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A Review on Integrated Control and Protection System for Photovoltaic Microgrids

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Abstract
A microgrid is defined as a type of the grid consisting of prime energy movers, power electronics converters, distributed energy storage systems and local loads. Microgrid network enables an improved management of energy. The main goal of power management is to stabilize the system, in terms of frequency and voltage. This paper includes issues such as faults during grid connected mode and faults during islanded mode, voltage control, load sharing through P-f control and various types of protection schemes are discussed. Overall stability and reliability of microgrid depends on these factors.

Keywords: Control strategies, Integrated protection, Microgrid, Operation modes.

I. INTRODUCTION

The growing penetration of Distributed Energy Resources (DER) in the distribution network has a deep impact on the network stability, reliability and protection. Traditional protection procedures and strategies need an extensive investigated as more and more DERs get introduced into the network. The latest versions of IEEE standard 1547 do not introduce a comprehensive adequate solution for fault current protection in the presence of various kinds of Distributed Generators (DG). Power electronic inverter-based DGs gain more attention in the distribution network protection as they are unable to provide sufficient fault current at the time of the fault. Besides, their controllers play a major role in the DG behavior. Accordingly, the effects of voltage and current controllers for inverter-based DGs on microgrids and distribution network protection schemes must be investigated.

It will be shown in this work that the type of controller and its design parameters at the time of the fault have a major impact on fault current levels and duration. On the other hand, these controllers actions' have to be coordinated with system protective schemes. An important design objective for protection engineers is to always ensure good coordination between the protection schemes of DERs, their controls and load capabilities in order to achieve reliable and stable operation of the modern power distribution [1]. This coordination requires a detailed and in-depth strategy to ensure that the protective relays are fully coordinated with the excitation systems of the DERs. In addition, the relays' settings must consider the full load capabilities and steady-state stability limits [1]. Besides, the protection schemes are also required to be coordinated with the network interconnections of neighboring DERs [2]. It has been also reported in [3] that malfunction of generator protection and lack of coordination were the main contributors of 2003 US and Canada blackout. The design details for necessary coordination shapes that ensure reliability of modern power systems.

II. MICROGRID

Architecture

The main components of a microgrid are distributed generators (wind turbines, photovoltaic arrays, rotating machines, fuel cells, etc.), distributed energy storage devices (flywheels, batteries, super capacitors, compressed-air systems, etc.), and local critical/noncritical loads. Distributed Generators (DGs) can generally be classified into two main groups, based on their interfacing media: (i) traditional rotating-machine-based DGs and (ii) electronically interfaced DGs. The first group are those that consist of direct-coupled rotating machines and are directly interfaced to the network through interconnection transformers (e.g., a synchronous generator driven by a reciprocating engine or an induction generator driven by a fixed-speed wind turbine). The second group, however, utilizes DC/AC or AC/DC/AC power-electronic converters as their coupling media with the host grid (e.g., photovoltaic systems or variable-speed wind energy conversion systems). The control techniques and characteristics of power-electronic converters are significantly different than those of the conventional rotating machines [10]. Moreover, due to the limited current rating of silicon devices, the fault current of electronically interfaced DGs should be limited to a maximum of about two times their nominal current.

Distributed Energy Storage devices (DESs) are mainly employed as energy-backup systems to compensate for the power shortage within the microgrid, particularly in the islanded mode of operation when the generators may not be able to satisfy the entire load power demand. They can also be employed in the grid-connected mode of operation to smooth out the intermittent power of renewable energy resources and/or to incorporate significant load changes [11]. Since, due to their inherent large time constants, traditional rotating-machine-based DGs cannot rapidly respond to power intermittencies, instability may occur in transient situations. Thus, the use of DESs is necessary to prevent such an issue. A DES is modeled in this thesis as a constant DC voltage source interfaced with the utility grid through a power-electronic converter. It acts as a controllable AC voltage sources (with very fast output characteristics) to face sudden system changes such as load or operational mode switching's. It should be noted that all DESs have a finite capacity for storing energy and, thus, can be in service for a limited period of time.

Fig. 1.1 illustrates a single-line schematic diagram of an example microgrid that embeds a Photovoltaic (PV) system, a variable-speed wind turbine, a battery energy storage unit, and a traditional rotating-machine-based generator. EC-DERs are interfaced with the point of common coupling of their corresponding bus through a power-electronic converter and a transformer. However, the rotating-machine-based DER is directly interfaced with its corresponding host bus through an interconnection transformer. The microgrid is connected to the interface bus (Bus 1) where it is interfaced with the host utility grid through the Main Microgrid Switch (MMS); Bus 1, in turn, is energized from a high-voltage transmission grid, through a substation transformer.

