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Design and Simulation of Solar Grid-Connected Charger for Electric Vehicles

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***Abstract*—Electric Vehicles (EV) are playing major role in decreasing carbon emissions. The major problem so far with the Electric Vehicles are overloading the Distribution Grids and availability of enough charging stations. The main objective of this research is to design and install a solar powered charging station for EVs in the UAE environment. This project aims to focus on the need for the shifting from the traditional gas and petrol vehicles to Electric vehicles in the UAE. Additionally, the project intends to ease the problem of the additional load that these EVs impose on the grid by powering the charging station from solar energy. This will help evolve the existing transport system of the UAE into a cleaner and greener system. The project is divided mainly into three important parts. First of all, the system components are designed to match with the ratings of available most common EVs. Then the system is modelled in DIgSILENT Power factory for simulation and validation of design. Finally, the results from calculations and simulations are described and compared.**

Keywords- Electric Vehicles; Charging stations; Green design; DC-DC power converters; Inverters; Simulation

I. INTRODUCTION

Our lifestyles today are highly dependent on the fast consumption of energy that is generated mainly by fossil fuels. These fossil fuels must be ignited to be used which produces harmful toxins that causes the environmental pollution and pose a risk to all living organisms. In order to prevent these adverse effects there is a lot of focus on renewable energy. A large proportion of these non-renewable energy reserves are consumed by the transportation industry. The traditional transportation system needs to undergo a lot of changes and new innovative measures are underway to modernize it. The shift towards renewable energy will require a parallel upgrade of vehicle technology [1].

However, the main problem with using Electric vehicles is that these Electric vehicles would again depend on the grid for charging. This means that non-renewable energy will be used again. This also puts up a lot of burden on the grid supply, as charging Electric cars requires a lot of electric energy. To solve the problem of the Electric Vehicle dependency on the grid this project would aim to set up a charging station for Electric Vehicle that is powered by solar energy. This would help in decreasing the burden on the grid and the electric vehicles would be dependent on a clean renewable energy source that way.

EVs can be classified into different types mainly Hybrid, Plug-in Hybrid Electric and Battery Electric vehicles. Hybrid electric vehicles don't need an electric charger and generate energy by the cars movements. The other two types however need an external charger for charging [2]. There are two basic setups for PV Electric Vehicle charging systems. The first is the PV-grid system, and the second is the PV standalone system. PV-grid systems are generally far feasible to operate than standalone systems, as standalone systems usually cannot support large scaled energy requirements [2].

There are various ways to charge these EVs. Some of the different types are home charging, charging by EVSE (Electric Vehicle Service Equipment) and then by charging stations. Home charging involves the use of charging the car using the on-board charger and connecting it to a wall socket at home. But this type of charging is extremely slow and inefficient [3]. That is why, there is prompt research required to design and install renewable energy based charging stations.

II. LITERATURE REVIEW

With the increase in population and economic growth, the need for sources of energy is also quickly increasing. Diesel and petrol availability is in serious questioning over the coming years to meet all those needs, and many people are going to shift their choice towards a car that they can run using a reliable and abundant supply of energy. Since the energy from the sun will be available abundantly as it has always been, and with the advancements, changes and developments in photovoltaics, solar power will remain as a great renewable energy option. [1-4]. Moreover, the introduction of these stations would encourage commuters in the Middle East to reconsider their transportation choices and to switch to emission free vehicles [5].

The basic components that are present in nearly every PV-grid set up are a DC charger, DC-DC converters and DC-AC converter which can be split as a combination of an AC-DC rectifier and inverter [2, 6, 7]. The DC-DC buck converters are one directional and are used to ensure that the power provided by the PV array is used only in one direction, and the current flow does not reverse back inside the grid the function of the MPPT. DC-DC Buck converter is to make the most of the Power supplied by the PV array, and use it to contribute to the bus voltage. Charging buck converter is used to lower the voltage to make it at a suitable level for charging [2, 7].

