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Advanced Smart Grid Functionalities Based on PowerFactory

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Chapter 6
Dynamic Stability Improvement of Islanded Power Plant by Smart Power Management System: Implementation of PMS Logic

Hamid Khoshkhoo and Ali Parizad

Abstract Power management system (PMS) which is a kind of special protection system is used to detect predefined conditions and execute timely remedial actions to prevent instability or improve operating point, especially in an islanded system. To this purpose, PMS usually includes several functions such as load shedding/sharing, generation shedding, and generation mode control which are automatically executed to improve operating point. In this chapter, to show the capability of DIgSILENT power factory to simulate smart grids functionalities, DIgSILENT programming language (DPL) is used to model PMS logic in automatically detecting islanding condition as well as executing load/generation shedding in an islanded system to prevent instability. Indeed, this modelling gives the possibility to check the impact of considered PMS logic under different operating conditions on the stability of the system.

Keywords DIgSILENT power factory · DPL · DIgSILENT simulation language (DSL) · Load/generation shedding · Power management system (PMS)
Special protection system

6.1 Introduction

During the last decade, several system instabilities have occurred in power systems all over the world which result in huge economic losses. In this regard, extensive investigations have been carried out to provide proper tools to assist system

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operators in timely executing remedial actions to prevent instability. PMS is an intelligent centralised system which measures required variables from different substations, performs required analysis (such as power flow), calculates intended variables (to detect predefined or abnormal conditions), and executes timely control actions [1–3]. Especially, after an unintentional islanding occurrence, which usually needs timely reaction of operators, PMS can play an important role to automatically detect islanding condition and perform proper remedial actions in a fraction of a second to regain operating point to the acceptable region. In this condition, to balance load and generation, PMS usually executes either load or generation shedding procedure, and then, it can execute secondary frequency control to precisely regulate the system frequency [1, 4, 5]. In addition to automatically execution of remedial actions, PMS provides the possibility for operators to monitor dynamic behaviour of the system and execute intended control actions.

Since PMS usually executes automatic control actions to improve the operating point, performing accurate offline simulations to assess the effectiveness of considered PMS logic is inevitable. Reviewing the literature shows that although papers discuss the impact of the PMS on the stability of systems, they have not explained the implementation of PMS logic in a simulation software and also have not discussed the detailed logic of PMS. This chapter aims to show the ability of DIgSILENT power factory in testing a PMS logic by simulating the execution of automatic remedial actions. In this regard, DPL which is a proper tool to simulate PMS logic is used to automatically detect system status, make a decision according to considered PMS logic and perform the selected control action(s).

Among different functions used in PMS logic, in this chapter, the load shedding, generation shedding, and secondary frequency control procedures of PMS have been explained in Sect. 6.2. Then, in Sect. 6.3, DPL is used to model PMS logic in performing load/generation shedding and frequency regulation. Finally, simulations results and conclusion have been presented in Sects. 6.4 and 6.5.

6.2 Functions of the PMS

If active power generation of a system is more/less than load demand, the frequency increases/decreases which may result in operation of frequency relays and system black out. Also, some loads, especially in industrial systems, are highly sensitive to frequency deviation and any under/over frequency may cause process failure and economic loss. Therefore, to precisely regulate frequency after an abrupt disconnection of the power plant from the grid, PMS automatically measures the amount of active power generation and load demand, calculates the amount of load/generation which should be shed, and executes load/generation shedding according to the priority list of loads and generators. In this chapter, among several PMS functions usually used to control the operating point, load shedding, generation shedding, and secondary frequency control procedures are implemented in DPL. In the following subsections, these procedures are introduced, briefly.

6.2.1 Load Shedding Procedure

When islanding condition occurs, if load demand exceeds active power generation, the amount of load which should be shed is calculated as follows and then a set of loads is selected according to priority list to shed:

$$P_{\text{To Be Shed}} = P_{\text{transfer}} - N_G \times SPRes + P_{\text{Offset}} \tag{1}$$

where P_{transfer} is the active power imported from the external grid before islanding condition, N_G is the number of the generator in running mode, *SPRes* is the active power reserve of each generator, and P_{Offset} is the extra load which should be shed to guarantee stability (in this chapter it is assumed that $P_{\text{Offset}} = 0$).

