Dynamic Modeling, Simulation and Data Logging of a Hybrid Power System for a Remote House in Qinghai Province in China

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Outline

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• Research Objective
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• Dynamic Modeling and Simulation
• Data Logging and Visualization
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1. Motivation

- Environmental policies in China not suitable for traditional power generation
- Decreasing coal storage increases the coal price in China
- Supportive government policies for renewable energy
- On-grid hybrid power system not permitted due to no feed-in tariff policy
- Off-grid hybrid power systems already successful in some remote communities
2. Introduction

- Development of Renewable Energy in China
  Supportive government policies above boost up the development of the renewable energy in China. The levelized costs of solar energy (0.075-0.155 USD/kWh) and wind energy (0.05-0.07 USD/kWh) are becoming affordable.
2. Introduction

• Development of Traditional Energy

Traditional energy takes 75.5% global power generation, leading to huge amount of green house gas emission [4]. Due to environmental restriction, the newly installed traditional generation is 38% of the global installation in 2016 [4].
2. Introduction

• Hybrid Power Systems

A hybrid power systems include traditional generation and at least one renewable generation. It includes [1]:

➢ On-grid hybrid power system: The hybrid power systems that can supply and receive power to and from power grids.

➢ Off-grid hybrid power systems: The hybrid power systems isolated from power grids.
2. Introduction

• Hybrid Power Systems
3. Research Objectives

• Size a hybrid power system with high renewable penetration and minimum cost
• Build the dynamic model and its control system based on the sizing result
• Test the model based on real-time conditions
• Design a low-cost data logging system for an isolated power system
4. System Sizing

• Site Location

The site located at a remote area in China. Its coordination is 37°50’N, 101°58’E
4. System Sizing

- Climate Data of Location

More than 3000 hours when wind speed larger than 3m/s. Results in $200W/m^2$ wind power density
4. System Sizing

- Climate Data of Location

The average daily solar irradiance is $4.51 \text{kWh/m}^2 \cdot \text{day}$ ($> 3 \text{kWh/m}^2 \cdot \text{day}$)
4. System Sizing

- Climate Data of Location

The overall temperature is relatively low around summer. Under same radiation the lower the temperature, the higher the generated solar power.
4. System Sizing

• Primary Load Data Generation

BEopt is chosen because of detailed options for thermal insulation and load
4. System Sizing

- Primary and Deferrable Load Data

\[ H_{\text{dynamic}} = \text{Vertical Lift} + \text{Friction Loss} + \text{Tank Pressure} \]

\[ \text{Required Renewable Power} = \frac{\rho mg H_{\text{dynamic}}}{0.7 \eta_{PV} \eta_{mpt} \eta_{BB} \eta_{PM}} \]
4. System Sizing

- System Configuration and Sizing Results
4. System Sizing

• Cash Flow of Selected Power System

Figure 13 Cash Flow of Selected System
5. Dynamic Modeling and Simulation

- General System Model

Figure 14 General System Model
5. Dynamic Modeling and Simulation

- Dynamic Model of MPPT

$$L = \frac{V_{in}(V_{out} - V_{in})}{\Delta I_{f_s}V_{out}}$$  \hspace{1cm} (5.1)

$$\Delta I_l = \frac{(0.2 \sim 0.4)f_sV_{out}}{V_{in}}$$  \hspace{1cm} (5.2)

$$\Delta V_{PV_{mppt}} = 0.05V_{mppt}$$  \hspace{1cm} (5.3)

$$\Delta V_{PV_{mppt}} = \frac{P_{mppt}}{2f_gC_{dc}V_{mppt}}$$  \hspace{1cm} (5.4)
5. Dynamic Modeling and Simulation

- Dynamic Model of Diesel Generator

\[
\frac{d i_a}{d t} = -r_a i_a - k_v \omega_r + \frac{v_a}{L_{AA}}
\]

(5.5)

\[
\frac{d \omega_r}{d t} = \frac{k_v i_a}{J} - \frac{B_m \omega_r}{J} - \frac{T_L}{J}
\]

(5.6)

