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Solar and Wind Energy Based Charging Station for Electric Vehicles

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ABSTRACT: This paper describes the solar and wind energy based charging mechanism (SWCM) to generate the power for charging the battery packs of electric vehicles (EVs). The renewable charging station consists of both the solar photovoltaic (PV) modules and a wind generator. The SWCM immensely reduce the requirement of fossil fuels to generate electricity which results in greatly reduced CO_2 and CO related emissions. The renewable sources such as wind and solar has been modelled using single diode model and an analytical modelling has been done for wind energy generation. The simulation model has been developed in MATLAB-Simulink for the proposed SWCM. The I-V and P-V characteristics of the solar panel have been studied under various irradiance levels and different parameters of wind turbine has been studied under two different loading (1 kW and 3 kW) conditions. There are two unidirectional direct current (DC) to DC converters are connected to the PV modules and the wind turbine and six bidirectional DC-DC converters are connected to ten charging points which provides charging to the electric vehicle. To balance the load demand, the proposed system is connected to the grid through a three phase bidirectional DC-AC (alternating current) inverter. The obtained results show that the proposed renewable charging mechanism is suitable for EV charging thus creating pollution free environment.

KEYWORDS: Electric Vehicles, Synchronous Generator, Recharging Mechanism, Solar Energy, Wind Energy.

I.INTRODUCTION

Since electric vehicles have been utilized in the 1990s, their dispersion into the vehicle market has not been up to the mark because of the reason that it is less cost effective and these vehicles need to recharge once in 60 to 70 km drive. The hybrid vehicles play a major role in the present market and it obtains their energy from the combustion engine. However, in order to alleviate the utilization of gasoline, the plug-in electric vehicles (PHEVs) entered into the market and it takes the energy from the grid for driving. To increase the life of storage system, cost reduction, and the flexible grid connectivity, the PHEVs are still under research.

Nowadays, the park stations, roadside units, and the standard home outlets are used to charge the battery packs of EVs. The storage system present in the EV takes a prolonged period for recharging the battery packs and it will vary depending upon the capacity. A new charging method is introduced by Chellaswamy et al. for recharging the EVs. The control system present in this mechanism automatically charges the battery packs without the contribution of the driver. The performance analysis has been done and the result is compared with other EVs [1]. The plug-in EVs are used to reduce the green house gas emissions. The high-frequency ac-dc converter is used to charge the traction battery packs and an electromagnetic interference (EMI) filter is connected with the high-frequency transformer to suppress the EMI noise has been studied in [2]. A high sampling rate camera with a sensor is used to estimate the slip angle measurement of EV. The performance of this model based estimator has been studied by Yafei et al. with the help of multi-rate Kalman filtering [3]. A linear programming is used to estimate the operating cost, optimal scheduling, and CO_2 emission of a hybrid EV under European regulation. This mechanism also controls the electricity consumption of EVs [4]. A control algorithm has been developed to equally maintain the state of charge (SOC) of all the NiMH battery packs which are present in the EVs. The SOC variation for different temperature and the percentage of improvement has been studied by Man et al [5, 6]. To limit the rate of charge and the cost a smart algorithm has been developed and the performance is studied by Mosaddek et al. An experimental setup has been implemented and electrifying the plug-

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in EVs by parking garage standard outlet. A comparative analysis has been performed for SOC under different temperature conditions [7].

Hybrid renewable energy (RE) based power generation become popular because of anxiety over the atmosphere. To eliminate the transmission loss and grid connectivity problems, RE based power generation is carried out in [8]. The wind power generation system has a less harmful impact compared to fossil fuels. The wind energy potential and electricity generation for recharging the storage system present in the EV has been studied in [9, 10]. Among different wind generators, the permanent magnet synchronous generator (PMSG) is more popular because of its generation capacity. The power quality is improved by Geng and Xu with the support of power electronics [11]. The maximum power tracking and control system has been introduced for increasing the amount of power generation of the wind turbine has been studied in [12]. The possibilities of providing electricity through a renewable hybrid energy system to a remotely located community, Bekele and Palm [13] and a renewable source for recharging the EV is discussed by Chellaswamy and Ramesh [14]. The hybrid energy system is a better alternative for pollution free atmosphere. This type of energy system is implemented in a region Hurghada in Egypt for reverse osmosis desalination is carried out by Fahmy et al. [15]. For minimizing the life cost, Hafez and Bhattacharya [16] proposed an optimal design of a hybrid energy system which includes PV, wind and a micro-hydro for generating power. To predict the exact behavior of PV panel by simulation, developing a suitable model is necessary [17, 18]. The single and double diode models have been familiarly used to extract the solar cell parameters has been studied [19, 20].