6.2.2 Generation Shedding Procedure

When islanding condition occurs, this procedure identifies the amount of excessive generation in the islanded system, selects a set of generation units according to a priority list, and sheds this set to prevent over frequency rapidly. Thus, the amount of generation which should be shed may be calculated as follows:

$$P_{\text{To Be Shed}} = P_{\text{transfer}} \tag{2}$$

where P_{transfer} is the active power exported to the external grid before islanding condition. It is worth mentioning that if load operation with speed control (LOSC) mode exists in governor logic [6], fewer generators can be shed. In this situation, the operating mode of other generators should change from load operation with load control (LOLC) to LOSC mode to decrease power generation and prevent significant frequency deviation, quickly. Indeed, in this condition, offline simulations are needed to calculate the exact amount of generation which should be shed (In this chapter 25% of P_{transfer} is shed, and operating mode of other generators are changed to LOSC.).

6.2.3 Secondary Frequency Control

Secondary frequency control is used to precisely regulate the frequency of system by changing the set point of governors. In this chapter, the set points of governors are changes with the step of $dw = 0.005$ p.u. to regulate frequency. Indeed, a proper value for *dw* should be obtained using offline simulations, and it should be small enough to prevent the oscillatory behaviour.

6.3 Application of DPL in PMS Modelling

DIgSILENT programming language is a proper tool to implement PMS logic and simulate its operation. To show this capability, in the test system shown in Fig. 6.1, DPL is used to simulate the load and generation shedding procedures. In this study, assuming generators and governors of test system are named G_i and pcu_i; $i = 1, \ldots, 5$, and one of the parallel transformers (i.e. *Tr230/400-2*) is out of service, two scenarios will be considered:

- When the active power imports from the grid to the plant, the second transformer (*Tr230/400-1*) is tripped by a protection relay which causes the frequency of plant to decrease. In this situation, a proper and timely load shedding procedure should be employed by PMS to balance load and generation.
- When the power exports from the plant to the grid, *Tr230/400-1* is tripped. In this condition, execution of timely generation shedding procedure by PMS is necessary to prevent over frequency.

Figure 6.2 shows the flowchart used to model DPL logic in detecting system condition and executing load or generation shedding procedure. Also, the hierarchical structure of DPL scripts prepared for this study is shown in Fig. 6.3.

