, which is an ancillary service for stabilizing the frequency at its nominal value [18].

This service can be divided into two categories concerning the path of the energy:

A. Unidirectional: The electricity just flows from or through the grid. Controllable loads such as batteries and flywheels are used to provide regulatory service and by regulating their play modes.
B. Bidirectional: flows of electricity to and from the grid. EVs are used according to the grid situation by loading or discharging them [19].

Control services have a substantial share of ISO’s overall ancillary service expenses and are considered lucrative for owners of EVs and network operators [26].

It can be applied by adjusting the generation and demand with two kinds of regulation in:

1- Regulation-down service: The frequency value increases when the output is greater than the demand. Charging the EV batteries can cause a raise in the excess power in the grid.
2- Regulation-up service: when generation is unable to meet all demand, power is injected to mitigate the impact of rising frequencies. The EV batteries have their energy discharged into grid [20],[26].

Preferred schemes to accomplish services of the Regulation:

1- state-dependent utility scheme

It depends on the charging level of the EV battery. In order to add or remove the power depending on the SOC of the battery. This avoids cases of charging batteries with tremendous amount of power when SOC is high in order to achieve Regulation-down services and the potential alternative scenario. Both are undesirable, and that is accomplished by this scheme algorithm.

2- Water-filling V2G Compliance algorithm

This algorithm is applied in wireless and wireline communication systems, and has been tested and has proven to be very effective in V2G regulatory services. It depends on having parallel channels, and the total limit must be the transmitted signal or power. Mos it must consider each channel 's initial state to determine that the path is ascending or descending and to avoid reaching undesirable point.

The water-filling algorithm is defined in figure (2) [27]. The parallel channels are the batteries of the EVs, and power is distributed by knowing the battery has the lowest SOC amount to be charged first in regulated-down case. Similarly, batteries with low SOC are avoided in regulation-up, and the process starts from the highest SOC value [28].

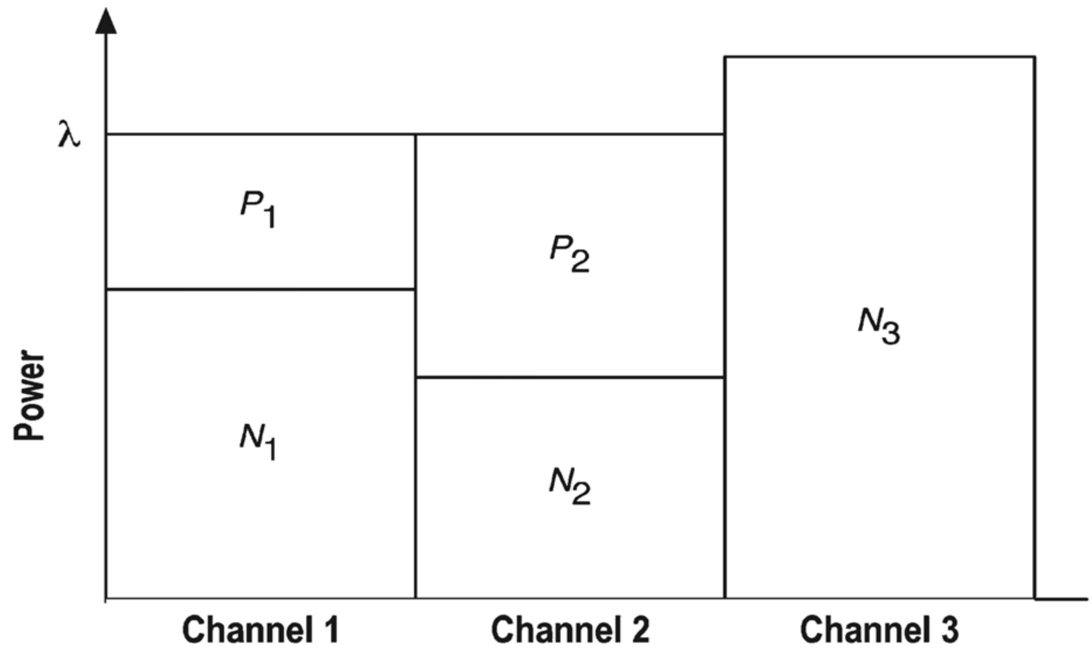


Fig.2: The Water-Filling Algorithm**.**

- Load Levelization

Load profile consists of periods of low load, periods of high load (off-peak) and peak times. The fluctuation in demand makes ISO and RTO monitoring, allocating resources, and forecasting a complicated task. With the introduction of EVs into grid and lack of proper charging process control, the procedure becomes more difficult. Here, by charging in low-load times, the aggregated EVs can lift the loads. The increased demand generated by EVs can be deployed in order to reduce the pressure to flat load curve in low load cycles in other times. Aggregating the batteries and paying attention to every single battery's SOC will ease the operation.

Therefore, load levelization provides the operators and customers with the correct implemented rates and opportunities to benefit [18].

- Delaying the start-up of the cycling and peaking units

Aggregated V2G EVs will delay cycling and peaking device startup. The most important task for the operator is to balance generation with load. For aggregated EVs, this can be done by adding the energy and power required, and starting the units a few hours before the time. Aggregated EVs' rapid response supports its position as an energy source and ensures that the ISO and RTO have all the demand necessary [25].

The effect of aggregated EVs in delaying the start-up of peak units is defined in Figure 3 [26].

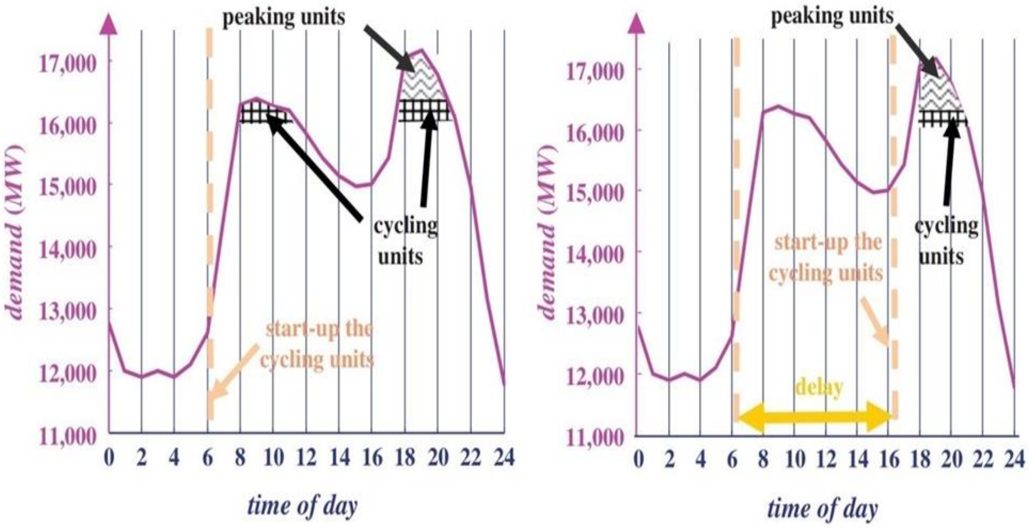


Fig.3: The Effect of Aggregated EVs in Delaying the Start-up of Peak Units**.**

2.6 Stability, Reliability and Security of Vehicle to Grid

2.6.1 Stability

Several metrics are known for assessment, such as system stability index for EVs and instability index variation coefficient. This increases customer satisfaction and quality.

Stability output and its indices are determined based on the V2G power charging rates. As a result, the stability curve is improved with a gentle slope, increasing the disparity between rates. It increases customer loyalty and efficiency.

It could reduce the losses in system power and deviation in voltage. This does enhance the price.

2.6.2 Reliability

CAIFI, SAIDI, SAIFI, and ASAI are reliability indexes known for measuring and evaluating.

The study of reliability of power systems with EVs is the approach of minimal road. It is achieved by creating a distributed network topology, giving numbers to all the buses and lines and showing each of the load points the longest and shortest ways. For non-short and short routes and for the entire network, loads d flow and reliability parameters are determined when determining a power rate of V2G.

Protection systems are the most significant element in the estimation of Reliability for non-short routes. When it occurs, it isolates the fault and the device stability or consumer is not affected by the malfunction. Reliability efficiency is severely impacted when there is no security and backup capacity. The value of incorporating and increasing the number of EVs into the grid occurs here. In the case of a failure, the effect of non-short route parameters on network reliability indexes can be minimized as the energy stored in the battery is used for backup.

The discharging rates often increase the stability of the system if they are within an appropriate range. Thus, optimizing an EV charging and discharge strategy would help to achieve a large, accurate and secure operating network [25].

2.7 Impact of V2G on Environment and Economy

In the grid, the method of delivery depends on percentage penetration of V2 G and actions of the V2 G owners. This may remove the need for improvements to Transmission and Distribution required to deliver more power from a central generation plant [29].

And it will be necessary for RES and storage systems to reduce frequency fluctuations and demands for load shifting caused by increasingly high intermittent power penetration. V2G would be a significant factor in offsetting distribution-level infrastructure costs.

Degradation of the lithium-ion battery is a serious concern. Determining whether or not V2G is hazardous to an EV battery is a complex problem which requires more testing. This test should be with V2G definition understanding, control algorithms and effects.

In Economy, distributed storage is needed to better manage grid operations and investments in improvements to the grid infrastructure, such as two-way controllers and smart meters. With the significant shift of utilities from running an unidirectional electrical grid network to one that completely facilitates transactions between utilities and consumers, these grid changes will occur at the same time. Smart grids will include the implementation of standards that resolve technological issues such as security and access to data and resources in vehicles; and a legal structure for accountability, data protection and privacy.

To optimize return on investment for the owner of EV needs a competitive market that adequately values export of V2G to the electric grid. Costs arising from deterioration of the lithium-ion battery for a given V2G transaction must be weighed. Criteria for energy assurance should include the required standards and rules for protecting the electrical grid as a critical infrastructure, particularly in protecting grid services from cyber-attacks. This could make service provision less receptive to customer need's precise timing. Nonetheless, when maintaining stability, a strong and diverse aggregate market can manage additional costs [30].

Answer to policies in the fields of air quality and climate change and the effect on EV absorption in Environment received similar responses from across the four regions. The main distinction was between those who had a heavy influence, and those who had a partial or indirect influence. All initiatives that respondents noted as having a strong impact were the programs for the purchase of electric vehicles, the policies that connect EV with renewable energy production and the development of zones for clean vehicles within urban areas [31].

2.8 Vehicle to Grid Challenges

Vehicle to grid technology is based on the bi-directional transfer of electricity, the technology moves beyond smart charging (flexible load control) and connects travel routines, electricity grid stress levels, and various electricity markets, but there are a lot of drawbacks and challenges that are yet to be solved these challenges include the battery degradation and state of charge, challenges facing the manufacturers and consumers of electric vehicles, utility challenges and security challenges.

This segment will address these challenges.

1. Battery charging status (SOC): Battery deterioration and charging status is one of the biggest challenges facing the production and use of electric vehicles and vehicles to grid.

Charging is the process of storing energy for a battery, and discharge is the process of energy dissipation. The onetime charge and discharge process complete one life cycle of the battery. Because of natural limits, battery use is limited to a fixed number of cycles, after which the battery is of no value to the owner of the EV [28].

2. Manufacturer challenges: The most critical two challenges facing automotive manufacturers are the production of battery storage and the commercialization of electric vehicles, since the idea of V2G relies on the integration of several EVs together to provide electricity to the power grid.

Two key players in the problems facing producers are fuel costs and the behavior of customers. Customers prefer to buy the EVs when fuel prices rise and when fuel prices drop the EVs are less common.

The figure below shows the impact of prospective gas prices on vehicle acquisition interest, the black dashed line illustrates the propensity to turn from PHEVs to BEVs at 4$/gal [32]

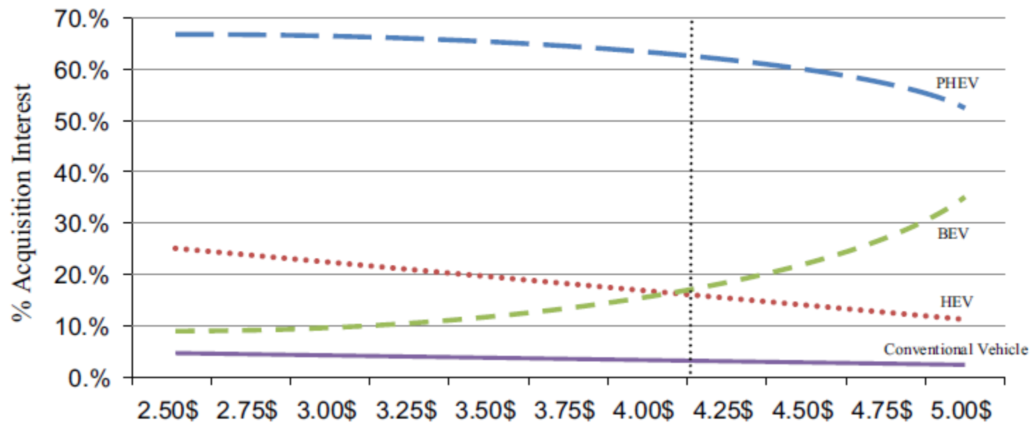


Fig.4: The Impact of Prospective Gas Prices on Vehicle Acquisition Interest**.**

1. Utility challenges: Development of infrastructure is needed in order to be able to contain the large numbers of electric vehicles integrated to the grid. PEVs need a communication and control infrastructure for fast and accurate responses to signals received from a central grid operator. Communications facilitate aggregating individual PEVs into a single controllable V2G system for providing effective grid services [33].

2. User challenges: Electric vehicle owners are not yet fully sure that utility providers will be able to use their cars to provide electricity as their batteries must be charged and discharged several times and the number of charging and discharge cycles must increase, impacting battery life and deterioration, so that manufacturers want to sell EVs that can go further [33].

There are other customer issues such as the presence of charging stations near their workplace or home, the effect of charging electric vehicles on their energy bills and the difference between the prices of electric vehicles and the prices of fueled vehicles.

3. Security: As drivers, electric vehicles don't want their personal details to be leaked out and as service providers don't want their customers to know who provides the service. There is a lot of confidential information about electric vehicles that consumers avoid sharing with the aggregators because they could be stolen or hacked [34].

Table (2): Typical Data of V2G Networks and their Privacy Impact [35].

Data	Billing relation	Reliability relation	Security relation	Privacy relation	Description
Customer ID			√	√	customer name, vehicle ID
Location data			√	√	charging location and schedule
Meter data	√				electricity consumed or supplied over a time period
Configuration data		√	√		system operational settings, thresholds for alarms, task schedules, policies, etc.
Control commands		√	√		inquiries, alarms, events, and notifications
Access control policies		√	√	√	permitted communication partners, their credentials and roles.
Time, clock setting	√	√	√		used in records and sent to other entities.
Payment and tariff data				√	informing consumers of new or temporary tariffs as a basis for purchase decisions.
Firmware, software, and drivers		√	√		software components installed and may be updated remotely.

Protection is a very critical matter to remember. The important knowledge in this phase can be linked to that. If owners 'information is compromised, other parties may create trends that explain the owners' behavior. When this information gets to the wrong hands, there might be a massive cycle of bribery of energy prices. Aggregators and local distributor side are required to do the same.

2.9 Vehicle to Grid Incentives

Electric cars require plenty of government incentives and the multiple electric vehicle manufacturers to allow people to purchase and use electric vehicles.

1) Free parking on public roads

2) Removal of import taxes

3) Free access to toll roads

4) 0% VAT

5) Access to the bus lane

6) Free access to road transport ferries

7) The government should be responsible for the maintenance and replacement of the batteries [36].

Some European countries are using these incentives:

1) Purchase, VAT, annual ownership tax exemptions.

2) Support for charging infrastructure.

3) Subsidy on new BEV (4000e) and PHEV (2000e).

4) Company car reduction like five-year exemption of annual ownership tax, 20% purchase tax until 5000 cars or 2019 (revising the phase out of tax exemptions (up at 40%).

5) Differentiated parking and Tax rebates for chargers. [37]

Not all of the benefits could be extended to Palestine. Obtaining government aid, for example, when the economic condition is not healthy. And, because of its efficiency the benefits related to the roads.

We can motivate owning by:

1- Free parking on public roads

2- Removal of import taxes

2.10 Development of Energy Policy Model

- Palestinian Council of Ministries

All the ministers are under control by the council.

- The Palestinian Legislative Council (PLC)

All the rules and laws are decided and approved by PLC. It is connected to the Palestinian Energy Authority, Ministry of Energy, Ministry of Telecommunications and Information Technology and the Council of Ministries.

- Palestinian Energy and Natural Resources Authority - PENRA.

It is connected with the Local Distributor and Regulators. Also, with the Ministry of Energy in a parallel relation.

- Ministry of Energy

It is connected with the local Distributor.

- Ministry of Telecommunications and Information Technology

It has its own Regulator which is connected with the charging stations for Information security.

- Local Distributor

It is related to the global aggregator and gives specific information about the grid statues with saving the privacy and security of information. Also, it is related with both PENRA and Ministry of Energy.

