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Renewable Power Generation Units through Micro Grid System

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ABSTRACT

Micro-grid system is currently a conceptual solution to fulfill the commitment of reliable power delivery for future power systems. Renewable power sources such as wind and hydro offer the best potential for emission free power for future micro-grid systems. This paper presents a micro-grid system based on wind and hydro power sources and addresses issues related to operation, control, and stability of the system. The micro-grid system investigated in this paper represents a case study in Newfoundland, Canada. It consists of a small hydro generation unit and a wind farm that contains nine variable- speed, double-fed induction generator based wind turbines. Using Matlab/Simulink, the system is modeled and simulated to identify the technical issues involved in the operation of a micro-grid system based on renewable power generation units. The operational modes, technical challenges and a brief outline of conceptual approaches to addressing some of the technical issues are presented for further investigation.

Keywords: Renewable power generation, Distributed generation, Micro-grid, Simulation.

I. NOMENCLATURE

CERTS = Consortium for electric reliability techno- logy solutions

FC = Fuel cell

HGU = Hydro generation unit

MG = Micro-grid

MCFC = Molten carbonate fuel cell

NEDO = New energy and industrial technology development organization

NPEP = Newfoundland power energy plan

PV = Photovoltaic

PCC = Point of common coupling

PAFC = Phosphoric acid fuel cell

SOFC = Solid oxide fuel cell

WT = Wind turbine

WPGS = Wind power generation system

II. INTRODUCTION

The demand for more power combined with interest in clean technologies has driven researchers to develop distributed power generation systems using renewable energy sources [1-3]. On the other hand, the integration of a large number of distributed gener- ations into distribution network is restricted due to the capacity limitation of the distribution networks and their unidirectional power flow behaviour [2, 4, 5]. Such barriers have motivated researchers to find an alternative conceptual solution to enhance the distributed generation integration into the distribution networks. An alternative approach called "Micro-grid" was proposed in 2001 as a means of integrating more distributed generations into the distribution networks

[5].Distributed generation in micro-grid operation provides benefits to the utility operators, distributed generation owners and consumers in terms of reliable power supply, transmission loss compensation, reduction in transmission system expansion and enhancement of renewable power penetration.A review of the existing literature reveals that the first micro-grid architecture was proposed by R. H. Lasseter [5, 6], and called CERTS micro-grid. The CERTS micro-grid generally assumes converter-interfaced distributed generation units based on both renewable and non-renewable power sources. Barnes et al [8] also proposed a micro-grid system under the frame of the European project "Micro-grids". The European micro-grid architecture con- sists of two PV generators, one wind turbine, battery storage, controllable loads and a controlled interconnection for the local low voltage grid. The NEDO in Japan proposed three micro-grid projects in 2003 [9, 10]. The first NEDO micro-grid (1.7MW) system comprises different kinds of fuel cells such as MCFC, PAFC, SOFC, and photovoltaic (PV) system and battery stor- age.The second NEDO micro-grid (610kW) configuration consists of PV, WT, biomass and battery storage. The third NEDO micro- grid (750kW) system consists of PV, WT, MCFC, biogas and battery bank, which has very low percentage (13 percent) of renewable energy generation. Micro-grid research in Canada has started in universities with the cooperation of the CANMET energy technology center at Varennes [9]. This research group has identi- fied industry cases, such as the isolated wind-diesel micro- grid system, and the Fortis Alberta grid-tied micro-grid system for investigation. Canada's micro-grid research and

development also evolved to develop a test bed for industrial-grade prototype testing and performance evaluation [9]. A study of micro-grid dynamic behavior, along with the control of the micro-generation units is performed by F. Kateraie [7]. This micro-grid system is based on the benchmark system of the IEEE Standard 399-1997 [11], which consists of three generation units comprising a diesel generator or a gas turbine generator, an electronically interfaced distributed generation and a fixed speed wind power generator. Research on micro-grid systems is also found in literature, where the generation units and loads combination are arbitrarily assumed [12-16].