The EV can be with or without an on-board charger. Electric vehicles with on board charger have the charger inside the vehicle themselves, and these chargers are equipped with bi-directional and one directional dc to dc converters as well as Boost converters in order to make the voltage suitable for the battery. An EV without an on board charger, has to have an external charger. Generally, external charging converters are preferred to on board systems, as it is easier to increase their power supplied to the EV, without being limited by the capacity of the on-board charger [10]. Also the electric vehicles without internal chargers cost and weigh much lesser than their rivals with on board chargers [10]. Since the system is tied to the grid, an AC-DC rectifier is used to provide power to the EV cars, in case the energy produced by the PV array is insufficient. Excess energy produced from the PV array is sent back to the grid, as there will be no energy storage system in the PV-grid system [7].

The authors in [7] have discussed an EV charging system that can provide charging to different Electric vehicles, with different energy needs through varying the DC voltage at two charging outlets. They use four strings of PV panels, with each string having 6 solar panels. The total power capacity of the system is 4.8 KW. This power is then lowered by using four buck converters, to bring the voltage to a lower level. The voltages at the 2 outputs can be further decreased, according to the needs of that car. Smaller vehicles are provided with a lesser range than larger cars. The system is grid tied by replacing a two directional AC/DC converter with an inverter and rectifier. Furthermore, an algorithm is used to control the overall system [7].

According to [8] the EV charging has to be performed cautiously, as any fluctuations in the level of charging could impair the EV battery. There are three basic charging types. The first type is charging by keeping current as constant while the other type keeps voltage constant. The third type has these two types combined. However, the combination of these two charging methods is considered the best, as it avoids the disadvantages present in using both these methods. Constant voltage charging is generally preferred to be charging at Constant current because the EV battery may be damaged when the incoming power is greater than the level it should be at, during constant current charging. It functions by first gradually increasing the current instead of an abrupt increase. This is then lowered, and the voltage made constant, after the maximum constant value of current is reached and the EV has been almost eighty percent charged [8].

In [9, 10] different charging systems are described. The charger that is internal to the EV has a charging circuit that modifies the voltage supplied according to the cars need. The AC input is first converted into DC voltage by a bi-directional rectifier. Any restoring changes to the power factor are made through using a bi-directional converter that is usually a boost converter. This input is then given to the battery after being passed through another DC-DC converter, to further lower the voltage supplied for battery charging [10]. Moreover, the authors describe three different set ups, being for integrating these chargers into the PV charging system. In a centralized set up, the PV arrays will be connected to a MPPT DC-DC boost converter that is central to the system. This boost converter is then further connected to various DC-DC Buck converters that are for charging the EV's. The number of Buck converters depends on the number of parking spaces that will have charging outlets [10].

In [11] the author designs a parking space-based charging station. This model would constitute of a PV system upon the parking rooftop, which provides both shade and power to the car parked below. Energy calculations were based upon the solar energy received by the array on the rooftop in both winter and summer seasons of New Jersey town where the project is implemented. It is discovered that during summer, the car can receive up to 12600 watts. This is far more than the winter power amount which is up to only 3780 watts. The author suggests modifications to be held to make more energy and greater flexibility of conditions during the winter season.

In [12] the requirements for the design of a fast-Electric vehicle charging station. The design used the Flemish Mobility as a criterion. The design is made such as to support the charging of one thousand cars. At first, the demand for the charging is determined. In the second phase of the project the findings from the first phase are used to demonstrate the workings of the station that could be used to meet the required needs. The energy in the station is managed and controlled by an algorithm. This will be responsible for the distribution of energy throughout the system. Additionally, a suitable covering factor is also obtained by taking out many charging areas or spots. The system is designed for 2020, and the number of Electric vehicles is thought to increase considerably by then. The demand of charging is calculated by the demand by the 1000 cars regardless of their travel destinations [12].

III. Design and Implementation

A. *Calculations for design*

The system design will depend on the output power that is expected from it. Important calculations will determine the system capacity and the resulting output power that is generated.

The Real charging system proposed will have the charging capacity of charging at least 5 cars. The designing of the system was based on a number of designing factors.