Different recharging stations for EVs and its analysis has been explained in [21, 22]. Variability in the PV produces major drawback of EV charging and it can be solved by using smart charging system. The smart charging has different benefits such as reduce the peak demand on grid and increasing the generation of PV [23]. The maximum PV utilization occurs when the charging profile of the EV has been varied with time [24] and the surplus amount of energy can be reduced by increasing the number of EVs [25]. On the other hand, the charging is done using a constant power EVs leads to follow the generated power of PV [26]. The wind energy conversion system consists of three important parts such as a rectifier, three phase generator, and maximum power point controller (MPPT) [27]. The wind turbine converts wind energy into corresponding mechanical energy and the speed is regulated by a MPPT controller [28, 29]. The tip speed ratio (TSR) of wind turbine [30] and the power signal feedback (PSF) can be controlled by a reference value [31].

Various EV charging stations and simulation models has been analysed in [32] and most of the literature deals with solar PV only [33]. In some literature only wind energy is used to generate the power for recharging the EVs and some EV charging station has hybrid (wind and other power sources) energy sources [34] and ideal simulation model is used to study the performance of the system [35]. In this paper, renewable energy (solar and wind) based recharging station has been designed. The polycrystalline solar module (SPM050-P), has been analysed using different irradiance level and the vertical type wind turbine model WKV-10000 has been analysed under different loading conditions. Finally, the hourly generated electricity and the load of EV for both the renewable sources has been studied. Moreover, the utilization of renewable charging station make green environment. The rest of this paper is organized as follows. The renewable based (solar/wind) charging station for EV charging is explained in Section 2. Section 3 describes the modelling of the proposed hybrid charging mechanism; section 4 present the MATLAB-Simulink model with the results; and finally, the conclusion is described in section 5.

II.DESIGN OF THE PROPOSED SYSTEM

The renewable charging station is constructed with the solar PV module of 10m×20m of SPM050-P and a vertical axis wind turbine (WKV-10000) with the rated wind speed of 12 m/h. The weather report has been analysed for the last five years (2012-2017) and the extracted statistical data shows that there are 276 sunny days are available during the year. The solar PV can generate full power during these days and it is very less in the remaining days, the power requirement can be managed by both the solar and wind power and the balance energy needed for charging EVs can be taken from the grid. The total power generated by the charging station from the solar PV modules and the wind turbine has to be estimated. The generated power should be managed the daily power demand. So that a statistical analysis has to be performed for the average number of PEVs and EVs charged per day around the vicinity of the charging station. The number of EVs charging hour by hour per day is shown in Fig. 1. The proposed SWCM consists of a wind energy

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conversion system, PV array, maximum power point tracking (MPPT) controller, unidirectional DC/DC converters for PV array, DC-AC inverter connected to grid, and bidirectional DC-DC converter for providing charging to EVs. In this study, the charging station is constructed in such a way that it can handle 10 EVs charging points. It is noted that the proposed charging stations can switch vehicle-to-grid (V2G) connection. An automatic system is incorporated to manage the charging of EVs and discharge the electric energy through the grid when the load demand of the grid is high.

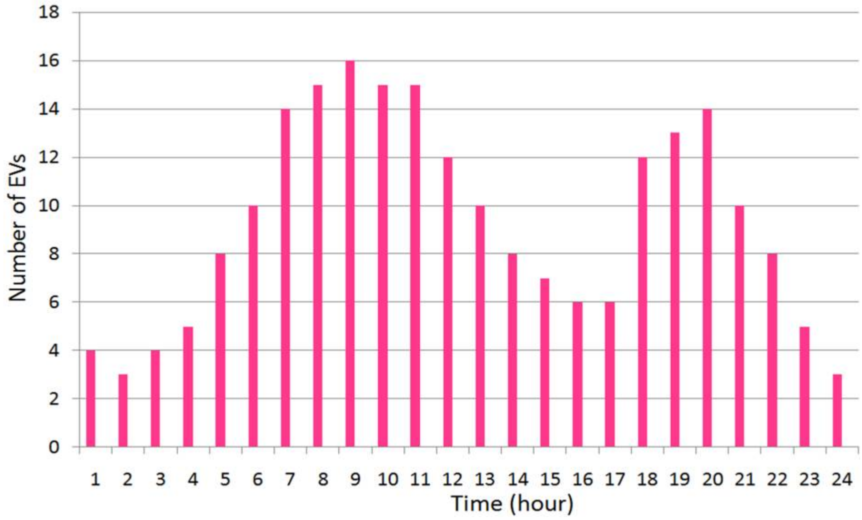

Fig. 1 Number of EVs charging per hour during a day.

The wind energy conversion system and the solar modules have been connected through the two identical DC-DC converters to the DC bus, and the PV array is continuously monitor and track by the controller and the DC-link voltage is taken as a reference for the controller. The implementation of the proposed charging mechanism for EVs is shown in Fig. 2. It reveals that the SWCM provides balance between the load demand of the grid and energy to charge EVs [36].