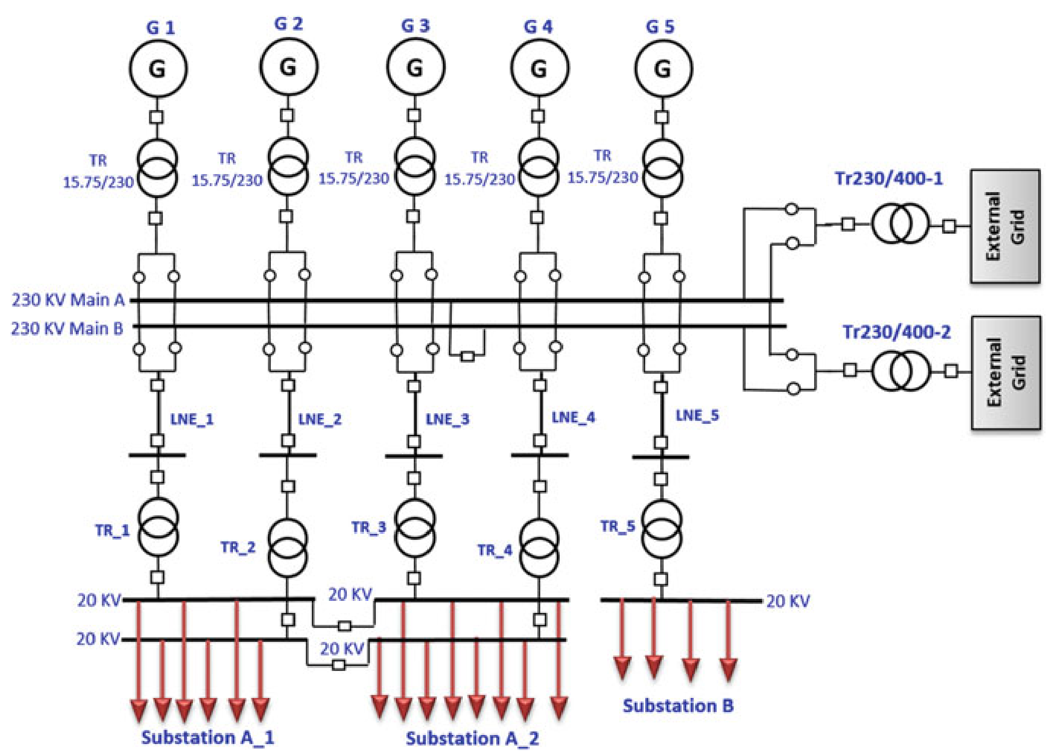

Fig. 6.1 Single line diagram of the test system

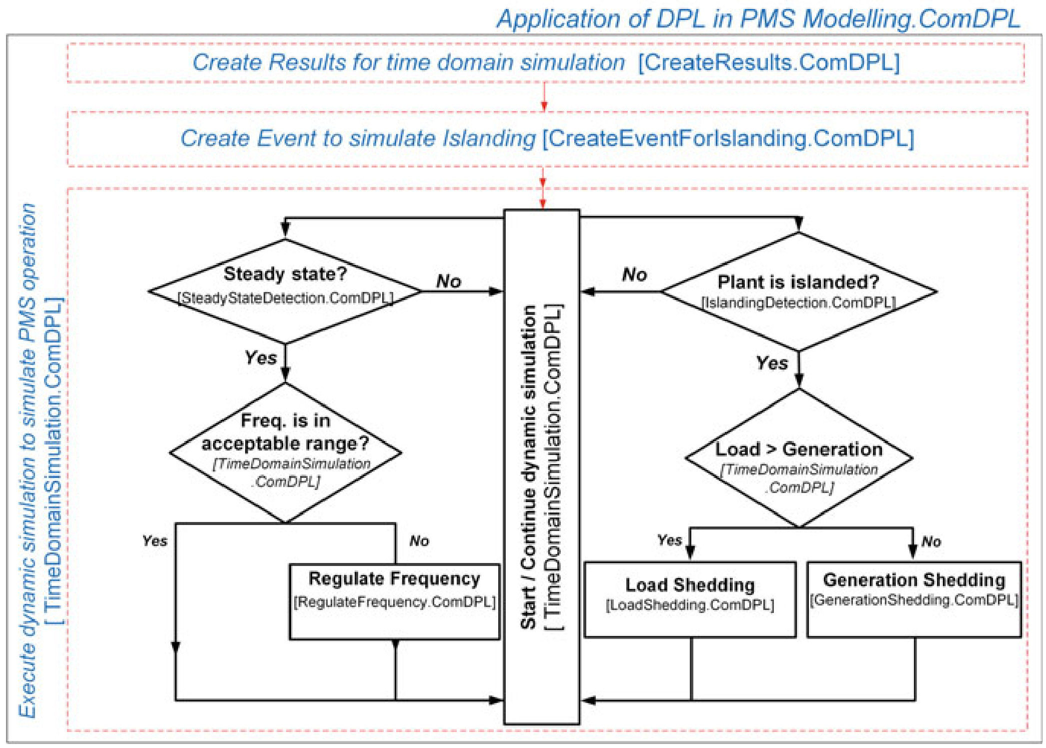

Fig. 6.2 Flow chart of the logic used to simulate PMS operation

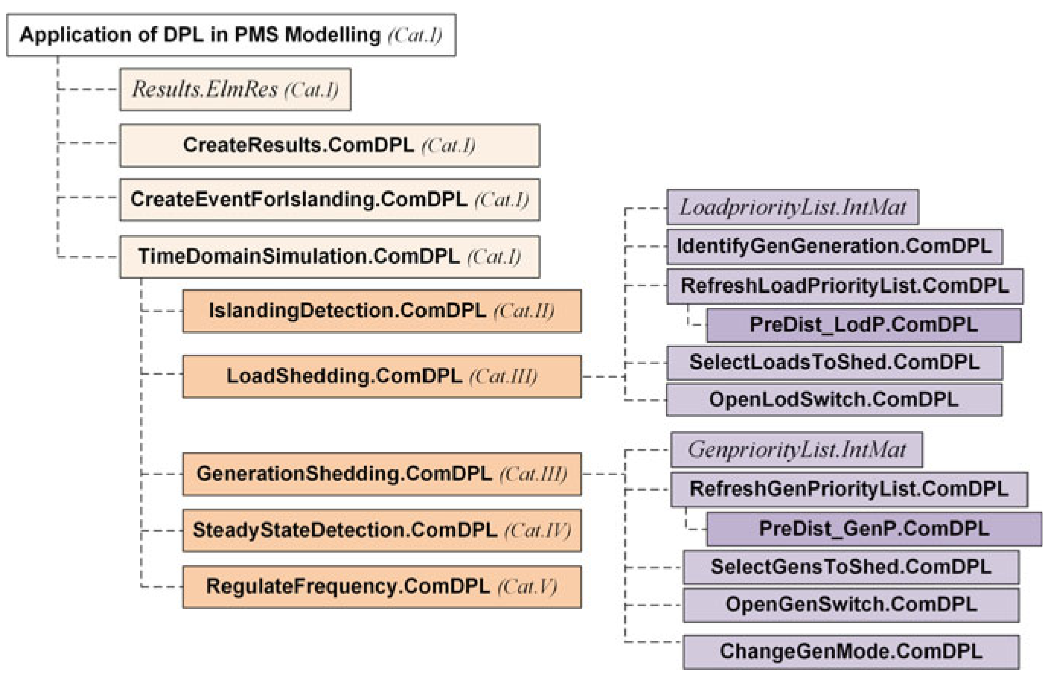

Fig. 6.3 Hierarchical structure of the program

Chapter 8
Dynamic Stability Improvement of Islanded Power Plant by Smart Power Management System—Principles, Descriptions and Scenarios

Ali Parizad and Hamid Khoshkhoo

Abstract During the last decades, insufficient investment along with an increase in power demand have caused power system operating points to get closer to their stability boundary. In this condition, the need to fast and precise assessment of system stability status and proper execution of remedial actions results in a tendency of dispatching centres towards special protection system (SPS). This system is a smart monitoring and control system which detects the predefined condition and automatically executes pre-specified remedial actions to improve system stability. Indeed, such system can reduce human faults and prevent economic loss. Power management system (PMS) is a kind of SPS which is usually implemented in industrial power plants to intelligently manage remote devices and perform required actions against system contingency, especially in islanding condition. PMS has significant functions such as load shedding/sharing, generation shedding, generation mode control and import/export control to the control voltage, frequency and active/reactive power of the system. In this chapter, PMS configuration and its major functions are explained, and its impact on system stability is analysed through detailed dynamic simulations in DIgSILENT PowerFactory software. In these simulations, DIgSILENT simulation language (DSL) is used to model turbine-governor, excitation system and signals.

Keywords Blackout prevention · DIgSILENT simulation language
