



Analysis, Modeling, and Control of an AC Microgrid System Based on Green Energy

M.F. Elsied^{1,2}, A. Oukaour¹, H. Gualous¹, Y. Slamani¹, R.Hassan² and A.Amin²

 ¹ Lusac laboratoire –, BP78 Rue Louis Aragon (Cherbourg-France) Université of Caen Basse- Normandie, Caen, France
Phone:0033 986 812685, e-mail: hamid.gualous@unicaen.fr
² Electrical Power and Machines Department Helwan University, Faculty of Engineering Helwan, Cairo, Egypt
Phone: 0033 689 326 447, e-mail: moataz.elsied@unicaen.fr

Abstract.

The integration of distributed generators (DGs), electric storage system (ESS), distributed electric loads and the utility grid through the point of common coupling is called microgrid (MG) .The coordinated operation of MG and the main utility grid with variable load demand is controlled by using microgrid control center (MGCC). MGCC methodology is introduced to regulate power flow for each source depends on the outputs commands from MG energy management center (MGEMC). This paper is focused only on developing an efficient and fast MGCC based on power control mode taking into account the outputs commands from MGEMC without considering its strategy. The MG in this paper is assumed to be interconnected to the main utility gird, and can purchase some power from utility grid at off-peak hours or when the production of the MG is insufficient to meet the load demand. On the other hand, there is a daily income to the MG when the generated power exceeds the load demand during on-peak hours. The proposed MGCC and electrical power system is simulated using Matlab/Simulink.

Key words

Distributed generators (DGs), microgrid (MG), energy management center (EMC), and Microgrid control center (MGCC).

1. Introduction

A Microgrid system is particularly a portion of the power distribution system that formed by integrating loads, DGs and energy storage devices .Recently, there has been a general upsurge of interest in the concept of using microgrids (MGs) and thus, they are being described as flexible and intelligent network or even active power network with a great potential to promote and to increase the renewable energy resources integration. At the same time, they are able to improve overall system reliability, efficiency and security [1].

MGs can operate in parallel with the main utility grid, as an autonomous power island (off grid mode) or in transition between main grid-connected mode and island operating mode (on/off grid mode) [2]-[3].

The power electronics interfaces circuits (PEICs) play an important role in interfacing different components within MGs [4]-[5]. MGs systems can be formulated according to PEICs topology into two main configurations (AC and DC microgrids).

AC microgrids (ACMGs) are feasible with all types DGs. They are gaining popularity due to the involving in many areas of applications such as in remote areas, commercial buildings and as backups for power supply and improve the power system infrastructure efficiency and reliability. DC microgrids (DCMGs) based on DG units produce the DC power which would be easily connected to the DC bus line. In this case, the AC DG units need an AC/DC power converter for their connection to the common DC bus line and DC/AC for their connection to the main AC grid (on grid mode) [6].

All technical issues of ACMGs and DCMGs are resolved via the control of their PEICs using an efficient and fast controller [7]-[8].

In recent years, all researchers in the field of online energy management and optimization for MGs are interested to present modern, fast and efficient online MGCC.

The role of MGCC can be concluded as (i) to receive reference power values for each DG, (ii) to compare DGs power measurement values with reference power values, (iii) to facilitate the DG unit to fast track the reference values. Moreover, MGCC can decide the operation of MG in grid-connected mode or in islanded mode. [9].

In grid-connected mode, the microgrid either draws or supplies power from or to the main grid, depending on the generation and load with suitable market policies. In addition, it can separate itself from the main grid whenever a power quality event in the main grid occurs [10]-[11].

In this paper, a MG model based on green energy like Wind and tidal generator is presented and formulated in details in grid connected mode (on grid mode) considering different scenarios. A proposed MGCC is also developed to verify load demand requirements during daily operation taking into account the outputs command from MGEMS. The complete electric power system and an efficient controller have been simulated and tested based on Matlab/Simulink to validate the results obtained from MGEMS and to achieve an online energy management methodology.

2. MG System description

The schematic diagram of the MGEMC and control system under consideration is shown in Fig. 1. There are four DGs as shown; microturbine (μ T), wind, Tidal and Fuel cell (FC). The integration of DGs is normally interfaced with the residential load demand and the main utility grid by PEICs. The different used topologies of PEICs are necessary to regulate power flow for each DG inside MG system. MGCC is aimed to develop the suitable control pulses for each converter by comparing reference power values delivered by MGEMC with the measured power values.





3. System modelling

In this section, simulations have been implemented using Matlab/Simulink to investigate the performance of the MGCC inside MG.

