Distributed Operation and Control in Power Systems

Class document

Abstract

1 Lecture 1

1.1 Aims

1.2 Foundations

1.3 Possible challenges

1. High penetration renewables in power system requires for new methods and technology for the stability to bulk grid, management, real-time calculation, low transmitting latency (0-1 bit transmitting),
2. AC-DC converters
3. Microgrid
4. Different / multi- time scales for power system operation: 1) controlling perspective: transient stability; 2) operation and energy management: steady state, economics.
5. What is and how to build and describe uncertainty ? Robust: worst scenarios, featuring computing efficiency, conservative; stochastic: expected cost function of different scenarios, less conservative; MPC: several steps ahead, frequency control and voltage control of system.
6. Where is the uncertainty from: market prices, renewables -> Gaussian distribution, prediction errors to decision error, end-to-end model???.
7. Several constraints: supply demand curves, congestions, power loss.
8. For different uncertainty sources, there may be different uncertainty processing way. e.g. renewables: worst, prices: new.
9. Robust security constraints: get some convex approximation of current problems given the new components of the system;
10. what is the resilient grid ?
11. Downward and upward flexibility.
12. Grid-connected entity, grid-forming converters;
13. cyber-physical system (CPS theoretic foundations' system ?)
14. How to calculate the gap between learning and optimizing ?
15. Carbon footprint calculation !!!

Generation side:

What is the flexibility from the system ? This can be categorized into two types: Midterm !!!!

1. Congestion;

Preprint. Work in progress.

2. Reserve;
3. Virtual inertia;
4. Power quality/ harmonics;
5. Black out;
6. Peak shaving;
7. Frequency regulation (Primary secondary, tertiary);
8. Power factor correction;
9. Ramping (eclipse condition);

1. VCC;
2. Power factor;
3. Active distribution networks;
4. High penetration of high renewables and power electronics;
5. Micro-grid;
6. pico grid;
7. vein system.
8. MPT plot figures;
9. Transition state;
10. Distinction between power density and energy density.

$$H\frac{d\Delta f}{dt} = D\Delta f - \sum_{j\in i} P_{ij} + P(t) + U$$

Network side:

Demand side:

1.4 Possible solution by distributed algorithm

1.5 Power flow of the system

2 Lecture 2

2.1 Possible distributed algorithm challenges

1. Online distributed learning algorithm considering the convergence speed the conventional iterative / consensus-based methods.

2. Learn from sparse communication networks and the fast sparse vunerality analysis of the network.

3. The calculation of LODF and shift factors is quite time-consuming which can further embeds some machine learning sparse matrix techniques.

1. Robust;
2. Stochastic;
3. MPC (applied for proposed methods) Distributionally robust optimization;

The formulation of load information is related the node voltage and frequency.

Two concepts of N-1 criteria: 1) corrective; 2) preventive for ship board power system.

Grid-tied formulation;

1. Current sources: P and Q;
2. Voltage sources: V and S;

Inertia related:

1. RoCof;
2. Nadir;
3. Steady frequency deviation;

Challenges for renewables:

1. low inertia;
2. intermittence / fluctuation;
3. harmonics;
4. uncertainty;
5. non-linearity;
6. lower market prices: power prices and capacity prices;
7. ramping reserve;

Frequency droop control: proportional and integral control, (PI control) steady state errors;

Structure of networks: mesh or ring networks.

Global control: 1) frequency; 2) reserve; 3) virtual inertia; 4) ramping; 5) blackout start; 6) peak-shaving.

Locational control: 1) congestion; 2) voltage; 3) harmonics;

Distance between generation and load for reducing the power loss: local balance.

50% by 2050

Price time: Time of use (ToU) price.

EV fleet: aggregation of EV devices.

Power networks and gas networks to lower the carbon emission.

Cyber physical power Systems

3 Lecture 3

Background: stop building fossil generators.

Discriminate the need of power demand and energy demand in power system, power density.

The location of wind rich and load dense area is not the same, which means the disparity of energy system.

The distribution of wind resources and solar with the potential of renewables is spatial and temporal.