- Transmission

It is connected with the Local Distributor and Distributed Generation units.

- Distributed Generation

It is related with global aggregator, Transmission and the local Distributor.

It can be:

1- Wind stations

2- Photovoltaic systems

- Global Aggregator:

Control the local aggregators. It is connected with PENRA, with regulator and the local Distributor.

When it is in service, and as it relates to the grid, it is concerned with:

1- Statues of the grid: By analyzing the supply of electricity and the quality of power.

2- The price of electricity: which is influenced by several factors starting from the price is taken from the local distributor, if there is a lack of demand and time resources [38].

It is facing two Power availability cases:

1) Excess Energy: the aggregator must determine the price which may be the following:

A) Very low selling price: to encourage local aggregators to buy the excess and store it in batteries or to make offers at that time for the prosumers to charge their EVs.

B) Very high purchase price: the price will be very high when some customers want to discharge their vehicles, as the grid is not in need.

2) Energy shortages: when a shortage occurs and demand cannot be supplied. The aggregator had to buy from the local aggregators and provide prosumers with an acceptable price to inject the available fuel.

- Regulators

Connected with the Energy Authority (PENRA) to review and supervise the process and the relationship between the parties concerned.

1- Electric Vehicle Regulator: To regulate the buying and sale process of owners of EVs.

2- Global aggregator regulator: since it is linked to several parts and receives from them a large amount of important information. It's also known as the network's most critical component.

- Local Aggregators:

It is related to the number of charging stations located in different locations and a process supervisor.

When allocating power to the charging stations the local aggregator takes these parameters into account:

1- Total circuit losses.

2- Injected phase current.

3- Injected power amount.

4- Harmonic Distortions.

5- Line loading limits.

6- EV penetration.

7- Number of charging stations in the same network.

- Charging stations

There are numerous charging stations connected to each local aggregator and connected to EVs, and two ways of charging are provided:

1) Fast charging

2) Full current charging

* * The most important criteria to remember when selecting the charging mode are:

1- time.

2- Potential

3- Price: It is related to the local aggregator price and could be traded for the sum of electricity.

* * Through knowing, the technological probability of loading and discharging may be decided:

1- Niveaus of voltage.

2- Power efficiency: the number of times charged and discharged affect quality and cause harmonic distortion.

3- The condition around frequencies

And according to many parties these are listed and are connected to many other parameters.

* * Choosing the amount of charging power is a process of optimization between:

1- Maintenance Costs

2- Charging time: the time available to the owners and to the charging stations

* * Time to fee depends on:

A) Battery bank capacity.

B) Charger power rating: The usable power levels that the grid could manage without doing any harm to any part of the network.

C) Connected

● Prosumers:

Owners of electric vehicles acting as producers when they sell power to the grid and consumers when charging their EVs. Electric vehicles and charging stations are related.

EV owners are affected by two factors when they take their call to charge or discharge their vehicles:

1- The state of battery charging

2- Their situation: whether the charges are urgent or they do not take part in the V2 G process. [39-41]

These situations concern the prosumers and the local aggregator:

A) Bidirectional: when owners of EVs are able to charge their vehicles and discharge their vehicles according to grid requirements and their own needs.

B) Unidirectional: This could be for the owner of an EV in two cases. Second, the battery is fully charged and power may be pumped into the grid but no energy charging and buying option. Second, the battery is flat, and the owner can charge and buy but cannot sell to the grid. Therefore, the local aggregator has to deal with these scenarios, determine how much power should be injected or removed from the charging station and offer the correct price.

C) Critical status: this is an emergency case when charging process is necessary.

2.11 PV Based Off-Grid Charging Station for Electrical Vehicles

Tulpule (2013) [42] proposed a financially intellect PV based CS at the parking structure. The cost examination of the system is viewed as utilizing stopping rate, establishment cost and expense discount. Also, the system is PV subordinate which is not maintainable because of the discontinuous idea of irradiance. Goli and Shireen (2014) [43] have introduced PV based accusing station of the grid. The grid is supporting the CS when PV vitality isn't adequate for the EVs. But the lattice isn't accessible at each area which decreases the manageability of the system.

Similarly, Hernandez and Sutil (2016) [44] have introduced a PV based CS with regenerative slowing down and battery storage to help the system structure during peak-load. The point of the researchers is to use the greatest measure of RES and lessen the charging cost. Also, Li (2013) [45] proposed a PV and wind-based CS with battery storage to deal with the power generation changes during variable natural condition. In their paper, they have introduced a SoC based control way to deal with defeat the issues happened because of RES. However, they didn't decide the best possible SoC estimation procedure for the EV battery.

These studies contribute some primer discoveries which are as the following:

- To diminish the weight on the network and utilization of EVs at distant areas, a sustainable power source based off-lattice EV charging station is presented.
- The unwavering quality of the off-network EV charging station is improved by utilizing vitality stockpiling system.
- The charging and releasing of the battery storage system is represented based on PV irradiance.

2.12 Energy Models

The objective of building up energy models is to develop EV energy utilization models dependent on certifiable estimations. The proposed models are factual models dependent on the fundamental physical standards of the vehicle elements and kinematics. As a definitive objective of this examination is all-electric range (AER) forecast for electric vehicles, the energy utilization considered in this paper is the energy utilization on a battery-to-wheel scope as characterized in De Cauwer [46] and relates to the energy drawn from the battery. In this way, energy misfortunes in the energy flexibly anchor before the battery are not considered as they don't affect the scope of the EV. In that capacity, matrix misfortunes and charging misfortunes are excluded from this model. As De Cauwer et al [46] contends, it does, in any case, impact true tank-to-wheel utilization and along these lines the expenses related with true EV use. The battery-to-wheel utilization of an electric vehicle is a component of the necessary mechanical energy at the wheels, controlled by the kinematic boundaries over a direction, the drivetrain effectiveness, and the energy utilization of helpers. The absolute required mechanical energy at the wheels as an element of the kinematic boundaries portraying vehicle development can be communicated in the vehicle dynamics equation [46]:

$$E_{ij} = \frac{1}{3600}\left[m_{ij}.g.(f.\cos\theta + \sin\theta) + 0.0386.\left(\rho.C_X.A.{v_{ij}}^2\right) + \left(m_{ij} + m_f\right).\frac{dv}{dt}\right]d_{ij} \tag{1}$$

Where:

E_{ij} = Mechanical energy needed at the wheels to drive on a distance d_{ij} [kWh]

m_{ij} = Total vehicle mass [kg]

m_f = Fictive mass of rolling inertia [kg]

g = Gravitational acceleration [m/s²]

f = Vehicle coefficient of rolling resistance [-]

θ = Road gradient angle [°]

ρ = Air density [kg/m3]

C_x = Drag coefficient of the vehicle [-]

A = Vehicle equivalent cross section [m2]

v_{ij} = Vehicle speed between the point i and the point j [km/h]

d_{ij} = Distance driven from point i to point j [km]

2.13 PV Sizing

Different intuitive methods have been produced for ideal sizing of standalone PV systems. Ahmad [47] built up an intuitive method for ideal sizing of the PV/battery mix in a standalone PV system for remote houses in Egypt. The researcher began the design by figuring the averages of the day-by-day load demand and getting the averages of the day-by-day solar radiation. By utilizing the straightforward numerical equations given in Sharma et al [48]. the size of the PV array and the limit of the storage battery are estimated. The battery charge controller and inverter are picked depending on longer lifetime and thinking about the greatest anticipated power. Nonetheless, the reliability level, which may prompt over/under sizing design was not considered in the standalone PV system estimating. In Bhuiyan and Asgar [49], ideal sizing of a standalone PV system depending on intuitive method was directed for private applications in an area in Dhaka, Bangladesh. The method evaluated the day-by-day load demand, enhanced the tilt angle and calculated the PV array size and the battery capacity depending on the similar equations utilized in Sharma et al.

Kaushika and Rai [50] built up an intuitive method for sizing the PV array and the batteries in a standalone PV system for certain locales in India. The intuitive method was utilized to build up a developed system as a component of topographical coordinates. Monthly averages solar energy information is utilized with the site coordination to advance the tilt angle. The main system may not be productive in contrast of the current programming devices which utilize progressively exact optimization methods. Also, the technical and financial viewpoints are not considered in sizing the standalone PV system. Chel et al [51] directed ideal sizing of building incorporated PV system for an area in India depending on basic counts utilizing every day load demand and peak sunshine hours (PSH). The ideal PV/battery sizing mix was gotten depending on least estimation of the expense of produced unit of energy, system life cycle and capital expenses.

Besides, Al-salaymeh et al [52] utilized an intuitive method for sizing a standalone PV system for residential buildings in Jordan. The researchers utilized averages of day by day meteorological and load demand information for this reason. Utilizing straightforward estimations, the researchers began the sizing.

2.14 Standalone

Goel [53] suggested that a PV system model has been created to enhance its size depending on a very much characterized solar energy potential and load. The created model contains models for PV array, storage battery and charge controller. Notwithstanding, the optimization puts into account the consolidated least cost with least loss of load probability.

Kaushika N, Gautam N, and Kaushik K. [54] proposed that enhancement of PV systems in Delhi has been finished utilizing the loss of power supply probability. A characterized load and every day solar energy has been utilized to figure the loss of power supply probability. At that point an estimating bend is produced depending on the determined loss of power supply probability. The quantity of PV modules and battery capacity are assessed depending on the base cost. A systematic strategy for measuring PV systems depending on the idea of loss of load probability has been likewise evolved [55]. The technique thinks about the standard deviation of the loss of load probability just as yearly number of systems break downs and the standard deviation of the yearly number of break downs. The streamlining of the PV array tilt angle is done as such as to augment the gathered yield.

In previous studies, models for the PV segments have been recommended to ideally structure these systems, none of these works has introduced an operational model for PV system to approve the proposed outcomes. Then again, a portion of the models proposed in the literature, for example, the works introduced in [56-59] principally center around the yield intensity of the PV array only, in the interim, none of these models have considered the energy follow in the entire system. In view of this, this paper presents energy stream models for a kind of PV systems, to be specific, standalone PV systems utilizing MATLAB. The principal target of this model is to foresee the exhibition of PV systems through a particular timespan which approves PV system sizing procedures.

Chapter Three
Modeling of Bus Energy Consumption

This study was carried out during the spring semester of 2020. The study's questions and objectives are mentioned in the first chapter. Characterization of the study contained geography and topography. Then, the researcher collected the data from different resources such as, specialized institutions and the public transportation drivers.

The data was analyzed in several ways. The road data, energy consumed per trip, bus demand, number of bus detection and the total energy needed per day were all analyzed following different equations and methods. Also, the used PV system components and design were studied. Finally, results, conclusion and recommendations were illustrated.

3.1 Data Collection

To conduct a research, it is necessary to have sufficient information to help doing the research and reach realistic results. For this, data collection is considered as one of the most important steps in a scientific research.

There are several methods to follow while collecting data. The researcher collected some of the data from specialized institutions and resources such as, the Ministry of Transportation to obtain a road plan, the number of current vehicles and the number of daily trips.

Table 3: Number of Passengers Per Hour

Hour	Passenger from Nablus to Ramallah	Passenger from Ramallah to Nablus
5	35	0
6	235	70
7	315	140
8	270	190
9	440	79
10	230	79
11	109	80
12	100	145
13	80	140
14	80	323
15	225	228
16	225	228
17	140	28
18	35	28
19	28	14
20	14	0

Also, verbal communication with public transportation drivers was made to obtain the number of daily trips per hour and match them with other information.

3.2 Road Data Analysis

The road plan from Ramallah to Nablus was obtained, as shown in the figure below This figure was analyzed and its coordinates represented the overall traveled distance, 50 km, and the street’s height above the sea. These coordinates were used to determine the vehicles’ energy consumption, whether electric or fuel energy, with accordance to the street’s angle. The traveled distance was divided into pieces of 25m each, an equivalent of 2000 point.

The following figure shows the profile and height of each point of Nablus-Ramallah run based on the adapted steps.

Fig.5: The Road Plan from Ramallah to Nablus.

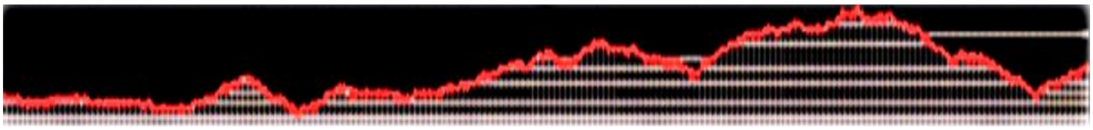


Fig.6: The Height of Each Point from the Street.

3.3 Energy Consumed Per Trip Calculation

Based on the road data analysis and previous studies and in order to accurately estimate the daily hourly energy profile of the run, the energy consumed by the adapted BV bus is needed to be modeled. Here, it is usually mentioned in the datasheet of any BV bus as energy consumption (kWh) per km. However, this consumption cannot be adapted as it is done under specific conditions of loading and road topology. Thus, accurate energy consumption calculation needs to be done.

The road angle (grade) is calculated by using the following equation,

$$\Theta = \tan\text{-}1\ (\frac{\Delta E}{\Delta D}) \tag{2}$$

Where, Θ is road gradient angle, E is the elevation and D is the distance covered.

Figure 6 shows the profile and height of each point of Nablus-Ramallah run based on the adapted steps.

In general, the energy utilization that is considered in this paper is the energy utilization on a battery-to-wheel scope as characterized in [60] and relates to the energy drawn from the battery. In this way, energy misfortunes in the energy flexibly anchor before the battery is not considered as they don't affect the scope of the EV. In that capacity, matrix misfortunes and charging misfortunes are excluded from this model. As De Cauwer et al in [60] concluded, the battery-to-wheel utilization of an electric vehicle is a component of the necessary mechanical energy at the wheels, controlled by the kinematic boundaries over a direction, the drivetrain effectiveness and the energy utilization of helpers. The absolute required mechanical energy at the wheels as an element of the kinematic boundaries portraying vehicle development can be communicated in the vehicle dynamics equation as follows,

$$E_{ij} = \frac{1}{3600}\ [M_{ij}.g.(f.\cos\theta + \sin\theta) + 0.0386.\left(p.C_x.A.{v_{ij}}^2\right) + \left(m_{ij} + m_f\right).\frac{dv}{dt}]\ d_{ji} \tag{3}$$

Where E_{ij} is the mechanical energy required at the wheels to drive on a distance, d_{ij} [kWh], M_{ij} is the total vehicle mass [kg], M_f is fictive mass of rolling inertia [kg], g is gravitational acceleration [m/s^2], f is vehicle coefficient of rolling resistance [-], θ is road gradient angle [°], ρ is air density [kg/m^3], C_x is the drag coefficient of the vehicle [-], A is vehicle equivalent cross section [m^2], V_{ij} is the vehicle speed between the point i and the point j [km/h] and d_{ij} is distance driven from point i to point j [km].

Here, the amount of energy consumed in the route in one direction differs from the energy consumed in the way back, due to the change of road angle in relation to the vehicle.

After that, equation (3) is used to calculate the energy consumed per trip through the route back and forth and compared with the amount of energy expected to be consumed, which is mentioned in the vehicle's data sheet [61].

3.4 Bus Demand Data Analysis

As previously mentioned, the data obtained from the Ministry of Transportation represented in the number of licensed public vehicles (Ramallah - Nablus), the number of daily trips and peak times for travel during the day were analyzed, as well as the information obtained from the drivers.

The number of trips per hour was multiplied by the amount of energy consumed per trip was calculated to know the number of daily trips per hour and the amount of energy consumed per hour. Accordingly, the number of passengers per hour from Nablus to Ramallah and vice versa was calculated.

3.5 Number of Bus Detection

After obtaining the number of passengers per hour, it becomes possible to determine the number of electric buses required every hour to cover the passengers demand, as one bus can accommodate 28 passengers.

Figure 7 shows the adapted methodology for calculating the number of buses required.

