Abstract
This paper applies new maximum-power-point tracking (MPPT) algorithm to a hybrid renewable energy system that combines both Wind-Turbine Generator (WTG) and solar PV Module ( SPVM).
In this paper, the WTG is a direct-drive system and includes wind turbine, three-phase permanent magnet synchronous generator, three-phase full bridge rectifier, and buck-bust converter, while the SPVM consist of solar PV modules, buck converter , maximum power tracking system for both systems, and load.
The used MPPT algorithms for realizing good performances mainly achieving maximum power at arbitrary wind speed and solar radiation. Several methods are applied to obtain maximum performances, the appropriate and most effective method is called gradient-approximation method for WTG approach, because it enables the generator to operate at variable wind speeds. Furthermore MPPT also is used to optimized the achieved energy generated by solar PV modules.
Simple and robust structure in construction and high power to weight ratio. The attractiveness of the permanent magnet generators is further enhanced by the availability the influence of synchronous generator parameters on the wind-energy power system capability.

Matlab /Simulink approach is used to simulate, discuss, and optimized the generated power by varying the duty cycle of the converters, and tip speed ratio of the WTG system. Good results are expected to be achieved.

KEYWORDS
Matlab simulation , Renewable energy, Solar energy, Wind energy, Hybrid energy Synchronous motors, Vector control, and PWM.

1. Introduction
Existing traditional energy resources are consumed extremely fast because of industrial growth and consumer behaviors. Therefore looking for another resources ( renewable energy resources) presents high priority for large number of industrial countries suffers from energy shortages and working on enhancing the surrounding environment. The use of renewable energies can mitigate the use of traditional resources and reduce significantly emission to meet the strict requirements stated in the Kyoto protocol [1], which is an agreement under which industrialized countries will reduce their collective emissions of greenhouse gases including Co2 in 2012 by 5.2% compared to year 1990.

Seveleral studies describing Hybrid Energy systems has been conducted in the past decade [2,3] ,where the design is based on particular scenario with a certain set of design values yielding the optimum design solution only. Because of that, these systems have been widely used for electricity supply in isolated locations far from the distribution
network. Well design of such systems leads to providing a reliable service and operation in an unattended manner for extended period of time. At the same time hybrid system suffer from the fluctuating characteristics of available solar and wind energy sources, which must be addressed in the design stages. Ekren [4] states that, the degree of desired reliability from a solar and wind process so as to meet a particular load can be fulfilled by a combination of properly sized wind turbine, PV panel, storage unit and auxiliary energy source. Fig.1 illustrates a schematic diagram of a basic hybrid energy system, where it seen that, the electricity produced via PV array and wind turbine are regulated by voltage regulator components and the excess electricity produced by this system is stored by the battery banks to be used for later lacking loads.

This paper discusses the Wind and Solar power generation. Especially, the variable speed and solar radiations control are addressed. Ying-Yi Hong and another researchers [5,6,7] stated that variable-speed is better than constant-speed because of the variable-speed

![Fig.1: Schematic diagram of a basic hybrid energy system](image)

control include : the maximum power extraction, improvement the dynamic behaviors of the turbine, and noise reduction at low speed levels. Realizing successful variable-speed control, two control sensors are required for Maximum Power Point tracking (MPPT), they are the wind-speed sensor (Anemometer) and rotor-velocity encoder (Tachometer). On the other hand SPVM consists of cells, modules, and arrays that must operates at maximum power level by applying MPPT system[ 8,9,10]. MPPT system operates successfully by existing radiation and temperature sensors. These sensors realized system operation at maximum power at variable radiations and surrounding temperature.

In this paper adaptive duty cycle method with gradient Approximated GA will be applied, where no PID is required, no need of speed sensors, and no information about the turbine generator characteristics are required [11]. Several research approaches were conducted in order to analyze the behaviors of wind turbine performances, and solar cell performances. Various conclusions, and recommendations were proposed with respect to
achieve maximum power ratings. Very efficient control algorithm was proposed by Datta and Ranganathan, where a generator velocity reference being dynamically modified in accordance with the magnitude and direction of change of active power [12]. The peak power points in the $P-\omega$ mechanical curve corresponds to $dP/d\omega = 0$. The duty cycle is adjusted by the steepest ascent algorithm in which the duty cycle is adjusted by the steepest ascent algorithm in which a derivative of electric power ($P_e$) with respect to (D).

