PV-Battery Hybrid Energy System For Electric Vehicle – Supervision and Control Strategy

P. S Vikhe¹, A. B Sabale², C. B Kadu³, V. V Mandhare⁴, and N. N Lokhande⁵

¹²³⁵Assistant Professor, ²PG Scholar, ³⁴Associate Professor
¹²³⁵Department of Instrumentation & Control Engineering, ³⁴Department of Computer Engineering,
Pravara Rural Engineering College, Loni-413736 (MS), India.
Email: ¹pratapvikhe@gmail.com, ²anilsabale2@gmail.com, ³chandrakant_kadu@yahoo.com,
⁴v_mandhare@yahoo.com, ⁵nnlokhande@gmail.com

Abstract
In today era, India has high solar potential, offers great opportunity in economic development. In this paper, PV with battery bank is studied and modelled to confirm feasibility for proposed hybrid electric vehicle (EV). The maximum power point tracking (MPPT) approach is applied to extract maximum power for PV system. In this work, perturb and observe (PandO) and fuzzy logic controller (FLC) techniques are compared for tracking MPPT. In the presented work smart power management of a PV system with battery storage is applied. Supervision unit is provided to allow maximum power transfer from PV generator, protect batteries against overcharge and deep discharge and satisfies the needs of energy. The application is designed to handle variable load condition of EV and PV source, subjected to varying environmental conditions. However, FLC provides better performance allows this method for MPPT tracking. The simulation results (SimPowerSystems) environment confirmed proposed supervisor makes autonomous PV system capable of working normally charging and discharging batteries to supply EV load without interruption.

Keywords: Photovoltaic (PV), Maximum Power Point Tracking (MPPT), Electric Vehicle (EV), Fuzzy Logic Control (FLC), Direct Torque Control (DTC).

I.INTRODUCTION
Today’s scenario of global warming and reduction of fossil resources require a mutation based on sustain energies, which are neat, clean, inexhaustible and easily accessible. They are able to fulfill our energy requirement. In presented application, it is primary to use an effective and efficient maximum power point tracking (MPPT) technique to track MPP for entire environmental conditions. This forces photovoltaic (PV) system to work at MPP point. In literature, many MPPT algorithms have been developed and presented, to enhance effectiveness of PV systems, like regular conventional methods (Perturb and Observe), Incremental Conductance (INC)) and advanced methods like fuzzy logic controller (FLC). The automobile contribution considered in air pollution and release of greenhouse gases [5]. However, energy management have limitation of battery load to a threshold minimum-maximum according to state of charge (SOC), supplies the electric motor, charging and discharging battery under different operating modes. Induction motor is used as propulsion of electric vehicle. Direct torque control (DTC) using space vector pulse width modulation (SVPWM) technique of induction motor is preferred due to its robustness and simplicity [8]. The use of electric vehicle is supported by an induction motor of around 3 kW. DC bus voltage is to maintain constant using direct torque control for its robustness and simplicity to use. In this paper, perturb and observe and fuzzy logic control based maximum power point
tracking approach is compared. Finally, proposed supervision system achieves maximum output from photovoltaic source, protect batteries against overcharge, deep discharge and fulfilled the energy needs. The obtained simulation results are presented to highlight effectiveness of proposed energy management.