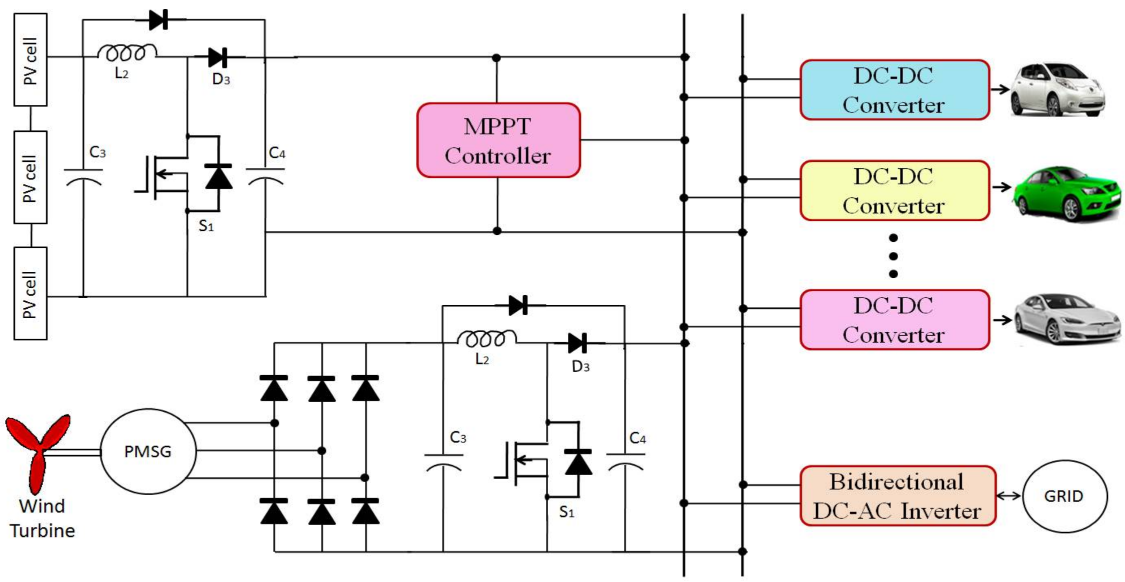

Fig. 2 Implementation of the proposed charging station for EVs.

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III.SOLAR AND WIND MODELLING

The hybrid renewable sources such as the wind and solar energy generation mechanism are used to generate electrical energy for recharging the battery packs of EVs. The characteristics (V-I and P-V) of solar module and the wind turbine performance have been modelled. The stochastic behaviour of both the renewable sources can be done by probability distribution function (PDF) in a statistical manner.

1.Modelling of Wind Speed

The wind accumulates in the turbine depends on the present speed of the vehicle. The stochastic behaviour of the wind speed in a specific time duration 't' can be described using Weibull PDF by Khatod et al. [37]. The wind speed S^t for 't' segment can be expressed by Weibull distribution as:

$$f^t(P) = \frac{\beta^t}{\alpha^t}\left(\frac{P^t}{\alpha^t}\right)^{\beta^t-1} exp\left(-\left(\frac{P^t}{\alpha^t}\right)^{\beta^t-1}\right), for\ \alpha^t > 1; \beta^t > 1 \quad (1)$$

where β^t and α^t are the shape parameters and it can be calculated as follows:

$$\beta^t = \left(\frac{\sigma^t}{\mu_p^t}\right)^{-1.086} \quad (2)$$

$$\alpha^t = \frac{\mu_p^t}{\Gamma(1+1/\beta^t)} \quad (3)$$

where μ_p^t and σ^t are the mean and standard deviation of wind speed at time segment 't'.

2.Wind turbine power generation model

The output power of the wind turbine depends on the speed of the vehicle. A specific time frame is divided into different states and the wind speed is within the specific limit. The probability of wind speed $P_s(S_k^t)$ for 't' time segment can be expressed based on [38] as:

$$P_s(K_n^t) = \begin{cases} \int_0^{(K_n^t+S_{n+1}^t)/2} f^t(K)\, dk\ , for\ n = 1 \\ \int_{(S_{k-1}^t+S_k^t)/2}^{K_n^t+K_{n+1}^t)/2} f^t(K)\, dk\ , for\ n = 2\ to\ Nw-1 \\ \int_{(K_{n-1}^t+K_n^t)/2}^{\infty} f^t(K)\, dk, for\ n = Nw \end{cases} \quad (4)$$

The power generation characteristics of the wind turbine are non-linear and it can be expressed for the average wind speed S_{avg} at k^{th} state based on [39] as:

$$P_{WT} = \begin{cases} 0, for\ K_{avg} \le K_{cut} \\ a * K_{avg}^3 + b * P_{rated}\ ,\ for\ K_{cut} \le K_{avg} \le K_N \\ P_{rated},\ for\ K_N \le K_{avg} \le K_{out} \end{cases} \quad (5)$$

where K_{cut} is the cut-in wind speed; K_{out} is the cut-out wind speed; P_{rated} is the maximum generated by the wind turbine; K_N is the nominal wind speed and the constants x and y can be obtained as:

$$a = \frac{P_{rated}}{K_N^3 - K_{cut}^3} \quad (6)$$

$$b = \frac{K_{cut}^3}{K_N^3 - K_{cut}^3} \quad (7)$$

From equation (4) and (5) the average output power of wind turbine for 't' time segment (P_{WT}^t) can be calculated as:

$$P_{WT}^t = \sum_{k=1}^{N_w} P_{WT} * P_n(K_n^t) \quad (8)$$

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3.Solar irradiance Model

The single diode model of a solar cell is shown in Fig. 3. The index terms I_{ph}, I_d, D, R_{sh}, and R_{ser} of Fig. 3 represents the photocurrent, diode ideality factor, p-n junction of a solar cell, shunt resistance, and series resistance respectively. By

using Kirchoff's current law, the governing equation for the total current I_t can be formulated as:

$$I_t = I_{ph} - I_d - I_{sh} \tag{9}$$

The diode ideality factor I_d can be modeled using Shockley equation, $I_d = I_{sd}[\exp(V_t + I_t R_{ser})/mV_T] - 1$, the thermal voltage $V_T = kT_c/q$, and the shunt current $I_{sh} = (V_t + I_t R_{ser})/R_{sh}$.