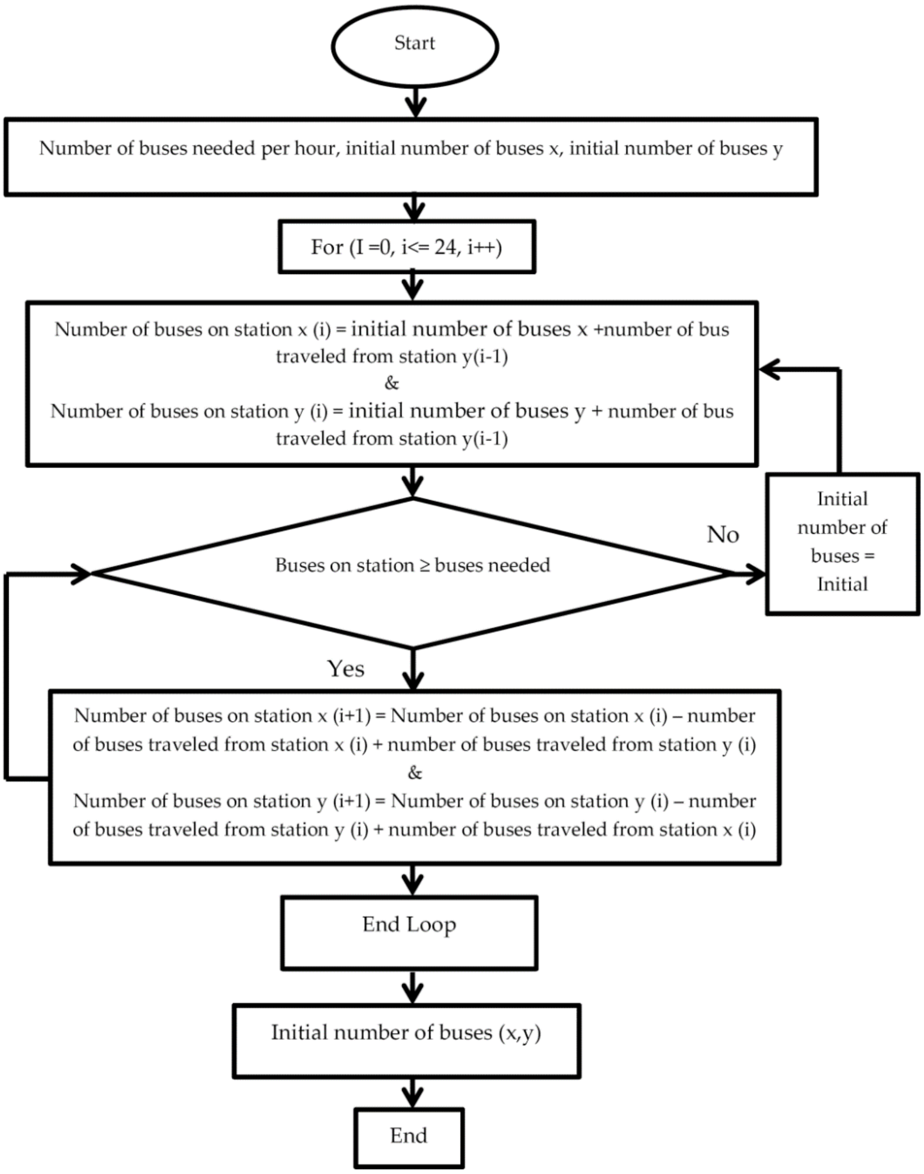


Fig.7: Adapted Methodology for Calculating the Required Buses**.**

A primary number of buses is assumed at the beginning of the daily road trips, in both Nablus and Ramallah stations, after that, the number of buses required is determined to ensure that there is no shortage of vehicles. Also, the number of buses that are required to be housed in Ramallah and Nablus are determined in this phase.

The number of buses needed is determined based on three scenarios. In the First Scenario, the buses will be charged at the end of the day only from the charging stations, while PV array will be charging the batteries of the charging stations all of the day. This scenario aims to harness the maximum energy collected by PV array during the day. In the Second Scenario, the buses will be charged by the PV system as a normal solar charger on the charging stations. The charging process will take up to 3 hours max to charge from 0-100 (PV will power the buses and in case of power deficit, batteries of the charging stations will charge the buses batteries). This scenario aims to minimize the size of required storage batteries, number of required buses and to assure a continuous charging process by the PV array. The S is quite similar to the Second Scenario. The difference between them is in the merging between diesel operating shuttles and electrical buses. It is assumed in the Third Scenario that the run’s demand will be covered during the peak period by the electric buses, while the demand during the off-peak period will be covered by the diesel operating shuttles.

3.6 Total Energy Needed Per Day

The amount of energy required per day was calculated by analyzing the daily number of trips of each bus and the amount of energy consumed in each trip. The relationship to calculate the total energy is as follows:

Total energy = energy per trip(N-R) * number of trips (N-R) + energy per trip(R-N) * number of trips (R-N) (4)

N-R: NABLUS TO RAMALLAH

R-N: RAMALLAH TO NABLUS

Taking into consideration the separation between the total consumption of the vehicles that will be launched from Ramallah and the vehicles that will be launched from Nablus, as each of them will be affiliated to a different charge station, in the first scenario. In the second and third scenario, the total will be dependent on the bus’s location when the battery runs out of energy to determine which station between Nablus and Ramallah will be responsible for its charging.

Chapter Four

Modeling of SAPV

A numerical simulation of the proposed system will be conducted using Matrix Laboratory (Matlab). MatLab is “A programming language for technical computing from The MathWorks, Natick, and MA, used for a wide variety of scientific and engineering calculations, especially for automatic control and signal processing”. (MathWorks)

Matlab simulation is supposed to give results similar to actual results. The supposed results are the energy generated per day and the loss of power supply probability.

PV systems are ecological, green, and energy-efficient. The establishment of PV systems played a significant role around the world. However, the disadvantage of PV systems is the high expense compared to ordinary energy sources. Nowadays, many researchers are concentrating on the optimization of PV systems in order to make the number of PV modules, capacity of storage battery, capacity of inverter and PV array tilt angle ideally selected. The size and execution of PV systems unequivocally rely upon meteorological variables such as solar energy, wind speed and ambient temperature. Therefore, to enhance a PV system, broad examinations identified with the meteorological variables must be carried out [62,63].

The modeling of PV components such as PV module/array, battery and inverter play important roles in optimizing PV systems. Arun, Banerjee, Bandyopadhyay [64] stated that the probabilistic methodology was utilized to upgrade PV systems by considering a probability function which is communicated as the probability of losing load, the situation when the energy source can't satisfy the load demand, with regard to battery, PV array energy output and load demand. Consequently, the assurance of an ideal storage battery depends on the reliability of the PV system, the ideal PV array size is calculated utilizing the worst month method.

In Europe, streamlining of PV system is accomplished for three sites in which streamlining considers PV array sizing curves derivation and minimum storage requirement in order to fulfill the desired load demand. The sizing curves of the PV array were useful in determining the PV array size depending on the needed energy production by the system [65].

4.1 Modeling for Standalone PV Power Systems

Modeling of standalone PV system, (SAPV) is significant in measuring system’s energy sources. consequently, numerous mathematical models have been portrayed for SAPV systems.

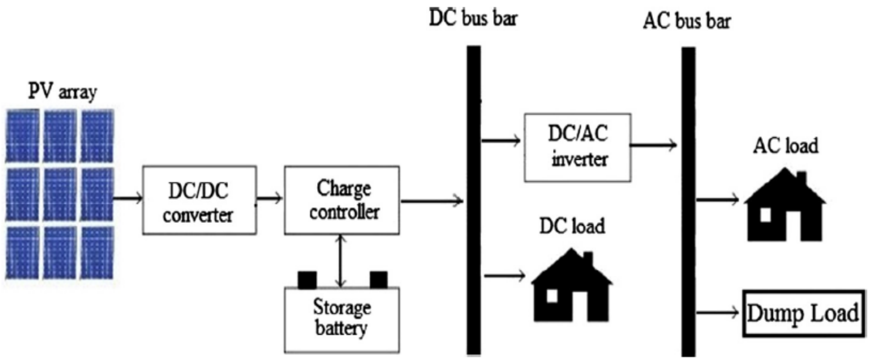


Fig.8: A Typical PV System Components.

Figure 8 shows a typical PV system comprising of a PV module/array, power conditioner, for example, charge controller or maximum power point tracking controller (MPPT), batteries, inverter and load [66].

When all is said is done, a PV array gathers energy from the sun and changes it to DC current. The DC current moves through a power conditioner to supply the load through an inverter. The daily yield power delivered by a PV module/array is given by [66],

$$P_{pv}(t) = P_{peak} * \left[\left(\frac{G(t)}{G_{standard}}\right) - \alpha_T[T_c(t) - T_{standard}]\right] * \eta_{wire} \tag{5}$$

Where:

$G_{standard}$ and $T_{standard}$ = the standard test conditions for solar radiation and ambient temperature. (G=1000W/m^2 & T= 25 c^o)

α_T = the temperature coefficient of the PV module power which can be obtained from the manufacturer datasheet. ($\alpha_T = -0.370\%/c^o$)

η_{wire} = the efficiency of wires. ($\eta_{wire} = 90\%$)

T_c = the cell temperature.

The cell temperature can be calculated by [66],

$$T_c(t) - T_{ambient}(t) = \frac{NOCT - 20}{800} G(t) \quad (6)$$

Where:

NOCT = the nominal operation cell temperature which is measured under 800 W/m^2 of solar radiation, 20°C of ambient temperature and 1 m/s of wind speed.

The calculation of energy produced by the PV array (EPV) relies upon the time venture of the climate information used. So, if the input solar radiation data are hourly, the power delivered by the PV array PPV(t) is equivalent to PV energy production EPV(t). But if the input data are daily solar energy then [66],

$$E_{pv}(t) = P_{pv}(t) * \mathrm{S} \quad (7)$$

Where:

S = the day length which can be given by:

$$\mathrm{S} = \frac{2}{15} \cos^{-1}(-\tan L \tan \delta) \quad (8)$$

Where:

L = the latitude

δ = the angle of declination, given by:

$$\delta = 23.45 \sin \left[\frac{360\ (284 + \mathrm{N}}{365}\right] \tag{9}$$

Where:

N = the day number

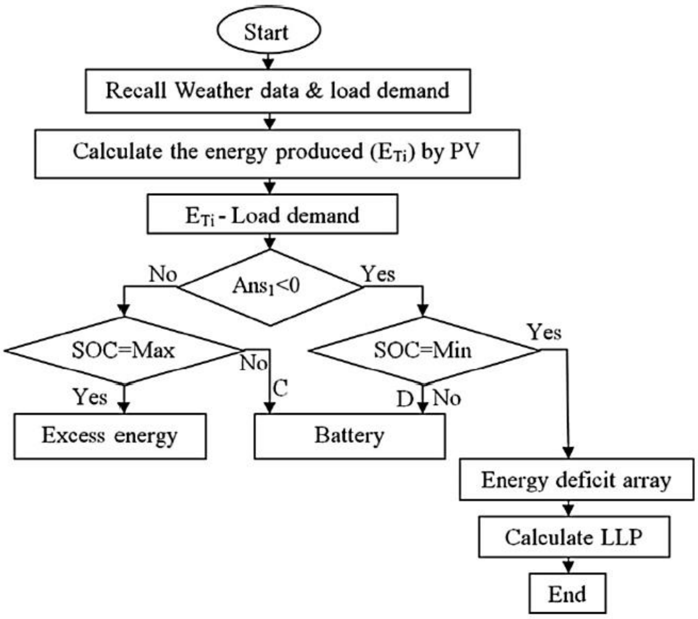


Fig.9: the Logic Diagram for Modeling Standalone PV System**.**

The energy at the front end of a SAPV system or at the load side is given by [60],

$$E_{net}(t) = \sum_{i=1}^{366} \left(E_{pv}(t) - E_L(t)\right) \tag{10}$$

Where:

$E_L =$ the load energy demand.

The result of Eq. (10) is either positive (E_{PV}>E_L) or negative (E_{PV}< E_L). If the energy difference is positive then there is an excess in energy (EE), if negative then there will be an energy deficit (ED). The excess energy is stored in batteries in order to be used in case of energy deficit. Meanwhile, energy deficit can be defined as the disability of the PV array to provide power to the load at a specific.

Consequently, the energy flow across the battery can be expressed by [66]

$$E_{Battery}(t) = \left\{ \begin{array}{ll} E_{Battery}(t-1) * \eta_{inv} * \eta_{wire} * \eta_{discharging} - E_L(t) & E_D < O \\ E_{Battery}(t - 1) * \eta_{charging} + E_{PV}(t) & E_D > 0 \\ E_{Battery}\,(t-1) & E_D = 0 \end{array} \right\} \quad (11)$$

The model above was described using a MATLAB code. To do so, first, the source file and the variables like, hourly solar radiation (G), hourly ambient temperature (T) and the hourly load demand (L) were defined. Also, some specification of the system should be defined like, the capacity of the PV array, the capacity of the storage battery, inverter rated power, the efficiency the PV module, the allowable depth of charge, the charging efficiency and the discharging efficiency.

The simulation process undergoes different stages. First, the produced energy by the PV array is calculated. Then, the energy net E_{net} is also calculated. The maximum condition of charge of the battery (SOC) is given to the variable (SOC) as an initial value. Moreover, metrics are characterized in order to contain the results of battery state of charge (SOC_f), damped energy ($Damp_f$), and energy deficits (Deff) are started and characterized.

Now a "For loop" is started to look through the values of the (E_{net}) array. At that point, the energy contrast is added to the variable SOC_i. Here, if the outcome SOC is higher than SOC_{max}, the damped energy is determined and stored in "$Damp_f$" array. Meanwhile, the Deff is set zero and the battery state of charge does not change. This condition speaks to the instance of the energy produced by the PV array and is higher than the energy demand. From this step, the battery is fully energized.

The second condition speaks to the case that the energy produced by the PV array and the battery together is lower than the energy required. Here the battery must quit supplying energy at the defined depth of discharge (DOD) level while the Deff equals the uncovered load demand. In addition to that, the damped energy here equals zero.

The last condition speaks to the case that the energy produced by the PV array is lower than the load demand, however, the battery can cover the reaming load demand. For this condition there is no damped nor deficit energy, while the battery state of charge equals the distinction between the maximum SOC and supplied energy.

Lastly, the battery state of charge values, deficit and damped energy values are reviewed and the loss of load probability is calculated.

Chapter Five

Design of Standalone PV System

Solar energy systems work as a clean and green source of energy. However, it is essential to design it in an ideal way in order to be an effective system and meet the load demand. Therefore, the designing process is an important and sensitive one, especially in the off-grid systems, because the solar system is the only source of energy in these systems.

In this chapter the main components of the solar system and the types used in the design will be discussed. In addition to technical parameters, economical parameters and optimal sizing equations for the solar system based on a numerical method are done.

5.1 Standalone PV System Configuration

A regular standalone PV system comprises of a PV generator, storage battery, DC/DC converter, charge controller, inverter, AC or potentially DC loads and damping load as illustrated in Fig. 9. A standalone PV system has no association with an electric utility grid. A PV generator is generally comprised of a PV array that is made out of numerous PV modules, while each PV module is made out of numerous solar cells. The storage battery stores energy when the power delivered by the PV generator surpasses the necessary load demand and frees it back when the PV generator production is lacking. The load demand for a standalone PV system can be of numerous kinds, DC or potentially AC load. The power molding unit functions as an interface between all the PV systems' components, gives control and secures the system. Generally, the regularly used components in the power molding unit are DC/DC converter, charge controller and inverter [67]. Moreover, the damping load is required for damping the excess energy that is delivered if the energy produced by PV array is more than the load demand and the storage batteries are completely energized, at the same time.

5.2 Technical Parameters

Because the solar radiation values are normally haphazard and vibrate, designers find it important to resolve the standalone PV system's availability in order to guarantee that the system can fulfill the load demand.

5.2.1 Loss of Power Supply Probability

Loss of power supply probability (LPSP) is characterized as the percentage of power supply that cannot fulfill the load demand. It demonstrates the reliability of power supply to load. LPSP is given by the proportion of summation of all loss power supply, LPS (t) at a particular timespan (t) over the summation of load demand, LD(t) simultaneously period (t). LPSP is mathematically conveyed as [68,69]:

$$LPSP = \frac{\sum_{t=1}^{N} LPS(t)}{\sum_{t=1}^{N} LD(t)} \tag{12}$$

In which:

$$LPS(t) = LD(t) - E_{Sys}(t) \tag{13}$$

Where:

$E_{Sys}(t) =$ the total generated energy from the system. (14)

In the meantime, if LPSP is equivalent to 0, it implies that the load demand is completely fulfilled at a particular timeframe (t). Then again, if LPSP is not equivalent to 0, it implies that the load demand is not completely fulfilled. For LPSP somewhere in the range of 0 and 1, it implies that the supplied power cannot completely cover the load demand in light of deficient solar radiation and the battery storage capacity.

5.2.2. Loss of Load Probability

Loss of load probability (LLP) demonstrates how regularly a system is not able to fulfill the load demand or the mean load percentage not met by the system. It is characterized as the proportion of total energy deficit to the total load demand during a particular timeframe. LLP can be expressed as [70]:

$$LLP = \frac{\sum_t^T DE(t)}{\sum_t^T P_{load}(t)\Delta t} \tag{15}$$

Where:

DE(t) = the deficit energy that is characterized as the incapacity of the system to supply power to the load at a particular timeframe.

P_{load} = the load demand simultaneously.

Δt = the time period of both terms.

5.2.3 Loss of Load Expected

Loss of load expected (LOLE), also called the shortage of energy, is characterized as not supplying the load demand with energy in the case when the load demand is more than the generated energy from the supplier because of the generating capacity deficiency, shortage in energy supplies and/or sudden increase in load demand. LOLE is given by Upadhyay and Sharma as [71]:

$$LOLE = \sum_{t=1}^{T} E[LOL(t)] \tag{16}$$

Where:

$E[LOL(t)]$ = the predictable amount of loss of load at a particular timeframe (t) which can be evaluated by:

$$E[LOL(t)] = \sum_{s \in S} T(s) f(s) \tag{17}$$

Where:

s = the current condition of loss of load.

S = the series of all the loss of the potential load conditions.

