Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 10 Issue 05, May-2021

The Study of Smart Microgrid Stability using Diesel Engine Governor and Excitation System Controllers

Ali H. Alramadhan
Systems Engineering Department
King Fahd University of Petroleum and Mineral
Dhahran, Saudi Arabia

Mohamed A. Abido
Electrical Engineering Department
King Fahd University of Petroleum and Mineral
Dhahran, Saudi Arabia

Abstract— **In recent years, the demand on renewables has been continuously increasing which is motivated by environmental policies to push for the retirement of fossil fuel power generations and to move toward zero carbon emissions. The driver of enhancing the power system reliability makes it feasible to interconnect conventional grid with renewables. The concept of smart grid has enabled the monitor, control and automatic dispatch of power flow in today power network. This paper will review the impact of renewables penetration on conventional grid stability, and also it will introduce some approaches to improve the power system stability. In the last sections of this report, the modelling of diesel engine with governor and excitation system controllers will be described and simulated in smart microgrid case study to evaluate the transient and small-signal stabilities.**

Keywords*— *Smart Microgrid,* Conventional *grid, Governor, Excitation, Stability

I. INTRODUCTION

Electrical power generations are strategically located closer to power resources or nearby water sources for the purpose of logistics and cooling respectively. As some of power grids are separated in remote locations, the economic advantage of integrating local grids with national grid could be not a cost-effective solution. However, as the power demand increases and the redundancy of the power supply to the customers is a reliability concern, interconnecting local grids can contribute sustainability to overall power generations and consumptions. In conventional grids, spare generators are hold on standby mode to overcome stability issues during peak times and prevent poor power quality and blackouts. In addition, at low power demand during the day, some turbine generators are required to be turned off. One solution to effectively utilize turbine generation is to motivate the change of power consumption behaviour by introducing dual tariff with low-rate charges, especially when power demand is low at night. There are other approaches that are not affecting the customer behaviour such as introducing power storage systems and renewables. Although the penetration of renewables can supply high clean energy, but there are some engineering designs concerns (such as power electronics harmonics and trading flexibility) of interconnecting renewables with national grid. As the technology advancing, it is possible exchange power information between power generators, storage systems, and customers through IT solutions. Furthermore, the implementation of remote power switching and isolations became smarter and safer at different power network levels in the generations, transmissions and distributions.

In this paper, the second section will review the impact of renewables penetration on conventional grid. The third section will introduce some approaches to improve the stability in smart microgrid. The fourth section will focus on the modelling of diesel generator governor and excitation system controllers to maintain frequency and voltage at the nominal values. The last section will illustrate a case study where smart microgrid will be simulated in Simulink to evaluate the performance of diesel engine governor and excitation system controllers during transient and small-signal stabilities.

II. REVIEW RENEWABLES PENETRATION ON CONVENTIONAL POWER GRID

In Conventional power grid, the power network is design in hieratical structure where high voltage power generations transferred through transmission lines into medium or low voltage distribution networks, feeding industrial, commercial and domestic loads. However, the integration of distributed renewables into main grid requires new formation of power grid topology. The distributed generation (DG) along with local loads can be named as micro-grid (MG), while the conventional main power grid is called macro-grid. Micro-grid can operate mainly into two modes; “grid-connected” to main grid which allows the power exchanged between the two grids, and “islanding mode” as it is isolated from the main grid[1]. When micro-grids connected to main grid, two-way communications need to be established between the grids to enable power flow monitor and control [1]. The retirement of thermal power generations (such as steam-turbines generators driven by nuclear reactors or diesel engines) and the substitution of renewables power generations can cause power system stability issues due to mainly reduction in power system inertia [2]. Also, the variation nature of renewable resources is another concern for the power dispatch and system stability during disturbances [1].