Now (1) can be expressed by using the Shockley equation based on [40] as:

$$I_t = I_{ph} - I_{sd}\left[\exp\left(\frac{q(V_t+R_{ser}I_t)}{mkT_c}\right) - 1\right] - \left(\frac{V_t+R_{ser}I_t}{R_{sh}}\right) \tag{10}$$

The solar irradiance R^t (kW/m^2) is considered in probabilistic nature and it can be expressed by Beta distribution function for a time segment 't' can be expressed based on [41] as:

$$f^t(R) = \frac{\Gamma(a^t+b^t)}{\Gamma(a^t)\,\Gamma(b^t)}(R^t)^{a^t-1}\,(1-R^t)^{b^t-1}, \quad for\ a^t > 0; b^t > 0 \tag{11}$$

where Γ represents the Gamma function; a^t and b^t are the shape parameters for the time segment 't'. The shape parameters of the Beta distribution function can be estimated in terms of mean (μ_R^t) and standard deviation (σ_R^t) for the time segment 't' is given by

$$a^t = \frac{\mu_R^t * b^t}{(1-\mu_R^t)} \tag{12}$$

$$b^t = (1-\mu_R^t)\left(\frac{\mu_R^t(1+\mu_R^t)}{(\sigma_R^t)^2} - 1\right) \tag{13}$$

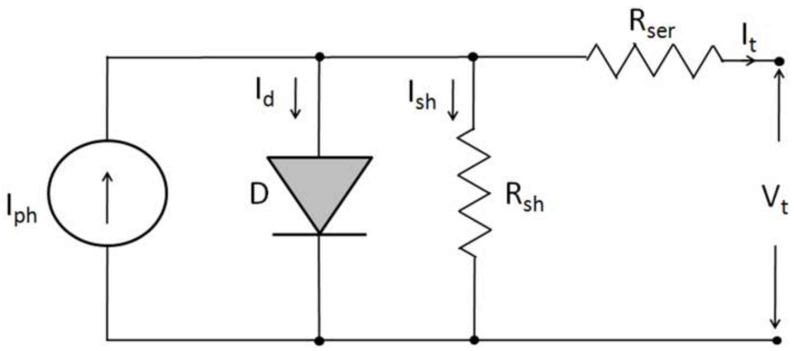

Fig. 3 Equivalent circuit of single diode model.

IV.RESULTS AND DISCUSSION

The simulation was developed using MATLAB-Simulink version 2016, Intel core i5, 2.3 GHz with 8 GB RAM computer. The simulation is carried out in the following ways. The doubly-fed 3-phase asynchronous machine having rating 1200 rpm, 13.4 kVA, 400V, 50 Hz with the 3-phase series resistive load. The isolated resistive load is connected through its stator windings and a dc motor is used to vary the speed of SG. The input speed of the SG is varied and the voltage and frequency of the load are kept constant. The performance of the model has been studied for different loads

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such as 1 kW and 3 kW are applied for various speeds of SG. To realize the performance of the proposed system, variable speed from 100-1200 rpm has been varied for the specified loads. Different parameters such as stator frequency, power, voltage, and rotor speed has been obtained. To study the parameters of the solar cell, the multi-crystalline module (SMP050-P) has been taken and studies the parameters under different irradiance. The electrical characteristic of the studied solar cell module is listed in Table. 1.

Table 1. Electrical Characteristics of SMP050-P.

Model	SPM050-P
Max Power (W)	50
Max Power Voltage (V)	18.8
Max Power Current (A)	2.65
Open-Circuit Voltage Voc (V)	21.3
Short-Circuit Current (A)	2.84
Cell Efficiency （%）	13.2
Module Efficiency （%）	10.0
Power Tolerance （%）	±3
Number of cells	36
Dimensions (mm)	760×668×35

The main focus of this work is to utilize both the renewable energies sources and recharging of battery packs of EV thus increasing the usage of EVs. The parameter values obtained numerically, simulated I-V data was generated using equation (10) and plotted against with experimental data is shown in Fig. 4. It is noted that the simulated data are closely matched with the manufacture data.