$T(s)$ = the term of loss of load.

$f(s)$ = the probability of meeting the current condition of loss of load.

5.2.4 Equivalent Loss Factor

Equivalent loss factor (ELF) term consists of the necessary information about load outages for number and magnitude of them, which is known as the rate of efficient timeframe in hours of load outage to the total process time in hours. ELF is formulated as [72]:

$$ELF = \frac{1}{T}\sum_{t=1}^{H}\frac{E\big(Q(t)\big)}{D(t)} \tag{18}$$

Where:

T = the extent of time.

$Q(t)$ = the amount of the unsupplied load demand at time t.

$D(h)$ = the power demand at time t.

Whilst, the accepted amount of ELF of a standalone PV system in remote areas is when ELF < 0.1. ELF = 0.0001 is aimed by electricity suppliers in advanced areas [73].

5.2.5 Total Energy Loss

Total energy loss (TEL) shows the energy loss because of the additional power generated from a standalone energy system. TEL has to be reduced by putting the rules in which power generation should not overrun the needed threshold at an analyzed timeframe T, which is assumed to be 8760 h. TEL is given by [74]:

$$TEL = \begin{cases} \sum_{t=1}^{T}\left(E_E - LD(t)\right), & if\ LD(t) < E_E \\ 0, & otherwise \end{cases} \tag{19}$$

$0 \ < TEL \leq THR$

Where:

$E_E =$ the additional generated energy from the system.

$LD(t) =$ the load demand.

$THR =$ a particular threshold over the time t, that is highly relying on the supplier energy production.

Whilst, the additional energy from the supplier might be damped using a damping load in a standalone PV system or might be sold to the grid if the grid is joined with a PV system.

5.2.6 State of Charge

State of charge (SOC) of a storage battery shows the amount of energy that can be saved in a system in order to choose a suitable battery capacity for a particular system. It can be evaluated by using a simplified mathematical equation as [75]:

$$SOC\ (t+1) = SOC(t) + \int_0^t \frac{I_{bat}}{c_{bat}}\ .dt) \tag{20}$$

Where:

$I_{bat} =$ the battery current, it can be either a charged or discharged current.

t =time.

C_{bat} = battery capacity.

5.2.7 Level of Autonomy

Level of autonomy (LA) is the time rate which expressed the proportion of load covered based on the operational time of the system. LA can be given as one minus the result of the not supplied number of hours of load to the system's operational time. It is given by [76]:

$$LA = 1 - \frac{T_{LOL}}{T_{Operation}} \tag{21}$$

Where:

T_{LOL} = the overall not supplied number of hours of load.

$T_{Operation}$ = the overall number of system operation hours.

5.3 Economic Parameter

Economic parameters are used to choose one of the three scenarios mentioned in Chapter Three, in addition to a fourth one, which is keeping the current system. The round-trip cost per passenger will be estimated. Also, a comparison between round trip cost per passenger and the proposed system and the current system which is based on seven passengers' van and diesel fuel will be conducted. In addition, the initial investment, savings and the simple pay-back period (SPBP) will be calculated.

5.3.1 The Initial Investment

The initial investment is the sum of the costs and, in our case, it includes the cost of buses, the cost of land and the cost of constructing solar energy stations.

5.3.2 Trip Price Per Person

The trip price for each person will be determined by calculating the costs of a single trip and dividing it by the number of passengers per trip (bus capacity). This will be applied in both cases, diesel and electricity.

5.3.3 Simple Payback Period

First of all, the saving in the new system will be calculated which includes the diesel cost and the salaries of the drivers. Then, the SPBP is calculated and finally the trip price per passenger will be determined by calculating the costs of a single trip divided by the number of passengers per trip (bus capacity) utilizing the following equation:

$$DIESEL\ CONSUMED\ = \left(Energy\ per\ trip(KWH) \times\ 3600\left(\frac{KJ}{KWH}\right)\right) \div 36\,\frac{MJ}{LITRE}$$

$$DIESEL\ COST = DIESEL\ CONSUMED(L) \times\ LITRE\ COST\ (\frac{\$}{L})$$

$$SPBP = \frac{initial\ investment}{savings} \tag{22}$$

$$Trip\ cost\ per\ passenger = \frac{\text{operation cost per year}}{\text{number of passengers per year}} \tag{23}$$

$$Operation\ cost = driver\ salary + depreciation + maintenance\ cost \tag{24}$$

5.4 PV System Components Used

5.4.1 Solar Cells Panels

It is considered as the main system where the transfer of radiation solar to electrical energy. The panels used in the design process are of a kind of Sunket with a capacity of 440 Wp. The main information of the data sheet for the PV module is shown in figures 10 and 11.

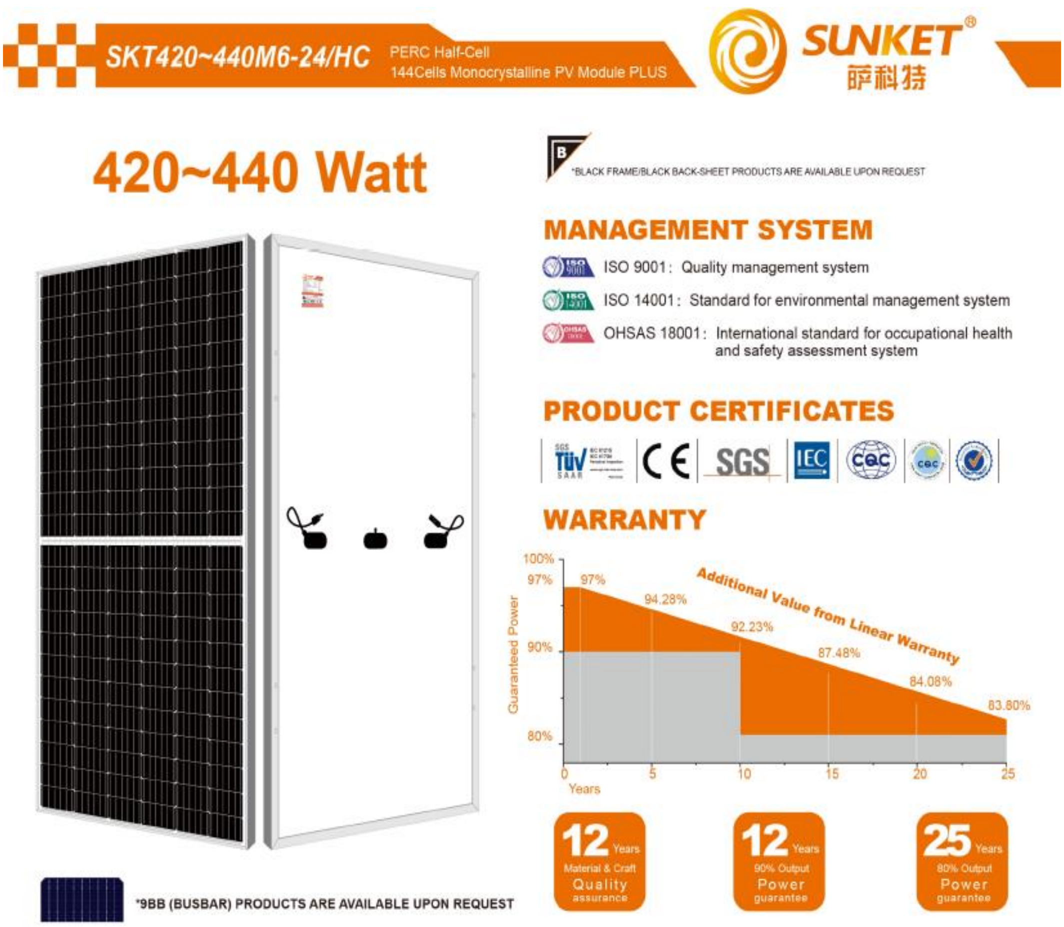


Fig.10: Data Sheet Information for PV Module 1.

Module Type	SKT435M6-24/HC	SKT440M6-24/HC
Maximum Power- Pmax(W)	435	440
Open Circuit Voltage - Voc(V)	49.4	49.6
Short- Circuit Current - Isc(A)	11.26	11.33
Voltage at Pmax -Vmp(V)	40.8	41.0
Current at Pmax - Imp(A)	10.67	10.74
Module Efficiency -ηm (%)	19.6	19.8

STC: Irradiance 1000W/m², Cell Temperature 25℃, Air Mass 1.5

Power Tolerance(W)	(0,+5W)
Maximum System Voltage(V)	1000/1500
Maximum Series Fuse Rating (A)	20

Temperature Characteristics

Pmax Temperature Coefficient	-0.370%/℃
Voc Temperature Coefficient	-0.286%/℃
Isc Temperature Coefficient	+0.057%/℃
Operating Temperature	-40~+85℃
Nominal Operating Cell Temperature(NOCT)	45±2℃

Fig.11: Data Sheet Information for PV Module 2**.**

5.4.2 Batteries

In the Off-Grid systems, the storage system is the basis, therefore it should be selected and its number should be calculated to ensure that the required load is met. In our system, the used batteries are of Lithium-Ion Battery (GT 12V600A) type, and its voltage is 12.8 volts and 600 Ah.

5.4.3 Charge Controller

It is an organizing device for the process of charging the batteries from the solar panels. It protects the batteries from the increase of load and also prevents the increase of voltages which may affect the efficiency and life of the battery.

5.4.4 Double Inductor Boost Converter

It is a DC-DC voltage transformer that relies on a new technology to double the conversion rate, as it raises the voltage to nearly ten times the original voltage. It is also used in the system to reduce the number of solar panels in series.

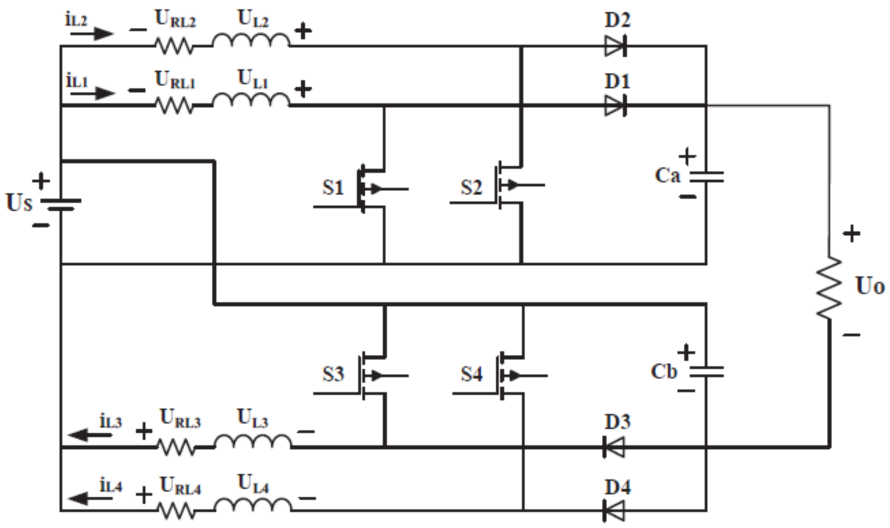


Fig.12: Double Inductor Boost Converter Circuit**.**

Voltage gain of the circuit can be determined by applying KVL in two separated circuits as follows [77]:

$$-U_O + U_{Ca} + U_{Cb} - U_S = 0 \tag{23}$$

$$U_O = U_{Ca} + U_{Cb} - U_S \tag{24}$$

Where:

U_S = DC input voltage

U_O = DC output voltage

U_{Ca} = Capacitor voltage across C_a

U_{Cb} = Capacitor voltage across C_b

Accordingly, the voltage gain of the circuit is as follows [77]:

$$= \frac{U_O}{U_S} = \frac{(1)}{(1-D)} \tag{25}$$

This means that the voltage can be raised over a traditional non-isolated boost converter which depends on the value of the duty cycle.

5.5 Inductance Design

Since the interleaving idea can lessens input current ripple likewise with inductance sizing, yet the converters have to be operated in a continuous conduction mode (CCM). With a maximum current ripple (IL), it is permitted to use for deciding a proper value of the current through the inductance as follows [77]:

$$L = \frac{D.U_S}{4.\Delta I_L .f_S} \tag{26}$$

5.6 Capacitance Design

The output voltage ripple of the circuit depends on the size of capacitor. In any case, there are two capacitors connected in series, which impact the output voltage ripple (U_{bus}). The estimation of every capacitor relies upon the output’s current (I_{out}), duty cycle (D) and depends contrarily with U_{bus} , exchanging recurrence (f_s) as follows [77]:

$$C_{bus} = \frac{I_{out}.D}{2.\Delta U_{bus}.f_s} \qquad (27)$$

5.7 Sizing of Standalone PV System

Generally, in the process of sizing a standalone PV system, areas of the system and meteorological data are acquired. The necessary kWh/yr to fulfill the load demand, the kWh/yr produced by the PV system, the Ah of battery banks, the place of the system and the system cost have to be studied when sizing the system [78]. Many sizing methods are used such as, intuitive, numerical, analytical, commercial computer tools, artificial intelligence (AI) and hybrid methods. The researcher's main concern will be on the intuitive method.

In [79] the methodologies of sizing standalone PV systems or solar chargers are investigated. In general, there are three main methods for optimally sizing solar chargers, which are intuitive, numerical and analytical methods. According to [79] the most accurate method is the numerical method whereas the system is designed first based on the intuitive method and then it is simulated and evaluated based on specific technical parameters. Based on the values of these technical parameters, a numerical iteration method is applied to the sizes concluded from the intuitive method so as to reach the optimum size(s) that fulfills the adapted technical parameters. After that, the resulted candidate(s) are evaluated based on economical parameters in order to achieve a reliable system at minimum cost.

Based on that, in this research the system is designed intuitively first based on the reported methodology in [81]. After that an accurate model of the charging system is adapted based on the validated models presented in [82] so as to simulate the system and refine its size numerically. Moreover, the model presented in [82] is used to validate the performance of the system.

The intuitive method utilizes an improved estimation without building up quantitative connection between the subsystems in a standalone PV system or thinking about the variance in solar radiation [82]. In this method, the size of PV array is gotten by the average energy that is delivered from the PV array during the structuring timeframe which overruns the load demand by a securing factor, which is chosen depending on the designers' experience, which may be inaccurate. The intuitive method estimates the components' sizes utilizing a straightforward estimation; however, it has a disservice where it might prompt over/under sizing of the stand $E_L$alone PV system that will cause low dependability for the system or/and expands system's capital, operational and maintenance costs [82]. Thus, this method is just reasonable to be utilized for assessing initial and rough approximation of the standalone PV system. The processes of the intuitive method are shown in Fig. 14. Basic numerical equations are utilized to estimate the ideal sizes of the PV array, P_{PV} and the storage battery are given as follows:

$$P_{PV} = \frac{E_L}{\eta_S \eta_{Inv} PSH} S_f \tag{28}$$

Where:

E_L = the load energy consumed daily.

η_S and η_{Inv} = the system's components' efficiency.

PSH = the peak sunshine hours.

S_f = the security design factor.

The capacity of storage battery can be expressed as:

$$C_{Wh} = \frac{E_L D_{Autonomous}}{V_B DOD \eta_B} \tag{29}$$

Where:

V_B = the battery's voltage.

η_B = the storage battery's efficiency.

DOD = the depth of discharge rate of the battery.

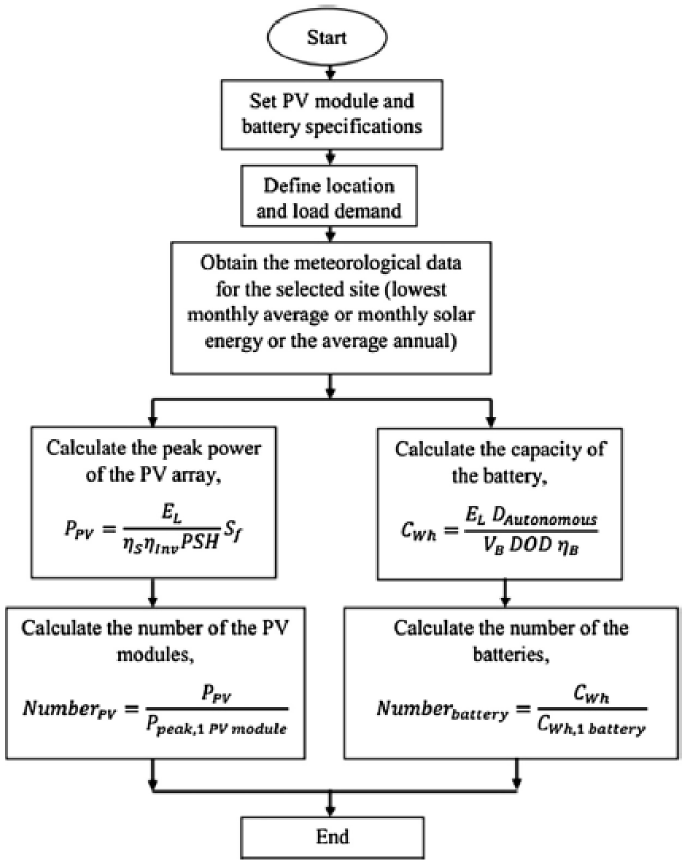


Fig.13: General Intuitive Method Flowchart**.**

The processes of the intuitive method work by estimating the averages of the day-by-day necessary load energy. At that point the PSH was utilized to acquire the PV array size. In any case, 10% of load demand utilization for 5 days during overcast weather was utilized to acquire the capacity of the battery.