III. REVIEW IMPROVEMENT APPROACHES FOR SMART GRID STABILITY.

There are several approaches that can overcome the stability concerns with high renewables penetration in the grids. Smart grid concept is introduced with advanced IT technology solutions to monitor and control several aspects of power system in real-time, including smart meters, global position system (GPS), phasor data concentrator (PDC), intelligent energy management system (IEMS) [1, 3]. Besides to that, the reliability of renewables can be enhanced with the advanced power electronic (such as convertors and compensators) to maintain grid synchronism at nominal frequency and voltage, even with the variations of wind and sunlight [1, 4]. To improve the smoothness of power flow and grid stability during load and generation disturbances, Energy Storage System (ESS) can guarantee uninterrupted power supply (UPS) with the aid from power electronic [5]. Local diesel generators in the micro-grid can also play the role to supplement the deficiencies in renewables by designing governor and VAR controllers. In [6], a robust governor control for small-signal and transient stability was achieved through two controllers with the same control structure but different gains. These two controllers are switched to one controller if the power drop is $\Delta P < 20\%$ of nominal value, and switched to another controller when $\Delta P \geq 20\%$. The purpose of small-signal (speed droop governor controller) is to maintain the speed and power at steady state within "droop characteristic" while transient (vast-valving controller) is to maintain system stability during sudden and large disturbances by rapid opening and closing of the valve [6]. In [7], Consumer Priority Assignment Units (CPAU) are installed in smart houses which allow customers to decide which selective loads can be shed during the emergency of underfrequency events that required load shedding.

IV. MODELLING OF DIESEL GENERATOR

For transient stability study, to maintain the electrical frequency and voltage of microgrid at nominal values through the governor of diesel generator, the overall diesel generator can be described by three main subsystems:

A. *Diesel Engine with Governor Model:*

The engine converts the thermal energy from fuel ignition to machinal power where the level of fuel consumption can determine the machine mechanical power, speed/frequency. In [8], the engine is simply represented with first order system where the governor (actuator) and controller (electrical box) are represented as 3rd order and 2nd order systems respectively (refer to appendix A). The range of model parameters can be selected as specified in [9]. The objective of the governor is to maintain the machine speed/frequency at the nominal value by controlling the of fuel consumption through valve opening and closing.

B. *Synchronous Machine Model:*

The synchronous machine converts the mechanical power from diesel engine to electrical power. The machine can be represented with 6th order electrical model and 2nd order mechanical model (refer to appendix B & C) [10,11,12].

C. *Excitation System Model:*

One of standardized excitation system is AC1A model in Simulink that is shown in appendix D. The main purpose of excitation system is to maintain the generator terminal voltage at the nominal value. The parameters for different excitation models can be chosen as per [13].

The complete model can be built in Simulink including diesel generator with governor control, synchronous machine, and excitation system as illustrated in Figure 1. For governor control, there is one measurement required from the machine which is the electrical speed, while for the excitation system, two measurements required from the machine which are stator terminal voltage and stator field current.

