Simulating a Power System

Presented by

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1. Motivations

In an actual power system, it is important to ensure the following aspects under disturbances:

a. Voltage magnitudes of each bus-bar must be maintained at their nominal values.

b. Frequencies of voltage and current signals must be maintained at their nominal values.

c. Low-frequency oscillations existing in these voltage and current signals must be minimized.

d. Eliminate sub-synchronous resonance to protect the shafts.

e. Maintain tie-line power at scheduled values.

f. ...
1. Motivations

The dynamic simulation of power systems contributes to

a. Dynamic estimation of variables in power systems;
b. Controller designs to realize a range of control purposes;
c. Renewable energy source integration;
d. Optimization of operating reserve planning;
e. ...
1. Motivations

Name a few published research work using such simulation platform.

Published in IEEE Transactions on Power Systems

State Estimation of Doubly Fed Induction Generator Wind Turbine in Complex Power Systems
Shenglong Yu, Student Member, IEEE, Kianoush Emami, Member, IEEE, Tyrone Fernando, Senior Member, IEEE, Herbert H. C. Lee, Senior Member, IEEE, and Kit Po Wong, Fellow, IEEE

Abstract—This paper presents a general framework for the doubly fed induction generator connected to a complex power system in order to facilitate the dynamic estimation of its states using noisy PMU measurements. State estimation considering the whole power system with the occurrence of electric faults is performed using the Unscented Kalman Filter (UKF) with a bad data detection scheme. Such a state estimation scheme for a DFIG is important because not all dynamic states of a DFIG are easily measurable. Furthermore, the proposed state estimation technique is decentralized and the network topology of the entire power system is considered, which is a cause of the need of controller designs and the unavailability of some states. The dynamic state estimation of synchronous generators are widely reported in the literature, see [10]-[13] and references thereof. These reported estimation schemes are typically based on Kalman filter techniques. Likewise, on a similar front, we report UKF and EKF based techniques for estimating the dynamic states of DFIG. The dynamic state estimation of DFIG is challenging due to the fact that the states are not measurable and the assumption on the availability of the states is not possible.

Published in IEEE Transactions on Power Systems

A Novel Quasi-Decentralized Functional Observer Approach to LFC of Interconnected Power Systems
Tyrone Fernando, Senior Member, IEEE, Kianoush Emami, Shenglong Yu, Herbert Ho-Ching Lee, Senior Member, IEEE, and Kit Po Wong, Fellow, IEEE

Abstract—This paper presents a novel functional observer based quasi-decentralized load frequency control scheme for power systems. Based on functional observers theory, quasi-decentralized functional observers are designed to implement any given state-feedback controller. The designed functional observers are decoupled from each other and have simpler structures in comparison to the state observer-based schemes. The proposed functional observer scheme is applied to a complex nonlinear power system and the proposed design method is based on the entire network topology.

Index Terms—Load frequency control, functional observer, interconnected power system.

Published in IEEE Transactions on Power Systems
1. Motivations

Name a few published research work using such simulation platform.

Published in IEEE Transactions on Power Systems
1. Motivations

For full publication list, see our Power And Clean Energy (PACE) research group official website.

http://pace.ee.uwa.edu.au/
2. Comparison between a standard electric circuit and a power system

- A power system is nothing but an electric circuit.
- Comparing to an electric circuit, a different set of data is provided in power system studies.
2. Comparison between a standard electric circuit and a power system

Given the information of the power sources and impedances in a power system, we are able to find the voltage magnitudes and phase angles of all the nodes, and also current magnitudes and phase angles of all branches, by simply using the KCL.

• For instance consider bus-bar NO.1.

![Diagram](image)

• According to Kirchhoff current law,

\[ I_1 = I_{12} + I_{13}, \]

Then

\[ I_1^* = I_{12}^* + I_{13}^*, \]
\[ V_1 I_1^* = V_1 (I_{12}^* + I_{13}^*), \]
\[ V_1 I_1^* = V_{12} I_{12}^* + V_{13} I_{13}^*, \]
\[ P_1 = P_{12} + P_{13} \]
3. Data set for power system analysis

Bus data sets

1. Bus-bars
   • Generator bus
     • The active power injected by a generator into a generator bus-bar the voltage magnitude of the generator bus-bar are specified.
   • Load bus
     • The active power consumed by the load and the reactive power either provided or consumed by the load are specified.
   • Swing bus
     • The voltage magnitude and phase angle are specified.