During the simulation, all possible electrical power system transitions were investigated and numerous waveforms, which reflect different situations of the electrical Power system.

A. Load demand profile

It is assumed that the load demand has the same profile as French national electricity load demand profile in real time and it is represented in this paper by bank of resistances controlled by control signal to achieve load power variation .The electricity demand varies according to some factors such, time of day, time of year, geographical location and climate change. Fig.2 shows an average daily electricity load profile in summer.



B. Microturbine model

In the current research work, the μT unit is treated and modeled as a compact block where the inputs is the fuel

power and the output are electric power and thermal power. The description of μT system, coupled generator and control system are shown in Fig.3.



1) Engine Dynamic Model

The μ T considered in this part as diesel engine is taken from Matlab Simulink as a diesel engine block model. The engine model includes diesel fuel engine with throttle actuator valve control, driveline output. The throttle signal directly controls the fuel flow as well the output torque that the engine generates. Moreover, it controls indirectly the speed at which the engine runs. If the engine speed exceeds the maximum speed that you specify, the engine generates no torque. The model does not include the airfuel dynamics of combustion.

The transfer function in Fig.4 represents the engine transfer function (throttle actuator and driveline output).

Throttle	1+T2s	Fuel	Time	Output
control / signal	s(1+T ₃ s)(1+T ₄ s)	Flow	Delay	Torque
0				

Fig.4. µT Engine transfer function

2) Synchronous generator model

The synchronous machine used in the simulations is based on Matlab Simulink synchronous machine block set. The machine parameters are given in Table I.

Table 1 Synchronous machine data						
Rated	Rated	Rated	No.of	Fs	Inertia	Stator
Power	Voltage	Speed	poles	(Hz)	$(Kg.m^2)$	resistance
(KW)	(V)	(rpm)				(Ω)
55	400	1500	4	50	0.5	0.1

3) Engine controller based on FLC

FLC is a model-free approach, and it does not depend on a model of the system being controlled. Model-free approaches make the controller design simpler, since obtaining a mathematical model of the system is sometimes a very complicated task. The configuration of FLC can be divided into three parts they are, Fuzzification, Knowledge Base, and Defuzzification as listed in [12].

4) FLC voltage control

The design of FLC is based on two inputs signal: the first input is the error signal (u), while the second input is the rate of change in the error signal ($\frac{du}{dt}$). FLC voltage regulator (FLCVR), the first input is the voltage error (Vref-Vabc) between the desired value of the generator voltage and its immediate value. The exciter control signal (ECS) will determine whether the field current needs to be increased or decreased to bring the voltage back to its desired value. The second input to FLCVR is the rate of change of voltage error, which will determine how fast the

output voltage is changing as shown in Fig.5. This is an important actor in a real-time control strategy for increasing the time response of the system.



5) FLC speed governor control

FLC speed regulator (FLCSR), the first input to fuzzy speed controller is the speed error (wref-wmech) between the desired value of the generator speed and its immediate value. The error signal will determine whether the fuel flow needs to be increased or decreased in order to bring the speed back to its desired value. The second input to FLCSR is the rate of change of speed error, which will determine how fast the output speed is changing as shown in Fig.6.



Fig.6. µT generator speed control based on FLC

6) Power conditioning system

The power conditioning system is consisting of an AC/DC uncontrolled three phase rectifier circuit, DC-link capacitor (4800 μ F), DC/AC three-phase voltage source inverter (VSI), an isolated transformer and L-filter (1mH). The output voltage control of the VSI is achieved through sinusoidal pulse width modulation (SPWM) techniques.

C. FC modelling

The schema in Fig.7 describes the model of fuel cell system. The model of the Solid Oxide Fuel Cell (SOFC) system predicts the output voltage and the partial pressures of hydrogen and oxygen in the FC stack which controlled to produce a certain electric current. The voltage signal is fed to a control voltage source in the simulation environment. The FC system consists of a FC stack with N_{fcs} cells in a series configuration.



Fig.7. FC system modeling

1) FC model

The Matlab/Simulink-based of SOFC system is designed and modeled by using equations that listed in [13]. Table. II. illustrates the specifications of the SOFC system. Table II. - FC parameters

3.2e-4 ohm		
1.3 V		
1.2 V		
400		
100		
343 [K]		
8314.47 [J/ kmol K]		

2) Flow rate regulator

The hydrogen flow rate regulator is responsible to regulate the flow rate of hydrogen according to output current change. Moreover; it controls the hydrogen flow as well output current to be in the normal limits.