Figure 17 Diesel Generator Model
5. Dynamic Modeling and Simulation

- Dynamic Model of Battery Storage

$$E_{\text{discharge}} = E_0 - \frac{KQi^*}{Q-i_t} - \frac{KQi_t}{Q-i_t} + \text{Laplace}^{-1}\left(\frac{A}{sBi_t+1}\cdot 0\right) \quad (5.7)$$

$$E_{\text{charge}} = E_0 - \frac{KQ_i^*}{i_t+0.1Q} - \frac{KQi_t}{Q-i_t} + \text{Laplace}^{-1}\left(\frac{A}{sBi_t+1}\cdot \frac{1}{s}\right) \quad (5.8)$$

Figure 18 Battery Model
5. Dynamic Modeling and Simulation

- Dynamic Model of Single-Phase Inverter

\[
L_{ac} = \frac{V_{dc}}{8\Delta I_{\text{ripple,max}}f_{sw}} \quad (5.9)
\]

\[
C_{ac} = \frac{\alpha P_{\text{rated}}}{2\pi f_{\text{line}} V_{\text{rate}}^2} \quad (5.10)
\]
5. Dynamic Modeling and Simulation

- 1\textsuperscript{st} Case Simulation Result

- Power of PV Array (W)
- Diesel Generator Power Output (W)
- Voltage (V)
- Inverter Output Voltage
5. Dynamic Modeling and Simulation

- 2nd Case Simulation Result
5. Dynamic Modeling and Simulation

• 3rd Case Simulation Result
5. Dynamic Modeling and Simulation

- Problems of the Designed Model

Figure 19 Unstable DC Input Voltage

Figure 20 Waveform Distortion of Inverter Output Voltage
5. Dynamic Modeling and Simulation

- DC Voltage Regulator of a Single-Phase Inverter
5. Dynamic Modeling and Simulation

- Mathematic Model and PID+R+CCF Controller of a Single-Phase Inverter

\[ G_{iC} = \frac{sC_{ac}Z_{ac}V_{dc}}{s^2L_{ac}C_{ac} + sL_{ac} + Z_{ac}} \] (5.11)

\[ G_{viC} = \frac{1}{sC_{ac}} \] (5.12)

\[ H_{delay} = \frac{1 - 0.5T_{delay}s + \left(\frac{T_{delay}}{12}\right)^2}{s^2} \] (5.13)

\[ H_{filter} = \frac{\omega_0^2}{1 + 2\zeta\omega_0 + \omega_0^2} \] (5.14)

Figure 19 Mathematic Model and PID+R+CCF Controller of Inverter
5. Dynamic Modeling and Simulation

- Calculations of Boost Converter

\[ V_{o_{\text{ripple ESR}}} = I_{in} \cdot R_{ESR} \] (5.15)

\[ C_{\text{min ripple}} = \frac{I_{in}}{V_{o_{\text{ripple C} \cdot fsw}}} \left(1 - \frac{V_{\text{in}}}{V_{o}}\right) \] (5.16)

\[ R_{DCR_{\text{max}}} = \frac{0.3P_{\text{total loss}}}{I_{in}^2} \] (5.17)

\[ P_{\text{total loss}} = P_{\text{total}} \left(\frac{1}{\eta} - 1\right) \] (5.18)

\[ L_{\text{max}} = C \cdot \left[R_{\text{max}} \cdot \frac{V_{\text{in max}}}{(10 \cdot V_{o})}\right]^2 \] (5.19)
5. Dynamic Modeling and Simulation

- Time-Delayed Controller of Boost Converter

\[
\frac{\Delta u}{\Delta t} = f(x, t) - B x, t + u(t) + f(x, t)
\]

\[
u(t) = B T - \frac{1}{B} \left( -V_o(t) - L + B u(t) - L + f(x, t) - L - f(x, t) + A m x m t + B m r t - K e t \right)
\]

\[
V_o(t) = V_o(t) C R L + R E S R - R L i(t) C R L + R E S R + R L i(t) C R L + R E S R u(t)
\]

\[
V_{ref} = -P V_{ref} + P V_o(t)
\]

\[
\frac{V_o(t)}{C R L} = \frac{V_o(t)}{C R L} C R L + R E S R + R L i(t) C R L + R E S R - R L i(t) C R L + R E S R u(t) - I r a C u(t) - L + P V_O - V_{ref}
\]
5. Dynamic Modeling and Simulation

