Fault analysis in grid-connected solar photovoltaic systems based on multi-objective grey wolf optimisation

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ABSTRACT
The renewable energy resources depend on environmental concerns. Photovoltaic (PV) systems are an interesting form of renewable energy resource. The two main problems associated with PV systems are non-uniformity of irradiation and temperature change. PV achieving maximum power point tracking are dependent on power electronics converters. Emissions are a key challenge for the future of conventional renewable energy resources, which play an important role in the generation system. It is crucial in applications and industry because the primary goal of optimization is to discover specific research. We offer using the population of search agents based on fitness, the multi-objective grey wolf optimizer, a more modern meta-heuristic based on the hunting habits and social structure of grey wolves, for optimizing adaptive controllers for failures in grid analysis and power system integration various faults in the grid cause several power quality issues. Harmonics, voltage sag and swell imbalances, and many power conditioning topologies. This was carried out using MATLAB/Simulink, and the results showed a superior and flexible performance in reducing voltage sag and voltage swell problems and imperfections at various loading situations.

Keywords: Artificial bee colony algorithm, Genetic algorithm, Maximum power point tracking, Multi objective grey wolf optimization, Particle swarm optimization, Photovoltaic model, Sag and swell

1. INTRODUCTION
Grid integrating photovoltaic (PV) systems because they concern various faults based on the normal operating conditions of the system [1]. PV is a reliable renewable energy source that provides numerous advantages. PV benefits include the reduction of operating costs. Uniform through these advantages, there may be some stability issues when utilizing PV [2]. As a result, operators should consider improving stability issues in order to improve the predictable improve the stability of grid-integrated PV systems [3]. The basic block diagram of a grid-connected solar PV system is shown in (Figure 1 in Appendix). The analysis of voltage sag, swell and analysis of total harmonics distortion various control method fault duration time reducing this formulation can approximate the true pareto-optimal solutions of multi-objective problems effectively.

2. MODELING OF SOLAR PV CELL
The maximum power point tracking, the use of power electronics converter equipment, and load changes produce multiple power quality (PQ) concerns many types of controllers are available in power

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electronics converters the standard equivalent circuit of the PV cell is shown in Figure 2. However, electrical parameter adjustment should be taken into account [4]. The problem considered by maximum power point tracking (MPPT) methods to find the voltage and current based on PV array delivers temperature and irradiance. In perturb and observe (P&O) method, the MPPT method based on the calculation of the PV output power and the power change by sampling both the PV array current and voltage [5].

![Figure 2. Equivalent circuit of solar PV cell](image)

The tracker operates by periodically incrementing or decrementing the solar array voltage is based on environmental conditions [6]. Furthermore, various faults nonlinear load in inverter to grid cause several PQ issues. Harmonics, voltage sag and swell inequities, and many power conditioning topologies, such as transient voltage, filters, interruptive power supplies, and so on, have been employed in the past to improve the PQ of power networks [7]. PV cell characteristics based on solar irradiation shown in Figure 3.

![Figure 3. PV cell characteristics based on solar irradiation](image)

Mathematical model PV cell: the photovoltaic cells are mathematically constructed using (1)-(5) of the PV cell is comparable to a single diode and different solar irradiance as shown in Figure 3. The following equations were utilized techniques of the PV cell. When we use KCL to analyses obtain [8].

\[
I = I_{ph} - I_d - I_{rp}
\]  

(1)

As shown in Figure 2, the determined the equation, where \( I_{rp} \) is the current flowing through resistance \( R_p \) (3):

\[
I_d = \left( \exp \left( \frac{V + Rs}{nVtN_s} \right) - 1 \right) * I
\]

(2)

where \( N_s \) is the cells are connected in series shunt resistance is given by (3), and current in solution is given by (4).

\[
I_{rp} = \left( \frac{V + I_s R_s}{R_p} \right)
\]

(3)

\[
I_{ph} = [\mu_{sc}(T_c - T_{ref}) + I_{sc}]
\]

(4)
The reverse saturation current is an (5) generally MPPT is installed in between PV system to load. There is a different power output at the level of solar insolation and temperature.

\[ I_o = I_{sc} / \left( \exp \left( \frac{qV_{oc}}{n_kT_C \cdot V_t} \right) - 1 \right) \]  \hspace{1cm} (5)

### 3. THE GREY WOLF OPTIMIZATION

This controller's reign is demonstrated using comparison optimization [9] different methods, such as genetic and artificial bee colonies and particle swarm optimization (PSO), a grey wolf optimization procedure with adaptive controller [10], the system response contributes to the preservation of system wolf optimization [11]. The powerful meta-heuristic are grey wolf optimizer (GWO). As a recently created optimization it may PSO, genetic algorithm (GA), and many others prevention of convergence [12].

