Controller parameters tuning of PV Based on PSASP/UD by AGA

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Abstract. Photovoltaic (PV) station generally adopts single-stage grid-connection inverter considering the cost and efficiency, and the controller parameters have great influence on the grid-connected performance of PV system. The PV array, maximum power point tracking (MPPT), the inverter and its control system models are built in PSASP/UD. The PI parameters of invert controller are tuned by adaptive genetic algorithm (AGA) and genetic algorithm (GA) respectively in single-machine infinite bus system (SMIBS) based on Simulink. Finally, single-machine infinite bus system (FMTAS) with PV based on PSASP/UD is used to verify the feasibility and effectiveness of models and validity of controller parameters.

1. Introduction
The establishment of photovoltaic model is closely related to photovoltaic grid connection analysis. An accurate photovoltaic model can bring more accurate analysis to the system. Considering the cost and efficiency of grid-connection photovoltaic (PV) power station, it generally adopts single-stage grid-connection inverter.

2. Model of PV system based on PSASP/UD

2.1. PV array and capacitance
The engineering model of photovoltaic array can be simplified as (1).

\[ I = I_{sc} [1 - C_1 \exp \left( \frac{V}{C_2 V_{oc}} - 1 \right)] \quad (1) \]

Where, \( I \) and \( V \) are the current and voltage of photovoltaic array respectively.

Dynamic equation of capacitance can be rewritten as (2):

\[ C_{dc} \frac{dV_{pv}}{dt} = I_{pv} - I_{dc} \quad (2) \]

Based on (1) and (2), PV array and capacitance can be modeled in user defined of Power System Analysis Software Package (PSASP/UD).

2.2. Maximum power point tracking
The variable step perturbation observation (P&O) method [1]-[3] is used in maximum power point tracking (MPPT).
2.3. Inverter and its control system

Inverter model can be expressed as (3).

\[
\begin{align*}
    u_{pd}(s) - u_{gd}(s) + L_f \alpha i_{pd}(s) &= (sL_f + R) i_{pd}(s) \\
    u_{pq}(s) - u_{gq}(s) - L_f \alpha i_{pq}(s) &= (sL_f + R) i_{pq}(s)
\end{align*}
\]  

(3)

Where, \( u_{pd} \) and \( u_{gq} \) are the voltage output by the bridge arm of the inverter, \( u_{pd} \) and \( u_{pq} \) are voltage output by grid of inverter, \( R \) and \( L_f \) are filtering resistance and inductance, \( i_{pd} \) and \( i_{pq} \) are grid-connected current.

There is a coupling between d-axis current and q-axis current. Therefore, in order to reduce the design difficulty of the controller, it is necessary to decouple the grid-connected active current \( i_{pd} \) and reactive current \( i_{pq} \). The structure of current controller and voltage controller is shown in Fig.1 and the model in PSASP/UD is shown in Fig.2.

![Figure 1. The structure of current controller](image)

![Figure 2. Models of inverter and its controllers in PSASP/UD](image)

3. Parameters optimization in voltage controller based on adaptive genetic algorithm

Fuzzy algorithm [4]-[6] is used in controller parameters’ design, but its precision is poor and will affect the dynamic performance of the system. However, Adaptive genetic algorithm (AGA) [7]-[8] is capable of serial search, multi-solution evaluation, self-organization, self-adaptation and self-study, and it can calculate approximate solutions in the process of generational evolution.

The objective function designed by Integral of time multiplied by the absolute value of error (ITAE) criterion can be expressed as (4).
\[ J = \min \int_0^t |e(t)| \, dt \quad (4) \]

Where \( t_s \) is adjustment time for dynamic response, \( e(t) \) is the difference between the actual value and the reference value of voltage controller during the dynamic response, \( K_{P(I)_{\text{min}}} \) and \( K_{P(I)_{\text{max}}} \) are upper and lower limits of voltage controller respectively.