II. RELATED WORK

Photovoltaic systems applications are smart homes, pumping for lift water in rural area, an electric vehicle or a variable load for electrification purpose. Hybrid power systems including use of proton exchange membrane fuel cell (PEMFC), wind energy conversion system found in the literature, Faika Zaouche [1]. Modeling, control and power management of hybrid PV fuel cell battery bank system supplying Electric vehicle is presented by Mokrani and Rekioua T[2]. MPPT algorithms were developed to enhance the effectiveness of PV systems, like conventional methods, Incremental Conductance (INC) and FLC proposed by Bendib and Krim [3]. This paper also investigates the role of battery storage in the smart-grid in mitigating solar plant output power oscillations where both rotary and electronically interfaced diesel generators are present in the system it is proposed by Koohi et al. [4]. Enhance the power management system of a stand-alone hybrid green power generation based on the FLC optimized by the H2O cycle algorithm. Sarvi and Avanaki [5] proposed an Indian city based residential home can meet energy demand proposed by Singh [6]. Optimization of Photovoltaic Power Systems: Modulization, Simulation and Control,” Green Energy and Technology presented by Rekioua and Matagne [7]. First, the design and the identification of the hybrid power system components has been made, then the proposed system was modeled and simulated under MATLAB/Simulink package, model and the control hybrid power system presented by Aissou et al. [8], DTC with loss minimization of IM drive which is proposed for EV applications. The objective of this design is to take benefits of the strengths of both methods DTC and optimal control is introduced by Tazerart et al. [9]. Fuzzy input parameters, dP/dV and variation of duty cycle (D), are used to generate the optimal MPP converter duty cycle, such that solar panel maximum power is generated under different operating conditions. MPPT for PV panel is proposed by Chouder and Silvestre[10]. Comparison study of two tracking methods for photovoltaic systems fuzzy logic-controlled design of a sustainable PV system presented by Attou A. and Chadli [11]. “Simulation Tool for Energy Management of Photovoltaic Systems in Electric Vehicles,” Energy Conversion and Management by Tina and Ventura,[12]. The main focus is optimization of energy extracted from renewable sources to and effectively control the charge and discharge of the battery, control and management of production systems focusing on energy from renewable sources is presented by Rabhi and Elhajjaji [13]. The performance evaluation of an autonomous PV system for recharging lithium-ion batteries for an EV. In this method, the power flow handle and control is performed via a DC-DC converter with a MPPT technique. It is deals with this method by Benaouad] M. [14].

II. PROPOSED APPROACHES

A. Modeling of Proposed System

System consists of an inverter providing supply to an electric vehicle, a photovoltaic panel, two DC converters and battery bank.

a. PV Panel - Modeling

Different mathematical models utilized for describing behaviour and operational working of photovoltaic. The model depicted in Fig. 1 is considered in this paper work.
Where, $I_{ph}$ is light-generated current, $I_d$ is diode current, $I_{Rsh}$ is shunt-leakage current, $R_{sh}$ is inversely proportional with leakage current to the ground and $R_s$ is series resistance. $I_{pv}$ characteristic of the model is given by Eq. (1) below:

$$I_{pv} = I_{ph} - I_{d} - I_{Rsh} \quad (1)$$

![Equivalent circuit of photovoltaic cell.](image)

In below table(I), parameters of SUNTECH 80S-12/Bb photovoltaic module used is given as per table I.

**TABLE I. PARAMETERS OF SUNTECH STOP 80S-12/BB PV MODULE [1].**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak power</td>
<td>80 W</td>
<td>$P_{pv}$</td>
</tr>
<tr>
<td>Maximum current at MPP</td>
<td>4.65 A</td>
<td>$I_{mpp}$</td>
</tr>
<tr>
<td>Maximum voltage at MPP</td>
<td>17.5 V</td>
<td>$V_{mpp}$</td>
</tr>
<tr>
<td>Short circuit current</td>
<td>4.95 A</td>
<td>$I_{sc}$</td>
</tr>
<tr>
<td>Open circuit voltage</td>
<td>21.9 V</td>
<td>$V_{oc}$</td>
</tr>
<tr>
<td>Temperature coefficient of short current</td>
<td>3 mA/°C</td>
<td>$\alpha_{sc}$</td>
</tr>
<tr>
<td>Voltage temperature coefficient of short current</td>
<td>-150 mA/°C</td>
<td>$B_{oc}$</td>
</tr>
</tbody>
</table>

A distinguish between perturb and observe and fuzzy logic control at standard temperature conditions (STC) is carried. Fig. 2 depicts the response obtained of power waveform obtained using FLC approach is quickly fast and precise compared to observe approach. However, oscillations appear in its steady state.

![Photovoltaic power waveform.](image)

In table II as given below, The response time of both methods are provided and computed.
TABLE II. RESPONSE TIME OF PANDO AND FLC APPROACH.