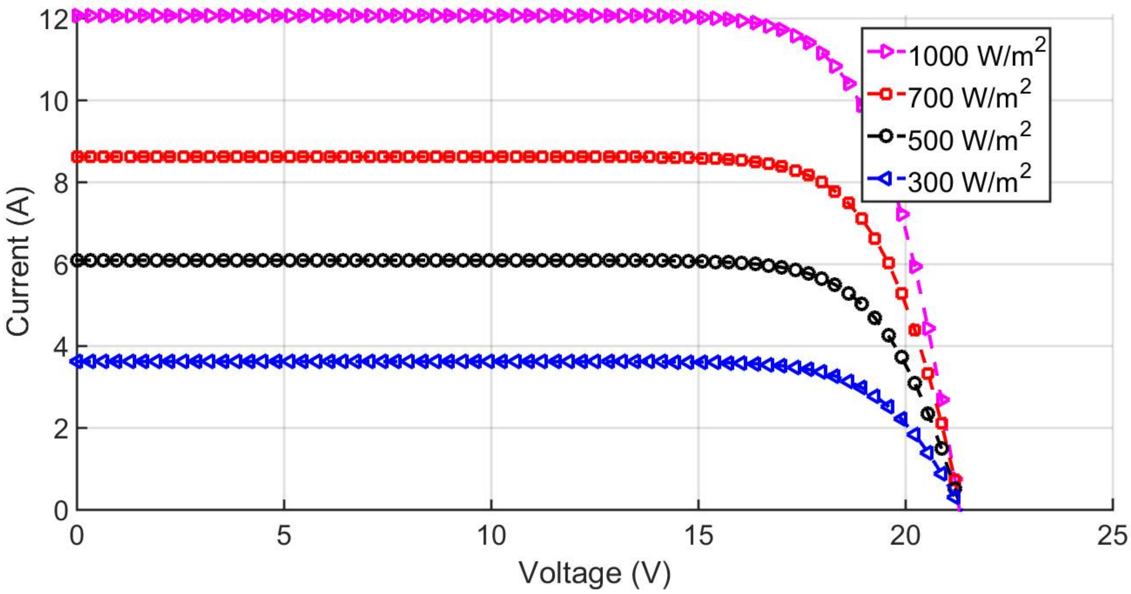

Fig. 4 I-V characteristics of SMP050-P module for various irradiance levels.

Now by examining the power-voltage characteristics of a solar module (SPM050-P), one can easily understand that the power generated by the solar cell depends on the level of irradiance. The power-voltage characteristic of a solar cell is shown in Fig. 5. Fig. 5 illustrates that the output power is high at high irradiance level. Moreover, the simulated values are closely matched with the manufacturer data at low irradiance level and it slightly deviates at high irradiance level

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(700 and 1000 W/m^2) of maximum power region. The performance of SWCM has been studied for different loads such as 1 kW and 3 kW are applied for various speeds of SG. To realize the performance of the proposed system, vary the speed of SG from 100-1200 rpm for 1 kW load. Various parameters of the wind turbine for EV charging is listed in Table 2.

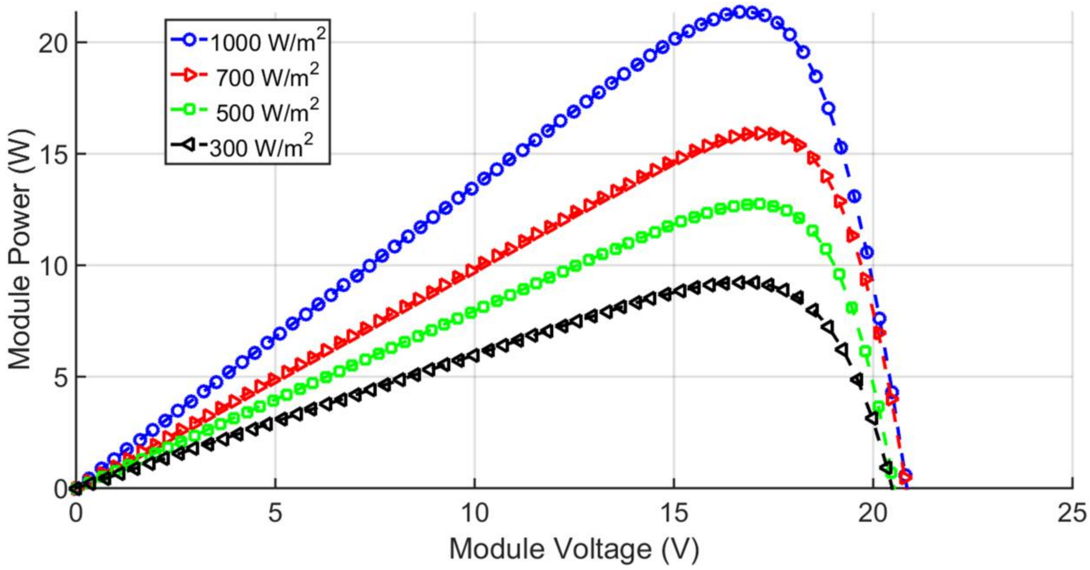

Fig. 5 Simulated P-V data for various irradiance level.

Table 2. Specifications of the PMSG and the Wind turbine for EV charging station.