2. Network
   Impedance values of transmission lines
4. Solving power flow with MATPOWER

- MATPOWER is a package of MATLAB® M-files for solving power flow and optimal power flow problems. It is intended as a simulation tool for researchers and educators that is easy to use and modify.

- All information can be found on http://www.pserc.cornell.edu/matpower/

- Consider an IEEE 9-bus test system
4. Solving power flow with MATPOWER

\[ \pi \text{ model of transmission lines} \]
4. Solving power flow with MATPOWER

Type 1: P-Q bus (load bus)
Type 2: P-V bus (generator bus)
Type 3: Swing bus (Slack bus)
4. Solving power flow with MATPOWER

```matlab
%% generator data

%% bus Pg Qg Qmax Qmin Vg mBase status Pmax Pmin
mpc.gen = [
    1 0 0 300 -300 1.04 100 1 250 10
    2 163 0 300 -300 1.025 100 1 300 10
    3 85 0 300 -300 1.025 100 1 270 10
];

%% branch data

%% fbus tbus r x b rateA rateB rateC ratio angle status angmin angmax
mpc.branch = [
    1 4 0 0.0576 0 250 250 250 0 0 1 -360 360;
    4 6 0.017 0.092 0.079*2 250 250 250 0 0 1 -360 360;
    6 9 0.039 0.17 0.179*2 150 150 150 0 0 1 -360 360;
    3 9 0 0.0586 0 300 300 300 0 0 1 -360 360;
    9 8 0.0119 0.1008 0.1045*2 150 150 150 0 0 1 -360 360;
    8 7 0.0085 0.072 0.0745*2 250 250 250 0 0 1 -360 360;
    7 2 0 0.0625 0 250 250 250 0 0 1 -360 360;
    7 5 0.032 0.161 0.153*2 250 250 250 0 0 1 -360 360;
    5 4 0.01 0.085 0.088*2 250 250 250 0 0 1 -360 360;
];
```
4. Solving power flow with MATPOWER

- Simple procedures of using MATPOWER (9 bus, 3 generator system)
  - case9.m
    - Input generator data, bus data, transmission data

- In MATLAB command window
  - Simply runpf(case 9), the result is shown here.
  - For the options used in the function, see the webpage.
  - The outcome shows the method it used to calculate power-flow, convergence time, generator data and branch data.
4. Solving power flow with MATPOWER

- Runpf (case9_Sauer) gives us

| Bus Data |
|----------------------|----------------------|----------------------|----------------------|
| Bus | Mag (pu) | Ang (deg) | Generation | Load |
| # | | | P (MW) | Q (MVAR) | P (MW) | Q (MVAR) |
| 1 | 1.040 | 0.000* | 71.64 | 27.05 | - | - |
| 2 | 1.025 | 9.280 | 163.00 | 6.65 | - | - |
| 3 | 1.025 | 4.665 | 85.00 | -10.86 | - | - |
| 4 | 1.026 | -2.217 | - | - | - | - |
| 5 | 0.996 | -3.989 | - | - | 125.00 | 50.00 |
| 6 | 1.013 | -3.687 | - | - | 90.00 | 30.00 |
| 7 | 1.026 | 3.720 | - | - | - | - |
| 8 | 1.016 | 0.728 | - | - | 100.00 | 35.00 |
| 9 | 1.032 | 1.967 | - | - | - | - |
| Total: | 319.64 | 22.84 | 315.00 | 115.00 |
4. Solving power flow with MATPOWER

- Runpf (case9_Sauer) also gives us

<table>
<thead>
<tr>
<th>Branch Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brach #</td>
</tr>
<tr>
<td>-------------</td>
</tr>
<tr>
<td>1</td>
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<tr>
<td>2</td>
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<td>7</td>
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<tr>
<td>8</td>
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<tr>
<td>9</td>
</tr>
</tbody>
</table>

Branch Charging 140.5 Mvar

Active power balance: \( P_{gen} = P_{loss} + P_{load} \), i.e., \( 319.64 \approx 4.61 + 315 MW \)

Reactive power balance: \( Q_{gen} = Q_{loss} + Q_{load} \), i.e., \( 22.84 \approx 115 + 48.38 - 140.5 MVar \)
5. Introducing a disturbance and the subsequent dynamic behaviour of a power system

A disturbance in power system can be:
1. Changes in active or/and reactive power at load bus bars;
2. Disconnection of a transmission line due to a fault;
3. Three-phase-to-ground fault at a certain point of a transmission line.

