Development of EV-PV Integration Model for Zero Running Cost Transportation

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***Abstract*—This paper put forwards a formula which correlates the area of solar panels required with the battery capacity of electric vehicles for the purpose of charging it. This work will reduce use of over rated or under rated solar panels. It will also remove need of having net metering associated with PV energy. It is extremely useful in crowded cities where solar energy charging of EV is implemented. It will also take us to completely green vehicle concept. In future EVs with PV panels could be sold where only one time investment will be required with zero running cost for vehicle.**

Index Terms— Energy, Solar, Vehicle, Photovoltaic

I. INTRODUCTION

There are two main types of natural resources, which are essential for sustenance of life on earth. These two categories are renewable resources and non- renewable resources. Renewable energy resources are those which are abundant in nature and can be reused. These include wind, solar, hydro, tidal waves, biomass, and biodiesel, geothermal whereas non-renewable energy resources include oil, gas and coal. It is not possible to have more of the energy from non-renewables forever because it gets exhausted once it is used. It is predictable that by the advent of next century the global energy demand could boom to five times of current energy demand [1]. Currently fossil fuels fulfil three-fourth of global energy demand. Fossils fuels and rare minerals are examples of non-renewable resources. Utilization of non-renewable resources is mostly through combustion of fossil fuels, resulting in release of large amounts of greenhouse gases and other toxic compounds. These harmful gases cause smog and deterioration of human health and plant health. Accumulation of these gases in the atmosphere leads to global warming, which further result in increased temperatures across the globe, melting of polar ice caps and drastic changes in climate. As renewable resources aren't utilized in this fashion, they aren't associated with release of such emissions. Problematic reduction in quantity of fossil fuels, issues in security of energy and surroundings lead societies to operate various energy sources [2]. In this context renewable energy resources are used for electricity production as many countries around the world are facing scarcity of traditional energy producing sources.

An electric vehicle abbreviated as (EV) uses electric motors for its propulsion. They comprise the collector system, which is powered by electricity either by external sources or by a battery [3]. Compared to conventional vehicles, EVs provide a host of benefits, the most significant one being that they release no carbon emissions. The rapidly growing transportation sector consumes about 49% of oil resources available. Following the recent trends of oil consumption and depletion of crude oil sources, the world's oil resources are predicted to be depleted by 2038 [4]. Therefore, replacing the non-renewable energy resources with renewable energy sources and use of suitable energy-saving technologies seems to be mandatory [5].

On a larger scale, for every EV that replaces other cars on the roads, the overall petroleum consumption by transportation industry reduces, thus decreasing dependence on it. These cars can be fuelled for very low prices, and EV companies offer great incentives for individuals to get money back from the government for going green. Electric cars are also a great way to save money from one's pocket [6]. EV's are also growing in popularity in recent times as they are nearly three times more efficient than cars with internal combustion engine. Rise in popularity brings new types of vehicles in the market. Two major trends in energy usage that are expected for future smart grids are a) large-scale decentralized Photo Voltaic (PV) systems. b) Emergence of battery Electric Vehicles (EV) as the future mode of transport[7]. The design and operation of the solar panels has also been extensively studied [8]-[10]. Charging systems used for photovoltaic charging have also been investigated by various researchers [11],[12]. Extensive study of various batteries and other components for integration of photovoltaic system and electric vehicles has been carried out [13],[14]. A lot of research work has also been carried out on solar panels to get a correct estimate of its output power by considering various factors such as humidity, temperature, etc.[15]-[17].

The research gap found is that there is no method of finding out the requirement of the number of solar panels for charging specific EV. Nowadays, the manufacturers of solar panels recommend their products based on vague thumb rules, the customers make the purchase and they end up with either solar panels occupying too much space or incapable of providing sufficient charge for use. It is believed that correct combination of EV and PV can give us zero cost transportation in daytime. Research regarding this topic is required considering various factors, which has been carried out and presented in this paper. Development of new empirical formula which co-relates EV with PV systems is the main innovation of this work.

The paper is organized as follows; Section 2 deals with necessary aspects related to batteries and solar cells. Section 3 discusses the proposed formula and the sub factors considered which innovation of the presented work is. Section 4 is about the cost analysis of the model. Section 5 is about the advantages and disadvantages of the EV-PV integration and section 6 presents concluding remarks.