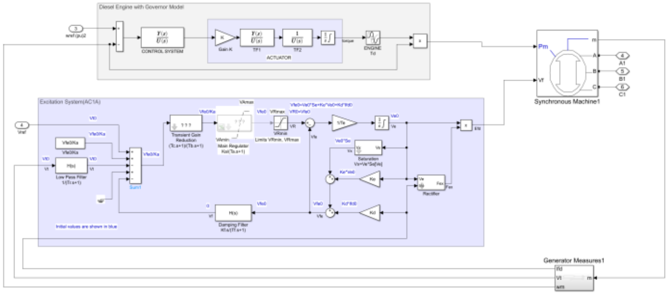

Figure 1 Diesel Generator with Governor and Excitation Control

V. CASE STUDY OF SMART MICROGRID

A. *Microgrid Configuration*

Simplified microgrid shown in Figure 2 was simulated in Simulink where there are four main electrical power supplies are delivered; PV solar farm, energy storage system (ESS), diesel generator, and main utility grid (infinite bus). The voltage from the utility grid is stepped down from 13.8kV to 400V through three-phase transformer to feed single 400Vac bus. The rest of power resources and the loads are also connected to the 400Vac bus. The maximum capacity of ESS battery bank is 540kW-hour, and it is designed to provide the microgrid with a constant 100kW rated at 400Vac. The output power of PV solar farm is simplified as sinusoidal waveform that varies between 450kW and 50kW, which can be expressed as $(P=200\sin(2\pi ft)+250)$kW, where f=1/120Hz. The diesel generator is rated at 1MW and in normal operation, it generates 500kW. In the microgrid, there are two types of loads connected to it; constant load consumes 500kW, and variable loads which consumes power between 200-500 kW. The study will focus on stabilizing the microgrid frequency and the voltage at nominal values (60Hz and 400V) through governor and excitation controllers at the diesel generator side. Several scenarios will be examined for sudden disturbances and gradual variations at the generations and loads when Microgrid is in "grid-connected" and "islanding mode". To make the simulation less ideal, a white noise has been superimposed into PV output power.

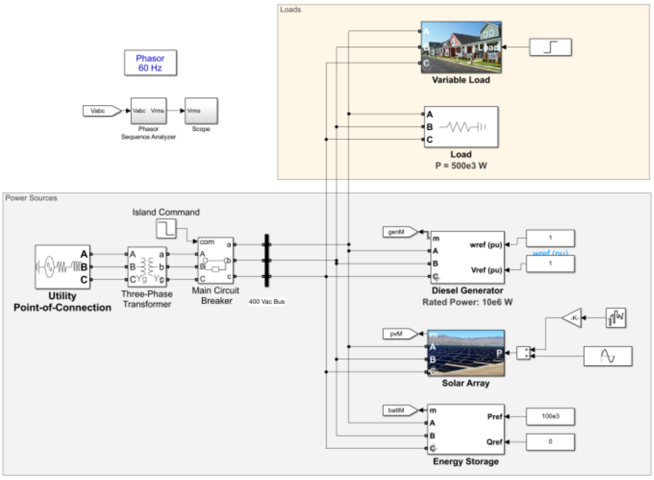

Figure 2 Simplified Microgrid [14]

B. *Microgrid Simulation Results*

Three main scenarios were simulated to evaluate the controllers' performance of the diesel engine governor and excitation system as shown in Figure 3. Initially, the microgrid is "grid-connected" with total generated power from microgrid is 850kW and the load is 500kW. So, the excessive power of 350kW is exported to the utilities. In normal condition, the frequency and voltage were at nominal values of 60Hz and 400V respectively. At time t=25 seconds, the utility main circuit breaker was opened to study the microgrid response during "islanding-mode". The frequency and voltage were disturbed due to sudden and significate loss of the utility, and both controllers (diesel generator governor and excitation system) were responded immediately. During frequency transient response, the generated power in the microgrid was higher than the load demand, thus the diesel engine speed was increased up to 60.07Hz, then it decreased to 59.98Hz before it recovered back to 60HZ within 4 sec. Although, the grid frequency recovery was much slower than the voltage, however the system voltage showed high spike approximately 1.5kV which has to be in considered in the protection design (for example including surge arrestors). The second event occurred at time t=50 seconds when extra load of 300kW was added suddenly which caused another disturbance to grid. As the load increased, the frequency transient of the machine slowed down to 59.9Hz, and then speeded up to 60.03Hz until it settled back to 60Hz within 5.6 sec. The last event occurred at time t=145 seconds, when battery bank level drained out to 10%. At this battery level, there is no power delivered by ESS and the lost power was compensated by the diesel engine. It can be observed during the simulation, as output power from PV was varying sinusoidally, this gradual variation was compensated by the diesel engine as well.