Each station's system was designed using the method mentioned in [83] in addition to the previews equations to design Off-Grid systems in an optimal way, the following tables were used [83].

Table 4 Corrected amp-hur Load Calculation

Total amp-hour load (Ah/DAY)	Wire efficiency factor (DECIMAL)	Battery efficiency factor (DECIMAL)	Corrected amp-hour load (Ah/DAY)
	÷ 0.98	÷ 0.9	=

Table 5 Design Current Calculation

Peak sun (HRS/DAY)		Design current (A)
Tilt Angle	=	

Table 6 Batteries Calculation

Corrected amp-hour	Storage days	Maximum depth of discharge	Derate for temperature	Required battery capacity (Ah)	Capacity of battery (Ah)	Batteries in parallel
	x ÷	÷ /		= /	÷	=

Table 7: Modules Calculation

Nominal system voltage (V)	Nominal battery voltage (V)	Batteries in series	Batteries in parallel	Total batteries
	÷	= /	X	=

Batteries in parallel	Capacity of selected battery (Ah)	System battery capacity (Ah)	Maximum depth of discharge (DECIMAL)	Usable battery capacity (Ah)
	X	=	x	=

Design current (A)	Module derate factor (DECIMAL)	Derate design current (A)	Rated module current (A)	Modules in parallel
	÷	=	÷	=

Nominal battery voltage (V)	Batteries in series	Voltage required for load (V)	Highest temperature module voltage (V)	Modules in series	Modules in parallel	Total modules
X	x /		÷	= /	X	=

<table>
<tr><td colspan="7">PV module information</td></tr>
<tr><td>Make\model</td><td colspan="3"></td><td>Nominal volts</td><td colspan="2"></td></tr>
<tr><td></td><td colspan="3"></td><td></td><td colspan="2"></td></tr>
<tr><td>Length</td><td></td><td>width</td><td></td><td>Thickness</td><td colspan="2"></td></tr>
<tr><td>Weight</td><td colspan="3"></td><td>Bypass diode</td><td>Y</td><td>N</td></tr>
<tr><td rowspan="2">Voltage (V)</td><td colspan="2">At STC</td><td colspan="2">Open Circuit</td><td colspan="2">At highest expected temperature</td></tr>
<tr><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td rowspan="2">Curent (A)</td><td colspan="2">At STC</td><td colspan="2">Short circuit</td><td colspan="2" rowspan="2"></td></tr>
<tr><td colspan="2"></td><td colspan="2"></td></tr>
</table>

<table>
<tr><td rowspan="5">Modules in series</td><td>Rated module voltage (V)</td><td>Array rated voltage (V)</td></tr>
<tr><td></td><td></td></tr>
<tr><td>x</td><td>=</td></tr>
<tr><td>Open circuit module voltage (V)</td><td>Array open circuit voltage (V)</td></tr>
<tr><td>x</td><td>=</td></tr>
</table>

Based on the previous tables, the entire system's size will be determined by the batteries and solar panels' distribution in the cases of in series and parallel distribution to Nablus and Ramallah stations in both scenarios.

Accordingly, the appropriate electronic devices for the systems and the location where the system will take place will be chosen.

5.7.1 Sizing of the First Scenario Charging System

In this scenario, the PV system will not charge the buses directly. It will only charge the batteries during the day. This means that we need a number of buses that covers the total daily demand and consequently a battery storage system that is able to charge these buses. Similarly, the required PV array size should also be able to fully charge the batteries during the day.

As for the simulation of the system, the flow chart illustrated in Figure 14 is used by utilizing a specific load demand that contains no loads during the day (load demand is zero) so as to assure a continuous charging of the battery. Meanwhile, during the night the load demand is set equal to the bus's energy demand. Here the charging process is distributed all over the night considering a fully charged buses by the early morning. This assumption is made so as to reduce the size of the DC system as fast charging DC system is not required in this case. Figure 15 shows the daily demand of the charging stations for the first scenario.

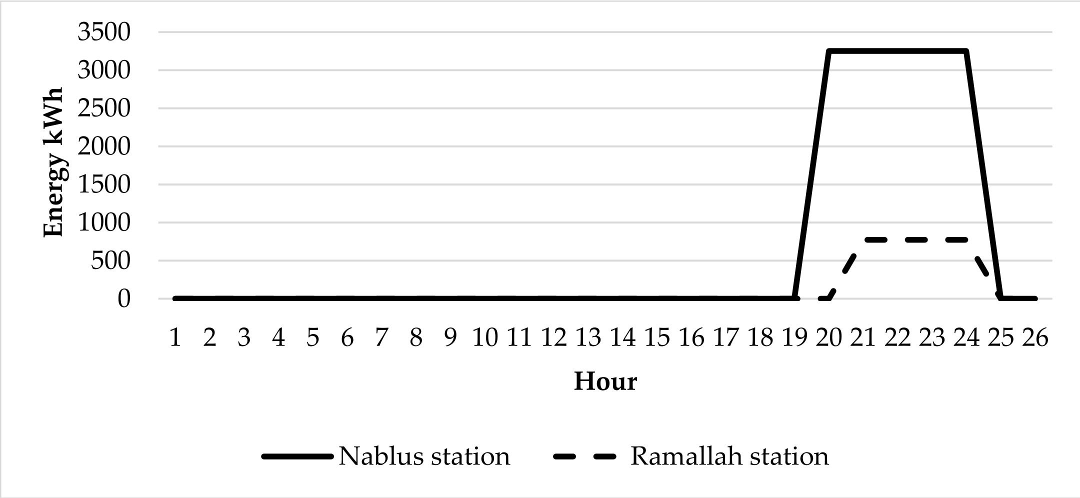


Figure 14: Charging Demand for the First Scenario**.**

In this scenario, the charging starts at the end of the day, in other words, it starts after the last trip. Knowing this and the daily trip schedule, the charging in Nablus' station is chosen to start at 19:00, and in Ramallah's station at 20:00. In order to reduce the discharging rate, the charging process is extended to 5 hours in Nablus' station and 4 hours in Ramallah's station. By doing so, the charging will be completed before the start of a new day. In this research a C60 discharging strategy is adapted for all scenarios so as to maximize the life time of the battery.

5.7.2 Sizing of the Second Scenario Charging System

In this case, the PV system is assumed to charge the buses directly, while solar batteries are used to charge the buses in case of having the PV system not able to fulfill the load demand. Thus, the PV array should be sized well to be able to provide enough charging current directly to the buses. Moreover, it should also be able to charge the batteries so as to achieve a reliable system. Thus, the intuitive method is used here first then, the system is simulated using the method illustrated in Figure 13 so as to modify the system until having a reliable system. It is worth to mention that in this research all of the systems are designed at a 95% availability and 5% loss of load probability. Figure 16 shows the daily demand of buses stations for the second scenario.

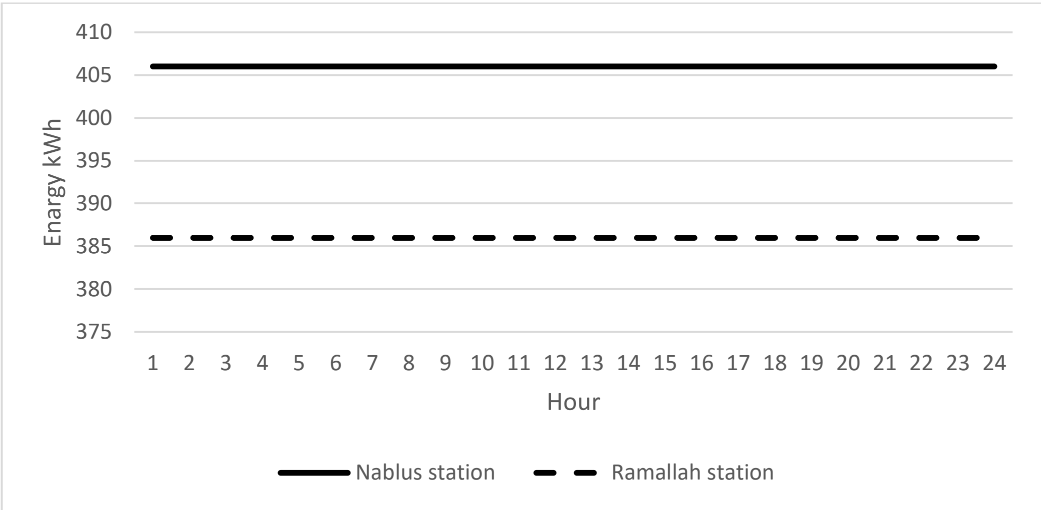


Figure 15: Charging Demand for the Second Scenario**.**

The second scenario depends on charging during the day, meaning that the bus will be charged whenever it needs charging not only at the end of the day. As shown in Figure 14 above, the load is almost stable the whole day. This stability happened by extending the charging process for over an hour and distributing it between the two stations. By this, we reduce the discharging rate and the batteries' size will be acceptable and not very large.

5.7.3 Sizing of the Third Scenario Charging System

As for this case, the charging process is similar to the second scenario. However, the load demand in this case is different as the BV buses will only cover the peak time, meanwhile, the demand during the off-peak period will be covered by the diesel operating shuttles. Figure 16 shows the daily demand of the buses considering the third scenario.

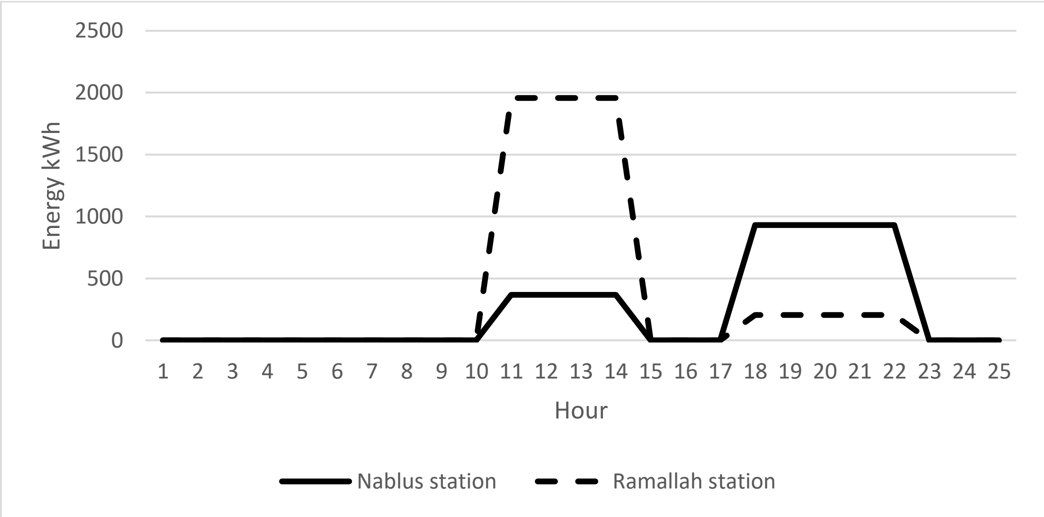


Figure 16: Discharging Demand of the Third Scenario.

In the third scenario, the load is divided into a morning shift and an evening shift, as shown in Figure 16. The morning shift represents the morning peak period, and the other shift represents the evening peak period. The charging process is also divided into two parts, one that starts after the morning peak period and lasts for 3 hours; in other words, it ends before the beginning of the evening peak period. This technique makes the buses ready for usage before the starting of the second shift. The second part starts after the end of the evening peak period and lasts for 5 hours in order to reduce the discharging rate.

Chapter Six
Results

6.1 Results for Run's Needs and Demands: Energy Demand and Number of Trips

Based on equation (2) and the data given in the data sheet, the energy consumed per trip is calculated for four main cases as shown in Table 8.

Table 8: Energy consumption per trip for the adapted runs.

Trip	Bus Load	kWh/trip
Nablus – Ramallah	Full	103
Nablus – Ramallah	Zero	67
Ramallah – Nablus	Full	95
Ramallah – Nablus	Zero	61

Unlike to the result extracted from the data sheet, which depends only on the traveled distance, the energy consumed for the trip, whether the starting point from Ramallah or Nablus, is 56 kWh /trip.

The number of daily trips in both directions is calculated based on the information obtained from the Ministry of Transportation and from the bus drivers. Therefore, the number of passengers is calculated and divided by the capacity of a single bus, which is 28 passengers. Thus, the number of daily trips equals to 99 trips from Nablus to Ramallah and 68 trips from Ramallah to Nablus.

In this research Porterra buses are used, specifically the Porterra electric bus 35 ft (10.7 m) model. This model can accommodate up to 28 passengers, as previously mentioned, and its battery specification capacity is 440 kWh with 75% DOD, voltage 660 v and 660 Ah. Based on these data, the number of buses is calculated for each of the three scenarios.

In the first scenario, the number of required buses is 59 distributed between Ramallah and Nablus. The starting point of 50 buses is Nablus, meanwhile, only 9 buses depart from Ramallah. In this scenario, the bus will make 3 round trips and then stop until the end of the day so as to be recharged. The number of the needed buses is calculated based on the number of daily trips. From Nablus' station, 99 bus trips are required, therefore, we need 50 buses to take off from Nablus. Each bus will cover 3 round trips, therefore, these 50 bused will completely cover the daily trips of Nablus, in addition to 50 trips from Ramallah's 68. This leaves 18 trips from Ramallah's station, for which we need another 9 buses to take off from Ramallah. By this, we calculated the number of buses that will cover all the daily trips.

Based on the number of daily trips and their distribution throughout the day and after calculating the energy consumed in each trip as shown in Table 7, the energy consumed per hour is calculated according to direction and load as shown in Figure 15 (for scenarios one and two). This energy is calculated by multiplying the number of trips per hour by the energy consumed for each trip. The sum of this energy is the total daily energy consumed.

On the other hand, in the Second Scenario, the bus will make 3 trips then, it will enter the charging process and then return back to service again; this reduces the number of buses required. Therefore, the total number of buses is 39. Thirty-eight buses depart from Nablus and the other one departs from Ramallah. In this case, the number of buses is calculated by assuming an initial number of buses and tracking their hourly route. Here, although the number of buses is reduced, but the energy requirement of trips along the road remains the same as Scenario 1 as shown in Figure 17.

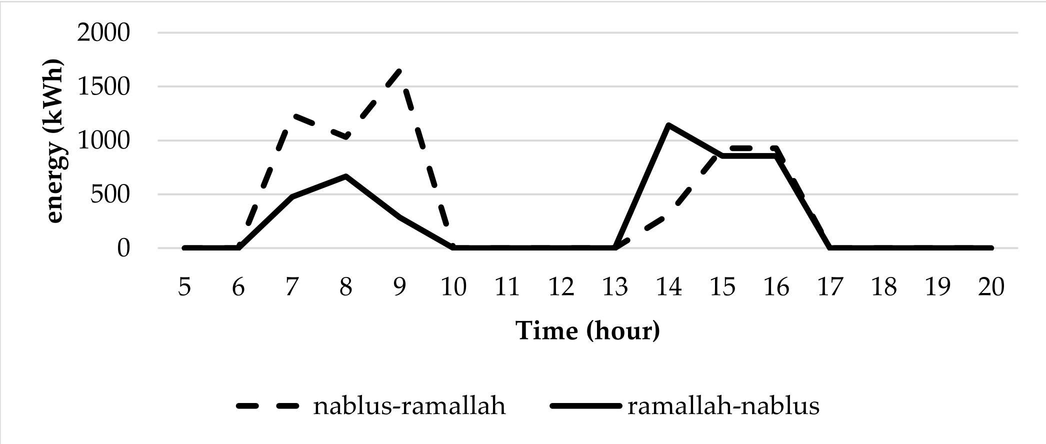


Figure 17: Daily Hourly Load Demand of the Adapted Run Round Trip for Scenarios 1+2.

As for the Third Scenario, the electric buses are assumed to cover the morning and evening peak times only, which are 6 hours divided into 3 hours in the morning and 3 hours in the evening. The rest of the times are covered by diesel buses. The total number of busses is, therefore, 31 buses distributed between Nablus and Ramallah. Whereas 26 buses depart from Nablus, and the other 5 depart from Ramallah. For this scenario, the number of buses is calculated using the same method shown in Figure 7. In this scenario, the number of buses is less than the previous ones. This reduction in number of buses is due to the distribution of the daily demand between electric buses and diesel buses. The energy consumed per day of this scenario is shown in Figure 18.