The diverse micro-generation units in a micro-grid system and the desire to integrate more clean power in future power network has led to a focus on a micro-grid system based on renewable power generation units in this research. As a whole, the characteristics of a micro-grid system depend
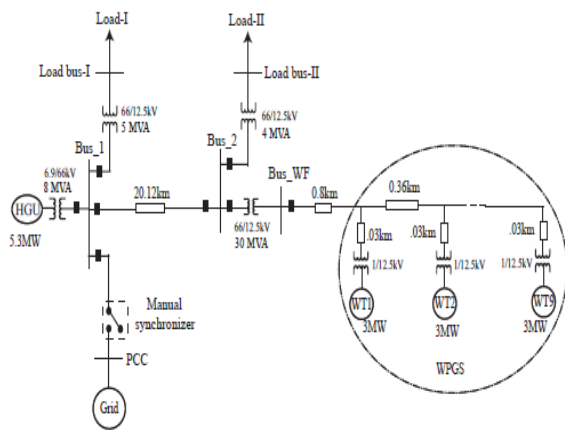

Fig. 1. The micro-grid system currently under investigation

projects in 2003 [9, 10]. The first NEDO micro-grid (1.7MW) system comprises different kinds of fuel cells such as MCFC, PAFC, SOFC, and photovoltaic (PV) system and battery stor- age.The second NEDO
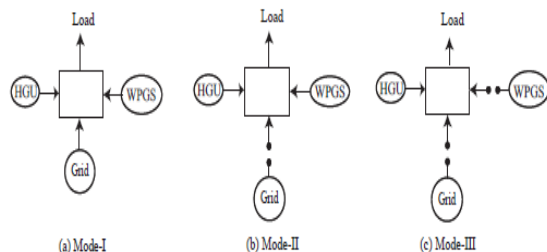

Fig. 2. Micro-grid operational modes

Considering these reasons, the technical challenges and methods for addressing them for the system shown in Figure 1 have not been investigated yet. This paper investigates the technical challenges as-sociated with the wind farm and hydro generation

based micro-grid system. In order to classify the technical challenges for the micro- grid system under investigation, three operational modes (Figure2) are considered: (a) grid connected system, (b) isolated system with wind power generation, and (c) isolated system without wind power generation

III. MICRO-GRID SYSTEM

The schematic of the micro-grid system shown in Figure 1 consists of a HGU, a WPGS, and two load areas represented as Load-I (3.94 MW, .9 MVar) and Load-II (2.82 MW, 0.84 MVar). The two load areas are connected through a 20.12 km transmission line and the two generating systems are connected through a 21 km transmission line. The wind turbines are connected to bus 2 using its own transmission lines and a 12.5/66kV, 30 MVA power transformer. Load bus-II is connected to bus 2 and the power is delivered to the load using a 66/12.5kV, 4 MVA power transformer. Load bus-I is connected to bus 1 and the power is delivered to the load using a 66/12.5kV, 5 MVA power transformer. The HGU is connected to bus 1 using a 6.9/66kV, 8 MVA power transformer. A conventional synchronous generator, equipped with IEEE standard excitation and governor system, is used for the HGU. A 66kV, 1000 MVA grid is connected to bus 1. Both power generation systems operate in grid connected mode. The automatic isolated operation of the HGU is not the current practice of the utility owner, and the WPGS is not allowed to operate in isolated mode. In the event that the grid power is lost due to faults or scheduled maintenance, a black out would result until the HGU comes in operation. Even with the HGU in operation, some load shedding may be necessary since the HGU would not be able to meet the load demand. Therefore, the consequences of the grid outage are the key drivers which dictate the operational modes of the micro- grid system.

IV. OPERATIONAL MODES OF THE MICRO-GRID SYSTEM

Technical issues such as control, power balance strategies, oper- ation, protection and storage techniques differ from one micro-grid to another. The main reasons are the integration of high number of distributed power generation units near to the electrical loads, the nature and size of the micro-generation units, and availability of primary energy sources for renewable power generation units.

V. MODELING AND SIMULATION

The components of the identified system are modeled using MATLAB/SIMULINK software tool. The HGU model is the com- bination of the model of synchronous generator, hydro turbine and turbine governor system, and excitation system. The

synchronous machine electrical system is modeled in a d-q rotor reference frame with the dynamics of stator, rotor and damper windings [17]. The synchronous machine parameters are obtained from Newfoundland Power, Canada and from [18]. Hydro turbine and turbine governor system model is given in [19]. The parameters for the hydro turbine and penstock are obtained from Newfoundland Power, Canada. The WPGS model consists of dynamic model of nine variable- speed doubly-fed induction generator based wind turbines. Vestas-90 wind turbine parameters are used in the developed wind turbine rotor model [20]. The induction machine electrical system is modeled in a d-q synchronously rotating reference frame [17]. Generator parameters are obtained from [20, 21].

