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Role of Microgrid during Grid Connected or Islanded

Sandeep A. Kale[1], Piyush O. Dhoke[2], Minakshi A. Kale[3]
[1] Department of Electrical Engineering, Dr. Babasaheb Ambedkar College of Engineering & Research, Nagpur, 441110, India.
[2]MTech student, Centre for Pollution Control & Environmental Engineering, Pondicherry University, Pondicherry, 605001, India.
[3]Department of Physics, Dr. Babasaheb Ambedkar College of Engineering & Research, Nagpur, 441110, India.
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Abstract: *Microgrid is a main concept in the arena of green power generation, which is substantially attracting many researchers' interest due to its potential to extend the applications of the distributed generations, especially the renewable energy. It can increase the reliability of energy supplies by disconnecting from the grid in the case of network faults or reduced power quality models for the main microsources/non conventional energy sources including Wind Turbines, Diesel Generator and fuel cells are properly established, in addition to the basic models of the power electronics interfaces being given simultaneously. This paper emphasizes modelling & simulation of a Microgrid to account for both the transient and steady-state system characteristics; the models can be integrated into a comprehensive simulation platform by MATLAB/Simulink, which can simulate both the steady and dynamic characteristics of the three-phase Microgrid. The result shows that there is an increase in power generation when the microsources/ non conventional energy sources connected within Microgrid which helps in different applications. The Microgrid model is capable of representing the dynamic behavior of micro-grids during either grid-connected or islanded operation.*

Index Terms: *Microgrid, Non conventional sources, Islanded, Renewable generation.*

I. Introduction

A variable/low voltage electrical network with small Distributed Generators (DGs), Energy Storage Devices, Controllable Loads & Protections. A distributed energy system running parallel or within the national grid system is called a Microgrid. Microgrid is a new concept in the arena of green power generation, which is substantially attracting many researchers' interest due to its potential to extend the applications of the distributed generations, especially the renewable energy. Microgrids can be connected to the main power network or be operated autonomously, if they are operated from the power grid, in a similar manner to the power systems of physical islands. The Microgrid concept has been proposed as a solution to the conundrum of integrating large amounts of micro-generations without disrupting the operation of the utility network.

Currently a lot of research is being undertaken into Microgrid technology and some topology architectures have been presented, but little has been done on the models to be integrated into a Microgrid. Modeling and simulation techniques of the system, so as to develop an appropriate control system, contribute to the leading front of the Microgrid research. Paper emphasizes mainly on the modeling of a Microgrid to account for both the transient and steady-state system characteristics, in which the following models are established: Wind Turbines, Diesel Generator, Fuel Cell and Inverter.

This paper aimed the modeling and simulation of a Microgrid to account for both transient and steady state system characteristics and also the dynamic behavior of Microgrids during either grid connected or islanded.

II. Structure Of Microgrid

Figure 1 shows the general Microgrid architecture, which consists of a group of radial feeders A, B and C together with a collection of loads. The radial system is normally connected to the large power distribution system through a separation device called point of common coupling, which is usually a static switch. The voltage feeders at the loads side are usually rated at 480V or less. Feeder A indicates the co-existence of several microsources with one providing both power and heat supply. Each feeder has a specific circuit breaker and a power flow controller. The controller regulates the feeder power flow at a certain level prescribed by the energy manager. As loads change randomly, the local microsources either increase or decrease their power output to hold balance of the power flow within the Microgrid. In Figure 1, feeders A and B are attached with critical loads which require local generations (microsources), while feed C is assumed to have non-critical loads which can be shed off if necessary When the Microgrid is grid- connected, the power from the local generation can be directed to the non-sensitive loads; when there are disturbances on the large distribution system the

Microgrid can be islanded for independent operation. The non-critical feeder can also be disconnected from the Microgrid.

