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Introduction

The term *power system stability and control* is used to define the application of control theorems and relevant technologies to analyze and enhance the power system functions during normal and abnormal operations. Power system stability and control refers to keep desired performance and stabilizing power system following various disturbances, such as short circuits, loss of generation, and load.

The capacity of installed inverter-based distributed generators (DGs) and renewable energy sources (RESs) individually or through the microgrids (MGs) in power systems is rapidly growing, and a high penetration level is targeted for the next few decades. In most countries including developing countries, significant targets are considered for using the distributed microsources and MGs in their power systems for near future. The increase of DGs/RESs in power systems has a significant impact on CO_2 reduction; however, recent studies have shown that relatively high DGs/RESs integration will have some negative impacts on power system dynamics, frequency and voltage regulation, as well as other control and operational issues. Decreasing system inertia and highly variable dynamic nature of DGs/RESs/MGs are known as the main reasons. These impacts may increase for the dynamically weak power systems at the penetration rates that are expected over the next several years.

In this chapter, a brief discussion on the power system stability and control in modern renewable integrated power systems and the current state of this topic are given. Data-driven wide-area power system monitoring and control is emphasized, and the significance of measurement-based dynamic modeling and parameter estimation is shown.

1.1 Power System Stability and Control

Power system stability and control was first recognized as an important problem in 1920s [1]. Over the years, numerous modeling/simulation programs, synthesis/

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analysis methodologies, and protection schemes have been developed. Power grid control must provide the ability of an electric power to regain a state of operating equilibrium after being subjected to a physical disturbance, with most system variables, i.e., frequency, voltage, and angle, bounded so that practically the entire system remains intact. Thus, the main control loops are known as frequency control, voltage control, and rotor angle (power oscillation damping) control [2].

In many power systems, advanced measurement devices such as phasor measurement units (PMUs) and modern communication devices are already being installed. Using these facilities, the parameters of existing power system controllers can be adjusted by an online data-driven control mechanism [3]. The PMU data after filtering are used to estimate some important parameters in the system (scheduling parameters). These parameters are then used in the control tuning algorithm that will adapt the controller parameters in frequency control, voltage control, and power oscillation control. Therefore, the controller's parameters are adapted according to the current status of the system.

One of the important steps of reliable and performant control system design is defining the performance specifications. It depends on the features of the controller design method, the constraints on the controller structure, the achievable performance that is limited by the physical constraints, the industrial standards on the limit of the variables, the limits of the actuators, etc. Finding the control specifications and making them compatible with the controller design approach require a deeper understanding of the physical system to be controlled.

The characteristics of three main control loops, i.e., frequency control, voltage control, and angle control, should be studied to enable the definition of achievable performance specifications and designing an effective control system.

- *Frequency control:* Since the frequency generated in an electric network is proportional to the rotation speed of the generator, the problem of frequency control may be directly translated into a speed control problem of the turbine generator unit. This is initially overcome by adding a governing mechanism that senses the machine speed and adjusts the input valve to change the mechanical power output to track the load change and to restore frequency to nominal value. Depending on the frequency deviation range, different frequency control loops, i.e., primary, secondary, and tertiary, may be required to maintain power system frequency stability [4].

  The secondary frequency control which is also known as load frequency control (LFC) initializes a centralized and automatic control task using the assigned spinning reserve. The LFC is the main component of an automatic generation control (AGC) system [5]. In large power systems, this control loop is activated in the time frame of few seconds to minutes after a disturbance. In a modern AGC system, based on the received area control error (ACE) signal, an online tuning algorithm must adjust the LFC parameters to restore the frequency and tie-line powers to the specified values.

- *Voltage control:* The generators are usually operated at a constant voltage by using an automatic voltage regulator (AVR) which controls the excitation of the machine via the electric field exciter system. The exciter system supplies the field winding of the synchronous machine with direct current to generate required flux in the rotor. A system enters a state of voltage instability when a disturbance changes the system condition to make a progressive fall or rise of voltages of some buses. Loss of load in an area, tripping transmission lines, and other protected equipment are possible results of voltage instability. Like frequency control, the voltage control is also characterized via several control loops in different system levels. The AVR loop which regulated the voltage of generator terminals is located on lower system levels and responds typically in a time scale of a second or less.
- *Angle control:* Rotor angle stability is the ability of the power system to maintain synchronization after being subjected to a disturbance. Angle stability refers to damping of power oscillations inside subsystems and between subsystems on an interconnected grid during variation beyond specified threshold levels. The risk of losing angle stability can be significantly reduced by using proper control devices inserted into the power grid to find a smooth shape for the system dynamic response.