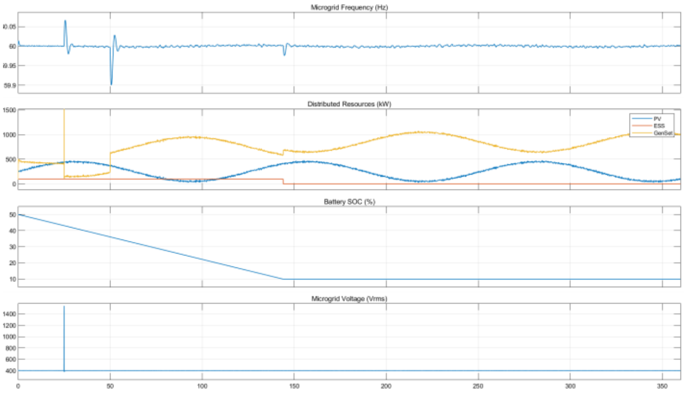

Figure 3, Microgrid performance with governor and excitation controls.

To compare the difference between the response of governor with the controller (in close loop) and without controller (in open loop), Figure 4 shows the response of diesel engine when the governor is in open loop and the microgrid is "grid-connected". Although, the frequency can be maintained at 60Hz at steady state, but there was high oscillation at the initial operation of the diesel engine and it always operated at its maximum capability. Figure 5 show the response of the system during "islanding-mode", the moment when the microgrid was disconnected at t=25sec, the frequency becomes unstable. In the other hand, small and gradual disturbances will not impact on frequency stability (for example gradual battery drained out).

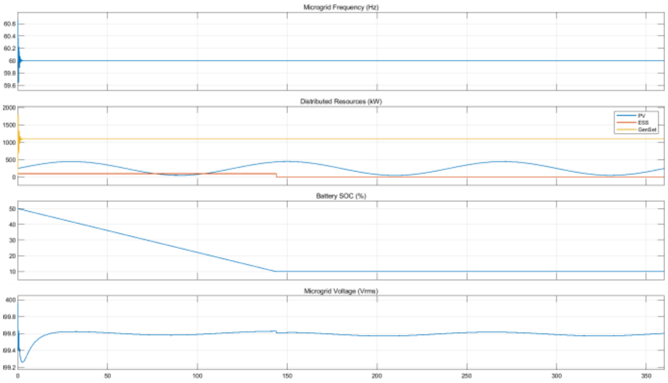

Figure 4, Microgrid "Grid-connected" without governor control

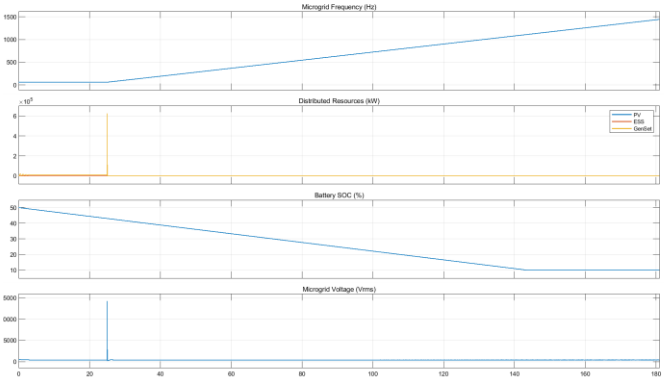

Figure 5, Microgrid "Islanding-Mode" at t=25sec without governor control

VI. CONCLUSION

The paper has reviewed the differences between conventional grid and smart microgrid in term their topologies, and physical location of power generations and loads. The impacts of renewables penetration on conventional grid were discussed, beside to introducing several approaches to improve the stability of the power network. A case study to maintain a smart microgrid frequency and voltage during transient and small-signal stability was achieved in Simulink simulation through the control of local diesel generator governor and excitation system. The controllers showed immediate response to maintain the voltage and frequency at nominal values when sudden and gradual disturbances occurred at the power sources and loads.

ACKNOWLEDGEMENT

The authors acknowledge the support of King Fahd University of Petroleum and Minerals in conducting this research work. The authors received funding from Saudi Aramco for this study.