1). Calculations for charging 1 car

Firstly, the watt-hour/mile rating range of Electric vehicles was considered. Most EV's have a Wh/mile consumption within the range of 250-400 Wh/mile [13]. To ensure that the charging station is able to power any Electric vehicle, 400 Wh/mile is assumed to be the total Energy consumption of 1 electric vehicle. Next, the average total daily distance of an Electric vehicle will be assumed.

The average total distance of 45 miles (70 kilometers) per day was assumed for calculation purposes.

The energy required by one car in kWh per day can then be calculated by multiplying the total energy consumption and the distance to be travelled.

The energy required by one car = 400Wh/mile×45 miles
= 18000 Wh = 18 kWh

Since there will be some energy losses, in the form of heat, the energy requirements will be taken by taking the efficiency of the car into consideration, and an efficiency of 85 percent will be assumed. So, the energy needed for 1 car after taking the efficiency into consideration is:

The energy required by one car = 18kWh/0.85
= 21.176 kWh

The average energy to be generated by the PV in one day has to be at least 21.176 kWh, hence the design is based on 23 kWh energy required. The energy requirement is increased so that the system designed will be able to support the electric vehicle charging by producing more energy than needed so as to avoid any energy shortage in case of more consumption [7].

The system capacity of the PV system can then be calculated by using the following formula [14]:

Output = Capacity x Peak Sun Hours x Effective Output

Capacity = Output / (Peak Sun Hours × Effective Output)

Where, effective output is after subtracting all losses and derating factors.

A value of 5.83 hours is the peak sun hours for UAE, and the effective output is of 75 %. This gives the system capacity in kilowatts [14].

System capacity = 23kWh/(5.83h×0.75) = 5.32 kW

The number of panels are then calculated by dividing the total system capacity, with the power rating of 1 panel.

The total number of panels = 5.32 kW/240 = 23 panels

The number of panels is up-scaled to 26 panels for the PV system. The total area of PV panels that must be exposed to direct sunlight to get this output can be calculated by multiplying the total number of panels with the area of 1 panel.

The total area = 1.703 m^2 × 26 panels = 44.3 m^2

The system will be using 26 panels to produce the required power for the changing needs of one car. A collective number of these solar panels will be connected with each other in series to form one string.

2). Calculations for charging 5 cars

Since the charging station is designed to charge a minimum number of 5 cars to cover their daily energy usage. Their total energy consumption, system capacity and total panels will be 5 times of these for single car and will be 105.88 kWh, 26.6 kW and 130 respectively. The area required will also be 5 times, which will be 221.39 m^2.

3). Calculation of Voltage and Current ratings

A number of the solar panels will be connected with each other in series with each other to form one string. These strings are then connected in parallel to get required power. The total voltage of the system should be in the range of 350-490 VDC volts, to meet the power requirements. This voltage is later stepped down to make it more suitable for the electric vehicles.

Since the number of panels required is 130 panels, then each string will have 13 panels connected in series with each other and there will be 10 strings in parallel. The series connection is necessary as the maximum voltage of 1 panel is only around 30.7 volts and when the panels are connected in series the voltage from one string will amount to:

$$13 \times 30.7 = 400 \text{ volts}$$

The solar panels will then be connected to MPPT DC-DC Buck converters, after being connected through a PV combiner box and the charge controller. PV combiner box is used as a joining point for the voltage and power output from different strings in the PV system. The box helps create a bus linkage for the PV system [15]. The box also serves as a protection system as it has instruments that help protect against sudden changes in the voltage or current. The essential quality to look for while choosing a PV combiner box is the encasing because it is what the combiner box's utility life depends on. In areas such as UAE where the temperature and humidity can rise, we will use a PV combiner box which comes with a encasing that has a vent installed. This helps the box to cool down as it minimizes the pressure on the encasing. The combiner box is most suitable for when output power is high. This box can be used to join the output from all the strings [15].The charge controller will regulate the current movement, and to direct the current to flow in one direction. It will also prevent the back flow of current into the PV array [16]