2. Characteristics of Wind-Turbine

The mechanical power of a wind-turbine is a function of the power coefficient $C_p$. Furthermore, $C_p$ is a function of the Tip Speed Ratio (TSR) $\lambda$, which can be formulated as follows [6]:

$$C_p = a + b\lambda + c\lambda^2 + d\lambda^3 + e\lambda^4 + f\lambda^5$$  \hspace{1cm} (1)

Where $a$, $b$, $c$, $d$, $e$ and $f$, are constants depending on the turbine performances and can be obtained by polynomial regression [13,14]. Fig.2 illustrates the relation between $C_p$ and $\lambda$. Fig.3 shows the relation between the generated power $P_e$ and the rotor wind speed $\omega_m$, where it can be found that the generated power corresponds to a certain given wind speed.

2.1 Wind-Turbine generation system

The wind turbines has various designed modification depending on the output parameters, generated power, reliability and cost reduction. There are WTG with full-sensor control, where the speed feedback signal is compared with actual one, and the results will be in form of switching pulses switched on the Buck DC/DC converter [x12’,x1’]. Another design modification is sensor less WTG called "adaptive duty cycle method with GA" as well shown on fig.3, where regulating the operation time of the chopper switching devices is achieved by regulating the duty cycle $D$, which is in turn is regulated by
applying the gradient approximation approach. Figure 4 illustrates the power versus the rotor angular velocity at various wind speed.

\[
\frac{d \omega_m}{dt} = \frac{1}{j} (T_m - T_e) = \frac{1}{j} \left( \frac{P_m}{\omega_m} - \frac{P_e}{\omega_e} \right) \tag{2}
\]

Where: \( T_e \) and \( T_m \) are the electromagnetic and mechanical torque respectively; \( j \) is the generator inertia; \( \omega_m \) and \( \omega_e \) are the mechanical and electrical angular frequency respectively.

2.2 Mathematical Modeling

Way out from the dynamic equation of the generator system is:
The static relation of the Buck-Boost converter can be expressed as follows:

\[ V_\text{os} = V_\text{rs} \frac{D}{1 - D}; \]
\[ P_\text{rs} = V_\text{os} I_\text{s}; \]

The above equations eq.(2), and eq.(3) will be used for the simulating the dynamic behaviors of a WTG. Furthermore there is no need to solve these equations. One only needs several measured signals of \(P_e\) and \(\omega_e\).

### 2.2.1 The Concept of Gradient Approximation Method (GA)

The main reason for applying the Gradient Approximation is that the maximum power curve cannot be formulated as a function of \(\omega_m\) and wind speed, therefore sensor less control is applied based on changing the duty cycle. GA is an optimization method by using Newton's method for maximum power optimization based on solving the nonlinear equation as follows:

\[ \frac{dF(x)}{dx} = 0; \Rightarrow X_{k+1} = X_k - F(X_k) \frac{dF(X_k)}{dX_k} \]  \hspace{1cm} (4)

Where \(k\) is the iteration index.

Achieving optimization condition can be realized by applying Lagrangian method denoted by \(L\) for solving unknown parameter \(\mu\). The necessary condition for obtaining the optimality is as follows:

\[ g(\mu) = \frac{\partial L(\mu)}{\partial \mu} = 0 \]  \hspace{1cm} (5)

Solving \(g(\mu) = 0\) in eq.(5) is the same as solving \(F(X) = 0\). Taking into account Lagrangian approach the GA optimization is expressed as follows:

\[ \mu_{k+1} = \mu_k - \alpha_k g_k(\mu_k) \]  \hspace{1cm} (6)

\[ \alpha_k = F'(X_k)^{-1}; \quad g_k = \left[ \frac{Y_k^+ - Y_k^-}{2C_k^2} \right] \]

Where,
\[ Y_k^+ = L(\mu_k + C_k) + \varepsilon_k^+ \]
\[ Y_k^- = L(\mu_k - C_k) + \varepsilon_k^- \]

Where \(C_k\) is a sequence of positive scalars such that \(C_k\) approaches zero, and the symbols \(\varepsilon_k^+\) and \(\varepsilon_k^-\) represent measurement noise terms.