<table>
<thead>
<tr>
<th>MPPT Algorithms</th>
<th>PandO</th>
<th>FLC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Response time</td>
<td>0.069 sec</td>
<td>0.36 sec</td>
</tr>
</tbody>
</table>

b. Battery Model

Battery is represented by impedance \( Z_{\text{batt}} \) with real part of resistance \( R_{\text{batt}} \) and imaginary component reactance \( X_{\text{batt}} \) to disturbance. In order to determine the battery’s internal impedance (12 V, 100 Ah), in Table III, obtained values were summarized.

Table III. Lead acid battery parameters (12V, 100 Ah) [1].

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( R_{\text{batt}} )</td>
<td>0.704 Ohms</td>
</tr>
<tr>
<td>( X_{\text{batt}} )</td>
<td>0.069 ohms</td>
</tr>
<tr>
<td>( C_{\text{batt}} )</td>
<td>45.6 mF</td>
</tr>
</tbody>
</table>

c. DC-DC Converter Model

DC-DC converter used boost chopper and is inserted between inverter and source. DC-DC boost converter is shown in Fig. 3, where \( D \) is duty cycle governed electronically.

\[ V_{\text{in}} = (1 - D) \times V_{\text{in}} \]  
\[ I_{\text{in}} = (1 - D) \times I_{\text{in}} \]  

Fig. 3. DC-DC boost converter [1].

The voltage \( V_{\text{DC}} \) and current \( I_{\text{DC}} \) expressions for DC-DC converter is given by Eqs. (2) and (3) respectively.

\[ V_{\text{DC}} = \left( \frac{1}{1-D} \right) \times V_{\text{in}} \]  
\[ I_{\text{DC}} = (1-D) \times I_{\text{in}} \]  

where, \( D \) is duty cycle, \( V_{\text{in}} \) and \( I_{\text{in}} \) are converter input voltage and current.

d. Electric Vehicle Model

EV model requires representation of traction force equation and types of forces occurs on EV.

1. Friction of vehicle tires on road causes rolling resistance force noted as \( F_{\text{tire}} \).
2. Friction of electric vehicle body moving through air causes aerodynamic drag force \( F_{\text{aero}} \).
3. Climbing force depends on road slope noted as \( F_{\text{slope}} \).

The total resistive force is the sum of forces mentioned. Parameters used for electric vehicle model are given in Table IV.
### TABLE IV. PARAMETERS OF ELECTRIC VEHICLE [2].

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle total mass</td>
<td>$m$</td>
<td>1300</td>
<td>kg</td>
</tr>
<tr>
<td>Rolling resistance force constant</td>
<td>$f_r$</td>
<td>0.01</td>
<td>--</td>
</tr>
<tr>
<td>Frontal surface area of vehicle</td>
<td>$A_f$</td>
<td>2.6</td>
<td>m$^2$</td>
</tr>
<tr>
<td>Tire radius</td>
<td>$r$</td>
<td>0.32</td>
<td>m</td>
</tr>
<tr>
<td>Aerodynamic drag coefficient</td>
<td>$C_d$</td>
<td>0.32</td>
<td>--</td>
</tr>
</tbody>
</table>

The profile of vehicle speed is depicted in Fig. 5.

![Vehicle Speed Profile](image)

**Fig. 4.** Vehicle speed profile.

#### e. Induction Machine Model

Eqs. (5) and (6) represents stator voltage in reference frame (stationary),

$$V_{\alpha} = R_s I_{\alpha} + \left( \frac{d\phi_{\alpha}}{dt} \right)$$

(5)

$$V_{\beta} = R_s I_{\beta} + \left( \frac{d\phi_{\beta}}{dt} \right)$$

(6)

where $V_{\alpha}$, $V_{\beta}$ are $\alpha$ and $\beta$ components of stator voltage, $I_{\alpha}$, $I_{\beta}$ are $\alpha$ and $\beta$ components of stator current, $\phi_{\alpha}$ and $\phi_{\beta}$ are $\alpha$ and $\beta$ components of stator flux and $R_s$ is stator resistance. The below Eqs. (7), (8) and (9) are of stator flux and electromagnetic torque,