  The power oscillation damping has been mainly guaranteed by power system stabilizers (PSSs). A PSS is a controller, which, beside the turbine-governing system, performs an additional supplementary control loop to the AVR system of a generating unit. Depending on the type of PSS, the input signal could be the rotor speed/frequency deviation, the generator active power deviation, or a combination feedback of rotor speed/frequency and active power changes. This signal to be passed through a combination of a lead-lag compensators. The PSS output signal is amplified to provide an effective output signal.

  In order to damp the inter-area oscillations, which have smaller oscillation frequency than the local oscillatory modes, a wide-area control (WAC) system is required. The WAC system is a centralized controller that uses the PMU signals and produces auxiliary control signals for the PSSs.
- *Virtual synchronous generator:* Additional flexibility may be required from various control levels so that the system operator can continue to balance supply and demand on the modern power grids in the presence of DGs/RESs/MGs. The contribution of DGs/RESs in regulation task refers to the ability of these grids to regulate their power output, by an appropriate control action. This can be regarded as adding virtual inertia to the grid and considered as a solution. Virtual inertia emulation requires the inverter to be able to store or release an amount of energy depending on the grid frequency's deviation from its nominal

value, analogous to the inertia of a conventional generator. This setup, which is known as virtual synchronous generator (VSG), will then operate to emulate desirable dynamics, such as inertia and damping properties, by flexible shaping of its output active and reactive powers as conceptually shown in Figure 1.1.

This VSG provides a promising solution to improve power grid stability and performance in the presence of a high penetration of DGs/RESs/MGs. The VSG is not only applicable for improving of frequency regulation and oscillations damping, particularly during the transient state following a disturbance, but also it is useful to support the voltage stability. The VSG system can use the available DGs/RESs, as primary sources to participate in power oscillation damping by adjusting their active and reactive power generations. The VSG is more discussed in Chapter 4.

1.2 Current State of Power System Stability and Control

Power system stability and control can take different forms, which are influenced by the type of instability phenomena. A survey on the basics of power system controls, literature, and achievements is given in [6, 7].

PMUs are sophisticated digital recording devices that communicate global positioning system (GPS) synchronized high sampling rate dynamic power system's data to the central control and monitoring stations. The recorded data by PMUs provide valuable information about the dynamic of the power system that can be used for data-driven modeling. An overview of system identification techniques for modeling of power systems using PMU data is given in [8]. In [9], a subspace identification method is used to identify a reduced order model for power oscillation control. The PMU data are used for the calibration of the parameters of the reduced-order model of a power generator in [10]. The feasibility of multi-input multi-output (MIMO) identification of power systems using low-level

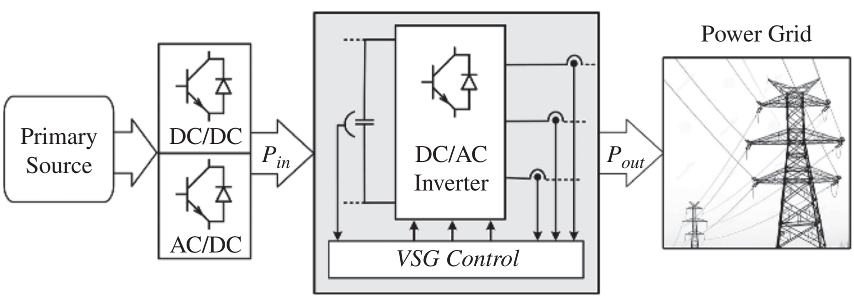

Figure 1.1 Conceptual structure of a virtual synchronous generator.

probing signal is shown in [11]. An online algorithm is used in [12] to identify the frequency response of power system dynamics, while it is combined with a selective modal analysis. The transfer function and state-space model identifications using PMU data are compared in [13] for electromechanical oscillation damping estimation. Several identification methods are compared for analysis of inter-area oscillatory modes of power systems [14].