The multi-model bench mark function, as shown in Figure 4. In general, the benchmark functions utilized are minimization functions and can be classified into four classes. Fixed-dimension multimodal and composite functions unimodal and multimodal. The GWO also produced very competitive results on the remaining composite benchmark functions. The social behavior of grey wolves suggests new optimization inspired by grey wolves and evaluates its abilities in tackling benchmark and real problems [13].

![Figure 4. 2-D versions of multimodal benchmark function](image)

#### 3.1. Mathematical model GWO

The dominance of grey wolves in hunting prey is represented in (6) and (7) in the following subsection. Prayer by higher-ranked value wolves is modeled using hunting prey and encircling prey. Wolves attack their prey:

\[ P_{loss} = \sum_{j=1}^{N_{pr}} R_j (I_j^2) \]  \hspace{1cm} (6)

\[ f_1 = \text{Min} \sum_{j=1}^{N_t} p^t \text{Loss} \]  \hspace{1cm} (7)

the fittest solution can be described as the alpha-best solution, with beta and delta accordingly in the mathematical model of the GWO method. The rest of the potential solutions are regarded as Omega grey wolf optimization with hunting prey is represented in (8) and (9).

\[ |\Delta V_2| = \sum_{i=1}^{N_{id}} |V_i - V_{base}| \]  \hspace{1cm} (8)

\[ f_2 = \text{Min} \sum_{i=1}^{N_t} |\Delta V_2^i| \]  \hspace{1cm} (9)

#### 3.2. Encircling prey

As previously stated, grey wolves encircle animals during the hunt in order to mathematically mimic encircling activity. The following equations are suggested, where \( t \) denotes the current iteration. The position vector of the prayer is \( (Xp) \), and \( \vec{A} \) and \( \vec{C} \) are coincident vectors. When \( \vec{X} \) represents the grey wolf's location vector, the vectors \( \vec{A} \) and \( \vec{C} \) are calculated as (10)-(13).

\[ \vec{B} = |\vec{C} \cdot Xp(t) - \vec{X}(t)| \]  \hspace{1cm} (10)

\[ \vec{X}(t + 1) = \vec{X}(t) - \vec{A} \cdot \vec{B} \]  \hspace{1cm} (11)
\[
\vec{A} = 2\vec{a} \cdot \vec{r}^1 - \vec{a} \\
\vec{C} = 2\vec{r}^2
\]

3.3. Hunting prey

The modeling hunting behavior average position moves the direction of goal [14]. The equation of hunting strategy is formulated as follows and \( \vec{C}_1, \vec{C}_2, \) and \( \vec{C}_3 \) are three coefficient vector aids in adjust distance vector and it is computed using (3). Position of vector of other grey wolf (omega) is (14)-(17).

\[
\vec{x}(t + 1) = \frac{\vec{x}_1 + \vec{x}_2 + \vec{x}_3}{3}
\]

\[
\vec{x}_1 = |\vec{Xa} - \vec{A}_1 \cdot \vec{Da}|
\]

\[
\vec{x}_2 = |\vec{Xb} - \vec{A}_2 \cdot \vec{Db}|
\]

\[
\vec{x}_3 = |\vec{Xd} - \vec{A}_3 \cdot \vec{Dd}|
\]

The population of search agents [15], [16] \( \alpha, \beta, \delta, \omega \) of based on fitness where \( \vec{D}_\alpha, \vec{D}_\beta, \) and \( \vec{D}_\delta \) are the modified distance vector between the alpha, beta, and delta position to the other wolves (18)-(20).

\[
\vec{D}_\alpha = |\vec{C}_1 \cdot \vec{Xa} - \vec{x}|
\]

\[
\vec{D}_\beta = |\vec{C}_2 \cdot \vec{Xb} - \vec{x}|
\]

\[
\vec{D}_\delta = |\vec{C}_3 \cdot \vec{Xd} - \vec{x}|
\]

3.4. Wolves attack the prey

As a result, the equation that describes how grey wolves behave (21):

\[
A = 2 - 2\left(\frac{t}{\max_t}\right)
\]

where \( t \) is a string of numbers between 0 and max (the maximum amount of iterations), indicating the number of times current:

The pseudo code of the GWO

Prepare based on the population of fit grey wolves \( \vec{X}_i \) (i=1, 2, n)

Prepare \( \vec{a}, \vec{A}, \) and \( \vec{C} \)

Determine optimization search by using this equation.