II. Battery and Solar Cell

The presented work focuses on three main categories of vehicles a) Two-wheeled vehicles b) Three-wheeled vehicles c) Four-wheeled vehicles. Multiple details were recorded e.g. C-rating of the battery, power rating, battery capacity, and minimum time required to charge the vehicle, etc. It has been observed that higher C-rates lead to a faster capacity loss per cycle. At low C-rates chemical mechanisms of degradation dominate over capacity loss while at higher C-rates dominance is shown by mechanical degradation [18].C-rates of 2-wheelers are analyzed and are found to be in the range of 0.2-0.5. For 3-wheelers they are in the range of 0.1-0.33, and for 4-wheelers it is in the range of 0.1-0.5.For 3-wheeled vehicles, it is observed that they possessed a mean battery capacity of 5.4 kWh and 2 wheelers possessed a mean capacity of 1.8 kWh. In the case of 4-wheelers, such as electric buses and trucks, capacities range from 100-200 kWh. For the smaller 4-wheelers it is observed that they had a mean battery capacity of 20 kWh.

There are three different generations of solar panels designated as first, second, and third, and differ according to their cost and efficiency. The first generation solar panels are high-cost, high-efficiency. The second generation solar panels are low-cost, low- efficiency. They are composed of thin film solar cells and other minimal materials. The Third-generation solar panels which are in the development stage use a thin-film technology. Some of them produce electricity utilizing natural materials, others use inorganic materials. After going through various vehicles, their batteries used and the solar panels suitable for such EV-PV model which is innovation in the presented work.

III. Proposed EV-PV Model

For deriving the formula to calculate the required area used by solar panels, information about system factors is needed such as,

a) The battery capacity of the vehicle in Q in Ah
b) Voltage of the battery V in volts
c) Desired charging time T in hrs
d) The output power of each solar panel W in Watt
e) Duration of expected sunlight t in hrs
f) Area a of a single solar panel in sq. meter

This information is taken into account and processed adequately to find out the total requirements of the solar panels needed to charge the corresponding vehicle on the regular basis. The proposed empirical formula is obtained as,

The total energy required by battery E_v is

$$E_v = Q \times V \tag{1}$$

The total energy produced by solar panel per day (E_s) is

$$E_s = W \times t \times CF \tag{2}$$

Where, CF is the proposed Correction Factor described subsequently.

The total solar panels required (n) is

$$\eta = \frac{E_v}{E_s} \tag{3}$$

That is,

$$n = \frac{Q \times V}{W \times t \times CF} \tag{4}$$

Area (A) utilized by the solar panel is,

$$A = n \times a \tag{5}$$

Where "a" is area of each panel. The correction factor is an essential component in determining the exact solar panel requirement because a solar panel can't provide the ideal amount of current daily. The current varies due to atmospheric conditions. The proposed CF depends on other parameters such as a) Temperature loss constant (k_t), b) Losses due to dust particles (k_d).

Warmer temperatures reduce photovoltaic cells' energy production, and panel manufactures use the temperature coefficient to predict the loss of efficiency for each degree above 25 °C which is the standard temperature conditions. In general, the temperature coefficient of a solar panel will tell how much a solar panel's efficiency will be affected when it gets hotter. More specifically, the coefficient predicts the decrease in efficiency for every degree above 25°C. Most of the solar panels have an efficiency of 15-20 %, a few of them has an efficiency of 22%, whereas 40% efficiency is achieved by some experimental solar panels. Also, the panel which produces more electricity is more efficient than the one which produces less electricity [19].Efficiency loss due to temperature can be calculated by multiplying the temperature co-efficient of the solar panels provided with every increase in standard temperature condition, which is 25°C. Most of the solar panels have a temperature co-efficient value range between 0.3 and 0.5

considering 0.4 as an average for most of the solar panels and a total efficiency of at most 20% due to several other factor proposed value for k_t is found and written in a tabular format in Table I.