Taking into account the proposed Lagrangian approach for achieving optimized power generation, several methods are applied, but most applied one due to its simplicity and less required preconditions is "Adaptive Duty Cycle method with GA" illustrated by Ying-Yi[6].

### 2.2.2 Adaptive Duty Cycle method with GA:

The proposed adaptive duty cycle method with GA does not require parameter setting, sensors, characteristics of the turbine-generator. Because \(P_e(n) = V_e(n) I_e(n)\) is expected to be maximized and GA is used for minimization, as well illustrated on fig.5.

The control variable is also the duty cycle of the DC/DC converter with the following expression at \(k\)th iteration:
\[ D_{k+1} = D_k + \alpha_k \left[ \frac{P_e(D_k + C_k) - P_e(D_k - C_k)}{2C_k} \right] \equiv D_k + \alpha_k \cdot g_k \]  

(8)

The duty cycle will be sent to the DC/DC converter through Pulse Width Modulation Controller as will shown on fig.4.

3. Characteristics of PV Panel

The simplest equivalent circuit of a solar cell is a current source in parallel with diode [14,15, 16]. The output of current source is directly proportional to the light falling on the cell, this current is called photocurrent \( I_{ph} \). During darkness, the solar cell is not an active device; it works as a diode as well shown on fig.6, where the flows current is called dark current \( I_D \).

Increasing accuracy, and complexity can be introduced to the model according to Francisco M. [8]:

- Temperature dependence of the diode saturation current \( I_0 \).
- Temperature dependence of the photo current \( I_L \).
- Series resistance \( R_s \), which gives more accuracy in shaping of maximum power point and MPPT. This resistance represent the internal losses due to current flow.

3.1 Mathematical Modeling

In an ideal cell \( R_s=0 \); which is a relatively common assumption. The net current of the cell is the difference of the photocurrent \( I_L \) and the normal diode current \( I_d \).

\[
I = I_e - I_d
\]

\[
I_d = I_0 \left( e^{\frac{q(V + IR_s)}{nKT}} - 1 \right)
\]

(9)

The Current-Voltage I-V Curve for a typical solar cell at a certain ambient irradiation \( G \) and a certain fixed temperature \( T \), is shown in fig.6 for resistive load \( R \). The load characteristic is a straight line with scope \( I/V=1/R \). It should be pointed out that the power delivered to the load depends on the value of the resistance only.
Depending on the load R value, the cell operates as current source or voltage source mode, therefore short circuit current $I_{sc}$ will be at small $R$, while open-circuit voltage $V_{oc}$ will be at large $R$ [17].

### 3.2 Maximum Power Point of Solar cells

A real solar cell can be characterized by short circuit current, open-circuit voltage, maximum power point operation, maximum efficiency, and filling factor.

- Maximum power point: is the operating point $A(V_{max}, I_{max})$ illustrates in fig.6, at which the power dissipated in the resistive load is maximum $P_{max} = V_{max}I_{max}$.
- Maximum efficiency: is the ratio between the maximum power and the incident light power:
  \[
  \eta = \frac{P_{max}}{P_{in}} = \frac{V_{max}I_{max}}{AGa}
  \]
  (10)

  Where $Ga$ is the ambient irradiation; and $A$ is cell area.
- Fill factor: is the ratio of the maximum power that can be delivered to the load and the product of $V_{oc}$ and $I_{sc}$:
  \[
  FF = \frac{P_{max}}{V_{oc}I_{sc}} = \frac{V_{max}I_{max}}{V_{oc}I_{sc}}
  \]
  (11)

![Fig 6](image)

**Fig 6:** a) A typical PV model, and b) current-voltage I-V curve for a solar cell.
The fill factor is a measure of real I-V characteristic. Its value is higher than 0.7 for good designed cells. Furthermore the fill factor diminishes as the cell temperature is increased.