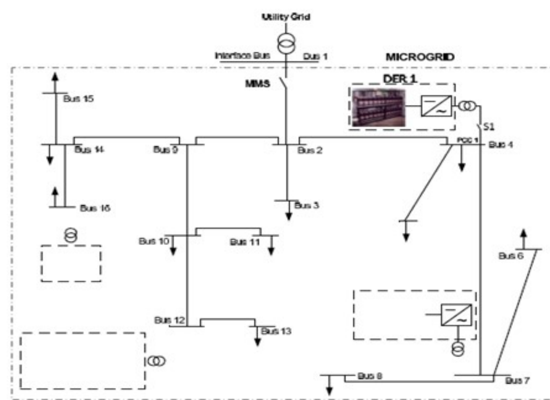

Figure 1: Single-line schematic diagram of a typical microgrid.

The microgrid of Figure 1 normally operates in the grid-connected mode where it is connected to the main utility grid. In this mode, DERs deliver constant real and reactive powers to the distribution network; the net difference between the aggregate power of DERs and local loads is balanced by the upstream host grid.

In case of an unplanned event, e.g., a network fault, the MMS is expected to disconnect the microgrid from the utility grid. Subsequently, the microgrid can continue to operate in the so-called islanded mode. While islanded operation is mainly to enhance the system reliability and is caused by unexpected incidents, it can also be intentional, e.g., for maintenance requirements, effective and optimized utilization of a system, and/or electrification of remote off-grid communities. The microgrid shall also be able to resynchronize itself to the host grid and smoothly switch back to the grid-connected mode.

III. LITERATURE REVIEW

Pooja R.Anap ET AL. (2017) In microgrid, if fault occurs or any other contingency happens, then the problems would be created which are related to power flow, also there are various protection schemes are used for minimize or eliminate these problems. Voltage control is used for reactive power balance and P-f control is used for active power control. Various protection schemes such as, over current protection, differential protection scheme, zoning of network in adaptive protection scheme are used in microgrid system.

Jiefeng Hu et al. (2017) an REIF test bed with PVs and a micro-turbine is investigated. The behaviors of PVs and the gas micro-turbine are first studied under various grid voltage conditions. The experimental results demonstrate the stable operation of the REIF under various generation and load conditions. In grid-connection mode, the PVs and the grid supply power to the load with surplus energy fed back to the grid. In islanded mode, a micro-turbine is used to produce a high-quality voltage to sustain the normal operation of the load and to provide the external voltage source to which the PV inverters can synchronize. In addition, the responses of the REIF under the short circuit fault condition are studied, and the protection mechanisms are proposed, providing a technical guideline for the future grid where a significant amount of distributed generation systems are included.

Laijun Chen et al. (2015) an integrated protection and control system with a hierarchical structure is proposed and a 100 kWp photovoltaic micro grid is built to validate the effectiveness and feasibility of the proposed strategy. Test results show that stable and flexible transition between different operation modes of the PV microgrid is achieved and the viability of the micro-grid under severe fault is greatly improved.

P. Ebrahimi Fard Zanjan ET AL. (2014) The concept of micro grid is quickly taking root not only in the research community, but also on the agendas of utilities, power system component manufacturers, and policy makers. Micro grids, by definition, should be operational both in grid-connected and islanded mode. This paper tackles this issue from the point of view of protection. In this paper, a micro grid protection scheme based on optimally sizing of FCLs and optimally setting of OCRs is proposed. Inductive type FCLs are located at the main interconnection point of the micro grid to the main grid. Inserting the FCL as an optimal parameter in the protection coordination problem affects the system admittance matrix which allows for changes in the fault current levels. Thus, the results show that it is possible to have one optimal relay setting and enforcement station that satisfies both micro grid modes of operation of the grids. In addition, without the FCL, it was found that it is difficult to set the relays and enforcement station and operational modes implementations. The proposed approach was tested on a typical radial distribution system of IEEE 30 equipped with CSG and the results confirm the effectiveness of the proposed method.

Sarina Adhikari et al. (2014) summarized as follows:

- This paper proposes and presents coordinated strategies of V-f control and P-Q control, respectively, for microgrids with PV generator and battery storage.
- In the control strategies, the PV generator is operated at MPP, and the battery storage acts as a buffer in order to inject and absorb deficit or surplus power by using the charge/discharge cycle of the battery. The paper contributes in demonstrating the control strategies with effective coordination between inverter V-f (or P-Q) control, MPPT control, and energy storage control.
- The proposed control strategy also provides a smooth transition of PV side PQ control in grid connected mode to V-f control in islanded mode. This is the most essential feature required in the modern microgrid controllers.
- The proposed control algorithms are also capable of handling the battery SOC constraint. An effective seamless transformation of controls from V-f to constant active power and voltage control at the PV side and from constant active power control to frequency control at the diesel generator is validated with satisfactory results. This feature helps the controller to adapt to the changing

irradiance levels while considering the battery availability.