\( \vec{X}_\alpha= \)Alpha is the best element of the population is responsible for decision making

\( \vec{X}_\beta= \)beta is ensuring that all subordinate should obey the order and feed back to alpha

\( \vec{X}_\delta= \)wolves dominates omega and report to alpha and beta

While (T< 1 wolves attack the prey)

For each search wolves update the position by using

End for

Update \( \vec{a}, \vec{A}, \) and \( \vec{C} \)

Fittenes of search wolves

Update \( \vec{X}_\alpha, \vec{X}_\beta, \) and \( \vec{X}_\delta \)

T=T+1

(\( T>1 \) wolves get away from the prey)

End while

Return \( \vec{X}_\alpha \)

The complexity of this approach is comparable to that of other computational complexity of N objectives in-heuristic optimization method. A flow chart of multi objective grey wolf optimization as shown in Figure 5.
4. RESULTS AND DISCUSSION

We have fault analysis of grid connected solar PV system comparison of various optimization algorithm based on power quality issues. Simulation results line-ground (LG) fault and line-line-line-ground (LLLG) faults in power delivery at nonlinear load [17], [18]. Figure 6 shows three-phase voltage sag LG faults based on GA-PSO proposed method in Figures 6(a)-6(c) presents various time durations. Three-phase voltage sag LG faults MOGWO methods. There phase Inverter to utility grid voltage faults at nonlinear load. Voltage sag LG faults comparison to simulation results.

Figure 6. Three-phase voltages sag LG faults (a) GA-PSO, (b) artificial bee colony (ABC), and (c) MOGWO
The renewable energy source that provides numerous advantages PV benefits of no pollution and the reduction of operating costs there may be some stability issues [19]–[21]. Figure 7 represents the simulation results for a three-phase voltage swell LLLG faults duration time references, which includes three sub figures. The voltage swell LLLG faults response is displayed in Figure 7(a) while the response of GA-PSO algorithm is respectively given Figures 7(b) and 7(c).

![Figure 7](image)

**Figure 7.** Three-phase voltages swell LLLG faults (a) GA-PSO, (b) ABC, and (c) MOGWO

Through results three-phase voltage swell LLLG faults MOGWO method conditions three-phase voltage swell LLLG faults comparison to simulation results [22]–[26]. Figure 8 shows and analysis of total harmonics distortion. When utilizing considers improving stability issues improve overall performance of the faults analysis the MOGWO is based on the proposed GWO, GA-PSO and ABC, MOGWO, reducing duration faults time and harmonics also increasing power factor. This research several simulation modeling and optimization control method for grid-connected solar PV systems as shown in Table 1.

![Figure 8](image)

**Figure 8.** Analysis of Total harmonics distortion
5. CONCLUSION

The GWO method to provide a better understanding of how we can apply it to solve some optimization problems. We introduced this method it is quite effective, and simple enough to be easily understood. Model of grid operation made includes control voltage fluctuation, and total harmonics distortion. In addition, three main steps of hunting, searching for prey, encircling prey, and attacking prey, are implemented to perform optimization. Multi objective grey wolf optimization approach also adapted optimization. According to the simulation results, grid integrating renewable energy systems based on environmental conditions. Exclusion of harmonics and variation in voltage power losses and voltage fluctuations are reduced time duration of faults at nonlinear load. The grid interface system’s overall harmonic distortions are 2.20% and 0.78.

APPENDIX

![Diagram of a grid-connected solar PV system](image)

**Table 1. A comparison of optimization control method**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Description</th>
<th>GA&amp;PSO</th>
<th>ABC</th>
<th>MOGWO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>Actual</td>
<td>415 v</td>
<td>415 v</td>
<td>415 v</td>
</tr>
<tr>
<td></td>
<td>sag</td>
<td>430 v</td>
<td>450 v</td>
<td>450 v</td>
</tr>
<tr>
<td></td>
<td>swell</td>
<td>340 v</td>
<td>390 v</td>
<td>390 v</td>
</tr>
<tr>
<td>Time</td>
<td>sag</td>
<td>0.1 sec</td>
<td>0.05sec</td>
<td>0.01 sec</td>
</tr>
<tr>
<td></td>
<td>swell</td>
<td>0.2sec</td>
<td>0.1 sec</td>
<td>0.01sec</td>
</tr>
<tr>
<td>THD</td>
<td>THD</td>
<td>6.64 to 6.85%</td>
<td>3.51% to 3.58%</td>
<td>2.20% to 0.78%</td>
</tr>
<tr>
<td>Power factor</td>
<td>Power factor</td>
<td>0.7</td>
<td>0.9</td>
<td>1 (unity)</td>
</tr>
<tr>
<td>Faults</td>
<td>Faults</td>
<td>LG, LLLG</td>
<td>LG, LLLG</td>
<td>LG, LLLG</td>
</tr>
</tbody>
</table>

**REFERENCES**


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