The individual’s fitness is larger, and the optimal solution is closer. Fitness function can be expressed as (5).

\[ F = J^4 \quad (5) \]

The probability of cross-over and mutation can be expressed by (6) and (7).

\[ p_c = \begin{cases} k_1 \frac{F_{\text{max}} - F}{F_{\text{max}} - F_{\text{avg}}}, & F \geq F_{\text{avg}} \\ k_2, & F < F_{\text{avg}} \end{cases} \quad (6) \]

Where \( F_{\text{max}} \) is the maximum fitness value in population, \( F_{\text{avg}} \) is the average fitness value in population, \( F \) is the larger fitness value of two individuals in the step of cross-over, \( k_1 \) and \( k_2 \) are constants in 0.4–0.99.

\[ p_m = \begin{cases} k_3 \frac{F'_{\text{max}} - F'}{F'_{\text{max}} - F'_{\text{avg}}}, & F' \geq F_{\text{avg}} \\ k_4, & F' < F_{\text{avg}} \end{cases} \quad (7) \]

Where \( F' \) is the fitness value individual in the step of mutation, \( k_3 \) and \( k_4 \) are constants in 0.001–0.2.

4. Case Study

Taking the PV connection to the single-machine infinite bus system (SMIBS) as an example (shown in Fig.3), AGA was applied in Simulink to set the PI parameters of the voltage controller.

\[ \begin{align*}
  & V_r \\
  & \text{Synchronous generator} \\
  & X_n \\
  & V_r \\
  & \text{PV system} \\
  & I_{pv} \\
  & \text{DC/AC} \\
  & V_{dc} \\
  & I_{dc} \\
  & X_{dc} \\
  & T \\
  & V_r
\end{align*} \]

\[ \text{Figure 3. PV sytem access to SMIBS} \]

P&O and variable step P&O were used to MPPT of the PV system. When illumination intensity descends from S=1000W/m\(^2\) to S=600W/m\(^2\) at 0.4s and ascends form S=600W/m\(^2\) to S=1000W/m\(^2\) at 1.0s, the reference value of PV output voltage obtained by the two methods is shown in the Fig.4.
Figure 4. The reference value of PV by different methods

Base on Fig.4, the following conclusions can be drawn: the time for variable step P&O to reach the steady state is shortened by 72.75%, with faster responsiveness and smaller fluctuation range.

Two optimization algorithms, AGA and genetic algorithm (GA), were applied to optimize the controller parameters respectively. The fitness values of the two algorithms are shown in Fig.5.

Figure 5. The reference value of PV by different methods

Fig.9 shows that AGA has a better initial solution and faster convergence because of adjusting the cross-over and mutation probability automatically.

When illumination intensity descends from \( S=1000\text{W/m}^2 \) to \( S=600\text{W/m}^2 \) at 0.4s and ascends form \( S=600\text{W/m}^2 \) to \( S=1000\text{W/m}^2 \) at 1.0s, the actual voltage before and after optimization is shown in the Fig.6.

Figure 6. The actual voltage of PV optimized by AGA
Conclusions can be drawn from Fig.10 and Table III: the overshoot of not optimized and optimized are 9.91% and 3.68% respectively, and the average time to reach steady state after optimization is shortened by 4.26% with faster response speed.

5. Conclusion

The PV array, MPPT, the inverter and its control system models are built in PSASP/UD. The PI parameters of invert controller are optimized by AGA and GA respectively in SMIBS based on Simulink. Finally, FMTAS with PV based on PSASP/UD is used to verify the feasibility and effectiveness of models and validity of controller parameters. The main conclusions are as follows:

1. AGA has better initial value and faster convergence speed than GA, and AGA also has obvious effect of parameter optimization;
2. The PV model based on PASAP/UD can output grid-connected voltage and current stably, which can be applied in engineering;
3. The parameters which have been optimized by GAG can be used in FMTAS based on PSASP, and optimized controller has tracking bus voltage faster.

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