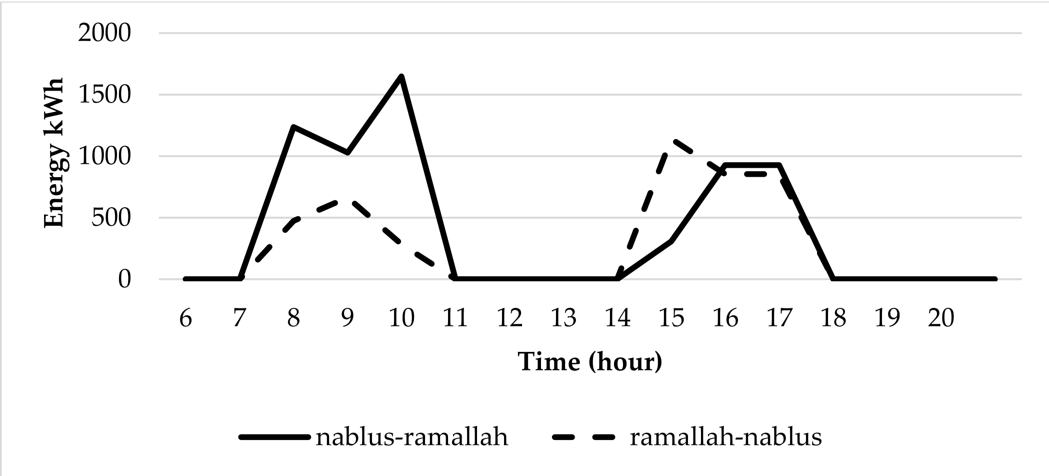


Figure 18: Daily Hourly Load Demand of the Adapted Run Round Trip for Third Scenario**.**

6.2 Sizing Results of Solar Charging Systems

In this research a photovoltaic module with a capacity of 440 Wp is used, and a 600 Ah/12.8 V battery is also used. In addition, a double inductor boost converter is used with a boosting ratio of 1:10. The sizing results of all charging stations are summarized in Table 9.

Table 9 Sizing results for all sizing stations

		No. of buses	PV array (MWp)	PV array configuration	Battery size (600/12.8v)	Battery configuration	No. of Charging ports
1st Scenario	Nablus station	50	4.5	2 X 5109	7164	6 X 1194	10
	Ramallah Station	9	0.75	2 X 855	2604	6 X 434	2
2nd Scenario	Nablus station	38	2.9	2 X 3295	2605	6 X 434	3
	Ramallah Station	1	2.8	2 X 3182	1692	6 X 282	6
3rd Scenario	Nablus station	26	1.64	2 X 1864	2736	6 X 456	2
	Ramallah Station	5	2.16	2 X 2452	2640	6 X 440	4

6.3. Schematic Diagrams for the Charging Stations

The Single-Line Diagram was drawn using the AutoCAD program to illustrate the distribution of the solar panels, batteries and electrical connections between the components of the system.

6.3.1. First Scenario

A. Nablus Station: the following figures show the Single-Line Diagram of the solar panels and of the batteries.

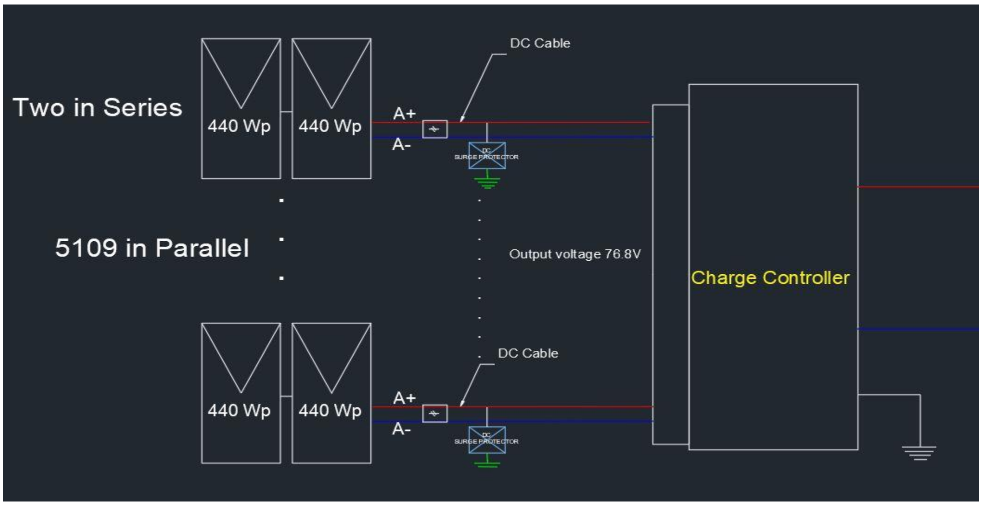


Fig.19: Single-Line Diagram of the solar panels.