Permanent magnet synchronous generator (PMSG)		Wind turbine	
Model	NH-10K-150	Model	WKV-10000
Winding type	Three-phase, star connection	Type	Vertical
Rated speed (rpm)	150	Rated power (kW)	10
Rated power (kW)	10	Size: height/diameter (m)	4.2 /5.7
Rated phase voltage (V)	110	Start-up wind speed (m/s)	1.5
Start-up torque (Nm)	<13	Blades material	Al. alloy
Nominal phase current (A)	30	Rated wind speed (m/s)	12
Weight (kg)	423	Survival wind speed (m/s)	60

The simulation model of the wind turbine has been developed using Matlab 2016 and is shown in Fig. 6. The performance of the proposed model has been studied for two different loads such as 1 kW and 3 kW are applied for different speed scenario of SG. To realize the performance of the proposed system, variable speed from 300-1200 rpm has been taken for 1 kW and 3 kW load. Different parameters such as stator voltage, frequency, power, rotor speed has been obtained for1 kW and 3 kW load and listed in Table 3 and 4 respectively.

From table 3 it is noted that the output voltage is proportional to the speed of SG. When SG is at minimum speed (100 rpm) the output voltage is 36.78 V and the speed is about 1200 rpm the stator voltage of SG is 311.13 V and frequency

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is 46.25 Hz. The output voltage (397.78) at rated speed is very close to rated voltage (400 V) and the frequency is same as the rated value (50 Hz). If the speed of SG is decreasing from 1200 to 1100 rpm, it will reflect in the voltage, power, and frequency (refer table 3). When the speed of SG decreases the load power and voltage is reduced from its rated value and the THD of voltage and current remains constant. The terminal output voltage and current of the proposed wind model is shown in Fig.7. From Fig. 7 one can easily understand that the terminal voltage and current of the proposed method is varying if the wind speed varies. The output is fluctuating at 0.035 and 0.14 seconds due to the variation present in the wind.

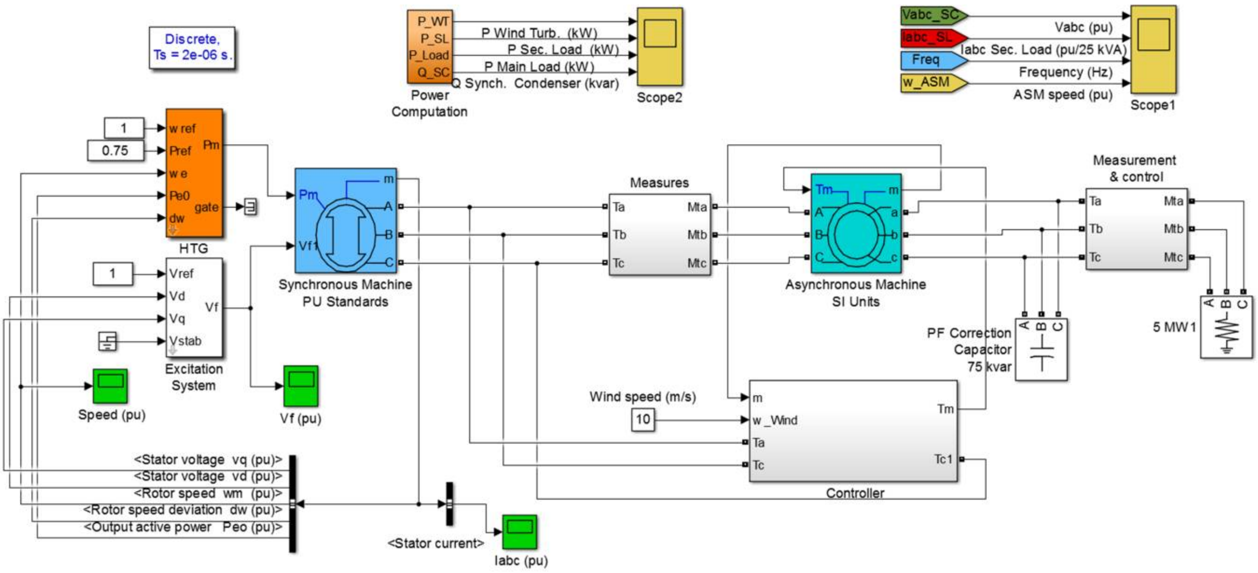

Fig. 6 Simulink model of the proposed wind power generation system for EVs.

Table 3. Different parameters obtained under various speed of SG at 1 kW load.