The data from PMUs have already been used for estimation of some important power system parameters. The electromechanical modes of a power system and their confidence intervals are estimated using PMUs operational data in [15, 16]. Amplitude, frequency, and damping of power system oscillations are estimated using PMU measurements in [17, 18]. The PMU data are used in [19–21] to identify the topology (or change in topology) of a power system. Recently, some system identification methods have been employed to estimate the power system inertia using the operational PMU data (with no external excitation signal) [22, 23].

1.2.1 Frequency Control

Preliminary efforts in the field of power grid frequency regulation are reported in [24]. Subsequently, an IEEE working group prepared some standard definitions of significant terms and concepts on power system frequency control [25]. Considering the physical constraints and to cope with the advances in technologies and the changed system environment, dynamic modeling developments, security constraints, and communication delays, as well as modifications on the frequency control definitions, have been discussed over the years [26–30]. A comprehensive survey and exhaustive bibliography on frequency control up to 2014 are given in [31, 32].

Frequency control analysis, frequency response modeling, nonlinearity and uncertainty presentation, specific applications, frequency bias calculation, control performance standards, load characteristics impacts, and parameters identification are presented in several documents [29, 32–42]. A Considerable research on the time-delayed system is contained in [4, 30]. In addition, regarding parametric uncertainty, several self-tuning, adaptive, and robust control strategies are widely applied for power grid LFC system synthesis over the years [4, 43–51].

Dynamic impacts of intermittent DGs and high penetration of RESs on power grids frequency response are discussed in [32, 52–56]. A low inertia can negatively affect the grid frequency dynamic performance and stability. A number of recent works have suggested the application of inverter-based virtual inertia emulators to improve frequency stability and frequency response performance [57–61]. Furthermore, numerous research works have been recently focused on the use of DGs, RESs, MGs, electric vehicles, and storage devices to provide frequency control supports in the power grids [62–69]. Providing frequency control support via controllable loads and smart load technologies using the concepts of demand response (DR) is discussed in [41, 42, 70–76]. Two recent works in this area are [77, 78], that discuss the impact of a high integration of MGs on the frequency control of power systems, and propose a decentralized stochastic frequency control of MGs.

PMU-based/data-driven online tuning frequency control approach is not addressed in the abovementioned worldwide published works. In most cases, the secondary frequency control is designed using conventional frequency response model, which is very difficult to realize in a modern power grid with a highly variable structure and penetration of DGs/RESs.

1.2.2 Voltage Control

Since 1990s, supplementary control of generator excitation systems, static var compensator (SVC), and high voltage direct current (HVDC) converters is increasingly being used to solve power system oscillation problems [7]. There has also been a general interest in the application of power electronics-based controllers known as flexible alternating current transmission system (FACTS) controllers for the damping of system oscillations [79]. Following several power system collapses worldwide [80–82], in 1990s, voltage stability has attracted more research interests.

Recently, following the development of PMUs, communication channels, and digital processing, wide-area power system stabilization and control have become areas of interest [83, 84]. A typical generic of different voltage control levels is discussed in [85]. Optimal voltage control has long been successfully implemented in power systems, including the three-level hierarchical automatic voltage control in Europe [86–88], and the adaptive zone division method in China [89].

A supervisory voltage control strategy for large-scale solar photovoltaic (PV) integration in power network is proposed in [90, 91] to enhance the voltage stability. A survey of methods, mostly based on PMU data, for long-term voltage instability detection is given in [92]. In [93], a two-stage distributed voltage control scheme is proposed. The first stage is the local control of each DG based on sensitivity analysis, and the second stage acquires reactive power support from other DG units. In [94], a consensus-based cooperative control is proposed to regulate voltage by coordinating electric cars and active power curtailment of PVs. In [95], a distributed voltage stability assessment considering DG units is developed based on distributed continuation power flow. Coordinated voltage control is a technique which provides voltage control by means of adjusting, sequencing, and timing various kinds of controllers within a system. Some relevant works are reported in [96–98].