The MPPT Buck converters will then be connected to charging DC-DC Buck converters. The MPPT converter will then be connected to charging converter from where they are input to the Electric vehicles. The system is also grid connected via a bidirectional AC/DC inverter which will convert the AC voltage supply to 400 VDC. The Fig. 1 shows the proposed System Architecture design for the solar powered charging station:

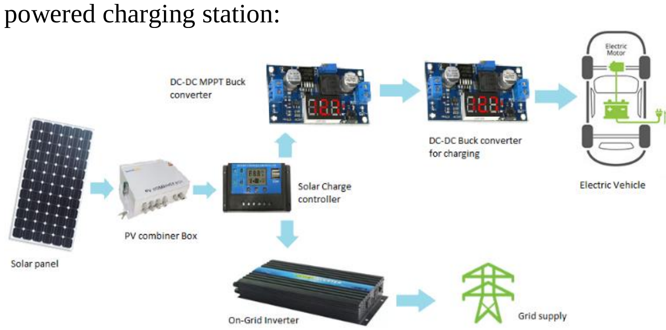

Fig 1: System Architecture

IV. Results

The simulation results have been obtained by modelling the system on the DIgSILENT Power Factory. The system was tested to display results for three important events: the first event is "night" time (The switch event is disconnecting the PV at sunset), the second event is "day" time (at sunrise the switch event is connecting PV again to the system) and the third event is "grid-off" (at a time when the grid supply is off while during the day time in emergency condition or islanded operation). The edges will be mentioned as sunset, sunrise and grid-off. The Fig. 3 shows the Power System used for simulation purposes.

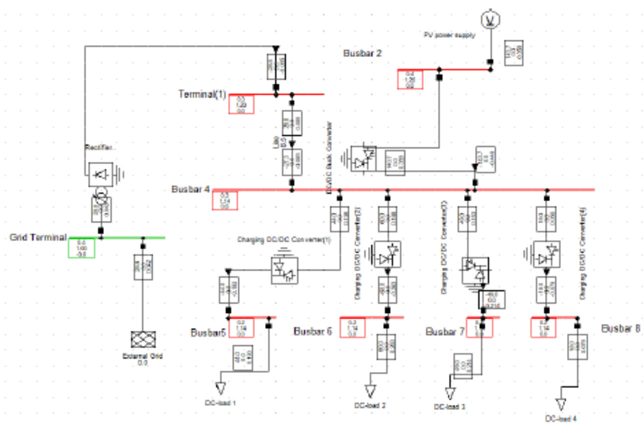

Fig. 2: System model in DIgSILENT Power Factory

A. *The Voltage*

The Fig. 3 shows the results of the simulation of the Voltage levels of the PV- grid power station that is obtained for the three simulation events: sunset, sunrise and Grid-off. From the graph it can be seen that the Voltage levels of all the different DC-DC converters that are present in the system are displayed. The Voltage across the DC-DC converter attached to Busbar-2 is represented by Light Blue. This is the main DC-DC converter which supplies voltage from the DC photovoltaic cells to the loads or Electric vehicles attached to the system. The Voltage across the DC-DC converter attached to Busbar-5 is represented by Green. Finally, the voltage across the line is represented by Dark Blue. The terminal is being supplied by the grid, so the graph basically represents the line Voltage of the AC grid supply.

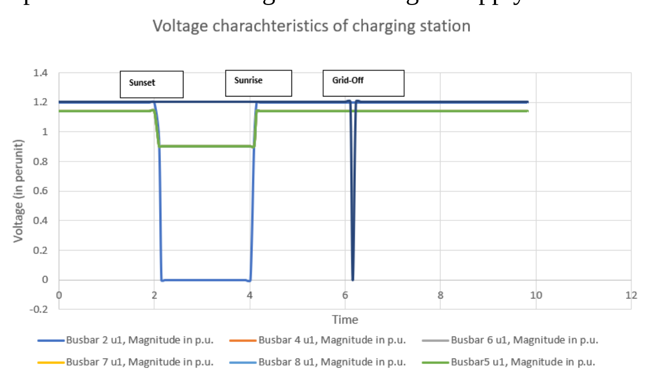

Fig 3: The voltage readings of the system for the three events.