Generation mode control · Import/export control · Load/generation shedding
Power management system (PMS) · Power system stability · Special protection system

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8.1 Introduction

Power system instability is one of the threats to power systems all over the world, and great efforts have been made to propose proper methods to assess (detect or predict) stability status of the system and to perform remedial actions to prevent instability [1]. If the power plant is disconnected from the grid, the operation of the islanded system may be interrupted because of the lack of generation resources. The non-critical loads have to be shed according to their priorities in order to prevent blackout event [2, 3]. Since system instability usually leads to huge economic loss, national dispatching centres prefer to use electrical power system management technology in power plant industry. Power management system (PMS) is one of the smartest technologies proposed to prevent system instability [4]. The term PMS was formerly used to describe arrangements for the automatic starting and stopping of electrical generators to meet the actual load requirements, but nowadays, it is implemented to a very wide range of control systems and is able to control system smartly [5, 6].

The PMS system plays a key role in intelligently performing automatic generation control, frequency/voltage control, Import/Export control, initiation of automatic generator synchronisation, automatic synchronisation of inter-tie feeder circuit breakers, rapid load/generation shedding under abnormal condition, secondary control and so on. Whereas an unwanted event causes power system instability, PMS is designed and implemented in a power plant (especially in islanding condition) to detect a disturbance, select the best function immediately and send a proper command to prevent system instability smartly [7, 8].