As mentioned above, several PMU-based voltage control methodologies have been reported worldwide; however, mostly presented a voltage recovery approach in an off-normal or emergency condition. Among existing three hierarchical levels of voltage control (primary, secondary, and tertiary controls), only few works are mainly focused on optimal supervisory on secondary voltage control, which is required to coordinate adjustment of the set-points of the existing voltage controllers. In this regard, the online adaptive tuning of available voltage control systems in a power grid with high integration of DGs/RESs is not well addressed. Furthermore, the overlap between voltage dynamics and frequency/active power as well as rotor angle dynamics in a modern power grid has not been highlighted in the published reports.

1.2.3 Oscillation Damping

Traditionally, the power system oscillations are damped through the generator local controllers, such as the exciter and governor, which are designed to ensure only the local stability of the generator (1–2 Hz). In order to increase the stability of the system, PSSs and power electronic converter-based FACTS are added into the grid [99–101]. In a broader context, the power system oscillation problem has also been related to voltage stability. The control interaction is discussed in [102, 103]. The exploitation of the wide-area measurements, provided by PMUs, for monitoring and controlling the power system led to the introduction of the wide-area monitoring and control (WAMC) systems [104]. The advent and application of synchronized measurement technology has enabled the detection and observation of poorly damped oscillations (such as the inter-area modes) and became the backbone for more development of the WAMC systems [105]. Inter-area oscillations are characterized by low frequency (0.2–1 Hz) and occur when generators of one group swing against generators of another group [106]. Integration of RESs into the WAC scheme for damping power oscillations is discussed in [107, 108]. The utilization of a networked control system model for the WAC design, according to linear matrix inequality techniques, is proposed in [111]. Furthermore, Ref. [110] presents a WAC design, based on particle swarm optimization, for improving the performance of the power system through the control of wind farms.

More specifically, WAC aims to utilize the synchronized phasor measurements in order to provide coordination signals to the local controllers, making them capable of damping effectively all the inter-area oscillations [100]. In the literature, various works deal with the development of a WAC system. The proposed WAC schemes are segregated mainly according to the components of the power system that the WAC is intended to coordinate [3, 110]. Multiple control methodologies have been developed for damping the inter-area oscillations deploying a WAMC. In [83], a decentralized/hierarchical architecture for wide-area damping control using PMU remote feedback signals was discussed. References [100, 111] proposed the design of wide-area damping controllers that provide supplementary damping control to synchronous generators (SGs). A networked control system model for wide-area closed-loop power systems is applied in [109]. A power oscillation damping controller is introduced in [112] based on a modal linear quadratic Gaussian methodology. A combination of controlling SGs and renewable sources in order to increase the overall damping capability of the system is shown in [101, 107, 108, 113]. Few LPV control solutions to power oscillation damping are proposed that use either a low-order first principle model of the system [114] or a reduced-order parametric LPV identified model [115].

In comparison of frequency and voltage control, a higher number of reports have been published in PMU-based oscillation damping (rotor angle control) field. However, most of the reported approaches require the detailed and accurate knowledge of the complete network model (both topology and parameter values), that is unavailable or corrupted in practice as a result of communication failures, bad data in state estimation etc. In addition, the impact of disturbances on the inter-area oscillations cannot be well captured by these methods.

1.3 Data-Driven Wide-Area Power System Monitoring and Control

Power grids modeling and control has become a more challenging issue due to the increasing penetration of RESs, changing system structure and the integration of new storage systems, controllable loads and power electronics technologies, and reduction of system inertia. Conventional modeling and control designs may not be any more effective to satisfy all specified objectives in various operation modes of modern power grids. These challenging issues set new demand for the development of more flexible, rapid, effective, precise, and adaptive approaches for power system dynamic monitoring, stability/security analysis, and control problems. Thanks to recent advances in control, communication, and computing technologies, it is possible to tackle mentioned challenges by implementing a data-driven-based modeling and control framework as shown in Figure 1.2.

The system data are collected from the distributed PMUs in the grid through a secure communication network. The development of information and communication technology (ICT) enables more flexibility in wide-area monitoring of power system with fast and large data transmission. Especially, the wide-area measurement system (WAMS) with PMUs is a promising technique as one of the smart grid technologies in the bulk power grid.