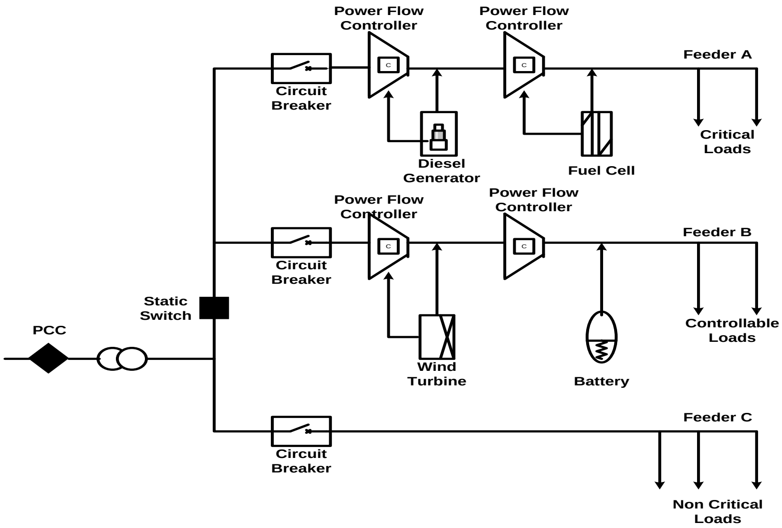

Fig 1 Schematic Microgrid Architecture

III. Modelling Of The Microgrid

Different microsources are considered to coexist in the Microgrid, and corresponding dynamic models are established and then integrated into the micro-system. A detailed description of the models adopted for solid oxide fuel cells and single shaft microturbines and the diesel generator is modeled as composed of a prime mover, a governor and a generator unit. The wind turbines comprise several subsystems that are of aerodynamic type and modeled independently. The generator is a mechanical one and the power converters are fitted in case of variable speed wind turbines Storage batteries are modeled as a constant DC source coupled with a static converter to be connected to the local electrical network. Usually its active power is injected into the Microgrid proportionally to the frequency deviation Microturbine generators, PV, battery and fuel cell generation systems have to be connected through inverters, and hence a simple model is hereby adopted for the inverters, in which the switching as well as the internal loss has been ignored.

A. FUEL CELL

Nowadays there are available five different types of Fuel Cells:

- *AFC* – Alkaline Fuel Cell
- *PEFC/PEM* – Polymer Electrolyte Fuel Cell / Proton Exchange Membrane
- *PAFC* – Phosphoric Acid Fuel Cell
- *MCFC* – Molten Carbonate Fuel Cell
- *SOFC* – Solid Oxide Fuel Cell

The Solid Oxide Fuel Cell (*SOFC*) technology offers higher efficiencies and provides a great amount of heat (with high operating temperature - between 600 and 1000 *ºC*) turning into an interesting technology for cogeneration and more specifically residential-building scale distributed generation. The *SOFC* model is described in this paper. A power generation fuel cell system has the following three main parts:

Fuel processor: The fuel processor converts fuels such as natural gas to hydrogen and by product gases.

Power section: The power section generates the electricity. There are numerous individual electrochemical fuel cells in the power section.

Power conditioner: The power conditioner converts *dc* power to ac power output and includes current, voltage and frequency control. Some control strategies of the fuel cell system, response functions of fuel processor and power section are added to the model the SOFC power generation system[4].

Fuel Cell (SOFC) Modelling

Some control strategies of the fuel cell system, response functions of fuel processor and power section are added to the model the SOFC power generation system [4].

(a) Although CO can be a fuel in SOFC, the CO-shift reaction is chemically favoured with present designs and operations if the fuel gas contains water. The CO-shift reaction is:

$CO + H_2O \rightarrow CO_2 + H_2$ --------- (1)

Based on this, we assume that only H_2 and O_2 enter into the fuel cells.