### 3.3 Maximum Power Point Tracker of Solar cells (MPPT)

MPPT for prediction the maximum power point occurrence by using perturb and observation algorithm in looking for maximum output parameters in terms of voltage and current, therefore increasing the fill factor. According to [7,18], the proposed algorithm reads the value from the solar PV module. The value of the power for two adjacent iteration points \( k^{th} \) and \((k+1)^{th}\) where \((dP/dV)<0\) at the right hand side of the curve, whereas \((dP/dV>0)\) at the left hand side. This means that the right side curve is for lower duty cycle \((D\rightarrow D_{\text{min}})\), whereas the left side is for the higher duty cycle \((D\rightarrow D_{\text{max}}\approx I)\). Correcting the duty cycle can be realized as follows:

\[
\begin{align*}
    dP &= P(k+1) - P(k); \\
    dV &= V(k+1) - V(k); \\
\end{align*}
\]

(12)

According to \((dP/dV)\) the algorithm decides whether to increase the duty cycle or to reduce it. The proposed algorithm flow chart is illustrated on fig.7

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![Fig 7: MPPT Algorithm of PV module.](image-url)
4. Storage Model

In practice there are many different options to store the produced energy of both WT and PV model, but in practice the commercially and affordable options are limited batteries [17,18]. Lead Acid batteries are suitable for storing the energy for medium term energy storage. Different ways are used to modeled the battery storage taking into account the complexity of their behaviors. According to Hraman and Kacholdt [19], two methods are used to analyze the storage model:
- Energy Transfer Model
- Simulation Model.

To avoid complexity, Energy Transfer Model is used in this paper, which gives the gross energy flow by using the information provided in the manufacturer's data sheets. This approach is concerned primarily with the summation of energy transfer to and from the battery.

During charging the resulting State of Charge \( SOC \) for acceptance of an amount of energy \( W_{inp} \) for a charging efficiency \( \eta_{ch} \) and rated battery capacity \( C_{rated} \) can be calculated as follows:

\[
SOC = SOC + \frac{W_{inp} \eta_{ch}}{C_{rated}}
\]  

(13)

When discharging an amount of energy \( W_{out} \), the resulting \( SOC \) is given by,

\[
SOC = SOC - \frac{W_{out}}{C_{rated} \eta_{disch}}
\]  

(14)

Where \( \eta_{disch} \) is the discharging efficiency.

The amount of energy transferred can be calculated using,

\[
W_{transfer} = P_{av} \Delta t
\]  

(15)

Where, \( W_{transfer} \) is energy transferred from the source to the load in kWh, \( P_{av} \) is the average power applied during energy transfer over the time interval in kW, \( \Delta t \) is the time interval in hours.

The input, output energy \( W_{inp}, W_{out} \) can be calculated as:

\[
W_{out} = W_{transfer} - \Delta P_{loss} \Delta t
\]

\[
\Delta P_{loss} = I^2 R_{tot}
\]

(16)

\[
R_{tot} = R_o \frac{N_s}{N_p}
\]
Where, \( \Delta P_{\text{loss}} \) - charging and discharging loss in watts, \( I \) - charging and discharging current in amps, \( R_{\text{tot}}, R_i \) - the total and internal battery in ohms respectively, \( N_S \) - number of series battery cells, and \( N_P \) - number of parallel cells. The minimum state of charge \( SOC_{\text{min}} \) is usually set at around of 30% with purpose to avoid excessive damage to the battery.

5. Hybrid Model

The hybrid model is controlled in such a way that the power output from the Wind turbine and PV panels is used for directly meeting the consumer demand. Excess power, if available, is stored in the battery, and energy taken from the battery is used to meet any shortfall. The control model is based on the state of charge of the battery bank. Depending on the current SOC decision has been made whether if would charge the battery or discharge from the battery depending on the availability of power. Flowchart of the control model is shown in figure 8.

Fig 8: Flowchart for Hybrid Model
6. Simulation Results.