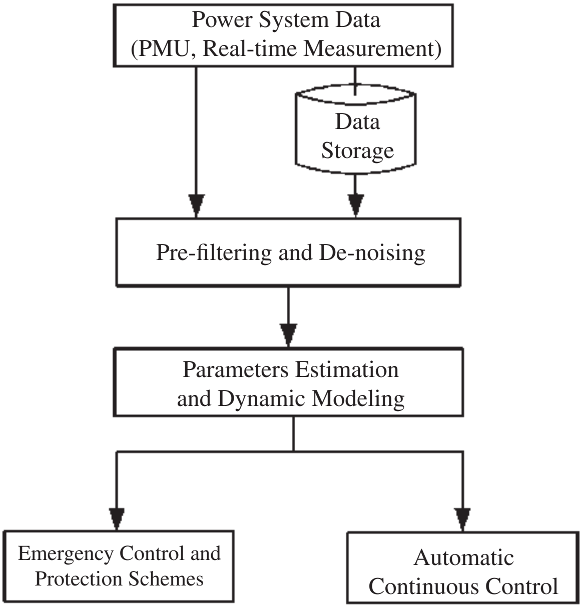

Figure 1.2 An overall data-driven control framework for renewable integrated power systems.

The measured data are locally saved and then collected by phasor data concentrators (PDCs) for the post analysis or sent to a remote location via a standard data format. These data with the time stamp of the synchronized GPS in real time may applied for parameter and state estimations and finally used for the system protection and/or real-time control. Figure 1.3 shows how a PMU-based WAMS can provide data for the power system control center to generate continuous (in normal states) and discontinuous control (in off-normal states) commands.

Before any application, the collected PMU data need to be cleaned and de-noised and employed by the data processors for estimation, modeling, and control purposes. The proposed de-noising method may use a rolling-averaging window with pre-specified length to remove noise from the recorded data. The block of parameters estimation algorithms contains high fast and precise algorithms for estimation of some important parameters and transient characteristics that are required to use in control tuning algorithm or to detect a contingency and triggering the emergency control and protection schemes. In case of crossing the assigned thresholds showing an off-normal and emergency condition, the recorded data and some estimated parameters are used to detect the amount of mismatch (size of disturbance) for the emergency control and protection schemes such as load shedding

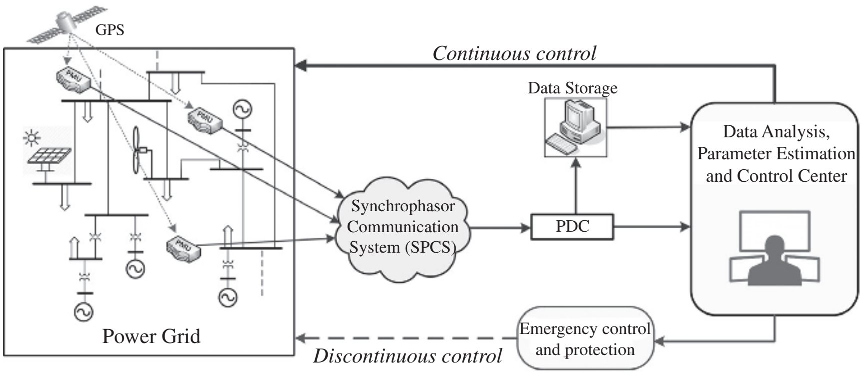

Figure 1.3 PMU-based wide-area measurement system and control.

algorithms. Otherwise, the estimated parameters such as scheduling parameters are employed by the continuous control systems.

As mentioned, using significant number of distributed micro-sources into power systems adds new technical challenges. As the electric industry seeks to reliably integrate large amounts of DGs/RESs into the power system in regulated environment, considerable effort is needed to accommodate and effectively manage the installed micro-sources. A key aspect is how to handle changes in topology and dynamics caused by penetration of numerous DGs/RESs in the network and how to make the power grid robust and able to take advantage of the potential flexibility of distributed micro-sources. In a modern control framework, a part of power produced by available DGs/RESs in the grid are used as a primary energy source of inertia emulator to provide virtual inertia as a supporting control for abovementioned controllers (like a fine tuner) to improve power grid stability.