SG speed (rpm)	V_s (V)	f_s (Hz)	P_o(W)	P_{MP} (W)	S_{rm} (rpm)	V_L (V)	P_L (V)	% THD of I_L	% THD of V_L	% η
100	36.78	17.78	78.94	793.91	1142	364.34	801.34	0.01	0.01	91.24
200	46.85	18.23	122.65	759.37	1061	369.65	810.78	0.01	0.01	91.46
300	76.29	23.24	195.74	728.74	977	374.12	849.23	0.01	0.01	91.24
400	103.78	26.45	268.84	698.53	903	381.63	888.67	0.01	0.01	91.45
500	132.89	27.78	343.63	662.73	825	356.12	924.37	0.01	0.01	91.67
600	154.57	29.23	418.26	613.84	742	388.45	948.86	0.01	0.01	91.34
700	176.38	34.56	492.63	550.42	653	391.13	958.73	0.01	0.01	91.50
800	201.27	37.45	564.73	484.97	586	392.67	964.78	0.01	0.01	91.24
900	227.16	38.68	639.61	418.53	508	394.85	972.79	0.01	0.01	91.45
1000	256.78	41.23	717.14	350.96	432	395.13	980.34	0.01	0.01	91.67
1100	281.35	44.70	792.38	281.52	354	398.23	986.08	0.01	0.01	91.56
1200	311.13	46.25	871.83	212.74	262	397.78	995.36	0.01	0.01	91.46

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The hourly generated electricity from the wind turbine for a day and the solar power in a day time from 5 A.M to 6 P.M is considered. The power produced by the renewable source (wind and solar) is depicted in Fig. 8. The power generated by the wind generator is more noteworthy than the power generated by the PV module. If the energy generated by the renewable source is less than the demand then the controller automatically link the grid and manage the power demand. At the same time, the renewable station generates more power than the required demand then it will send the power to the grid.

Table 4. Various parameters obtained at different speed of SG at 3 kW load.

SG speed (rpm)	V_s (V)	f_s (Hz)	P_o(W)	P_{MP}(W)	S_{rm}(rpm)	V_L (V)	P_L (V)	% THD of I_L	% THD of V_L	% η
300	73.34	21.42	919.45	1515.72	1200	366.34	2264.37	0.01	0.01	92.36
400	98.78	24.78	972.78	1627.60	1100	370.84	2415.67	0.01	0.01	92.43
500	127.23	27.35	1029.23	1707.49	1000	374.24	2552.34	0.01	0.01	92.46
600	153.67	30.68	1108.47	1675.34	900	378.78	2583.86	0.01	0.01	92.24
700	186.89	33.45	1382.25	1504.56	800	382.35	2679.23	0.01	0.01	92.43
800	208.23	35.23	1590.67	1348.89	700	386.68	2745.57	0.01	0.01	92.44
900	231.54	38.68	1832.23	1182.36	600	389.24	2803.26	0.01	0.01	92.51
1000	254.78	41.89	2052.58	1012.72	500	392.73	2856.74	0.01	0.01	92.47
1100	283.12	42.56	2284.68	822.28	400	394.14	2896.48	0.01	0.01	92.43
1200	302.67	44.47	2532.29	623.42	300	396.63	2926.83	0.01	0.01	92.44

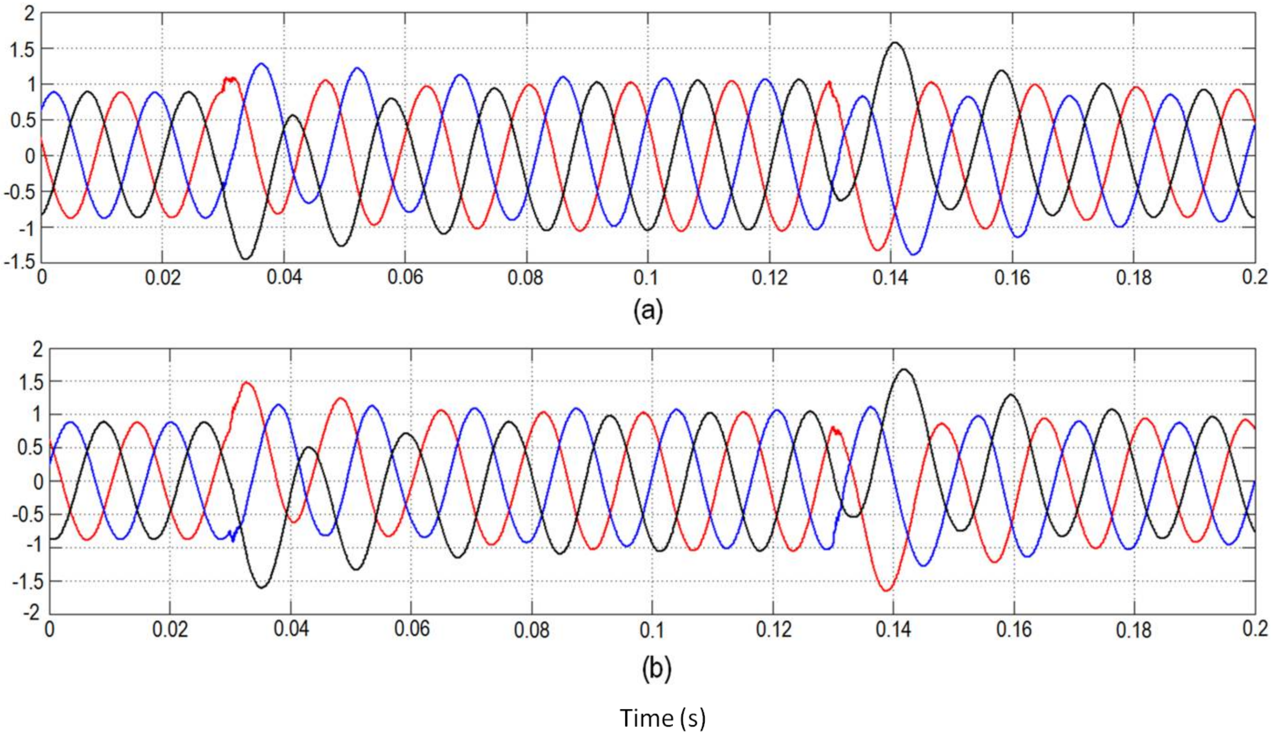

Fig. 7 Terminal output of the proposed wind model (a) voltage (b) current.