Figure 8.1 illustrates the differences between systems with/without PMS. In a system without PMS, controllers work individually and send required set points or commands to their own generator. In contrast, in the smart system, PMS gets required a signal from the entire network (globally) and then sends set points or commands to equipment, considering whole power plant conditions.

In [9], a scenario-based approach has been described to minimise the amount of load shedding to prevent system instability. Similarly in [10], load shedding is used to minimise the frequency swing in unwanted disturbances. It can be defined by a

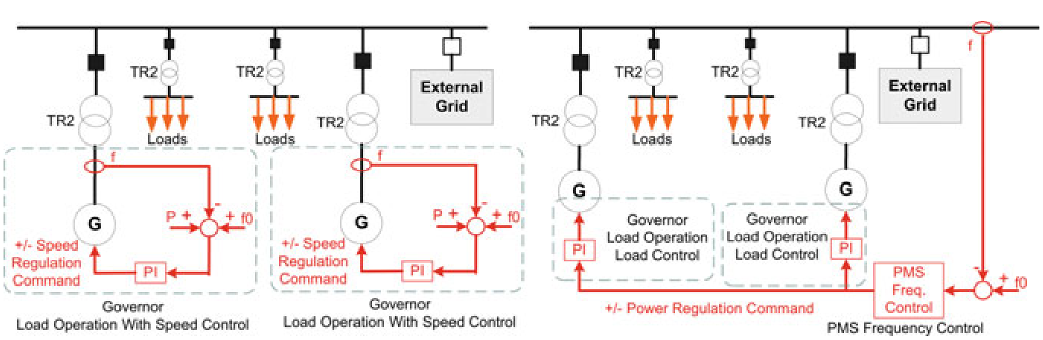

Fig. 8.1 Differences between systems with/without PMS

series of predefined operational scenarios. PMS components, such as automatic generation control, volt/VAR control, load shedding, etc. are discussed in [11]. Then related components are implemented in an industrial refinery to test the PMS system functionality.

In this chapter, some of the PMS applications such as load/generation shedding and load sharing are described. Although it has been described in [11] by some means, this chapter explains it differently in several aspects. First, generation mode control which is an important function in PMS is explained and implemented. The turbine-governor along with the changeover switch is simulated in DSL in order to change governor mode in disturbances rapidly. Second, to assess PMS application in DIgSILENT software, several scenarios are considered and studied in a test system. In these cases, DSL is implemented to simulate signals and system controllers such as AVR and governor. In [11], no simulation results are presented. Furthermore, the operator action is simulated; this way, the operator can correct frequency/power deviation manually when the system has reached its steady state stability. It provides a safe training method for operators while the systems remain undamaged.

An islanded power system encounters with different dynamics operational scenarios rather than those connected to a strong grid. To this purpose, different contingencies have been applied, and in each one, power plant stability is investigated and PMS functions are implemented, where required. This makes the critical scenarios to be detected in the power plant. By applying the smart PMS in the power plant, in the occurrence of the critical scenarios, the appropriate remedial actions such as changing set points, loads shedding and generation control will execute to prevent voltage/frequency instability. Also, it prevents sequential events which cause blackout.

8.2 Description and Implementation of a PMS

A power management system (PMS) is an integrated set of sensors, actuators, communication devices and networks, control logic and operator interfaces, which is used to provide real-time monitoring and smart control of the power system, especially in islanded condition, to improve its operation. To this purpose, different functions such as frequency, voltages and generation controls are continually executed by PMS to make system operation safe and efficient [6, 11]. Figure 8.2 shows a basic configuration of a PMS. In this structure, programmable logic controls (PLCs), where the PMS logic is implemented, are used to connect central control room (CCR) to the power plants and remote substations. So that required parameters such as frequency, voltage, active and reactive power and status of breakers are monitored through communication lines (e.g. fibre-optic cables).