1.4 Dynamics Modeling and Parameters Estimation

From a system dynamic point of view, the bulk generating units, due to their high inertia, provide a long time constant; such that the rotor speed and thus the grid frequency cannot alter suddenly, while the load changes. Hence, the total rotating mass enhances the dynamic stability. In future, a significant share of DGs/RESs/MGs in the electric power grids is expected. This increases the total system generation power, while does not contribute to the system rotational inertia. System dynamics are faster in power systems with low rotational inertia, making control and power system operation more challenging [32].

A complete understanding of reliability considerations via effective modeling/aggregation techniques is vital to identify a variety of ways that power grids can accommodate the large-scale integration of the distributed micro-sources in future. An accurate dynamic model is needed for the stability analysis and control synthesis in a grid with a high degree of DGs/RESs penetration. A proper dynamic modeling and aggregation of the DGs/RESs and MGs, for performance and stability studies, is a key issue to understand the dynamic impact of distributed micro-sources and simulate their functions in new environment.

The power system is a nonlinear multivariable time-varying system. It is represented by a nonlinear set of equations for the generators (swing equations), for the transmission lines and for the loads, which for a typical power system has a few hundreds of states. For the control design purpose, usually a reduced-order linearized model around an operating point is used and it is assumed that all system parameters are known and time-invariant. These assumptions, however, are not valid in a real power system with dominated DGs/RESs/MGs. The main dynamic modes of the system are varying stochastically during a day because of the variation of load and aggregated inertia. The dynamic modes will change more significantly by integration of new RESs into the power system (e.g. because of long-term variation of the mean value of the aggregated inertia). Therefore, a fixed linearized time-invariant model will not represent correctly the behavior of the power system.

The frequency response of the system can be identified offline/online using the data for different load and generation configurations (when the share of DGs/RESs is increased) and saved in a database for the models. The small variation of the system (originated from measurement noise, load variation, and system nonlinearity) will be modeled by frequency domain uncertainty. The long-term effect of change in system inertia can be considered by identifying several frequency-domain models for different levels of RES penetration. One can represent this model's database by an LPV model [116]. It should be mentioned that the model of the power system for the frequency, voltage, and rotor angle is different because they have different inputs and outputs and scheduling parameters.

1.4.1 Modeling of Frequency, Voltage, and Angle Controls

The participant bulk SGs with different participation factors are the main actuators for the frequency control system. Following a disturbance, the variation of frequency and tie-line power is applied to the LFC system via the ACE signal. Then, depending on the accessible amount of regulation power, the LFC system will be activated to compensate the power grid frequency and return it to the nominal value. The LFC system can attenuate the frequency and active power changes from tenth of seconds to few minutes. Therefore, the ACE signal may provide the output of system model for frequency control. Considering the frequency response dynamics [32], the candidate scheduling parameters are system inertia, aggregated generating time constant, droop and damping coefficient. The measurement-based dynamics identification and system modeling will be for adaptive control and online parameters tuning of the LFC system. The increasing size and diversification of demand/power sources magnify the importance of this issue in the modern power grids.

Unlike grid frequency, since the voltage is known as a local variable, a higher number of measured points are required. For proposing the data-driven models, several concepts like Thevenin equivalent system and oscillation model will be applied and the results will be used for the grid voltage analysis, and then optimal tuning of AVRs. The measurements of voltage, current, and phase deviations of existing nodes are considered as the most important inputs of model. The system output can be the terminal voltage change of the SGs. In order to construct an appropriate LPV model for voltage control, relevant scheduling parameters must be selected. There are several choices for the scheduling parameters (low-frequency resonance mode, reactive power of the system, Thevenin equivalent impedance/admittance, etc.) that must be compared and discussed using effective analytical and simulation-based studies. In choosing efficient scheduling parameters, a tradeoff between accuracy and simplicity of the resulting LPV model is needed. The measurements are also used to perform some important graphical tools and curves to evaluate the stress conditions and to analyze the voltage stability criteria. For instance, the data are fitted to the active power–voltage curve (PV curve) of the equivalent system by suitable fitting approaches such as least squares method.