TABLE I. PROPOSED LOOK UP TABLE FOR k_t SUB FACTOR

Temperature (°C)	**Efficiency (%)**	**Proposed Sub factor (k_t)**
30	19.6	0.98
35	19.2	0.96
40	18.8	0.94
45	18.4	0.92
50	18.0	0.90
55	17.6	0.88

Dust particles are formed in the atmosphere due to various factors. The structure, type and texture of the particles dependent on their sources of origin. Coarse particulate matter are defined as particles which has a diameter greater than 2.5 μm (e.g.PM_{10} – 10 μm), and fine particles which has diameter less than 2.5 μm ($PM_{2.5}$).Dust is an unavoidable factor as solar panels are open in atmosphere. The dust accumulated can be varying according to places and climatic conditions. For example in places like Rajasthan, India the dust accumulated will be more compared that of Maharashtra, India. There are seasonal changes in this parameter. In summer seasons, the dust particles getting accumulated are more as compared to the rainy season as rain will help in cleaning the solar panel. The mean daily energy loss along a year of a PV module due to dust deposition on its surface was recorded to be around 4%.If there are no rainfall solar panels will get dustier resulting in an energy loss of more than 20%.So to find the energy loss due to dust particles, an experiment is conducted based on a research conducted by E. Suresh Kumar [20]. In which a solar panel of size 12.5cm by 8cm is introduced towards a light source (a tube light) having constant radiation, at constant temperature. The solar panel gives an output power of 502 mW when it was introduced to light making sure that the solar panel is so clean an contains no dust particles at all. Then to examine the effect of dust, add 100mg of finely ground clay (bentonite) evenly over the photovoltaic panel and record the output using the help of a multi meter. The experiment showed that by adding dust per 100mg the output power gets reduced in a somewhat linear manner. When the first 1mg of dust gets added the power output comes out to be 452mW. From this information, the efficiency is related to dust particle (in mg/cm^2) as follows,

$$\eta = \frac{P_d}{P_{nd}} \tag{6}$$

P_d represents the output power of the solar cell with no dust accumulation and P_{nd} is the output power when there is dust. Analyzing the data acquired from the experiment conducted a graph was drawn with dust present in 1sq.cm of solar panel in x-axis and efficiency in y-axis which is shown in Fig. 1.

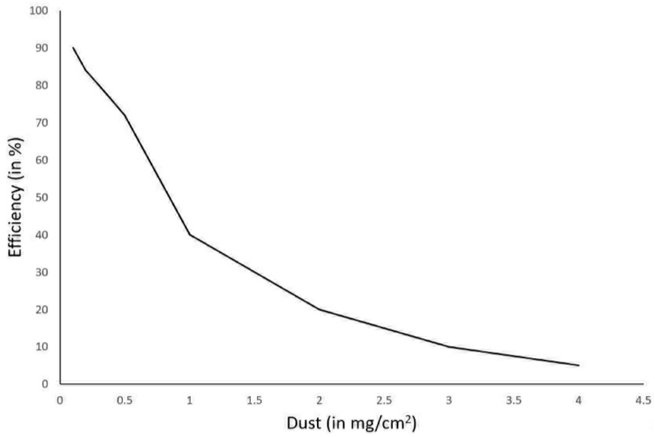

Fig. 1 Effect of dust on efficiency

From the experiment a generalized value for k_d can be proposed, which is given in the form of a look up table in Table II.

TABLE II. PROPOSED LOOK UP TABLE FOR k_d SUB FACTOR

Dust (in mg/cm^2)	**Proposed Sub factor (k_d)**
0.1	0.9
0.2	0.84
0.3	0.80
0.4	0.76
0.5	0.72
1	0.40
2	0.20
3	0.10
4	0.05

Snow-factor (k_s), Wind factor (k_w) and humidity factor (k_h) can be taken and integrated into this equation, work on which is still under progress as it involves some nonlinearity.

As part of the experiment, a solar panel of 12.5cm by 8cm producing 500mW of power and having a temperature co-efficient of 4/°Cis taken and conditions are created such that every factor except temperature and dust remains constant. Then the total energy produced by the solar panel for 5 hours at 25°C and 0 grams of dust came out to be approximately 2.5kWh. When the temperature changed from 25°C to 35°C and the dust from 0 to 0.1 gram, the energy produced in 5 hours turned out to be 2.16kWh. The experiment has been conducted for different values of temperatures and weights of dust particles and the total energy produced has been recorded. The output power is the product of the maximum power, dust correction factor and temperature correction factor. So the output energy can be written as,

$$E_s = W \times t \times k_d \times k_t \tag{7}$$

So the proposed formula to find the area acquired by solar panel is

$$A = (\frac{Q \times V}{W \times t \times k_d \times k_t}) \times a \quad (8)$$

The results from the above experiment are recorded in a tabular format shown below as Table III.