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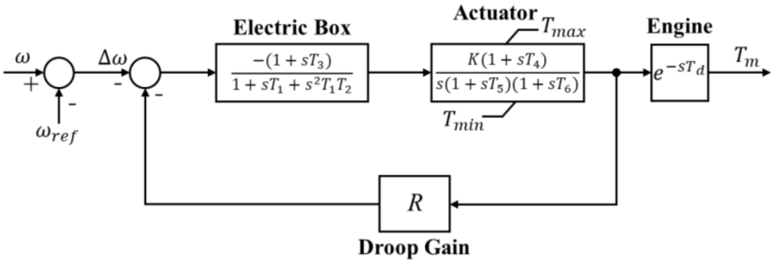
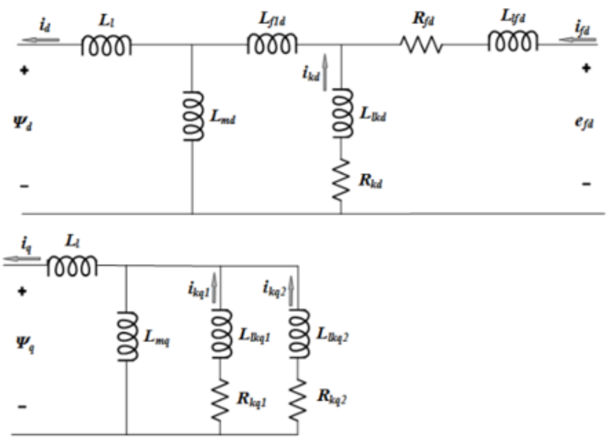
APPENDIX

A. Diesel Generator with Governor



B. *Electrical Modelling*



$$V_d = -i_d R_s - \omega\psi_q + \frac{d\psi_d}{dt}$$

$$V_q = -i_q R_s + \omega\psi_d + \frac{d\psi_q}{dt}$$

$$V_0 = -i_0 R_0 + \frac{d\psi_0}{dt}$$

$$V_{fd} = \frac{d\psi_{fd}}{dt} + R_{fd} i_{fd}$$

$$0 = \frac{d\psi_{kd}}{dt} + R_{kd} i_{kd}$$

$$0 = \frac{d\psi_{kq1}}{dt} + R_{kq1} i_{kq1}$$

$$0 = \frac{d\psi_{kq2}}{dt} + R_{kq2} i_{kq2}$$

$$\begin{bmatrix} \psi_d \\ \psi_{kd} \\ \psi_{fd} \end{bmatrix} = \begin{bmatrix} L_{md}+L_l & L_{md} & L_{md} \\ L_{md} & L_{lkd} + L_{f1d} + L_{md} & L_{f1d} + L_{md} \\ L_{md} & L_{f1d} + L_{md} & L_{lfd} + L_{f1d} + L_{md} \end{bmatrix} \begin{bmatrix} -i_d \\ i_{kd} \\ i_{fd} \end{bmatrix}$$

$$\begin{bmatrix} \psi_q \\ \psi_{kq1} \\ \psi_{kq2} \end{bmatrix} = \begin{bmatrix} L_{mq} + L_l & L_{mq} & L_{mq} \\ L_{mq} & L_{mq} + L_{kq1} & L_{mq} \\ L_{mq} & L_{mq} & L_{mq} + L_{kq2} \end{bmatrix} \begin{bmatrix} -i_q \\ i_{kq1} \\ i_{kq2} \end{bmatrix}$$

Where
d,*q* — *d*- and *q*-axis quantity
R,*s* — Rotor and stator quantity
l,*m* — Leakage and magnetizing inductance
f,*k* — Field and damper winding quantity

C. *Mechanical Modelling*

The mechanical system can be described by swing equation which can be approximated by second order transfer function [12]

$$\Delta\omega(t) = \frac{1}{2H}\int_0^t (Tm - Te)\ - Kd\Delta\omega(t)dt$$

$$\omega(t) = \Delta\omega(t) + \omega_0,$$

where

$\Delta\omega$ = Speed variation with respect to speed of operation
H = constant of inertia
Tm = mechanical torque
Te = electromagnetic torque
Kd = damping factor representing the effect of damper windings
$\omega(t)$ = mechanical speed of the rotor
ω_0 = speed of operation (1 p.u.)

D. *AC1A Excitation System Model*