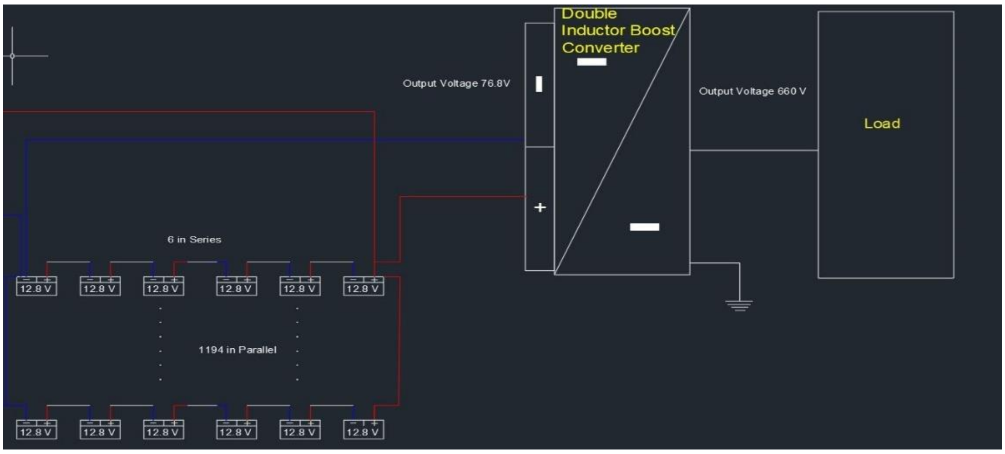


Fig.20: Single-Line Diagram of the Batteries**.**

B. Ramallah Station: the following figures show the Single-Line Diagram of the solar panels and of the batteries.

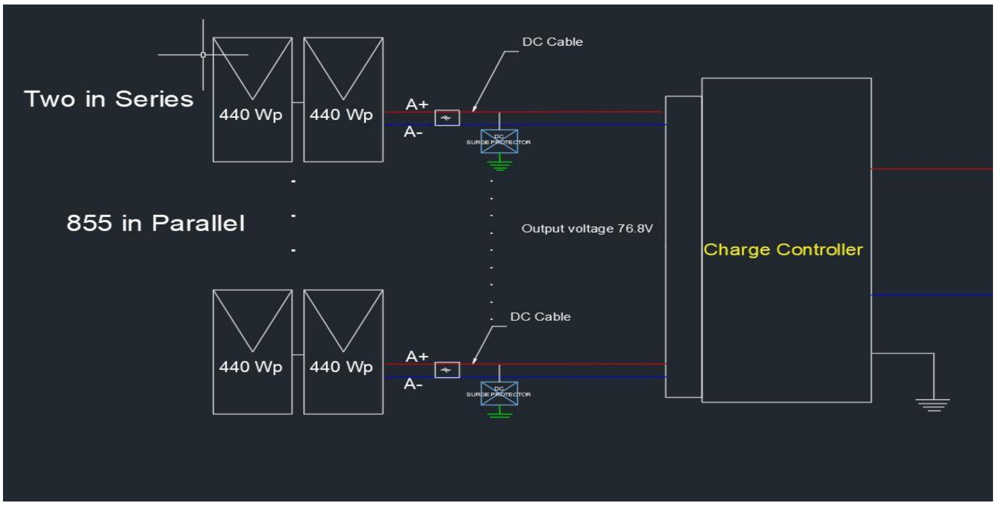


Fig.21: Single-Line Diagram of the Solar Panels**.**

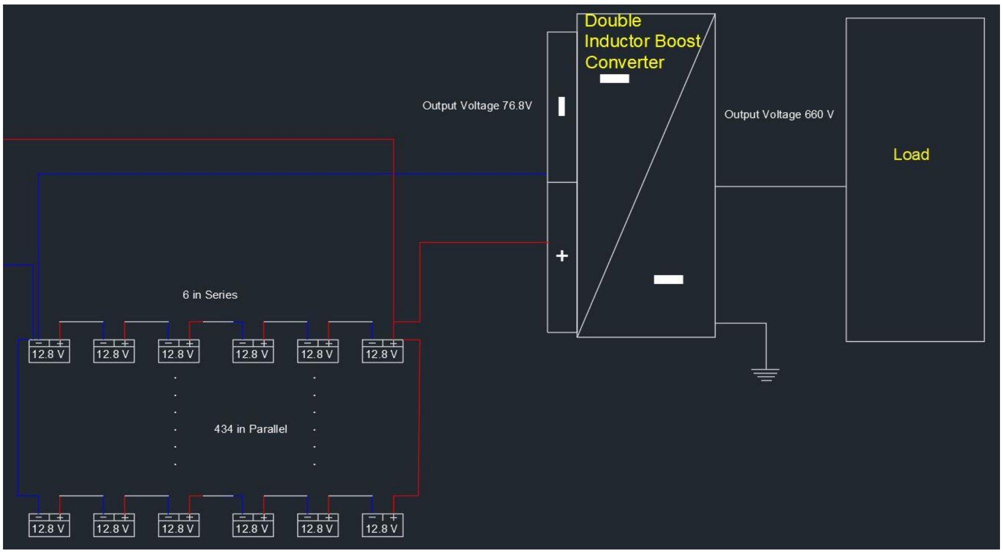


Fig.22: Single-Line Diagram of the Batteries**.**

6.3.2 Second Scenario

A. Nablus station: the following figures show the Single-Line Diagram of the solar panels and of the batteries.

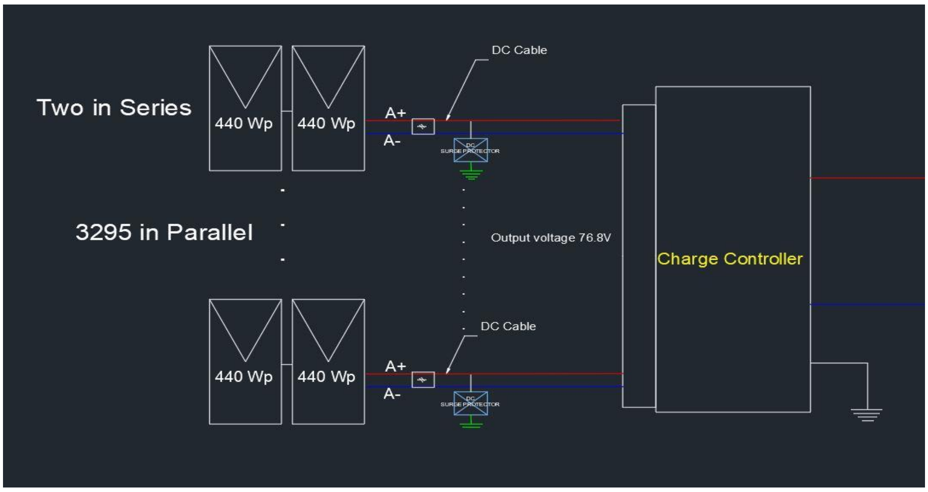


Fig.23: Single-Line Diagram of the Solar Panels**.**

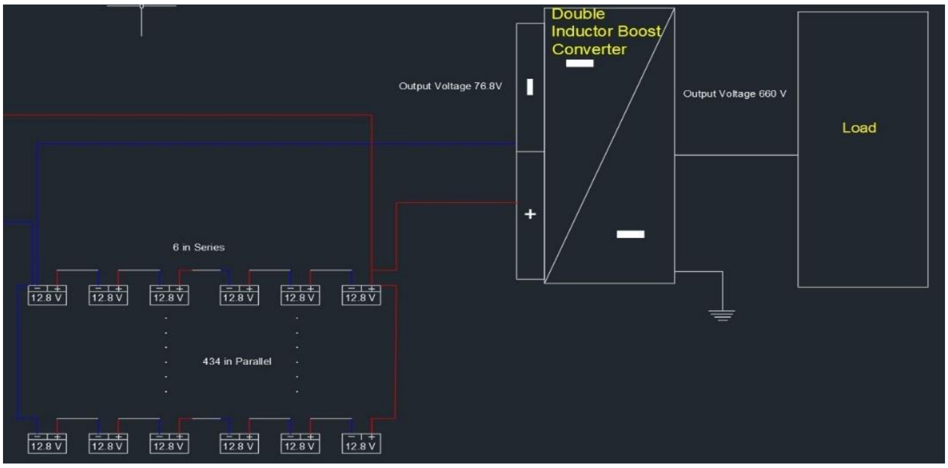


Fig.24: Single-Line Diagram of the Batteries**.**

B. Ramallah station: the following figures show the Single-Line Diagram of the solar panels and of the batteries.

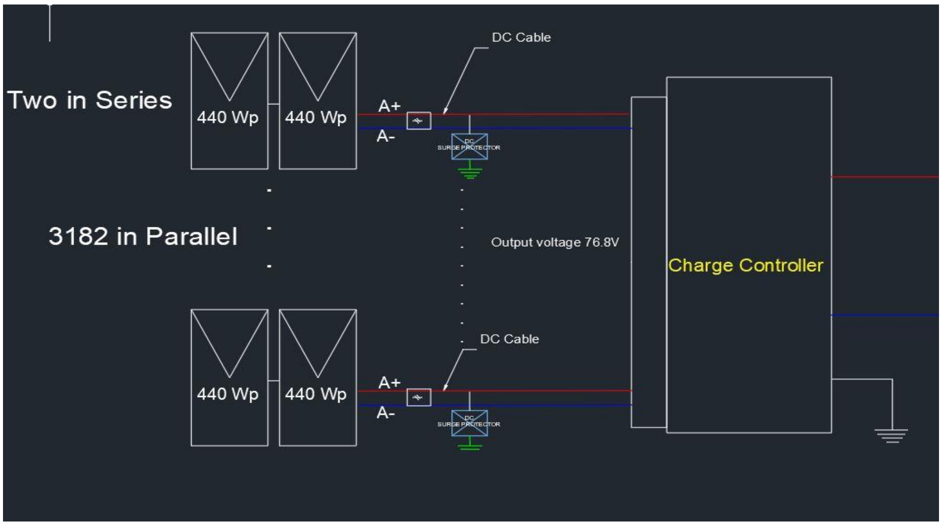


Fig.25: Single-Line Diagram of the Solar Panels**.**

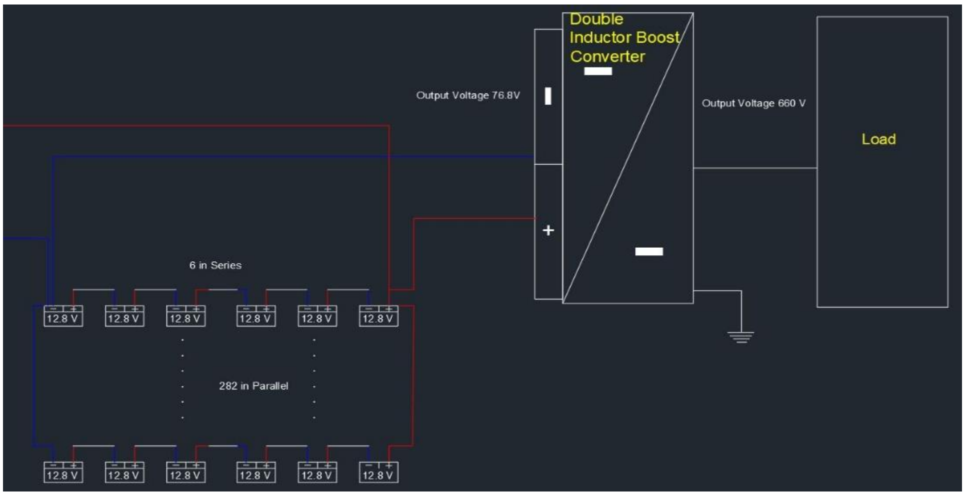


Fig.26: Single-Line Diagram of the Batteries**.**

6.3.3 Third Scenario

A. Nablus station**:** the following figures show the Single-Line Diagram of the solar panels and of the batteries.

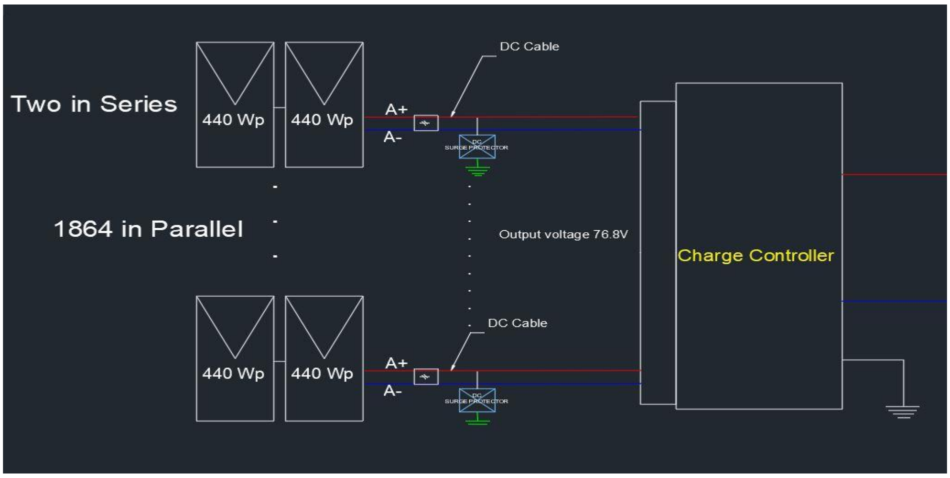


Fig.27: Single-Line Diagram of the Solar Panels**.**

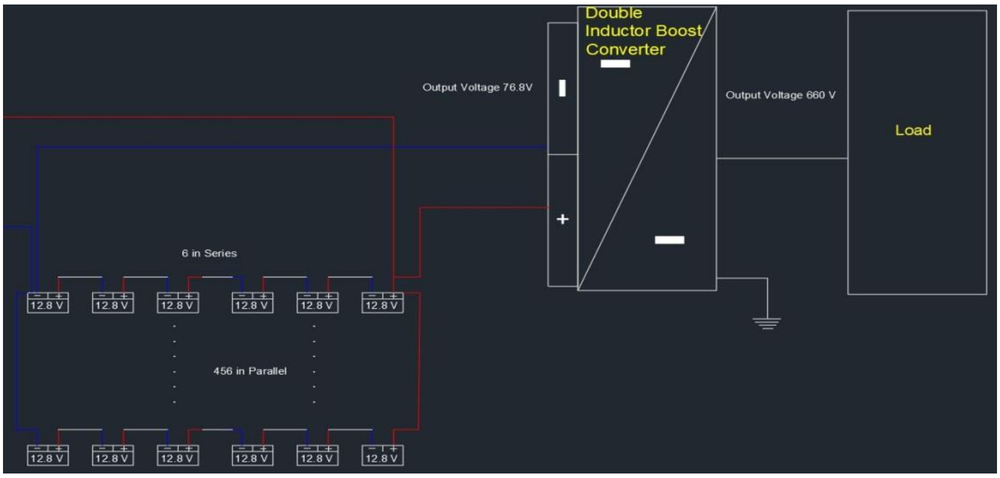


Fig.28: Single-Line Diagram of the Batteries**.**

B. Ramallah station**:** the following figures show the Single-Line Diagram of the solar panels and of the batteries.

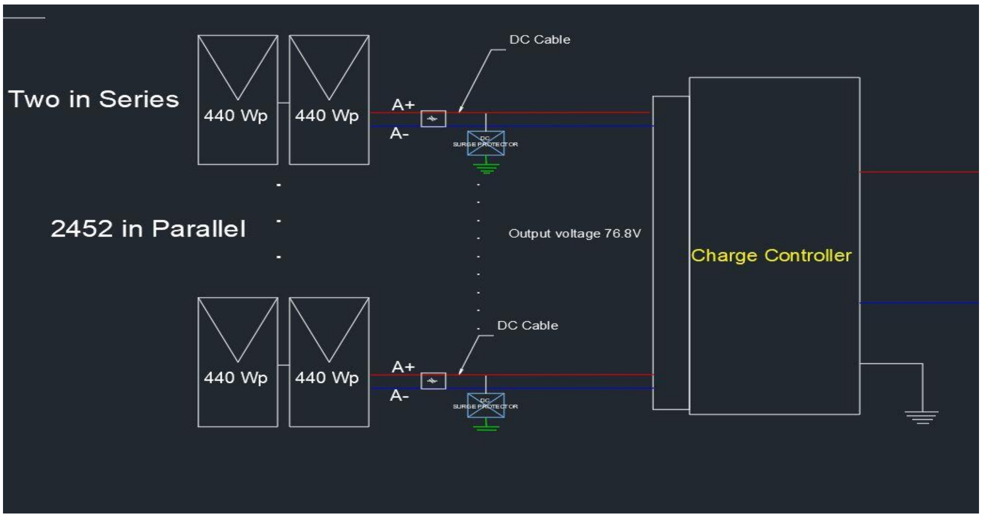


Fig.29: Single-Line Diagram of the Solar Panels.

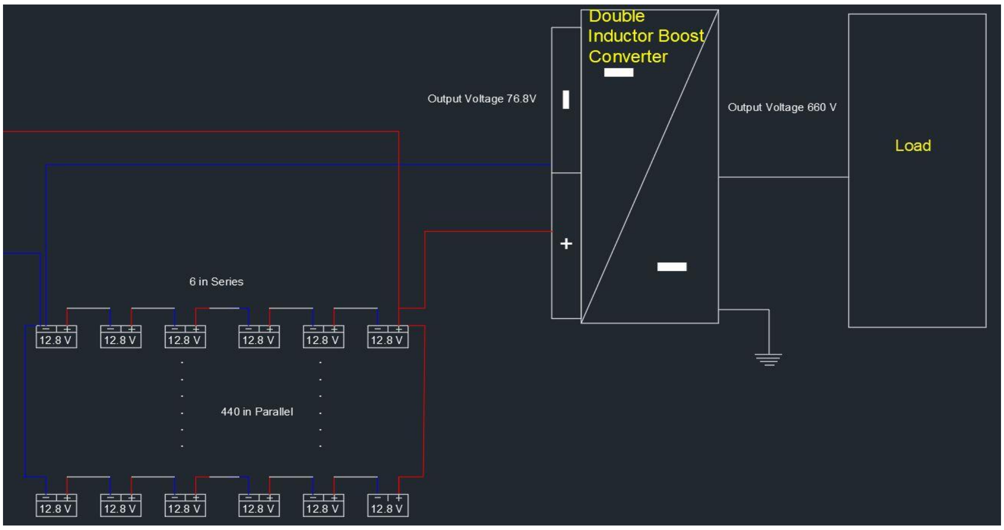


Fig.30: Single-Line Diagram of the Batteries.

6.4. System Simulation

6.4.1 First Scenario

Figure 17 shows the proposed system performance for the first week in the year for Nablus station. The first subplot shows a comparison between system charging load and PV power production. Based on this comparison the control of the system is done, and the state of the charge (third subplot), excess energy (fourth subplot) and deficit energy (fifth subplot) are calculated. In general, the PV system produced about 8.88 GWh, which means that the yield factor of the system is about 1973 kWh/kWp while the capacity factor is about 45%. Meanwhile, the excess energy recorded is about 3.3 GWh, which is about 37% of system's production. This large amount is due to the large size of the PV array installed so as to fulfill the demand of the associated batteries. Moreover, this shows the importance of utilizing the energy during the day for direct charging. On the other hand, the system is found relatively reliable whereas most of the deficit cases occurred in winter with a loss of load probability of 5%.

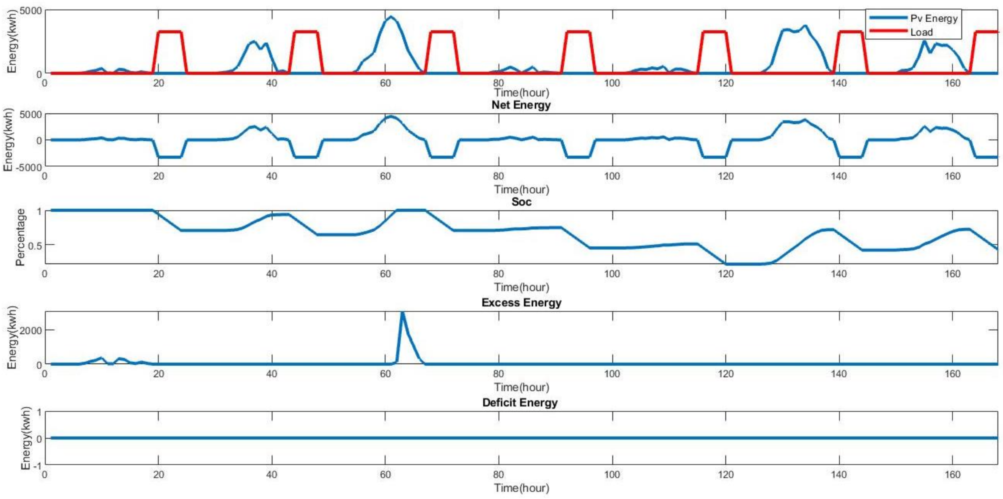


Figure 31: System Performance Sample for First Scenario, Nablus Station**.**

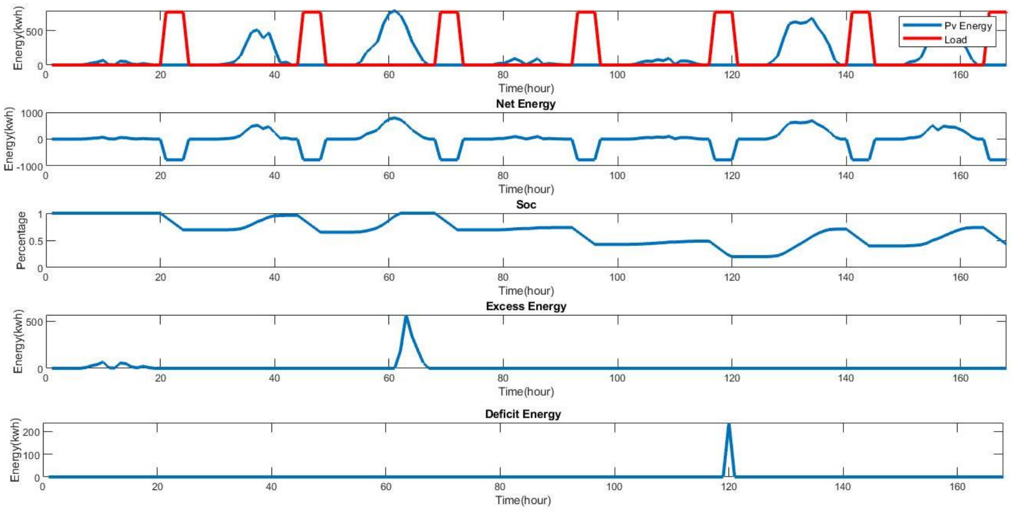
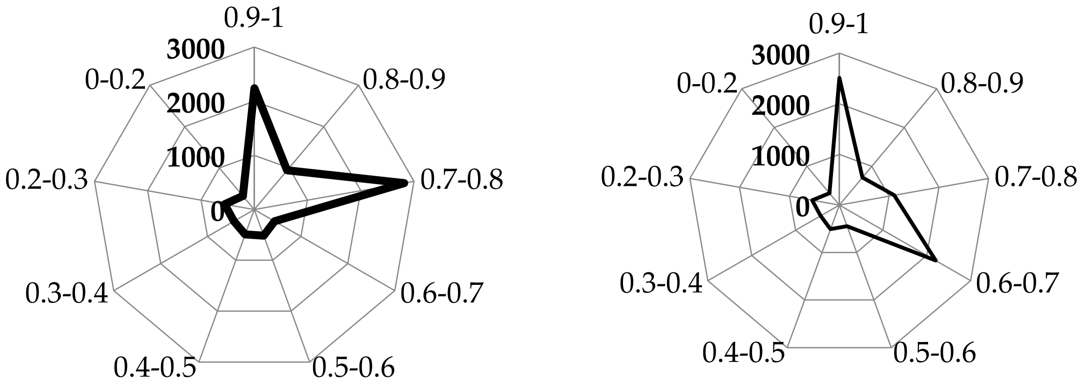


Figure 32: System Performance Sample for First Scenario, Ramallah Station**.**

As for Ramallah station, the situation was quite similar whereas the reliability of the proposed system is found to be acceptable with a loss of load probability of 5%. Figure 32 shows the performance of the system including hourly simulation of the first week in the year. The system generated about 1.63 GWh where 35% of this energy is wasted as excess energy. The yield factor is found higher here with an amount of 2173 kWh/kWp with a capacity factor of 49.6%

Figure 33 shows the radar charts for battery usage in both Nablus and Ramallah stations. From these figures, it is quite clear that the utilization of the battery in both cases is at border line level, whereas in Nablus station, about 32% of the time the state of charge of the battery is in the range of (70-80) %, while about 26% of the time of the year the battery state of charge is in the range of (90-100) %. On the other hand, In Ramallah station the situation was better whereas about 25% of time of the year the state of charge of the battery is (60-70) %. Meanwhile, is about 29% of the time in the year, the battery was slightly used whereas the state of charge is in the range of (90-100) %.



(a) Nablus Station (b) Ramallah Station

Figure 33 : Usage of Battery in Nablus Station and Ramallah Stations**.**

This level of utilization is expected actually and it is also associated with the high percentage of excess energy; this is because of the high availability assumed (95%). According to [80], the most recommended availability of solar charging system is 95%, however, when reducing the availability to 90%, the excess energy can be reduced by almost (25-30)%. On the other hand, the usage of the battery will also be boosted by (25-30)% by considering the percentage of $SCO_{80\%}$, whereas $SCO_{80\%}$ is a ratio that shows the number of hours that the battery has a state of charge higher than 80% as compared to the total number of hours in the year. However, considering the adapted case study, this deficit should be covered by conventional vehicle so as to assure the reliability of the service. Such an idea is highlighted later in the third scenario.

6.4.2 Second Scenario

Figures 34 and 35 show the hourly simulation of the proposed system for Nablus and Ramallah stations, respectively. The production of the system in Nablus station is 5.7 GWh while it is 6.1 GWh in Ramallah station, the yield factor for both stations is approximately 2150 kWh/kWp with excess energy percentage approximately equals to 42% in both cases. Finally, the loss of load probability of both systems is 5%.

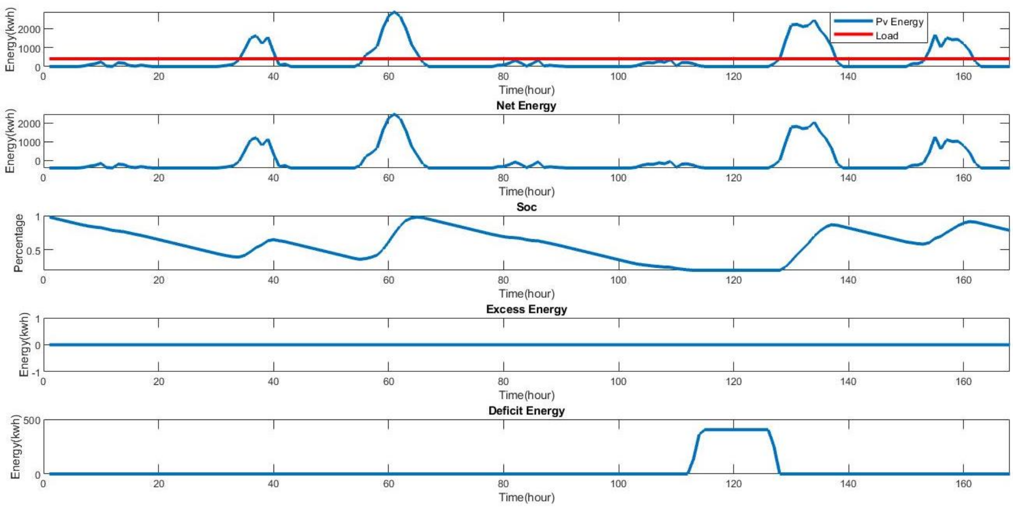


Figure 34: System Performance Sample for Second Scenario, Nablus Station**.**

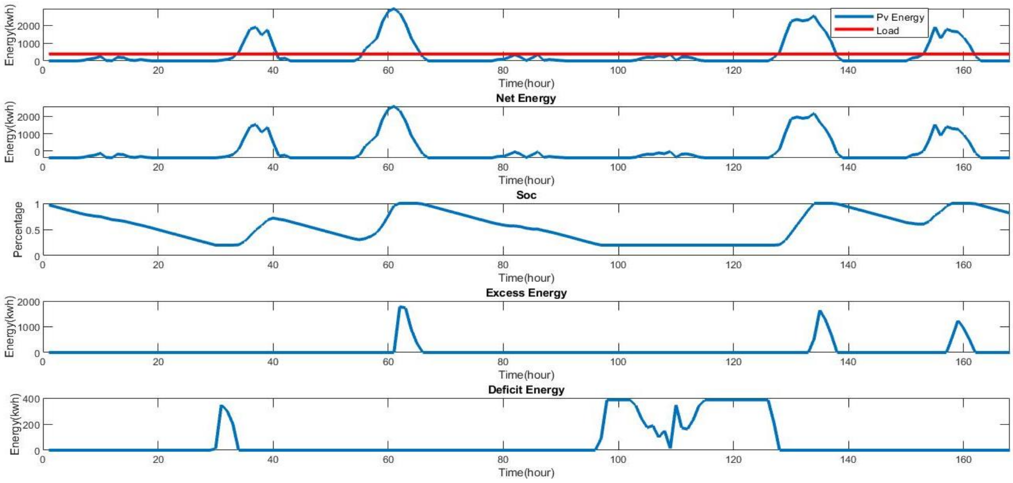
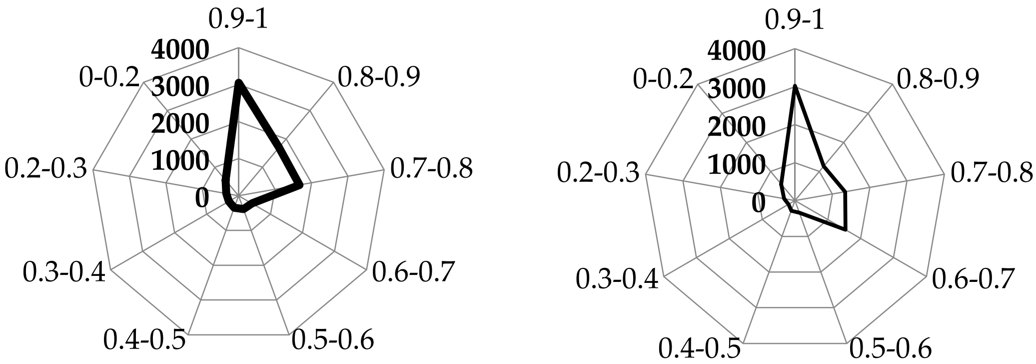


Figure 35: System Performance Sample for Second Scenario, Ramallah Station**.**

Figure 36 shows Radar chart for the usage of tee battery in both stations.