Based on the above-mentioned monitored data, in CCR, the structure of the system is identified using PMS logic, and then the stability status and power quality of operating point are assessed. Also, automatic or non-automatic (i.e. using

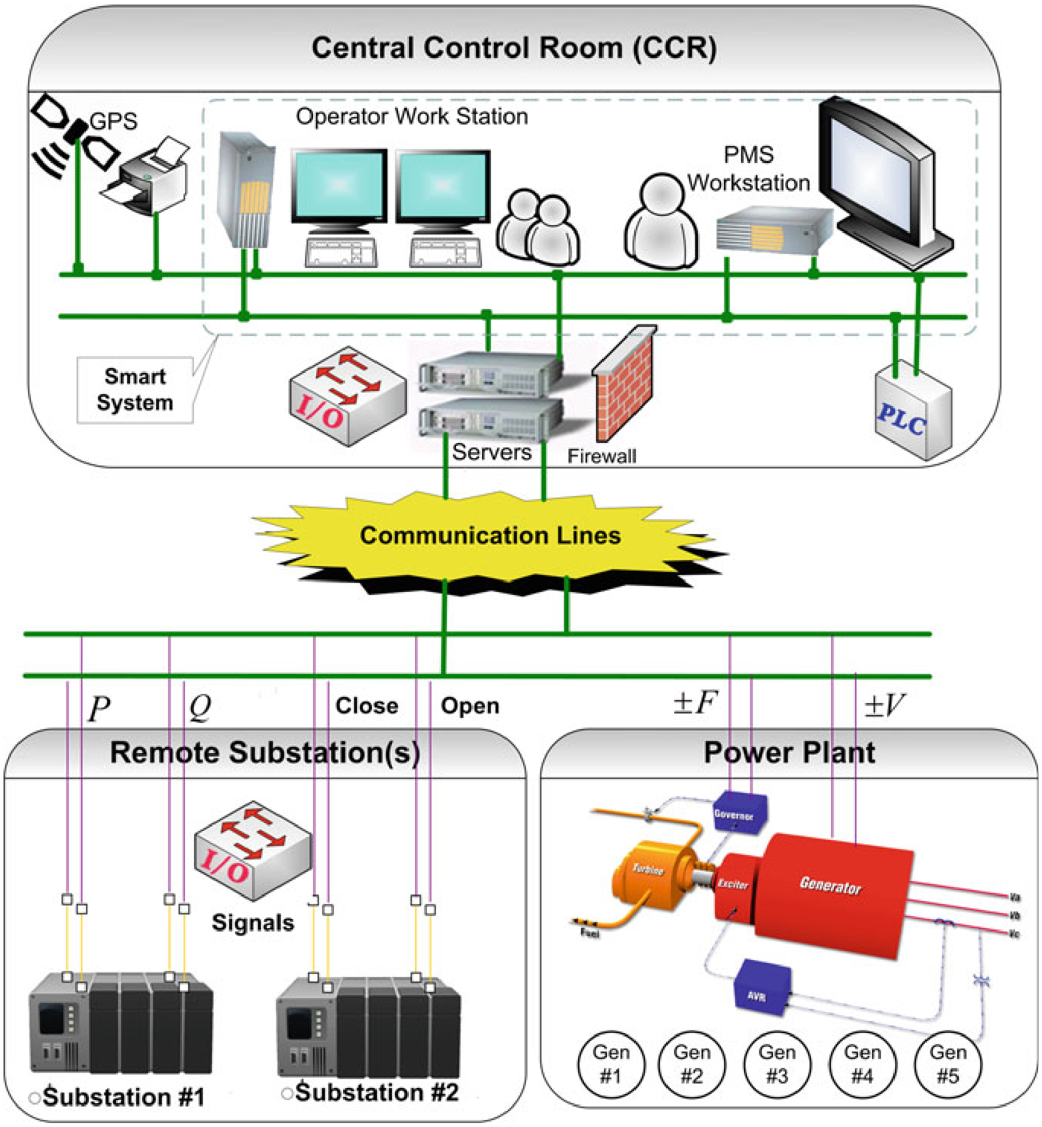

Fig. 8.2 Typical configuration of a PMS

operators' actions) remedial actions such as changing set points, loads shedding and generation control may be executed to improve system operation. Since the effectiveness of these remedial actions depends on their execution time, fast determination and execution of remedial actions are a matter of great importance.

8.2.1 Data Integrity Validation

All decisions made by PMS, for example, changing set points, are based on the data that have been collected from the various measuring devices of the power system. Since incorrectly measured data may result in the execution of inappropriate control