3) Power conditioning system

Interfacing fuel cell system to the grid needs a DC/AC three-phase two level voltage source inverter (VSI), Stepup coupling transformer with ratio (200/400) v and low pass filter (1mH). The output voltage control of the VSI is achieved through sinusoidal pulse width modulation (SPWM) techniques.

D. Wind / tidal modelling

A generic model of the wind or tidal turbine, No Storage, is presented in [14]. This scheme of turbine generator has been developed by Hydro-Quebec to reduce the cost of supplying electricity in island operating mode and grid connected mode. At high grid power tariff, wind as well tidal generator are required to feed the load and send the remaining power to the grid when the turbine generator power exceeds the load demand. It is possible to shut down the turbine at low tariff of grid power or storing the turbine power into battery system. In this paper, MGCC sends to wind and tidal circuit breaker (C.B) control signal to stop the generation at low grid power tariff. In order to analyze the dynamic behavior of a wind and tidal turbine generation systems, different blocksets exist in the Matlab/ Simulink environment are used. The configuration of the overall turbine system is shown in Fig.8.



Fig.8. wind and tidal system configuration

1) Wind and Tidal power availability

The availability of wind and tidal power during operating mode depends on wind and wave speed respectively. Fig.9 and Fig.10 show the hourly wind and wave speed profile considering the time of day, time of year and climate change and the expected output power for wind and tidal generator according to turbine parameters which listed in Table III and Table V. The data of wave and wind speed was taken from Raz Blanchard area in France during one day in summer [15].





2) Turbine model

The turbine is composed of a directly coupled with squirrel cage induction generator through a gearbox. The turbine rotor model provides the aerodynamic power extracted from the wind by the following equation:

$$P_m = (0.5 * \rho * A * v^3 * c_p) \tag{1}$$

The wind and tidal turbine design is considered as a classic three-bladed horizontal-axis (main shaft). The output mechanical power (P_m) available from a variable speed turbine can be expressed in the following way where ρ is the air density for wind power and water density for tidal power, $A(pi * r^2)$ is the blades swept rotor area, v is the wind or wave speed and c_p is the power coefficient of the turbine. The power coefficient c_p is a nonlinear function of the tip-speed ratio λ at zero degree of bitch angle as given by:

$$\lambda = \binom{W_t * r}{\nu} \tag{2}$$

Where r is the radius of the turbine blades and w_t is the angular speed of the turbine rotor shaft. The power coefficient c_p is given in terms of the tip-speed ratio λ [16].

$$c_p(\lambda) = 0.5(\frac{98}{\lambda_i} * -5)e^{-(\frac{16.5}{\lambda_i})}$$
(3)

$$\lambda_i = (\frac{1}{\lambda + 0.089} - 0.035)^{-1} \tag{4}$$

3) Mechanical shaft model

The turbine rotor dynamics is modeled as:

$$T_e = T_l + T_f + J \frac{aw_m}{dt}$$
(5)

Where T_e the electromagnetic torque of the electric machine, T_l is the load torque, T_f is the friction torque (equal to the viscous friction coefficient multiply by rotor shaft speed), J is the moment of inertia of the turbine, generator and gear box and w_m is the generator rotor mechanical speed after gearbox ratio [17].

4) Squirrel cage induction generator(SQIG) and synchronous motor modelling

The induction machine and synchronous machine used in the simulations is based on Matlab Simulink machine block set. The reactive power absorbed by IG is partly compensated by capacitor banks connected at wind or tidal generator bus .The rest of reactive power required to maintain the 400V at wind generator bus is provided by a synchronous machine. It works as a synchronous condenser and its excitation system controls the grid voltage at its nominal value using PI controller ($K_p = 0.5$ & $K_i = 10$). The frequency and power flow of turbine generator are controlled by inverter control system and it will be presented in details in MGCC system description.

All The used machines parameters and turbine specification of the turbine for wind and tidal are listed in Table.III and Table.IV respectively.

Table III wind system parameters		
Wind turbine power (KVA)	40	
wind air density ρ (Kg.m ⁻³)	1.225	
blades swept rotor area A (m ²)	78.5	
Power coefficient c_p	0.48	
Gear box ratio	1:20	
Wind IG power (KVA)	50	
Capacitor bank(KVA)	10	
Synchronous condenser(KVA)	50	

Table IV. – Tidal system parameters		
Tidal turbine power (KVA)	55	
Tidal air density ρ (Kg.m ⁻³)	1225	
blades swept rotor area A (m ²)	3.8	
Gear box ratio	1:20	
Power coefficient c_p	0.45	
Tidal IG power (KVA)	60	
Capacitor bank(KVA)	10	
Synchronous condenser(KVA)	70	

5) Power conditioning system

For turbine system power conditioning circuit is consisting of an AC/DC rectifier circuit, DC/AC threephase voltage source inverter (VSI) and DC-link capacitor (1800 μ F). Sinusoidal pulse width modulation (SPWM) is used to control the VSI output voltage. The connection to the utility grid is made by means of a step-up coupling transformer v and L-filter (1mH). The VSI structure uses two level inverter circuits. This device is analogous to the grid-side VSI and converts the variable amplitude and frequency output voltage of the IG into a roughly constant DC voltage level of the grid-side VSI inner bus.