The power system will settle at a new operating point after a disturbance. The dynamic behaviour of electrical signals, including voltage, frequency, power, etc, from the original operating point to the new operating point is the transient behaviour, i.e., the dynamic behaviour of the power system.
6. Slow and fast subsystems and DAE formulation

- We have a Differential Algebraic Equation (DAE) formulation of a power system.
- To solve the following DAE

\[
\begin{align*}
\dot{x} &= f(x, u), \\
0 &= g(x, u),
\end{align*}
\]

\(x_0\) and \(u_0\) are required.
7. Computing the Initial Condition $x_0$ and $u_0$

Step 1: Use MATPOWER to find $u_0$.

Step 2: Solve

$$f(x, u_0) = 0,$$

for $x$ and the solution is $x_0$.

- Use $fsolve(\ )$ command in MATLAB.
8. Dynamic simulation of a power system

Obtain $u_0$ from MATPOWER

Obtain $x_0$ by solving $0 = f(x, u_0)$

Disturbance in network

$g$ changes to $g^*$

Obtain $u^*$ by solving $0 = g^*(x_0, u)$

System evolves according to

\[
\dot{x} = f(x, u),
\]

\[
0 = g^*(x, u),
\]

with $x_0$ and $u^*$ being the initial condition, until it reaches a new steady state.
9. Case study

We now consider an IEEE standard 9-bus system. The system initially operates at steady state, and at $t = 2s$, the transmission line between bus 4 and bus 5 is disconnected due to a fault. The rest of the system configuration remains the same.
9. Case study
Thank You
6. Slow and fast subsystems and DAE formulation

A practical power system, comprised of mechanical and electrical components, can be considered as a constitution of two subsystems: a subsystem with fast dynamics and a subsystem with slow dynamics.

Generators have rotating mechanical components which respond more slowly to disturbances than electrical signals in the transmission networks which can change much faster.

When modelling a power system, we use differential equations to describe the behaviour of the subsystem with slower dynamics, and use algebraic equations to describe the behaviour of the subsystem with faster dynamics.

We therefore have a **Differential-Algebraic-Equation (DAE)** formulation of a power system.
6. Slow and fast subsystems and DAE formulation

A power system can thus be formulated with the following DAE compact form:

\[
\begin{align*}
\dot{x} &= f(x, u), \\
0 &= g(u),
\end{align*}
\]

where \(x\) is the generator dynamic state vector, whereas \(u\) represents the algebraic variable vector.

Assuming the power system is initially operating at steady state, with MATPOWER, we can obtain the initial algebraic variables, i.e., elements in \(u_0\), then the initial values of the dynamic states can be obtained by solving the following equations:

\[
0 = f(x, u_0),
\]

The solution of \(x\), named \(x_0\) is the initial condition of the power system operating at a particular steady state. In MATLAB, we make use of “fsolve” command to solve for the initial condition \(x_0\).
7. Dynamic simulation of a power system

1. The initial steady state values of all the variables will remain unchanged until a disturbance occurs.
2. Immediately after a perturbation, the function \( g \) changes to a new function \( g^* \) since the system configuration is different now.
3. The function \( f \) remains unchanged as the structure of generators stays the same.
4. The values of algebraic variables \( u \) after the disturbance can be computed by solving the following equation:
   \[
   0 = g^*(x_0, u),
   \]
   where \( x_0 \) is the pre-fault values of the states, which cannot change instantaneously. The solution of the equation is \( u^* \).
5. Use \((x_0, u^*)\) as the initial condition to solve for the dynamic transience during the faulty condition. Then the system evolves and eventually settles to a new operating point.