The utility grid is represented by an equivalent model of 66kVthree phase voltage source with the short-circuit capacity of 1000MVA and the reactance to resistance ratio of 22.2 [11]. A constant impedance load model is used in the system. The parameter information about the line, transformer and load are obtained from the utility company, Newfoundland Power.Simulations for three operational modes (Fig. 2) are performed and the simulation results are presented in the following sections. The measurements presented in the simulation results are in per unit, while the base power is 27 MVA. The simulation was performed for a 60 seconds interval. The wind speed model [22] is used as the wind profile for the wind turbine rotor. WPGS with no output power represents the lack of sufficient wind velocity to generate electric power. The grid is isolated from the system at t=5 seconds because of a fault or regular maintenance in the transmission systems. The fault in the grid transmission systems (unintentional islanding) or their regular maintenance (intentional islanding) is simulated using a three phase circuit breaker with specific time settings.

A. Mode-I: Grid connected mode

The simulation results for Mode-I are represented in Figures 3(a- d), while WPGS and HGU are connected to the grid. No initial transient indicates the steady-state operation of the system in grid connected mode. Figure 3(a) shows the wind speed profile provided into the wind turbine rotor. Figure 3(c) and 3(b) show the generated power by the HGU, and by the WPGS, while nine wind turbines are in operation. The output of the WPGS varies due to the wind speed variation. Figure 3(d) represents the voltage at bus 1 which is in its rated value. These results indicate that the operation of the HGU and WPGS in grid connected mode is dictated by the grid with the expected system voltages and frequency set by the grid.
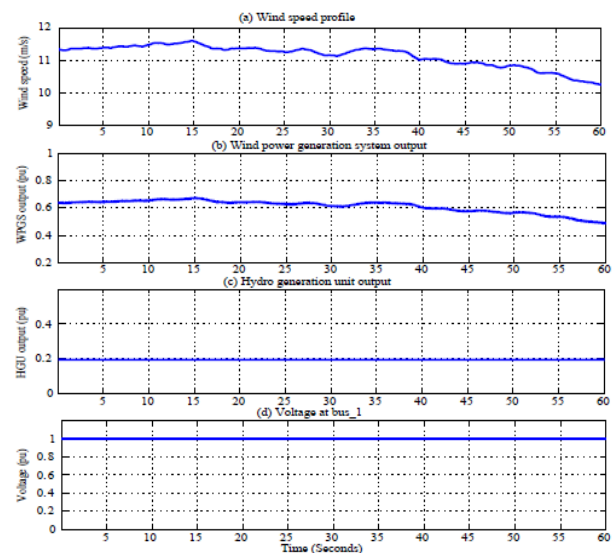

Fig. 3. (a) Wind speed profile, (b) WPGS output power, (c) HGU output power, (d) Voltage at bus_1

B. Mode-II: Isolated system with wind power generation

The system operation follows the Mode-I until t=5 seconds. After t=5 seconds, the grid is isolated from the system. Figure 4(a) shows system. Figure 4(b) and 4(c) show the power contribution by the two generation units into the micro-gird, while assuming only one wind turbine is in operation in the WPGS after t=5 seconds. As HGU is the firm power generation system, it is decided to operate the HGU during the entire operation. However, the operation of WPGS with one or more wind turbines is decided based on load demand. Voltage at bus 1 is shown in Figure 4(d) which decreases after grid isconnection. This indicates the lack of sufficient reactive power in the micro-grid system, which was actually supplied by the grid in the grid connected mode. More than one wind turbine operating in the WPGS will deliver more active power in the micro-grid system than the load demand. In such case, the reactive power demand will also increase in the micro-grid system which results in more reduction in voltage level at different locations in the micro-grid system.
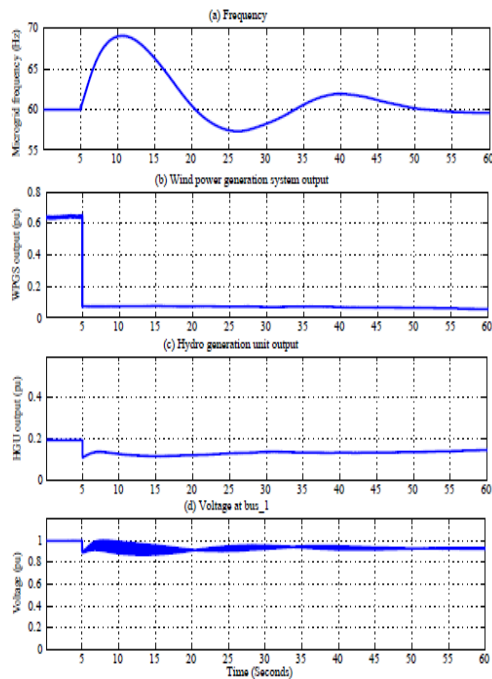
Fig. 4. (a) Micro-grid frequency (Hz), (b) WPGS output power, (c) HGU output power, (d) Voltage at bus_1

