IEEE Power Case Competition Website Instructions and Problem Statement

2018

The Website

Displayed at http://ieee.toronto.edu/pcc/design is the model that the problem is based on - a variation of the IEEE 14-bus modified test system. You'll see 14 nodes, representing busses of the system, and 20 edges, representing transmission lines. Clicking on a bus will bring up its demand profile, showing the number of MegaWatts that it consumes over a span of 24 hours. Clicking a transmission line will show the power injection limit (the maximum power that it may transmit between two busses).

Click on a bus and scroll down; this is the inventory of generators available. Each generator has a set capacity profile, which varies over 24 hours. This is the maximum power that a generator may output over time. You may place at most one generator at each bus. This essentially turns a bus which was considered purely a load, into a generator with an associated load.

Once you have attached the generators, you may submit by entering your chosen team name, and assigned key.

If your submission is successful, runopf will begin executing to calculate a minimum cost dispatch of your system, over 24 hours. One the calculation is complete (after approximately 40 seconds), a results page will appear with your scores. You may investigate the graphs here, or download a .csv with complete output data from PyPower for analysis as you please. You can also login and see your previous results (also at http://ieee.toronto.edu/pcc/design/result).

Note: Please avoid sharing the key with other groups! If you do not have a team name or experience login issues, please find one of the supervisors or email Robert with the names of your group members (robert.fairley@mail.utoronto.ca).

The Problem

Each bus has a set demand (load) that must be met, and they are connected with transmission lines which limit power flow between busses. At your disposal are the inventory of generators, which each have set capacities throughout the day. The aim is, given the data, to figure out which configuration of generators minimizes cost, while limiting CO2 emissions and power lost due to transmission.

The optimal power flow algorithm (runopf, from PyPower), will determine the power output for each generator at each hour, such that the demands are met, at a minimal cost for the configuration. This power output is determined within the constraint for capacity (maximum power output) shown in the capacity profile. The algorithm is not aware of transmission limits, and the limits that we impose may be surpassed. To summarize, runopf will find an optimal cost for your configuration; <u>your job is to find a configuration that results in the least cost, and best CO2 balance</u>.

Penalties:

If total demand for an hour is not met, a penalty of $20 000 is given for that hour to import power from elsewhere. For each transmission line violation, a cost of $100 is added for repairs. For each MW of power that is dispatched from a CO2-producing generator (gas), environmental policy sets a fine of $50.

Scoring:

To score your solution, we account for cost, CO2, and transmission limits as follows:

score = (total cost) + 100*(# line violations) + 50*(# MW CO2-gen)

(the aim is to minimize the above score)

Presentation:

There are several ways to approach the problem: trial and error, use of tools to solve or display data, or by a particular rationale. To showcase your model, and thought process in getting to the model, you will be giving a presentation to the judges which will also be considered in your score. Feel free to consider principles from your previous design courses!

Notes

Example of input and output to our system and PyPower:
http://ieee.toronto.edu/pcc/pp_inout.md

Detailed generator, demand, cost data:
http://ieee.toronto.edu/pcc/competition_data.zip

Cost functions (cost with respect to usage up to full capacity):

Hydro:	C = 0.4x^2 + 15x
Nuclear:	C = 0.1x^2 + 15x + 10
Wind:	C = 0.8x^2 + 20x
Gas:	C = 0.3x^2 + 5x + 7
Solar:	C = 0.8x^2 + 20x
Biofuel:	C = 0.8x^2 + 20x

Feel free to ask any of the volunteers or judges/speakers questions as you work through the problem!

IEEE Power Case Competition Tutorial Documentation

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Introduction

Welcome to IEEE's Power Case Competition! We are excited to have you here with us today, and we look forward to guiding you throughout the competition. We hope that you enjoy the design process and learn something new at the end!

The purpose of the Power Case Competition is to expose students to the various components of a power system, and the economic dispatch problem. Given a hypothetical collection of generators, students must determine which generators should be selected in an area in order to meet load profiles and minimize the total operating costs in this area. Dispatch modelling involves constraints and objectives, and is routinely done in industry as well. The demand of the grid varies from day to day, hour to hour. It is necessary for the electricity distribution entity to ensure that electricity gets where it needs to go, without compromising the integrity of the grid and minimizing costs and negative impacts where possible.

In short, you will be choosing generators for a simple system for a 24-hour time frame.

Fundamentals[1]

Phasors

A sinusoidal voltage or current at constant frequency is characterized by two parameters: a maximum value and a phase angle. A voltage:

$$v(t) = V_{max}cos(\omega t + \delta)$$

has a maximum value V_{max} and a phase angle δ when referenced to $cos(\omega t)$. The root-mean-sqaure (rms) value of the sinusoidal voltage is

$$V = \frac{V_{max}}{\sqrt{2}}$$

We can use Euler's identity to express a sinusoid in terms of a phasor:

$$V = Ve^{j\delta} = V\angle\delta = V cos\delta + jV sin\delta$$

For example, the voltage, $v(t) = 169.7cos\,(\omega t + 60°)$ volts, has an rms phasor representation in polar form of $V = 120\angle 60°$ volts.

Complex Power

Let the voltage across a circuit element be $V = V\angle\delta$, and the current into the element be $I = I\angle\beta$. Then the complex power S is calculated as:

$$S = VI^{*} = VI\angle(\delta - \beta) = VIcos(\delta - \beta) + jVIsin(\delta - \beta) = P + jQ$$

where P is called the average/real/active power, and Q is called the reactive power.