$$\phi_{\alpha} = L_s I_{\alpha} + M I_{\beta}$$

(7)

$$\phi_{\beta} = L_s I_{\beta} + M I_{\alpha}$$

(8)

$$T_e = \frac{3PM}{2} (\phi_{\alpha} I_{\beta} - \phi_{\beta} I_{\alpha})$$

(9)

where, $I_{\alpha}$, $I_{\beta}$ are $\alpha$ and $\beta$ components of rotor current, $L_s$ is stator inductance, $M$ is mutual inductance, $T_e$ is electromagnetic torque, $P$ is number of pole pairs and $\phi_{\alpha}$, $\phi_{\beta}$ are $\alpha$ and $\beta$ components of rotor flux. Parameters of induction machine used are identified and summarized in Table V,
TABLE V PARAMETERS OF INDUCTION MOTOR [2].

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Value</th>
<th>Unit</th>
<th>Parameter</th>
<th>Symbol</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shaft power</td>
<td>$P_u$</td>
<td>3</td>
<td>kW</td>
<td>Mutual Inductance</td>
<td>$M$</td>
<td>0.183</td>
<td>H</td>
</tr>
<tr>
<td>Number of pole pairs</td>
<td>$P$</td>
<td>2</td>
<td>--</td>
<td>Stator Inductance</td>
<td>$L_s$</td>
<td>0.0198</td>
<td>H</td>
</tr>
<tr>
<td>Stator resistance</td>
<td>$R_s$</td>
<td>1.76</td>
<td>Ω</td>
<td>Inertia moment</td>
<td>$J$</td>
<td>0.02</td>
<td>Kg-m$^2$</td>
</tr>
<tr>
<td>Rotor resistance</td>
<td>$R_r$</td>
<td>1.95</td>
<td>Ω</td>
<td>Viscous friction</td>
<td>$f$</td>
<td>0.0001</td>
<td>N.m.s$^2$</td>
</tr>
</tbody>
</table>

B. Supervision Strategy

The key decision factors for supervision strategy are power level provided by photovoltaic generator and state of charge (SOC) of batteries. Depending on different tests as follow:

**Mode 1**: Power generated by photovoltaic source is sufficiently more compared to power demanded by load ($P_{av} = P_{pv} - P_{load} \geq 0$). Hence extra power will be utilized to charge batteries if state of charge is less than its maximum limit (state of charge < $SOC_{max}$).

**Mode 2**: Power generated by photovoltaic source is less compared to power demand of load ($0 < P_{pv} < P_{load}$). In this case, difference in power will be supplied through battery if state of charge is more than its minimum limit (state of charge > $SOC_{min}$), battery start discharging.

**Mode 3**: If batteries are already charged to its maximum level and power generated by photovoltaic source is sufficiently available ($P_{av} = P_{pv} - P_{load} \geq 0$), and battery is charged to maximum level (state of charge ≥ $SOC_{max}$), then batteries need to be disconnected in order to protect from overcharging.

**Mode 4**: No power is generated in this mode by photovoltaic source ($P_{pv} = 0$). This arises due to foul weather condition. Thus, battery alone supply total load demand if state of charge is more than its minimum limit (state of charge > $SOC_{min}$).

**Mode 5**: Power generated by photovoltaic source is less than power demand of load ($0 < P_{pv} < P_{load}$). Electric vehicle are de-accelerating (on a downward slope). Hence not imposing load on system (change in load demand $\Delta P_{load} < 0$). Thus, extra power will be used to charge battery if state of charge is less than its maximum limit (state of charge < $SOC_{max}$).

**Mode 6**: Power generated by photovoltaic source is sufficiently more than power demanded by load ($P_{av} = P_{pv} - P_{load} \geq 0$). Electric vehicle is de-accelerating. Hence not imposing any load on system (change in load demand $\Delta P_{load} < 0$). But this extra power is not useful to charge battery if state of charge is less than its maximum limit (state of charge ≥ $SOC_{max}$).