- Simulation Results
- Maximum Load with Transient Voltage Disturbance
5. Dynamic Modeling and Simulation

- Simulation Results
- Maximum Load with Low-High Voltage Transition
5. Dynamic Modeling and Simulation

- Simulation Results
- Maximum Load with High-Low Voltage Transition
5. Dynamic Modeling and Simulation

- Simulation Results
- Light-Heavy Load Transition
5. Dynamic Modeling and Simulation

- Simulation Results
- Heavy-Light Load Transition
5. Dynamic Modeling and Simulation

- Simulation Results
- Tuning of Time Delayed Controller
- Tuning of $I_{ra}$, $R_{Lra} = 4R_L$

![Boost Converter Voltage Output](image)

$I_{ra} = 42.182$
5. Dynamic Modeling and Simulation

- Simulation Results
- Tuning of Time Delayed Controller
- Tuning of $R_{L,ra}$, $I_{ra} = 42.182$
6. Data Logging and Visualization System

- Overall System Schematic, System Setup and Detailed Wiring Diagram
6. Data Logging and Visualization System

- PV System

![Diagram of PV System]

- 18V 260W PV Array
- 20A Fuse
- MPPT
- 25A Fuse
- 12V 200Ah Battery
- Load
- Power from PV array
- 20A Fuse
- Battery Box with 25A Fuse
6. Data Logging and Visualization System

• Sensors and Real-Time Measurement Calculation

<table>
<thead>
<tr>
<th>Type of Sensor</th>
<th>Measurement Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV Current</td>
<td>$I_{real} = \frac{Data}{38.51} - 13.32 (A)$</td>
</tr>
<tr>
<td>PV Voltage</td>
<td>$V_{real} = Data \times \frac{Ratio}{51.15} (V)$</td>
</tr>
<tr>
<td>Battery Current</td>
<td>$I_{real} = \frac{Data}{38.51} - 13.32 (A)$</td>
</tr>
<tr>
<td>Battery Voltage</td>
<td>$V_{real} = Data \times \frac{Ratio}{31.19} (V)$</td>
</tr>
<tr>
<td>Temperature</td>
<td>$T = \frac{Data}{1.945} - 50$</td>
</tr>
<tr>
<td>Solar Radiation</td>
<td>$Ra = 0.0079 \times 10^{(2.5311 - \log(55.7 + Data/(1170.31 - Data))]}$</td>
</tr>
</tbody>
</table>
6. Data Logging and Visualization System

- Radio Communication System
6. Data Logging and Visualization System

- Programs on Data Loggers (Arduino Boards)
6. Data Logging and Visualization System

- Python Program on PC
6. Data Logging and Visualization System

• Data Visualization

- Field 5 Chart: Temperature
- Field 6 Chart: Solar Radiation
- Field 3 Chart: Voltage_pv
- Field 4 Chart: Current_pv
6. Data Logging and Visualization System

- Data Visualization
6. Data Logging and Visualization System

• Data Analysis
6. Data Logging and Visualization System

- Visualization of Data Analysis
8. Conclusion

- The designed hybrid power system achieves reliability, high renewable penetration and suitable payback time.
- The designed dynamic model can realize stable operation under real-time conditions.
- The DC voltage regulator can output stable DC voltage under extreme conditions.
- The PID+R+CCF controller increases the waveform of the inverter.
- The data logging system with synchronized radio communication can collect most recent sensor data and eliminate long cables between data loggers.
- The python program on PC can achieve robust data transfer to thingspeak server.
9. Future Work

- Design a solar-wind-diesel hybrid power system for the selected location
- Develop a time-delayed controller with parameters adjusted by fuzzy logic
- Develop a hardware for the voltage regulator&inverter system
- Include the function of data analysis in the python program
- Enable the Internet load control of the PV system
10. Publications


Thanks!