C. Mode-III: Isolated system without wind power generation

The system operation follows the Mode-I until t=5 seconds. However, at t=5 seconds, the grid is isolated from the system.Concurrently, the WPGS has no output power as there is insuffi- cient wind resource to produce electricity. This mode of operation is simulated, and the results are shown in Figure 5(a-d). Figure5(a) shows the micro-grid frequency, which is not tolerable by the system. This also indicates that the power generation and consumption in micro-grid system is not balanced. Figure 5(c) shows the HGU output power and the zero output power from the WPGS is shown in Figure 5(b). The voltage level at bus 1 is shown in Figure 5(d) which is much lower than its rated value. This indicates the requirement for reactive power in the micro-grid system. As the WPGS is not able to deliver power (Fig. 5(b)) after t=5 seconds due to the lack of sufficient wind, the requirement of additional power from a reliable storage system is essential.Based on simulation results, the issues related to micro-grid operation of the system under investigation can be summarized as:

• Active power imbalance and/or variation occurs in isolated micro-grid mode when wind power is available. A control scheme is required to maintain active power balance by storing or dumping surplus power. Motor-pump sets can be used to pump water using surplus power. However, a dump load is required to achieve better accuracy in power-frequency balance.

• Active power imbalance will occur between generation units and loads when wind power is not available in isolated micro- grid mode. A suitable storage system along with a control scheme is required to maintain power-frequency balance.

• Reactive power is required during isolated micro-grid operation to maintain the expected voltage level at different buses in the micro-grid system. The reactive power demand can be provided by STATCOM during isolated system with wind power generation and by storage unit during isolated system without wind power generation.

In addition, a control coordinator and monitoring system is re- quired for the micro-grid operation. A load flow based micro-grid monitoring and control coordinator scheme can be chosen for the proposed micro-grid system operation
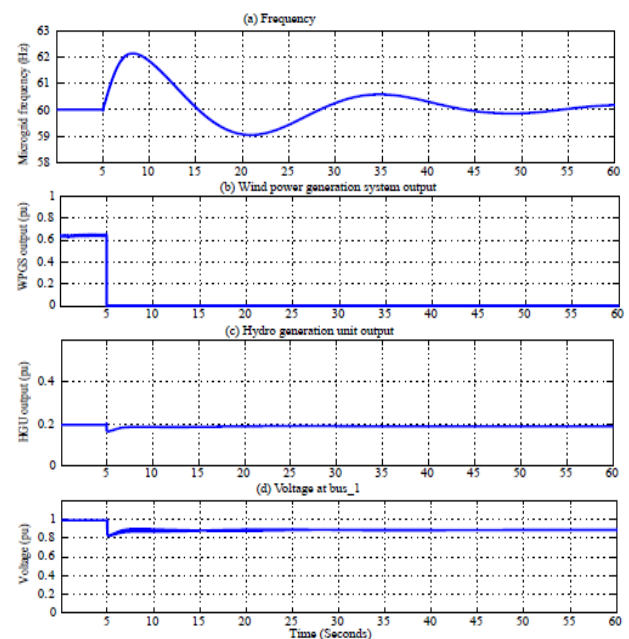

Fig. 5. (a) Micro-grid frequency (Hz), (b) WPGS output power, (c) HGU output power, (d) Voltage at bus_1

VI. CONCLUSIONS

Micro-grid operation of a system based on renewable power generation units is presented in this paper. The system behavior and technical issues involved with three operational modes in micro-grid scheme are identified and discussed. The investigation is performed based on simulation results using Matlab/Simulink software package. Simulation results indicate that dump load and suitable storage system along with proper control scheme are additionally required for the operation of the study system in a micro-grid scheme. A control coordinator and monitoring system is also required to monitor micro-grid system state and decide the necessary control action for an operational mode. The required control schemes development for the proposed micro-grid system is currently under

investigation by the authors

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