Taking into account the proposed mathematical models, there are three applied simulation models using Matlab/Simulink and system data illustrated in table 1.

<table>
<thead>
<tr>
<th>WT Data:</th>
<th>Table 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of G. unit</td>
<td>Gen. rating, VA</td>
</tr>
<tr>
<td>1</td>
<td>1000</td>
</tr>
</tbody>
</table>

| PV Data: |
|-----------------|----------|
| Number PV panels | Rated voltage of panel, V | Open Circuit voltage, V | Rated power of panel, W | Peak Ampere, A | Total amperes, A |
| 4               | 22       | 24               | 60              | 3.3   | 13.3A |

| Battery Bank, |
|-----------------|----------|
| Number of Parallel batteries, Np | Number of Series batteries, Ns | Battery capacity, Ah | Battery voltage, V | Minimum State of Charge, % | Discharging efficiency , - |
| 10             | 1        | 24               | 12              | 30%   | 80% |

6.1 Simulation of WT Model:

A simulation model of WT system is built in Matlab/Simulink environment, where four main units are designed and linked together to form the WT model, as well shown in Fig. 9.

- **Main model**
- **Wind Turbine model**

Fig. 9: Matlab/Simulink of WT Model
The wind turbine speed is assumed to vary in wide range with purpose to predict the changes in the turbine power, voltage and current. Figure 10, figure 11, and figure 12 illustrate the results of such variation respectively. It clearly seen that the circuit parameters varies consequently as varying the wind speed.
Figure 11: Main WT performances
6.2 Simulation of PV Model:
A simulation model of PV model is build in Matlab/ Simulink environment, where a set of PV arrays were connected with DC charging system with MPPT system that energized a DC buck-Boost chopper with appropriate gate pulses having variable time duration.

Figure 13 illustrates the model subsystems, while fig.14 presents the obtained simulation results for some of the model performance (duty cycle, open circuit voltage, chopped voltage, current, and output power). As well shown from these
Fig. 14: Simulink results at continuous duty cycle change. 

results that as the duty cycle decreases the output voltage and power raises, which means
that the power will perturb at it's maximum value as a result of MPPT subsystem. Another study case is when the duty cycle has predetermined sequence, where, the obtained results are illustrated on figure 15.

![Duty Cycle](image1)

**a) Duty cycle**

![Gate Pulses](image2)

**b) Gate Pulses**

![Chopped Power](image3)

**c) Output Power for one cell**

Fig.15: Simulink results at given variation of duty cycle.
a) Main Battery Charging model

b) Power diagram

c) Charging-discharging diagram

Fig. 16: Matlab/Simulink of battery model
6.3 Simulation of Battery Model

A simulation model of Battery charging-discharging process is illustrated on fig.16, where the main model, generated power, consumed power and charging-discharging diagram are displayed, taking into account eq.13,16 ; and the battery data sheet. From this model it's show that the battery will start to discharge in to the load when deficit in generated powers form WT and PV modules are incapable to meet required consumed power.

7. Conclusion

In this work, three main components Wind Turbine with ac to dc converter, PV panel with dc chopper and battery charging system were studied. According to the consumer needs the battery will charge or discharge the required amount of power aiming at meeting the power shortage mainly at peak loading intervals.

Gradient Approximation method with adaptive duty cycle approach is applied at almost optimal value of power coefficient. This method is efficient for looking for optimum MPPT operation of the wind turbine and PV photovoltaic modules.

Matlab/ simulink environment is applied for simulating the proposed mathematical models starting from power generation to power consuming, where the effect of velocity variation, temperature change, and irradiations levels in additional to loading diagram are discussed.

This paper is the first step to develop a complete Wind-Solar power generation unit with the needed power conversion subsystem. Prototype modules has been designed for three subsystems. LABview software is applied to control the generating and consuming process of the designed units.

Good results are expected to be achieved, where power sizing of this design will be the next step with purpose to fulfill some of power needs for a remote rural area, money saving for long term vision, and to increase the awareness of the importance of renewable energy resources.

8. Acknowledgment

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9. Reference

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