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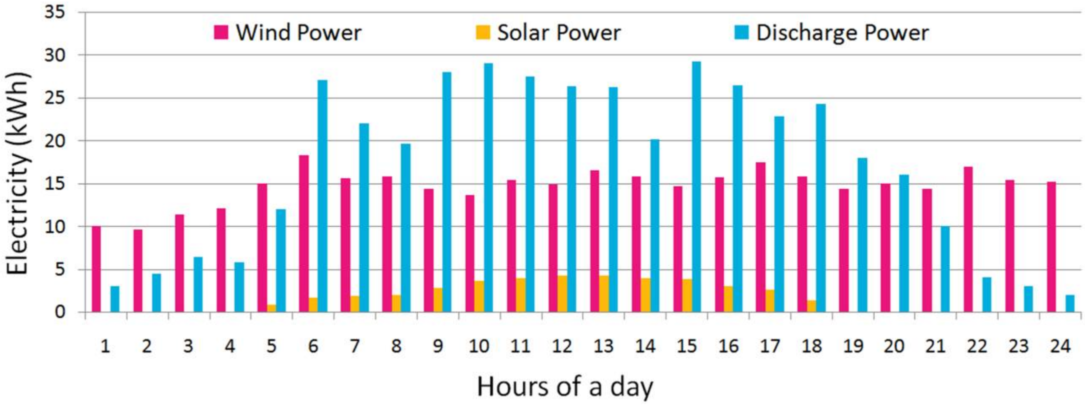

Fig. 8 Hourly generated electricity by both wind and solar from the proposed method.

The hourly required load, the total power generated by the recharging station, and the power supplied to the grid are shown in Fig. 9. In some cases such as hour 1-3.5 and 12-16.5 the station supplies few kilowatt of power to the grid.

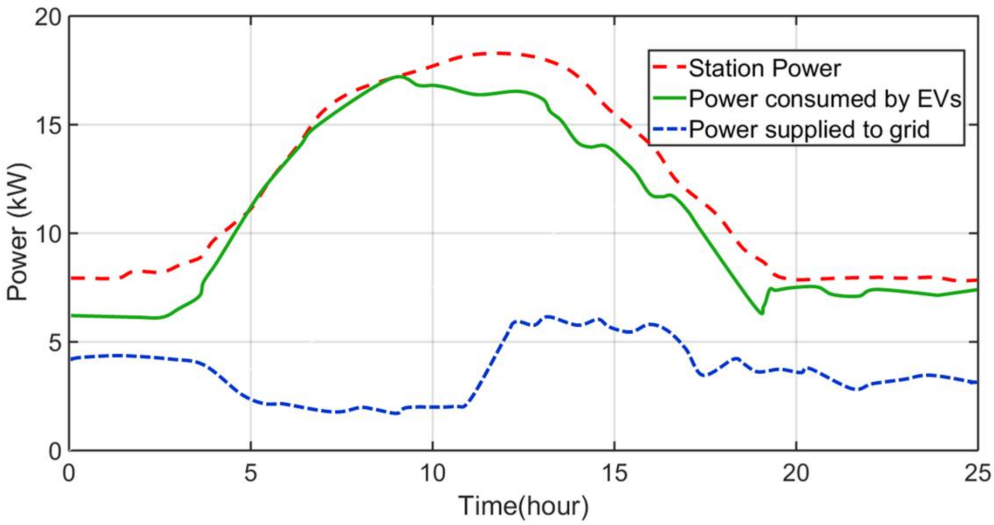

Fig. 9 Hourly power measured during a day.

V.CONCLUSION

In this paper, a new recharging mechanism for electric vehicles is proposed using solar and wind energy. The usage of EV is directly affected by the present charging technique. Recharging stations are necessary for longer drive vehicles and it is commonly used in few countries. The traveling distance depends on the capacity of energy storage present in the vehicle. The recharging stations are needed for long distance travel. In this paper, we have introduced a new hybrid renewable charging mechanism for EVs. A simulation model has been developed using MATLAB-Simulink and the performance of solar and wind energy has been studied. Various parameters of the solar module have been verified under different irradiation level. The SG has been studied under different loading condition. Finally, the hourly load of EV versus generated electricity has been analyzed. From the output generated by the hybrid system, we strongly say that the proposed SWCM provides enough power for recharging the electric vehicle and the time taken for charging can be avoided by battery swapping method. At last, we are concluding that this approach reduces the pollution and increase the usage of EVs as a result creating pollution free environment.

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