1) *The voltage at sunset*

The sunset section shows the results of the simulation of the voltage levels of the PV- grid power station that is obtained at sunset when the solar intensity is at its lowest. The voltages are represented in per unit. From the graph it can be seen that the Busbar-2 is being supplied by the DC supply and represents the PV panels Voltage, whereas the voltage across the Busbar-5 represents the voltage that will be supplied to the load attached to Busbar-5 from both the grid and the Panels. From the graph it can be seen that the two voltages are at a fairly constant level before the onset of sunset, with the value of the Busbar-2 being slightly higher than that of Busbar-5. This is because the Busbar-5 receives Power supply from the PV panels and the grid that has been reduced due to losses in the lines.

2) *The voltage at sunrise*

At sunrise the voltage from the PV panels will start increasing. Initially the increase will be very slow as the light intensity will be too low. But as the light intensity continues to increase the DC voltage would increase as well. The voltage from the DC voltage source will be at its highest when the light intensity is the maximum at noon.

B. *Current*

The Fig. 4 shows the results of the simulation of the current levels of the PV-grid power station that is obtained at the three different simulation events : Sunset, Sunrise and Grid-off. From the graph it can be seen that the current levels of all the different DC-DC converters that are present in the system are displayed. The legends indicate the current in various sections of the system.

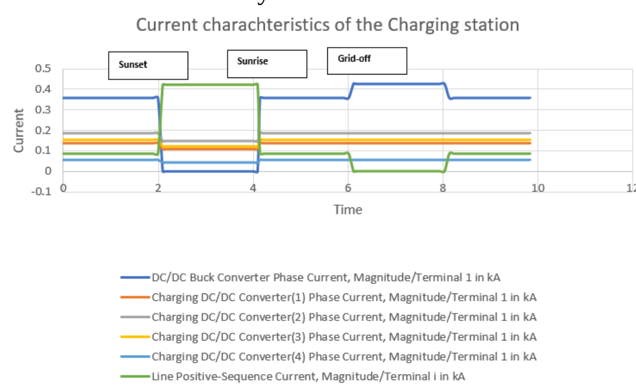

Fig 4: The current readings of the system for the three events.

1) *The current at sunset*

The sunset section shows the results of the simulation of the current levels of the PV-grid power station that is obtained at sunset when the solar intensity is at its lowest. At 2 seconds when the power supply from the Photovoltaic DC system is cut off, the current then starts increasing sharply because the system loads will entirely depend on the grid supply. Hence as soon as the current from the DC source becomes zero, the current from the grid supply will reach its maximum point.

2) *The current at sunrise*

At sunrise, with the increase in light intensity, the current from the DC source starts increasing. The grid current starts decreasing at the same time, as the DC power source will start providing the system with the solar power being produced. The grid current will decrease and become at the same level that it was prior to sunset. It then becomes constant. The DC source current, which was initially at 0 Amperes, will start increasing and reach to the point that it was prior to sunset. The current will then become constant at this value. The current level from the source is at a slightly reduced level than that of the grid. The remaining 4 parameters show the current that is owing across the DC-DC converters of the 4 loads attached. It can be observed that all 4 graphs start increasing slightly at sunrise and become constant at the same level of current that they were at prior to sunset.

3) Current at Grid-off

In the third part of the simulation, the current is observed when the grid is switched off. It can be seen that the grid current continues to drop steeply until it reaches a value of 0 amperes altogether. This clearly suggest that there is no ow of current from the grid to the system. On the other hand, the current from the DC-DC converter increases and reaches its maximum value. This converter acts as a common converter between the PV panels, the loads and the grid.

C. Power

The Fig. 5 shows the results of the simulation of the Power levels of the PV- grid power station that is obtained at the three different simulation events: Sunset, Sunrise and Grid-off. From the graph it can be seen that the Power levels of all the different DC-DC converters that are present in the system are displayed. The pattern of power flows is similar to current flows. Also, the lines and converters are the same through which current and power results are taken.

