

Module 5 : Real and Reactive Power Scheduling

Lecture 21 : Introduction

Objectives

In this lecture you will learn the following

- What is scheduling?
- Examples of control variables and constraints
- Objective functions

Control and Scheduling

In previous lectures, we have seen how various quantities like voltage, frequency and power flow are controlled. Speed governors, AGC, voltage and power flow regulators are essentially automatic feedback controllers which work without manual intervention and ensure that these quantities are maintained within acceptable ranges.

Most automatic controllers ensure that these quantities are *regulated*, i.e., their values are maintained at a certain **set-point**. A set-point is a reference value which is given to these controllers by an operator. There exists some flexibility in deciding the exact value of the set point.

Consider the following examples:

1. A plant operator may increase the value of the voltage setting of a [automatic voltage regulator](#) from 1.0 pu to, say, 1.02 pu. This will increase the reactive power output of the generator. Note that while 1.0 pu is the nominal value of terminal voltage, it is not sacrosanct and an operator may change it to a value near-about it as long as it does **not** violate any limit (see [capability of a generator](#)).
2. Following a sudden load increase, governors respond and try to restore frequency by increasing generated power. Subsequently AGC ensures that tie line power flow and frequency is brought back to the nominal value. However, a system operator may wish to alter the sharing among various generators (say, to decrease overall cost of generation).
3. If due to line tripping, a system is in the alert or insecure state, then a system operator may reduce power flow through certain lines by changing the power output of different generators.

Manual control actions by a system or plant operator which essentially change the set point of various automatic controllers is termed as "scheduling". Scheduling may be done in order to achieve a certain economic objective or may supplement the existing automatic controller action in ensuring secure system operation.

Control Variables

A system or a plant operator has the flexibility to set several variables (not only the generator power) in order to meet certain objective(s).

A tentative listing of such variables are:

- a) Real Power Output of generators which are on-line. This is done by changing the load references of the prime-mover control systems -- also known as "scheduling" or "tertiary control". Primary control (governors) and Secondary control (AGC) settings are not usually changed by a system operator.
- b) The decision of whether to engage a generator, at what time and for how long. This is called the unit commitment problem.
- c) Reactive Power output of generators (obtained by changing the voltage reference of Automatic Voltage Regulators).
- d) Tap settings of transformers.
- e) Phase shift setting of phase shifting transformers.
- f) Circuit breaker positions for switching in or out Shunt Reactors/Capacitors.
- g) Circuit breaker positions for bypass or insertion of Series Capacitors in transmission lines.
- h) HVDC power flow.
- i) References of Static VAR compensators, and other Power Electronic Controlled devices.

These variables may be set by an operator based on certain objectives. All these variables -- we shall call them *control variables* -- have limits, some of them take on discrete values while others can be varied continuously.

The freedom to set all control variables may not be there in the hands of one system operator, but may be in the hands of many operators who belong to different entities.

Constraints on System Operation

While an operator has the flexibility to set some or all control variables listed in the previous slide, it has to be done with utmost care so as to not violate any constraint. Some constraints are given below:

- a) Kirchhoff Voltage and Current Law should be satisfied.
- b) Load/Losses and generation should be matched at near-about nominal frequency.
- c) Voltages at buses or along a transmission line should be within limits.
- d) The transmission lines should be loaded below their thermal limits.
- e) Phase angles differences between 2 nodes should not be too large -- the angular stability constraint.
- f) The settings of all controllable devices should be within their available range, eg, Generator output should be within the capability curve.
- g) Constraints of energy supply systems (water usage in hydel-plants, availability of fuel etc.)
- h) Constraints on turbine and boiler operation may restrict the power output range (minimum and maximum) in which they can operate.

In general constraints can be classified as equality constraints which usually can be expressed as algebraic equations as follows :

$$g(x,u) = 0$$

where, u : control variables (which can be set by an operator)
 x : auxiliary variables like voltage and phase angle at buses

and inequality constraints :

$$h_{\min} \leq h(x, u) \leq h_{\max}$$

An example of an equality constraint equations are the real and reactive power balance equations at every node (or equivalently Kirchhoff's law).

An example of inequality constraint is that voltage magnitude at a load bus should be within minimum and maximum limits.

Objective Functions

There is no unique way that an operator may run a power system. For example, if five generators are to meet a certain load demand, there are many ways that they can be scheduled to share the load.

The main aim of a system operator is to achieve certain objective(s) by appropriately setting the control variables, and satisfying all constraints. Rather than making random adjustments, a system operator will attempt to make optimal settings according to some objective (or "cost") function. A cost function is a mathematical function of the control and auxiliary variables. The control and auxiliary variables are also constrained as discussed in the previous lecture. The basic optimization problem can be therefore formulated by the following equations :

Minimize

$$J(x, u)$$

subject to

$$g(x, u) = 0$$

and

$$h_{\min} \leq h(x, u) \leq h_{\max}$$

Common objective functions are:

- a) Schedule generation to minimize generation Cost.
- b) Schedule real and reactive power controls to minimize Active Power Losses.
- c) Unit commitment (decide whether to engage a generation unit and for what duration based on cost and prime mover/energy supply constraints).

The time frame of optimal flow can vary; the unit commitment problem involves several days or months, while generation scheduling based on cost and active loss minimization can be "online", i.e. of the order of an hour. Strictly speaking, all the objectives listed above are coupled, i.e., active power losses affect generation requirement which in turn affect their schedule and also affects unit commitment. However, these couplings are not very strong and in order to make the problems tractable, these are decoupled. For example, in the generation cost minimization problem ("economic dispatch"), only generators which are online (decided a priori by the solution of the unit commitment problem) are considered and losses are neglected.

Since generation, transmission and distribution, and loads are not necessarily owned by the same entity, an objective function depends on the entity which is carrying out the optimization. In systems where generation, transmission and distribution is a part of a single entity -a "vertically integrated" utility, a system operator would try to minimize cost of electricity to a consumer while ensuring that the transmission system and generators can recover their costs (including a rate of return on investment). In systems which are not vertically integrated, where there are several

"players", the problem becomes more complex.

We shall discuss the mathematical procedure for optimizing objective functions under equality and inequality constraints as well as discuss the nature of objective functions in the following lectures.

Recap

In this lecture you have learnt the following

- What is scheduling as opposed to control ?
- Examples of control variables, constraints and cost functions.

Congratulations, you have finished Lecture 21. To view the next lecture select it from the left hand side menu of the page.