(b) Fuel utilization is the ratio between the fuel flow that reacts and the input fuel flow.

$$U_f = \frac{q_{H_2}^r}{q_{H_2}^{in}}$$ ------------ (2)

Typically, 80 - 90% fuel utilization is used.

For the value of H_2 the value of q_i^r we have,

$$q_{H_2}^r = \frac{N_0 I_{fc}^r}{2F} = 2K_r I_{fc}^r$$ ----------- (3)

For a certain input hydrogen flow, the demand current of the fuel cell system can be restricted in the range.

$$\frac{0.8 q_{H_2}^{in}}{2K_r} \leq I_{fc}^{in} \leq \frac{0.9 q_{H_2}^{in}}{2K_r}$$ -------- (4)

(c) The real output current in the fuel cell system can be measured, so the input fuel flow can be controlled to control U_f at 85%, so

$$q_{H_2}^{in} = \frac{2K_r I_{fc}^r}{0.85}$$ ------------ (5)

(d) The peak power capacity is the ratio of maximum theoretical power delivery to the rated power in the fuel cell system. It is only determined with the available active fuel cell area. For the highest possible total efficiency and the dynamic load-following behaviour, p_k should be as large as possible. As this value is directly proportional to the effective fuel cell area for a constant output, cost considerations restrict the upper value with values between 130 and 180% is preferred. In practice, this upper value is also restricted by the safety of system operation. In order to prevent damage to the electrolyte, the fuel cell pressure difference between the hydrogen and oxygen passing through the anode and cathode gas compartments should be below 4 kPa under normal operation and 8 kPa under transient conditions. Because different fuel cell systems have different peak power capacity, by simulation it is shown that pk in our fuel cell system model should be below 170%, which means the maximum power delivery of our fuel cell system is below 1.7 times of the rated power.

(e) It is assumed that the anode is supplied with only H_2 and the cathode with O_2 only, so that the only reaction that occurs in the fuel cell is:

$$\frac{1}{2} O_2 + H_2 \rightarrow H_2O$$ ----------- (6)

So, the stoichiometric ratio of hydrogen to oxygen is 2 to 1. Oxygen excess is always taken in to let hydrogen react with oxygen more completely. Simulation in our fuel cell system shows that r_{H2O} should be kept around 1.145 in order to keep the fuel cell pressure difference below 4 kPa under normal operation. So the input oxygen flow $q_{O_2}^{in}$ is controlled to keep r_{H2O} at 1.145 by speed control of the air compressor.

$$q_{O_2}^{in} = r_{H_2O} \cdot q_{H_2}^{in}$$ ---------- (7)

(f) The chemical response in the fuel processor is usually slow as it is associated with the time to change the chemical reaction parameters after a change in the flow of reactants. This dynamic response function is modeled as a first-order transfer function with a 5-s time constant.

(g) The electrical response time in the fuel cells is generally fast and mainly associated with the speed at which the chemical reaction is capable of restoring the charge that has been drained by the load. This dynamic response function is also modelled as a first-order transfer function but with a 0.8-s time constant.

(h) Through the power conditioner, the fuel cell system can output not only real power but also reactive power. Usually, PF can be in the range of 0.8 - 1.0. Because the response time of the power conditioner is less than 10 ms, it is not necessary to include its detailed model in our slow dynamic fuel cell system except we can assume that PF can be adjusted accordingly by the power conditioner.

The potential difference between the anode and the cathode is calculated using the *Nernst's* equation and *Ohm's* law:

$$V_{fc}^{r} = N_0.\left[E_0 + \frac{RT}{2F} \times ln\frac{P_{H_2}.P_{O_2}^{1/2}}{P_{H_2O}}\right] - r.I_{fc}^{r}$$

(8)

Where, E_o – The Voltage associated with reaction free energy (V)
P_{H2}, P_{O2}, P_{H2O} – The Partial Pressures of the component (N/m^2)
N_o – The number of cells
r – The Electrical resistance of the fuel cell or ohmic loss (Ω)
R – The Universal Gas constant (J/mol K)
T – The channel or Absolute Temperature (K)
F – The Faradays constant (Coulombs/mol)
I_{fc}^{r} – The reaction or Output Current (A)

The partial pressure of the components is related to its molar flow. The ideal gas law leads to the following relationship:

$$p_i.V_{ch} = n_i.R.T \qquad \text{--------} \quad (9)$$

Where,
V_{ch} is the volume of the channel (*m3*) and
n_i is the number of moles of the element *i* (*moles*).