Features of wind power:

1. Effect of a plate on a wind flow;
2. Wellbull distribution;
3. MPPT;
4. Inertia from the wind turbines inertia deduction from the controlling policy, from the perspective of SCUC;
5. Higher total capacity;
6. Virtual inertia control policy and its trading, marketing mechanism design to incentivize the participation;
7. Swing equation from the systems;
8. Coupled system and decoupled systems of dynamics frequency analysis under the context of AC-DC-AC formulation;
9. Security analysis;
10. Economics analysis;
11. The number of blades in the wind turbines: aerodynamic analysis with changing of the blades of wind turbines to get the critical point between 3 and 4;
12. The places of wind turbines can be located in off-shore;
13. Output curve of wind power output with the relationship between the wind speed and wind power output;
14. Maximum peak power tracking (MPPT);
15. PMSG control;
16. DFIG control policy, park transformation;
17. Grid forming system: voltage source based inverter, voltage reference voltage amp. & freq. (weak grid and bulk grid)
18. Grid feeding control: current-source based inverter, current reference, active & reactive power;
19. Virtual inertia emulation support system;
20. Variable-speed wind turbine with hydrogen storage system;

$$S^2 = P^2 + Q^2$$

$$\frac{1}{1+\tau s}$$

HVDC system formulation:

1. Lumped model;
2. Long distance >= 100 km and power 200-900 MW;
3. DC: frequency;
4. features of HVDC transmission;

5. vertical design system;
6. of the wind turbine design

Some discussion, what is the problem with rooftop WT ? (Midterm test)

Solar power features:

1. Imputed silicon;
2. Silicon is 2^{nd} abundant element on earth;
3. Conductor, semi-conductor, insulator;

PV / WT problem for more stringent problems by shaping the peak here:

1. congestions;
2. over voltages;
3. Power ramping control (ramping constraints);
4. Curtailed power generation;
5. Delta power reserve control;

Modifying MPPT algorithm for PV and WT; Comparison clear day and cloudy day.

Ramping control of the systems;

Power reserve from the renewable energies for power reserve control turning the MPPT control to reserve control for participating different markets(energy market, reserve market) and some penalty inclusion system;

Offset prediction errors and participate in reserve market;

Delta power reserve control:

Feasible power region:

Reverse / inverse probation:

Control requirements and features for PV systems:

1. PV panels
2. Fault ride-through;
3. Pros and cons of PV power;
4. Energy storage system;
5. Uncertain system;
6. Solution of the system for green house emission;
7. How to recycle the PV panels in the system;
8. further consider the accurate control policy of renewable energies
9. sizing and siting the PV and wind turbines to achieve ...

4 Lecture 4

Diversify energy sources;

Some discussion on EV:

1. V2G;
2. G2V;
3. V2h: utilize vehicle to support the home energy management;
4. Price-incentivized method;

5. Different price means different states of the system;
6. How to allocate the number/capacity of V2G, G2V, V2h for smart charging/discharging for energy arbitrage?
7. First we need to accumulate the info.
8. Final project on this topic to solve the power outage in the V2h scenario.

Target of future power grid:

1. High flexibility;
2. High efficiency;
3. Modular components: Plug-in and play system: plug-in and play learn-to-optimize;
4. Demand response;
5. Integrated energy system;
6. Improved dynamics performance;
7. Reliable optimization;
8. Scale and operation rules;

5 Lecture 5

VPP ignores the topology of the systems, which provide the service based on this feature.

Wake the sleeping resources in the energy system.

Virtual hydrogen power.

VPP provides a possible initial optimal value for AC power flow.

6 Lecture 6

$$f_i = a_i P_i^2 + b_i P_i + c_i \text{Reserve requirements:} R_i \text{Probability:} \gamma$$

$$\begin{aligned} f_i = a_i P_i^2 + b_i P_i + c_i \\ \text{Reserve requirements:} R_i \\ \text{Probability:} \gamma_i \\ \mathbf{P}(P_{max} - P_i \geq R_i) \geq \gamma_i \end{aligned} \tag{1}$$

7 Lecture 7

Transmission networks: R << X;

Distribution networks: R $\approx$ X;

Microgrid: R

$$>>$$

X;

$$\Phi(x) = \sum_{t=1}^{T} []$$

What is the influence of massive DER in power system ?

AC power flow needs some approximation.

Fast Frequency Regulation.

Physical level of system.

Local control of system.

Power factor correction.

Frequency, voltage fluctuation.

Harmonics, distortion, low-inertia, load profile distortion, bidirectional (reverse) powerflow, excess power loss,

Low inertia (stability), over loading problem.

EV problem

Prediction problems (load shedding, day ahead scheduling.)

N-1 security constraints.

Upstream networks.

Microgrid control architecture.

Why step-response not sine curve ? Because the step-response including a high spectrum of sine wave.

8 Lecture 8

References