The SGs equipped with a PSS and RESs participating in power oscillation damping are considered as the main actuators of the control system. It is assumed that some of the RESs are not operating at their maximum generated power, so that they can help for power oscillation damping by reducing/increasing a small percentage of their power generation. The system to be controlled is a multivariable system, where the inputs are the reference voltages for the AVR of the SGs as well as the auxiliary signals that will be added to the reference active and reactive powers of RESs. The system outputs can be the active power or the speed (or both, depending on the type of PSSs) of the SGs and the measured active and reactive powers of the RESs. In order to construct an appropriate model for power oscillation damping, we need to choose the scheduling parameters.

1.4.2 Parameters Estimation

For estimation of all required parameters, the recorded data from the installed PMUs can be used. As shown in Figure 1.2, firstly, a de-noising methodology, mostly based on rolling averaging windows, can be employed to prepare the received PMU data for further processing. Afterwards, some data-driven-based algorithms are used to estimate the most important parameters (e.g., system inertia, droop characteristic, and damping factor) required for building low order power system models such as frequency response model [32] and oscillation model [3]. In real-time operation, an accurate and fast estimation of parameters is required. The estimated parameters can be used in the auto-tuning algorithm of the controllers.

In a modern power system, in addition to scheduling parameters, several algorithms need to be developed for online estimating of other important system parameters such as synchronizing coefficient between various areas, rate of change of frequency/voltage (ROCOF/ROCOV), frequency/voltage nadir, and time occurrence of frequency/voltage nadir. The estimations must be fast enough and should cover the issues related to the existing time delay. These data-driven-based estimation algorithms can be analytically developed based on the concept of swing equation, base-case systems, regression, and curve fitting. These measurement-based dynamics identification and system modeling can be used for adaptive online parameters tuning of the targeted controllers. The increasing size and diversification of demand/power sources magnify the importance of this issue in the modern power grids. The estimation approaches may be applicable for both on-line and off-line methods. However, for on-line applications, shorter data windows must be used.

PMU data-based power-load imbalance estimation is a key estimation to successfully handle the emergency control strategies, e.g. load shedding, and protection plans. In case of detecting a contingency or an emergency condition, following comparing of frequency, voltage, and their rate of changes with the specified threshold values, an estimation algorithm must estimate the size of disturbance to use in the available emergency control systems and special protection schemes. This online estimation is an important issue to realize a successful load-shedding scheme with minimum amount of shed load.

Conventionally, for the estimation of the size of load-power mismatch, the swing equation is used. The estimated imbalance based on this method may far from real power mismatch as it relies on three worst assumptions: (i) there is no additional active power variation except for that of disturbance, (ii) there is a negligible reactive-power imbalance in response to sudden active power imbalance, and (iii) the inertia constant assumed to be known. This under/over-estimation causes inaccurate calculation of total amount of load to be shed.

In [117], for estimating the size of disturbance, some appropriate base-case features are selected from a set of pre-defined base cases. Moreover, an efficient yet simple logic is defined to select appropriate base-case for the received data. This approach benefits from the use of PMU data to precise calculation of the required amount of load to be shed, in one-step and in a short time in comparison with the actual time. The proposed scheme relies on fast, yet iterative, estimation of frequency nadir, and time of minimum frequency occurrence. Accordingly, the inertia constant as well as the size of power mismatch are estimated which, in turn, compares with the maximum size of imbalance, satisfying the pre-specified thresholds, to determine the amount of shed load.

1.5 Summary

Modern power grids face new technical challenges arising from the increasing penetration of power-electronic-connected RESs/DGs. Increasing MGs/DGs penetration level may adversely affect frequency response and voltage and system control and lead to degraded performance of traditional control schemes. This, in turn, may result in large deviations and, potentially, system instability.

This chapter provides the pre-requirement terminology and general background for the next chapters of this book. The term power system stability and control with an updated brief review on the areas of frequency, voltage, and angle controls, concerning the penetration of RESs/DGs, is discussed. In response to the existing challenges in penetration of more RESs/DGs to the grid, the necessity of using data-driven modeling, parameters estimation, and control synthesis in wide-area power systems is emphasized.

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