The following differential equations describe the chemical behaviour of the reaction.

$$\frac{dp_i}{dt} = \frac{RT}{V_{ch}}\frac{dn_i}{dt} \qquad \text{----------} \quad (10)$$

and

$$\frac{dn_i}{dt} = q_i^{ch} = (q_i^{in} - q_i^{r}) \qquad \text{-------} \quad (11)$$

Where,
q_i^{in} is the flow of the i^{th} element of input,
q_i^{r} is the flow of i^{th} element that reacts.

All the reactions that occur in the fuel cell have some time delay associated.

B. WIND TURBINE

A wind turbine transforms the kinetic energy in the wind to mechanical energy in a shaft and finally into electrical energy in a generator. To reduce the price further and to make wind energy more competitive with other production methods, wind turbine manufacturers are concentrating on bringing down the price of the turbines themselves. Other factors, such as interest rates, the cost of land and, not least, the amount of wind available at a certain site, also influence the production price of the electrical energy generated.

It is considered that the wind turbine is equipped with asynchronous generator. Wind generators are considered as asynchronous motors in generating operation (negative loads). The rating of the wind turbine generator is 200kW.

The asynchronous wind turbines are largely used for the production of electricity particularly in remote areas. The figure 4 shows the wind turbine model [10]. The Wind Turbine block uses a 2-D Lookup Table to compute the turbine torque output (Tm) as a function of wind speed (w_Wind) and turbine speed (w_Turb).

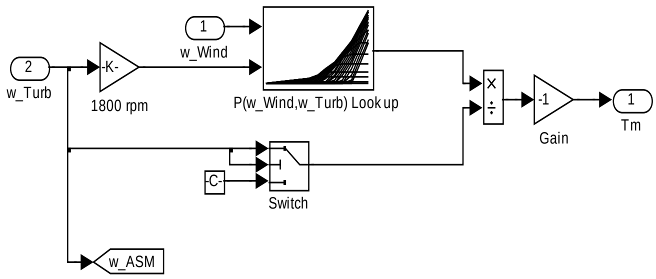

Fig 4 Wind Turbine Model

A wind turbine shown above in which a constant wind speed of 10m/s & a variable turbine speed or rotor speed (ωm) are applied to a look up table block which will give the power generated by wind turbine. In order to generate the torque power gets divided by variable turbine speed and finally multiplied by -1 by using the gain block to generate a negative torque which is applied to asynchronous generator.

C. **DIESEL GENERATOR MODEL**

Diesel Engines, developed more than 100 years ago, were among the first ones to have been used in the distribution generator technologies. There are many methods already proposed for diesel generator modeling. Here the Diesel generator model includes a diesel engine system and a generator unit. From the control system point of view, a diesel engine can be considered as a speed-feedback system. Fig.2 shows the diesel engine system model including a prime mover and a governor.