TABLE III. CORRECTED OUTPUT AFTER CONSIDERING VARIATIONS DUE TO DUST AND EXTERNAL TEMPERATURE

Dust (in mg/cm^2)	Temperature (°C)	Total output energy without correction factor (kWh)	Total output Energy (kWh)
0	25	2.5	2.5
0.1	35	2.5	2.16
0.2	30	2.5	2.05
0.5	40	2.5	1.69
1	55	2.5	0.88
3	45	2.5	0.23

IV. COST ANALYSIS

An Electric two wheeler is considered, having battery capacity 20 Ah and 48 volts. The power produced by the solar panel taken for the experiment is 100 W with 0.0625 sq. meter area. The solar panel receives 5hrs of sunlight daily. The temperature is 28°C in day time. The proposed temperature sub-factor is found to be about 0.988. The dust found in 1 sq.cm is about 0.1 mg per sq.cm, so the proposed dust factor is about 0.9. By substituting the given information to the equation, the required number of solar panels was found to be 3.23. Solar system suppliers often round it to 3 or 4 depending on budget of customer and hence end up in giving oversized or under sized PV system. If customer is aware of the proposed rule, he or she can insist for solar panel of 3.5 capacity or change complete design.

If the cost for solar panels are considered, different countries provide solar panels for different rates. For example in countries like India a solar panel producing 100W will cost around 46.52 USD and the total entire installation including the cost of 100 USD approximately and in countries like America it will be around 200USD. Even though the initial cost for entire installation is high the running cost for solar panel is zero as the solar panels has very few technical issues after the first installation. Whereas while using non-renewable energies the installation cost is less but the running cost is high. Considering the current value for petrol in India a two wheeler of 50kmpl mileage will use more than 100USD in just driving 3500Km distance. It is believed that correct combination of EV and PV can give us zero cost transportation in daytime.

V. ADVANTAGES AND DISADVANTAGES OF PROPOSED MODEL

Around 30% of greenhouse gases in the world are produced by petrol and diesel engines. If this engine is replaced with an electric one, it will be a massive advantage for earth and humanity in the long run. Electric cars run on electrically powered engines, hence there is no need to carry out any maintenance tasks that are usually associated with a gas engine. Therefore, the maintenance cost of these cars is relatively very low and it doesn't have to be sent to a service station as often as required for a standard gasoline-powered car. Solar energy is a renewable energy which is extracted with the help of solar panel. The only cost of using solar energy is its initial installing cost. If it's done then there is no need of any other source for the running of the vehicle. When petrol cars of mileage 15 kmpl are used, the cost of fuel for travelling 6000 km will exceed the cost for installing a solar panel. So using solar panels is a cost effective and environment-friendly process.

The main disadvantage of the proposed equation is that it doesn't include the real time factors effecting the efficiency of solar panels like atmospheric fog, wind speed, hence by including these factors the equation might become non-linear. Thus finding the exact efficiency and cost is hard but studies is being conducted so all the factors can be considered and find the perfect value.

VI. CONCLUSIONS

In this paper, empirical formula has been proposed which will aid businesses and individuals in calculating the rooftop area required to set up solar panels at their offices or homes so as to facilitate day- time charging of their EVs when they arrive for work. It takes into account the external factors which affect the efficiency of solar panels. In the presented model, the proposed correction factor depends on temperature and dust. For these factors, new sub- parameters k_t and k_d respectively have been introduced. This model gives the precise number of solar panels required for customer use, thus protecting the customer from getting over-rated or under-rated solar panels and will aid in buying the exact number of panels of the particular rating. Setting up such systems provides an independent, uninterrupted power source for the sole purpose of charging EVs, which shall further motivate the public to adopt EVs as a preferred means of transport over conventional transport. It will remove requirement of net metering associated with PV charging. It will make vehicles green in true as EV charging will be at zero cost.

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