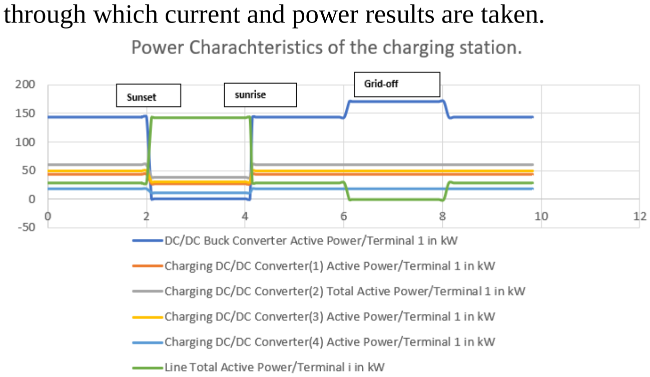

Fig 5: The Power readings of the system for the three events.

1) The Power at sunset

Initially the power was shared between the Photovoltaic and the grid. But at sunset the power from the photovoltaic cells is suddenly cut out. This leaves the system being entirely power dependent on the grid.

2) Power at sunrise

At sunrise, the power is shared between the Photovoltaic and the grid again as the power from the photovoltaic cells starts getting generated. This decreases the burden and dependency on the grid.

3) Power at grid-off

In the third part of the simulation, the power is observed when the grid is switched off. It can be seen that the line power (that is representing the grid power) continues to drop steeply until it reaches a value of 0 Watts altogether.

D. Simulation results compared to manual calculations

Manual calculations were performed to validate the simulation results. From the simulation, we can see that there are 5 main DC converters. The DC-DC converter 1 is the DC converter that is the main DC converter that is supplying the loads with solar DC voltage. The first step is to find the Duty cycle out of each DC-DC converter. This can be calculated using the below formula:

$$D = \frac{V_{out}}{V_{in}}$$

The Duty cycle obtained is then compared to that stated in the simulation. The percentage difference between them is then calculated by the formula: (Difference/measured) × 100

The next step is to calculate the current I_{in} that is entering into the DC-Dc converter.

This can be done by using the following formula:

$$I_{in} = \frac{P_{in}}{V_{in}}$$

The next step is to calculate the output current or I_{out} that is leaving the DC-DC converter. Since we know that

$$D = \frac{V_{out}}{V_{in}} = \frac{I_{in}}{V_{out}}$$

The output current I_{out} can be calculated using:

$$I_{out} = \frac{V_{in} I_{in}}{V_{out}}$$

The comparison of calculations is given in the table 1.

V. Conclusion

Availability of EV charging is one of major problems to demotivate a transition towards electric vehicles. This project will help in evolving the existing transport system into a cleaner and greener system. Another main problem with Electric Vehicle usage was the burden that these vehicles impose on the grid by charging. In this research a charging station that is dependent on solar energy has been proposed for use. The results that were achieved through simulation analysis of the system modelling are then shown. Suitability of PV charger for EVs will encourage the customers to shift to EVs with time.

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Table 1: Comparison of manual calculations and simulation results

DC	V_{in}	V_{in}	Pin	I_{out} (sim)	I_{in} (sim)	D (sim)	D (manual)	I_{in} (manual)	I_{out} (manual)	ΔD(%)	ΔI_{in} (%)	ΔI_{out} (%)
DC-1	400	300	143700	449	359	0.8	0.75	359.25	479	6.67	0.0696	6.263
DC-2	300	200	44000	193	138	0.714	0.667	146.667	220	7.1	5.909	12.272
DC-3	300	200	60000	263	188	0.714	0.667	200	300	7.1	6	12.333
DC-4	300	200	49000	214	153	0.714	0.667	163.333	245	7.1	6.327	12.653
DC-5	300	200	18000	79	56	0.714	0.667	60	90	7.1	6.667	12.222