- The proposed V-f control method shows a very satisfactory performance in reviving highly reduced voltage and frequency back to the nominal values in a matter of only 2 seconds. It is much faster than the diesel generator control which takes around 10 seconds to settle down. Hence, PV and battery installations might be applied effectively in restoring the microgrid frequency and the voltage at PCC after disturbances.
- Similarly, the proposed integrated and coordinated P-Q control algorithm can be effectively used in supplying some critical loads of a microgrid with solar PV and battery.
- In the present methods, the control parameters are dependent upon the PV, battery, and external grid conditions and must be re-tuned with the changing conditions. This can be overcome by using an adaptive method to obtain these parameters dynamically based on the system conditions. The adaptive control methods could be a very useful and promising future direction of this work.

Chengshan Wang et al. (2013) An approach based on matrix perturbation for the coordinated optimization of droop coefficients in a micro-grid has been proposed in this paper. Parameter perturbation analysis is made on the droop coefficients to identify the manner and degree of parameters' influence on the state matrix. The increments of Eigen solutions are then obtained based on the first-order perturbation items. In the optimization process, a comprehensive objective function is proposed to ensure the stability of the system, to enhance the damping characteristics, and to maintain a stability margin for a wide range of operating conditions. The computational flowchart is presented for the proposed optimization algorithm based on matrix perturbation. Numerical examples are performed using a benchmark low-voltage micro-grid. In the examples, the parameter-optimization process is analyzed in detail. And the time-domain simulations are carried out to illustrate the responses of the DG units during mode transitions and under disturbances. The robustness analysis of the optimized coefficients to the change of the exchanging power between the micro-grid and the main grid is presented as well. Theoretical analysis and evaluation results have confirmed the effectiveness of the optimization approach, the feasibility of the objective function, and the robustness of the optimized parameters.

WANG ChengShan et al. (2012) proposed a control strategy for the seamless operation mode transition for a master-slave controlled microgrid. The control strategy, focused on the master DG unit in the microgrid, consists of the control state and reference current compensation algorithm and separation switch control logic. Conclusions drawn from the validation are as follows.

- When the microgrid switches from grid-connected operation to stand-alone operation, the proposed control strategy can effectively suppress the transient distortions of the microgrid voltage and master DG unit's output current, ensuring a smooth transient with minimum impact on the microgrid loads and DG units.
- When the microgrid transfers from stand-alone operation to grid-connected operation, the proposed strategy can make the amplitude and phase angle of the microgrid voltage and the utility grid voltage the same. With appropriate compensation control, a seamless transition can be achieved.

Bo Zhao et al. (2012) An integrated microgrid laboratory system with multiple DGs and energy storage systems was developed and tested. The system structure was flexible as the microgrid system had several different topological structures according to different requirements. Control strategies for application during grid-connected mode, islanded mode, and mode transition were proposed. Many tests of the control strategy, protection, and power quality were carried out to obtain the optimal control method and operating conditions. The tests demonstrated the flexibility of mode transition, stable behavior under different conditions, and high quality of power supply. All the results show that the microgrid system performs as expected and has a high level of robustness. As most components of the microgrid laboratory are real, it can also serve as a verification platform for engineering applications. Since microgrid projects are often constructed in remote areas, such as islands, it is difficult to validate the functions of equipments due to the adverse power situation. Thus, debugging and validation of equipment, such as converters, can be carried out with the aid of the microgrid laboratory. Because of the flexibility and controllability of the microgrid laboratory, the control systems of the project can be debugged and validated more conveniently and easily by simulating different working conditions. We can adopt a verified method in the microgrid laboratory and then transfer it to projects. In this way, the microgrid laboratory has played an important role in our construction of an island microgrid project, Dongfu island wind-solar-diesel-battery-seawater desalination project. Thus, the microgrid laboratory also has a vital role to play in the construction of microgrid projects. Relevant information about the project will be presented in detail in the future. In the second phase of this integrated microgrid laboratory system, a monitoring system based on the IEC 61850 standard will be imported. The whole microgrid system will be connected to a distribution automation system. Additionally, more types of energy storage, such as compressed air, lithium batteries, sodium–sculpture batteries, super-capacitors, and electric vehicle devices will be employed. The integrated microgrid laboratory system will be further improved. Furthermore, continuing work will be carried out in the near future in order to conduct further research on key issues.

IV. CONCLUSION

In microgrid, if fault occurs or any other contingency happens, then the problems would be created which are related to power flow, also there are various protection schemes are used for minimize or eliminate these problems. Voltage control is used for reactive power balance and P-f control is used for active power control. Various protection schemes such as, over current protection, differential protection scheme, zoning of network in adaptive protection scheme are used in microgrid system.

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