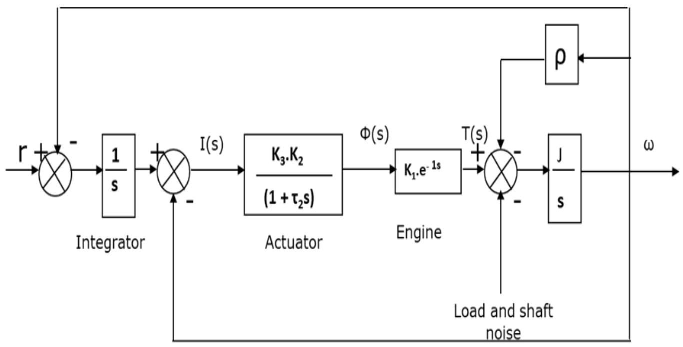

Fig 2 Block Diagram of Diesel Engine system

The general structure of the fuel actuator system is usually represented as a first-order phase-lag sector, which is characterized by a gain K_2 , a time constant τ_2 and the current driver constant K_3 in Equation 1. The output of the actuator is the fuel-flow$\phi(s)$, while the input is current $I(s)$.

$$\varphi(s) = \frac{K_3 K_2}{(1+\tau_2 s)} I(s) \quad \text{-------(1)}$$

Fuel Flow $\phi(s)$ is then converted into a mechanical torque $T(s)$, with a time delay and an engine torque constant K_1 . $T(s) = \phi(s) K e^{T_1 s}$ The flywheel represents the complex dynamic effects of the engine inertia, the angular speed w of the flywheel, the viscous friction coefficient and the loaded alternator. Its model is assumed to have an integrator with a flywheel acceleration constant J which serves to filter a large proportion of the disturbance and noise. The noise itself is an inherent property of an internal combustion engine. An integrator is added between the reference signal r and the engine actuator. It is necessary to eliminate the speed droop in steady-state operation by raising the order of the whole system as shown in Fig. 2. It has additional improvements to the results without using the integrator. The typical set of per unit values used in the simulation is taken from [2]. The diesel generator is treated as a standard second order Park model and the AVR model was constructed according to the standard type. The diesel generator is treated as a standard second order Park model and the AVR model was constructed according to the standard type.

IV. Simulations And Validation

The Microgrid and distributed generators are modeled within a platform by MATLAB/Simulink, in which a 300kW diesel generator, a 200kW wind turbine generator, the controllable loads and a 100kW fuel cell are incorporated into the Microgrid. To examine the validity of simulation platform, various operating conditions and disturbances are considered, such as the dynamic behaviour of micro-grids during either grid is connected or islanded, disconnection of microsources from Microgrid or load changes in the Microgrid, different wind speed etc. To examine the validity of the simulation platform, various operating conditions and disturbances are considered, such as different wind speed, disconnection from the main grid or load changes in the Microgrid. The reference frequency is provided by the unity during the grid-connected mode, while in the islanded mode, a controllable load is used to provide the frequency reference. The following figures demonstrate the simulation results. In the beginning the diesel generator experiences a starting period, but after about one second the system arrives at stable status.

Microgrid with Non Conventional Sources/ Microsources -

It has been observed that when there are non conventional sources/microsources are present then the Active and Reactive powers at Bus 1 are increases with some transient. Diesel Generator is present at Bus 1. Therefore the average active and reactive powers are as follows:

At variable load R=100Ω & L=0.005H, P = 0.07 pu and Q = 0.04 pu as shown in figure 5

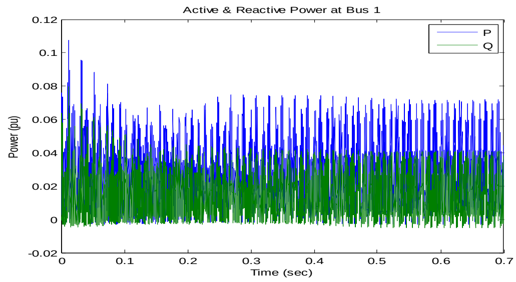

Figure 5 Active Power & Reactive Power at Bus 1

When variable load changes R=50Ω & L=0.002H, average Active power & Reactive power, P = 0.14 pu and Q = 0.07 pu as shown in figure 6.