We can also define the following quantities:

$$Apparent\ power:\ |S| = VI$$

$$Power\ factor:\ pf = cos(\delta - \beta)$$

Note that the real power, P, can be conveniently calculated as apparent power multiplied by the power factor. The unit for real power is watt (W), for reactive power is volt-ampere reactive (var), and for complex/apparent power is volt-ampere (VA).

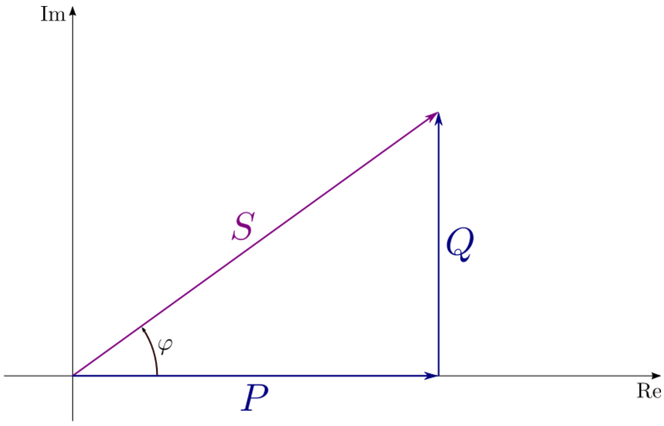
The power triangle, and following expressions summarize the relationships among real power, reactive power, apparent power, and power factor angle:

$$|S| = \sqrt{P^2 + Q^2}$$

$$(\delta - \beta) = tan^{-1}\,(\tfrac{Q}{P})$$

$$Q = P\,tan\,(\delta - \beta)$$

$$pf = \frac{P}{|S|} = \frac{P}{\sqrt{P^2+Q^2}}$$



Power Triangle by Eli Osherovich (Own work) [CC BY-SA 3.0 (https://creativecommons.org/licenses/by-sa/3.0)], via Wikimedia Commons

[1]J. D. Glover, M. S. Sarma, T. J. Overbye. *Power System Analysis and Design.* Stamford, CT: Cengage Learning, 2012.

Power Flow

Introduction

Successful power system operation requires:

1. Generation supplies demand (load) and losses;
2. Bus voltage magnitudes do not go outside of acceptable ranges;
3. Generators stay within specified real and reactive power limits;
4. Transmission lines and transformers are not overloaded.

A power flow algorithm calculates real and reactive power flows, bus voltages, and equipment losses in a power system under steady-state conditions. In contrast, traditional nodal or loop analysis is not suitable for such computations because input data are usually in terms of power, not impedance.

Buses and Lines

A power system consists of buses and connections (lines), and their data are inputs to the power flow program. Each bus resides in a specific geographical location, and transmission lines connect the buses across the power system. A bus is one of the two types:

1. **Demand (load)**: A requirement for electricity, for example, people residing in the region, or industries using electricity for their processes;
2. **Generator**: This is where production of electricity occurs.

Different load buses have different properties, depending on their types:

1. **Residential** demand profiles peak at morning and night times (when people wake up to go to work, and when they return home from work);
2. **Industrial** loads have profiles that are more evenly distributed across the hours of the day.

Each generator is capable of generating from zero to its generation capacity. A generator will be charged a generation cost per MWh of energy it generates (with exception of wind/solar, see "Solar/Wind Generation").

Transmission lines are typically represented by their equivalent π circuit.

Generation

Generation Cost

The cost of generation for each generator is computed as:

$$(Hourly\ generation\ cost) \times (Generation) \ = \ Generation\ cost$$

This formula does not apply to generation utilizing solar/wind sources; see "Solar/Wind Generation" for different formulas.

The total generation will be summed up for each hour and displayed in a graph for the students.

Environmental Footprint

The environmental footprint for the fossil fuel generator is computed as:

$$(Hourly\ environmental\ footprint) \times (Generation) = Environmental\ footprint$$

The total environmental footprint will be summed up for each hour and displayed in a graph for the students.

Dispatchable Generation

Dispatchable generation refers to sources of electricity that can adjust their power output at the request of the system operator or power plant owner in order to meet the demands of the population or fulfill market needs. Most conventional dispatchable sources include hydro and fossil fuel.

Solar/Wind Generation

Wind and solar generation are considered non-dispatchable because energy can only be produced when the sources are present. For each wind/solar generator in Ontario, the government signs a contract with the owner of the generator.

Despite the intermittent generation for each renewable generator, the owner gets paid for the total capable capacity of the generator. This is provided by the government as an incentive for owners to pursue renewable avenues.

These total capable capacities vary with weather, and the percentage capacity profiles will be provided.

Nuclear Generation

Unlike hydroelectricity and gas generators, it is very difficult for nuclear generators to change their generation output. But nuclear generation does not have intermittency issues similar to solar and wind. In fact, whether it is considered as dispatchable or non-dispatchable generation is still debatable due to its unique nature. Therefore, nuclear generation is classified as the third type of generation considered in the Power Case Competition.

Additional Constraints

Line Capacity Penalties

Due to safety factors in the power system, a small cost penalty will be added to the total billable whenever a line carries power above 90% of its capacity limit.

The total cost will be computed as (for each hour):

$$Total\ cost\ penalty = (Total\ capacity\ of\ the\ line\ transmission\ limit\ in\ MW) \times (Line\ penalty\ cost)$$

The exact value of the line penalty differs for each power system, and will be given at the day of the competition.