E. MGCC system description

Most distributed generation units (DGs) like μ T, FC, wind and tidal are usually connected to the main grid using power electronics converters. In normal mode, the converter controls are working in a power control mode to control the power flow between the DGs and main grid.

The MGCC system description illustrated in Fig.11 is implemented in dq0 reference frame to achieve full decoupling between active and reactive power control loops. The power reference (P_{ref}) is subtracted from measured DGs output power (P_{DG}) and the error signal is feed to the active power controller (PI control with $K_p=1$ and $K_i=3000$) to generate the reference current I_d in dq0 frame. I_d , I_q are transferred to abc frame using park transformation.

In order to implement park transformation within the control system, phase looked loop (PLL) is required. The PLL is used to synchronize the inverter with the AC grid. PLL concept is based on aligning the output frequency with d axis in dq frame by forcing the q component to be zero using PI controller (K_P =0.1316, K_i =3.0703) controllers. After dq/abc transformation, I_{abc} is considered to be the reference current for hysteresis band current control to control the inverter output current [18].



Fig.11 MGCC system description

F. MGEMC system description

MGEMC methodology is introduced to deliver the optimized power values to MGCC considering the outputs commands from the optimization algorithm. The optimization algorithm based on Genetic algorithm (GA) is built as listed [19] taking into account the system variables, DGs constraints, Grid parameters and the cost and emission objective functions. The optimization algorithm methodology is not considered in this paper Fig.12 shows the optimum power allocation after solving the optimization problem .These results are considered as a references power values for MGCC.



G. AC grid modelling

The electrical grid can be represented by a three-phase simplified circuit .An inductance L works as line filter is mounted between the utility grid and VSI having internal resistance R. The potentials of the utility grid denoted as U_{ga} , U_{gb} and U_{gc} . The grid parameters used in simulation are listed in Table V. The assumption of the balanced state of the grid is presented; therefore, it can be represented by the equations as:

Table V. - Grid system parameters

Parameters
V _{grid} =0.4KV
F _s =50Hz
L=1.2mH
R=0.05Ω

4. simulation results and discussion

Based on the block diagram of the control strategy in Fig11, simulations have been implemented using Matlab/Simulink to investigate the performance of the MGCC during operating hours. During the simulation, all possible electrical power system transitions were investigated and numerous waveforms, which reflect different situations of the electrical Power system. Simulation studies are carried out for a typical day in

summer. The methodology of grid connected mode is summarized in how the variable controlled by the converter follow the reference active and reactive power which coming from MGEMS.

Fig. 13, Fig. 14, Fig.15 and Fig16 show the voltage source converter (VSC) output power profile of FC unit μ T, wind and tidal respectively. It can be observed from the figures that the real output power produced by VSC is tracking MGEMC reference power profile.

The small difference between the two waveforms (VSC output power and EMS reference power profile) is due to the fact of dynamic response time of the system.



Fig.16 hourly tidal output power profile compared to ref value

Fig.17. shows the profile of main grid active and reactive power. In the first interval of the day (00hr till

06hr), the grid delivers active power, in order to meet the required load power. In the remaining hours of the day (07hr till 24hr), MG DGs power capacity is higher than load demand power. Therefore, the grid receives an active power which equals to the difference between DGs total power and load demand power. The fact behind the variation of grid active power related to the grid tariff variation during operating hours.

Moreover, the figure shows the reactive power of the grid is equal to zero according to setting value of the reactive power controller as shown in Fig.11. The total load demand profile, DGs power profile and grid power profile (simulation output) are shown in Fig. 18. It is clear from the figure that both of grid power and the DGs power can meet the active power of load demand.



CONCLUSION

A simulated MG model of electric power system, power converters and control system for each DG and main grid system has been built based on Matlab/Simulink program. This Simulink model is used to achieve online energy management technique which designed to control the power converters of each DG unit in an efficient and high speed way. In such a way, The MGCC is allowed to receive reference power profile from MGEMS and try to keep fast tracking these profiles.

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