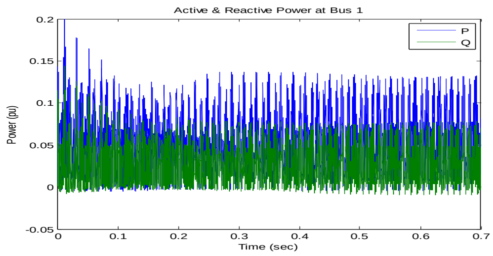

Figure 6 Active Power & Reactive Power at Bus 1

It has been observed that when there are non conventional/microsources sources are present then the Active and Reactive powers at Bus 2 are increases with some transient. Wind Turbine Generator is present. Therefore the average active and reactive powers are as follows:

P = 12 pu & Q = 17 pu as shown in figure 7

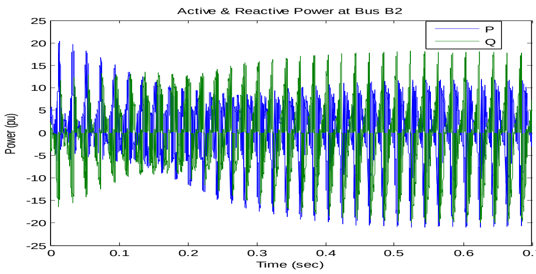

Figure 7 Active Power & Reactive Power at Bus 2

Grid is disconnected from Microgrid

When the grid is connected the powers P =1.2 pu & Q = 1 pu approx. but when fault occurs at t = 0.2 and clear at t = 0.3 after that the value of both powers get decreases to 0.1 pu. As shown in figure 8

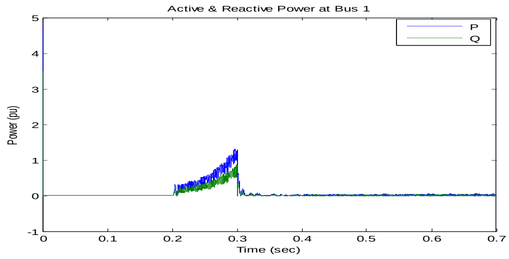

Figure 8 Active & Reactive Power at Bus 1

At time t = 0.2 to t = 0.3 the transient behavior shows in figure 9 due to the fault takes place. The values of Active & reactive powers are large as compared to rest of the time.

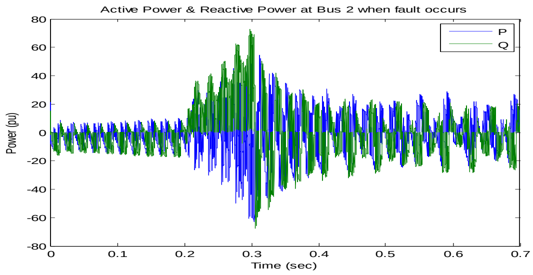

Figure 9 Active & Reactive Power at Bus 2

V. Conclusions

Microgrid is a well known concept with growing interest in arena of power generation now days. It is the solution for the difficult problems without disrupting the operation of the utility network. The Microgrid concept assumes a cluster of loads and micro sources operating as a single controllable system that provides both power and heat to a local area, for which some forms of energy storage equipments are usually required. Non convention energy sources are cheap & renewable.

A dynamic model including different microsources/ non conventional energy sources has been established for the Microgrid system. The dynamic performance of the Microgrid is studied with various disturbances. The Modelling & Simulation of a Microgrid to account for both the transient & steady-state system characteristics is studied. The simulation result shows the dynamic behavior of micro-grids during either grid is connected or islanded. The characteristics is observes for various disturbances such as change of loads and speed of wind turbine generator. The diesel generator is used to compensate the disturbances. By using non conventional energy sources the operating cost is less to fulfill the desired condition in case of grid failure with more efficiency. It concludes that there are increases in power generation when the microsources/ non conventional energy sources connected within Microgrid which helps in different applications. It also found that when the Grid is disconnected and the power is supplied to the load due to the Microgrid where the microsources/ non conventional energy sources are connected.

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