(a) Nablus station (b) Ramallah station

Figure 36: Usage of Battery in Nablus and Ramallah Stations for the Second Scenario**.**

From these figures, the battery in this scenario is also not utilized that much whereas the $SOC_{80\%}$ for Nablus station is 54%, while the $SOC_{80\%}$ for Ramallah station is 48%. This is also due to the low loss of load probability considered whereas these numbers can be significantly recued in case of reducing the availability of the system to 90%, for example. However, this is still an option, as alternatives should always be available to the E-buses such as conventional buses so as to maintain the reliability of system. Such an idea is considered in the following third scenario for better comparison.

6.4.3 Third Scenario

Figures 37 and 38 show samples of the performance of the proposed system at both Nablus and Ramallah stations. The PV array generates 3.2 GWh per year and 4.7 GWh per year for Nablus and Ramallah stations, respectively. Meanwhile, the excess energy percentage for both cases is 35% with a loss of load probability of 5%.

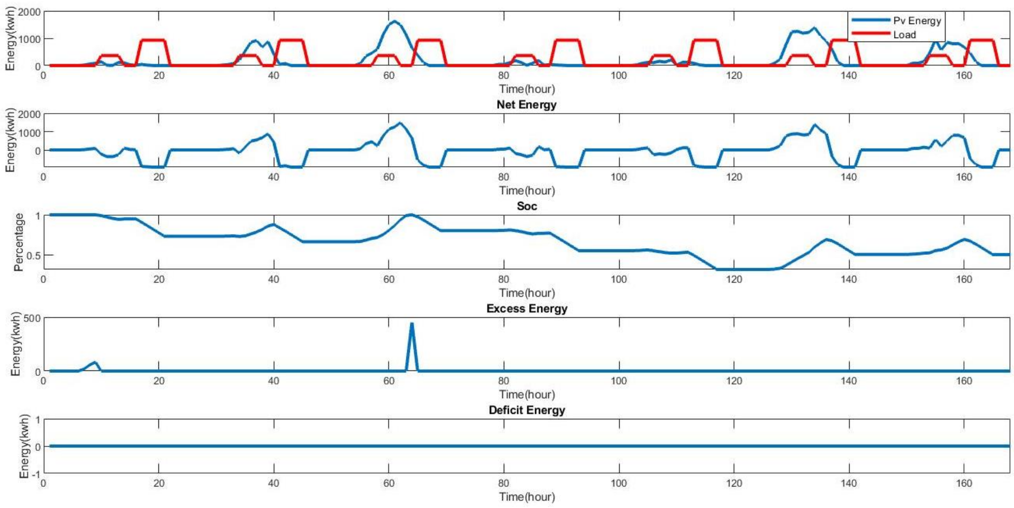


Figure 37: System Performance Sample for Third Scenario, Nablus Station**.**

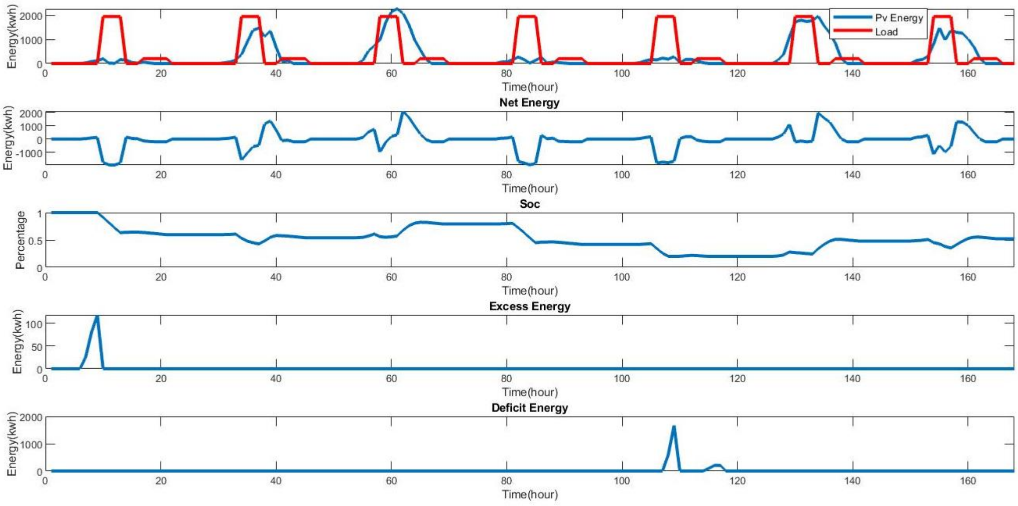
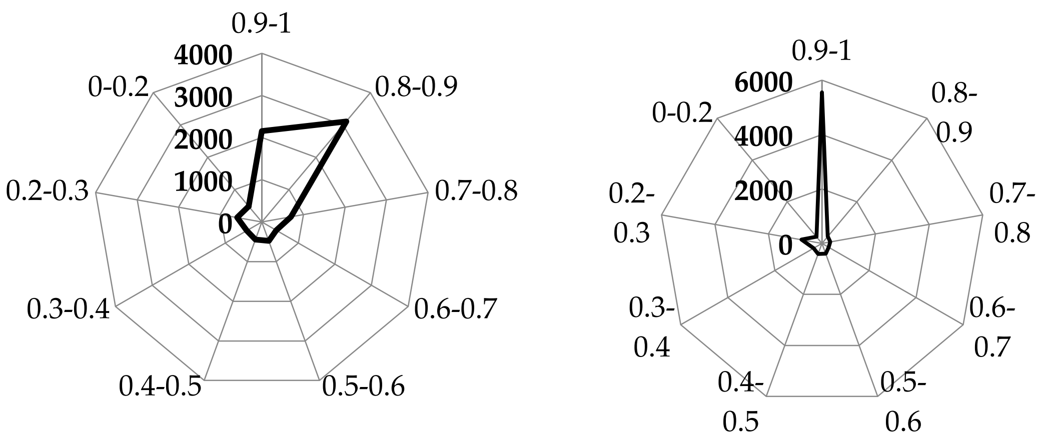


Figure 38: System Performance Sample for Third Scenario, Ramallah Station**.**

Figure 39 shows a radar chart for the battery usage in the third scenario. In this scenario, the battery is not utilized that much, whereas the $SOC_{80\%}$ for Nablus station is approximately 60%, while $SOC_{80\%}$ for Ramallah station is 67%. However, it is worth to mention that the size of the batteries in this scenario is about 55% of the size of the batteries in the first scenario and 140% of the battery size of the second scenario.



(a) Nablus station (b) Ramallah station

Figure 39: Usage of Battery in Nablus and Ramallah Stations for the Third Scenario**.**

6.5 Proposed System Evaluation and Comparison

Table 9 shows a comparison between the proposed scenarios as well as the current situation. It shows a comparison between the required PV panels and batteries, buses as well as CO_2 amount reduced. However, it is quite difficult to judge the proposed scenarios without calculating their initial costs, payback periods and costs per passenger. The initial cost of the system system's component's price is calculated considering the price of the 1 kWp with batteries of PV system, which is 2023 USD, meanwhile the cost of the additional batteries is 1.3 USD per 1 Ah/12V. As for other system's component price, it is considered 212 USD per kWp. The bus price is estimated at 200,000 USD, while the land's cost is assumed at $45 per 1.0 m^2 (suburbs). Based on the current prices, the price of diesel liter is estimated as 1.3 USD. The cost of the trip for each person is calculated according to Equation (13), while the depreciation for the components of the solar system is 5% and for the buses it is 10%, the annual salary of the driver is 12,000 USD and the maintenance cost is 150 USD per kWp. Finally, the amount of the mitigated CO_2 is found by calculating the amount of diesel saved in each scenario (measured by the number of trips). Therefore, the amount of the mitigated CO_2 is the same in the first and second scenarios.

Table 10: Comparison of the proposed scenarios.

	PV panel (MWp)	No. of batteries (600/12.8v)	Initial cost (USD)	SPBP (Years)	Saving (USD)	land required (m^2)	No. of buses	Trip cost per passenger (USD)	CO_2 (kg/year)
1st Scenario	5.2	9,768	32,740,200	14.8	2,210,375	42,000	59	2.85	1,629,387
2nd Scenario	5.7	4,297	22,365,000	10.0	2,230,375	45,000	39	2.05	1,629,387
3rd Scenario	3.8	5,376	15,910,000	9.4	1,691,202	30,000	31	2.42	1,012,632

From Table 10, it is clear that the second option is the best among the three considering the trip cost per passenger. Thus, the three proposals exceed the conventional option. Based on that, it is recommended to adapt the second scenario considering the trip cost per passenger, investment payback period and amount of CO_2 mitigated.

6.6 Brief Social Impact Assessment of the Proposal on the Current Jobs and Passengers

As mentioned earlier, currently there are 110 drivers who are employed by this line with 2 other employees for management issues. The average monthly salary for each driver is about 1,000 USD per month (84 hours a week). Meanwhile, the management employees’ average salary is about 800 USD (60 hours a week). However, according to the Palestinian labor law, the maximum number of working hours per week should not exceed 50 + 6 hours for lunch.

Considering the recommended scenario, there will be a need for (59) drivers, (21) management staff as site coordinator, ticket fees collectors, accountant, managing officer and guards and security officers, (2) technical staff for the monitoring of PV system, (2) technical staff for the monitoring of the buses performance, (4) technicians for maintaining the PV system, as well as (4) technicians for buses maintenance. All these job tasks are supposed to be working 40 hours per week. The total number of the required staff is 92, whereas 78 of them can be from the drivers themselves while 10 of them can also be hired from the drivers after some specific trainings.

Although, such a project has created about 92 green job opportunities, with much better salaries (150% of the old salaries) and working conditions (about half of working hours), about 20% of the old staff will lose their jobs. Therefore, this cannot be neglected actually, but it is quite expected as we moved from conventional methods to smart systems. Thus, the government here should help with these regards by developing rehabilitation courses for those who are working in conventional jobs. On the other hand, the project will have a positive social impact on the passengers themselves considering the convenience, energy reliability and sustainably of the proposed system.

Chapter Seven
Conclusions

This thesis presented a novel design and operation of solar based charging system for a 50 km run road located in Palestine between two main cities; Nablus and Ramallah. The proposal aimed to replace 110 existing diesel vehicles with electric buses considering three main operational scenarios. The first scenario assumed electric charging of the electrical buses at the end of the day only while batteries were in charging model all of the day. The second scenario aimed to utilize the direct power of the photovoltaic modules and the batteries available at the charging stations at the same time. The third scenario was a hybrid system between electric buses and diesel vehicles so that electric buses cover the morning and evening peak periods. Results showed that the first scenario is practically unsuccessful, as it needs a high cost to meet the main goal due to the large required photovoltaic system and number of buses (59 buses). Meanwhile, the second and third scenario were close to each other considering the payback period. However, due to trip cost per passenger as well as the amount of CO_2 mitigated, the second scenario was preferred. Finally, the proposed system was found to be socially accepted whereas most of the current employees would keep their jobs with higher salaries by about 145% and less working hours by 50%. In addition, the proposed system significantly increased the reliability, convenience and sustainability of the adapted transportation line.

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Appendices

```
%%(1)Data sources

fileName = '';

sheetName = '';

G= xlsread(fileName, sheetName, 'A1:A8760');

L= xlsread(fileName, sheetName, 'b1:b8760');

%%(2)System specifications

PV_Wp=; % the capacity of the PV array (Watt)

SOCmax= ;% battery capacity kWh/day

PV_eff=; % efficiency of the PV module

V_B=; % voltage of the used battery

DOD=; %allowed depth of charge

Charge_eff=; % charging eff

Alpha= ; % alpha

Wire_eff=;

SOCmin=SOCmax*(1-DOD);

%%(3.1) Simualtion of the SAPV system
```

```
E_PV= ((PV_Wp)*(G/1000)) ;

x=sum(E_PV)/365000;

E_net=E_PV-L;

SOCi=SOCmax;

SOCf=[];

Deff=[];

Dampf=[];

for i=1:length(E_net);

SOCi= E_net(i)+SOCi;

if (SOCi > SOCmax);

Dampi=SOCi-SOCmax;

Defi=0;

SOCi=SOCmax;

%%(3.3)

elseif (SOCi<=SOCmin);

Defi=SOCi-SOCmin;

SOCi=SOCmin;
```

```
Dampi=0;
%%(3.4)
else
Defi=0;
Dampi=0;
end
%%(3.5)
SOCf=[SOCf; SOCi];
Deff=[Deff; Defi];
Dampf=[Dampf; Dampi];
end
SOCf;
Deff;
Dampf;
SOC_per=(SOCf./SOCmax);
LLP_calculated=abs(sum(Deff))/(sum (L))
subplot(5,1,1)
```

```
plot(E_PV)

hold on

plot (L, 'red')

subplot(5,1,2)

plot (E_net)

subplot(5,1,3)

plot(SOCf)

subplot(5,1,4)

plot(Dampf)

subplot(5,1,5)

plot(SOC_per)
```

جامعة النجاح الوطنية

كلية الدراسات العليا

تصميم محطات شحن الحافلات الكهربائية والتي تعمل بالطاقة الكهروضوئية بطريقة مثلى: طريق نابلس – رام الله نموذجاً

إعداد

محمد عزام فخري سلامة

إشراف

د. تامر الخطيب

د. خالد الساحلي

قدمت هذه الأطروحة استكمالاً لمتطلبات الحصول على درجة الماجستير في هندسة الطاقة النظيفة وترشيد الاستهلاك، بكلية الدراسات العليا، في جامعة النجاح الوطنية، نابلس– فلسطين.

2021

تصميم محطات شحن الحافلات الكهربائية والتي تعمل بالطاقة الكهروضوئية بطريقة مثلى: طريق نابلس – رام الله نموذجاً

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محمد عزام فخري سلامة

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د. خالد الساحلي

الملخص

تبحث هذه الأطروحة في تصميم وتشغيل نظام شحن قائم على الطاقة الشمسية لسيارة كهربائية تعمل بالبطارية لتسير مسافة 50 كم. ويهدف الاقتراح إلى استبدال 110 مركبات ديزل قائمة بـ 39 حافلة كهربائية. يتم تقديم وتحليل العديد من سيناريوهات التشغيل لمحطات الشحن. وتشمل السيناريوهات منهجيتين مختلفتين لشحن البطاريات واحدة هجينة بين الحافلات الكهربائية ومركبات الديزل. تم في البداية تطوير نموذج طاقة للحافلات الكهربائية التي سوف يتم استخدامها. بعد ذلك، تم تحديد حمل الطاقة المطلوب والاحتياجات بما في ذلك عدد الرحلات اليومية، وعدد الركاب في الساعة واستهلاك الطاقة بالساعة على أساس النموذج المقدم والمعلومات التي تم الحصول عليها. تظهر النتائج أن 5.7 MWp من نظام الخلايا الشمسية مطلوب لتشغيل خط النقل هذا مع احتمال فقدان الحمل بنسبة 5٪ وتكلفة الرحلة لكل راكب 2.05 دولار أمريكي. تم التوصل الى فترة الاسترداد البسيطة لرأس مال النظام لتكون 10 سنوات، وتمثل هذه 40 ٪ من عمر النظام. ويقدر مقدار ثاني أكسيد الكربون من خلال النظام المقترح بـ 387 629 1 (كغم/سنة). وقد وجد أن الأثر الاجتماعي للمشروع المقترح مقبولاً في حين أن معظم الموظفين الحاليين سيحتفظون بوظائفهم برواتب أعلى بنحو 145% وساعات عمل أقل بنسبة 50%. وعلاوة على ذلك، من المتوقع أن يزيد المشروع المقترح في موثوقية عملية النقل واستدامتها.

الكلمات المفتاحية: أجهزة الشحن الشمسية؛ الحافلات الكهربائية؛ نظام نظام فوتوفولتا الضوئي؛ النقل المحافظ على البيئة.