TABLE VI. STATE OF THE OPERATING MODES OF SWITCHES.

<table>
<thead>
<tr>
<th>Modes</th>
<th>$K_1$</th>
<th>$K_2$</th>
<th>$K_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode (M1)</td>
<td>On</td>
<td>On</td>
<td>Off</td>
</tr>
<tr>
<td>Mode (M2)</td>
<td>Off</td>
<td>On</td>
<td>On</td>
</tr>
<tr>
<td>Mode (M3)</td>
<td>Off</td>
<td>On</td>
<td>Off</td>
</tr>
<tr>
<td>Mode (M4)</td>
<td>Off</td>
<td>Off</td>
<td>On</td>
</tr>
<tr>
<td>Mode (M5)</td>
<td>On</td>
<td>Off</td>
<td>Off</td>
</tr>
<tr>
<td>Mode (M6)</td>
<td>Off</td>
<td>Off</td>
<td>Off</td>
</tr>
</tbody>
</table>
Thus, all switches are off (open). Different modes depend on state (On/Off) of three switches $K_1$, $K_2$ and $K_3$ as in Table VI.

**III. Simulation results and discussion**

The model of proposed system with photovoltaic and battery supplying EV is driven using induction motor with space vector pulse width modulation based direct torque control. Fig. 6 highlights simulation results of different power generated and consumed in proposed system. The proposed approach operates effectively as electric vehicle is supplied continuously as per requirement. It can be observed from Fig. 6 that till $t = 1.3$ sec, energy produced from photovoltaic is sufficient to supply for electric vehicle. From $t = 1.3$ to $1.45$ sec, PV generation exactly matches load demand and from $t = 1.45$ to $3.1$ sec, load demand is more than photovoltaic output. Hence, additional power is supplied from batteries. During time duration $t = 3.1$ to $3.8$ sec, PV generation exactly equal to demand load and from $t = 3.8$ sec onwards, load demand is less than photovoltaic output, but battery is charged to maximum value.

Fig. 6 Simulation results of different power generated in proposed system

Fig. 7 Simulation representation of operating modes of studied case.

Fig. 7 depicts different operating modes for studied case. In mode 1, extra energy is available and is used to charge battery. Battery aiding photovoltaic source to supply EV load in mode 2. In mode 3, extra energy is available as batteries are charged to maximum level and is not in use. However, battery alone can supply load in mode 4. For mode 5 and 6, EV is in braking mode and no energy is required to propel the electric vehicle.
State charge of battery is as illustrated in Fig. 8. Initial state charge of the battery is assumed to be 80% at start of simulation.

The minimum and maximum level for state of charge is considered as 30% and 90% respectively. Initially excess energy is available; hence batteries get charged to maximum level in 0.3 secs and remains fully charged till 1.45 secs. Further, from 1.45 to 2.8 sec as power from photovoltaic source is insufficient to supply load, battery start discharging, to supply power deficiency. As braking mode starts at 2.8 sec, battery starts charging and remains in maximum state of charge. Figs. 9, 10, and 11 demonstrate characteristics of induction machine. In this stator current has a sinusoidal waveform and electromagnetic torque reaches the load torque during all functioning keeping flux constant.

Fig. 10 demonstrates electromagnetic torque (N-m) variation for an induction motor. Electromagnetic torque matches load torque requirement as seen in Fig 10.

Fig. 11 illustrates induction motor rotor speed (radian/sec) with respect to time. The rotor speed is observed to be decreasing slightly with increase in load torque.
IV. Conclusion

In this paper, a case study of hybrid photovoltaic/battery bank system supplying to electric vehicle is presented. In this work energy management was proposed to ensure supply of electric vehicle. The photovoltaic system, maximum power transfer algorithms, electric vehicle model, inverter control, direct torque control of induction motor, modelling and smart energy management strategy are significant steps of this work. The modelling and simulation results were carried out to validate system performances. The obtained simulation results highlight effectiveness of adopted control approach. The proposed control strategy allows an optimal operation of system with high performances of photovoltaic system with meteorological and variable speed conditions.

REFERENCES


