AUTOMATIC GENERATION CONTROL SYSTEMS: THE IMPACT OF SOLAR ENERGY RESOURCES IN MULTI-AREA NETWORK

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DECLARATION

I declare that this thesis entitled “AUTOMATIC GENERATION CONTROL SYSTEMS: THE IMPACT OF SOLAR ENERGY RESOURCES IN MULTI-AREA NETWORK is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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APPROVAL

I hereby declare that I have checked this report entitled "AUTOMATIC GENERATION CONTROL SYSTEMS: THE IMPACT OF SOLAR ENERGY RESOURCES IN MULTI-AREA NETWORK" and in my opinion, this thesis it complies the partial fulfillment for awarding the award of the degree of Bachelor of Electrical Engineering with Honours

Signature : ....

Supervisor Name : DR. NORHAFIZ BIN SALIM

Date : 4th JULY 2021

DEDICATIONS

This project is dedicated to all my dear family, my father, who has been massively my supporter until this project was fully finished, and my mother who, for the past months and years, has encouraged me with all her attention to accomplish my work with truthful self-confidence as well as my brother and sister.

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ABSTRACT

This research study and investigate on the impact of solar energy resources on Automatic Generation Control (AGC). AGC is a system that responsible in balancing the system frequency and tie-line power between the generator and the load. AGC maintain the system frequency of the whole power system. A few changes or issues occurred on AGC with the integration of solar energy as the power sources in a multi-area interconnected power system. Solar energy resources with its unpredictability nature will certainly affect the AGC. Hence, this study will investigate the effect on frequency stability in AGC systems with solar sources integration using AGC30 model of Japanese power system with MATLAB Simulink. A different set of scenarios and cases will be conducted in the study of the frequency stability with the integration of renewable energy sources on the AGC of a multi-area network power system.

ABSTRAK

Kajian selidik ini menyiasat impak tenaga solar terhadap Sistem Kawalan Penjanaan (AGC). AGC merupakan sebuah sistem yang bertanggungjawab terhadap kestabilan frekuensi and talian kuasa sistem antara janakuasa and bebanan. AGC menjaga kestabilan frekuensi sistem ke atas seluruh sistem kuasa. Sedikit perubahan dan isu berlaku terhadap AGC dengan kemasukkan kuasa solar bersama dengan sifat ketidakjangkaan mereka akan semestinya memebrikan kesan terhadap AGC. Oleh itu, kajian ini akan mangaji kesan ke atas kestabilan frekuensi terhadap sistem AGC dengan kehadiran kuasa solar. Sebuah simulasi akan diadakan untuk mengkaji kesan-kesan tersebut menggunakan model AGC30 daripada sistem kuasa di Jepun menggunakan MATLAB Simulink. Beberapa senario dan kes akan dijalankan untuk mengkaji sishan frekuensi dengan kehadiran tenaga boleh ubah ke atas AGC di sistem kuasa rangkaian pelbagai kawasan.

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LIST OF SYMBOLS AND ABBREVIATIONS

AGC	-	Automatic Generation Control
RES	-	Renewable Energy Sources
LFC	-	Load Frequency Control
AVR	-	Automatic Voltage Regulator
ECC	-	Energy Control Center
PID	-	Proportional Integral Derivatives
PV	-	Photovoltaic
CSP	-	Concentrated Solar Power
SME	-	Small and Medium Enterprise
DFIG	-	Doubly-Fed Induction Generator
MPPT	-	Maximum Power Point Tracking
DMPC	-	Distributed Predictive Control
QP	-	Quadratic Programming
DE	-	Differential Evolution
WOA	-	Whale Optimazation Algorithm
PV	-	Photovoltaic
GF	-	Governor Free
EDC	-	Economic Dispatch Control

CHAPTER 1

INTRODUCTION

1.1 General

System frequency is one of the basic control parameters for a stable interconnected power system. Automatic generation control (AGC) maintains these parameters close to their nominal values by balancing the power generation and load consumption in addition to associated losses for each area of the system[1]. The power generation and load balance are vital in an efficient power system, hence frequent adjustments to the output of generators are necessary. The integration of renewable energy sources will make the process more complicated due to their unpredictability nature.

1.2 Motivation

This project will focus mainly on frequency control in Automatic Generation Control (AGC). AGC is a very important section in a power system. A lot of design and methods has been existed in the construction of an AGC. However, it can be tricky with the integration of renewable energy sources (RES) being implemented. The unpredictability nature of RES can be a problem for the AGC to operate in maintaining the balance of the power system. So, the design of the AGC model will be challenging. The purpose of this project will be to study the frequency stability in the AGC along with its changes with the implementation of RES.

There are a lot of advantages that can be gain from the use of RES. However, to fully gain those advantages, a few weaknesses from the RES needs to be overcome. One of the weaknesses is the control of its generation part if being implemented in a power system. That is why this project will be important as the effect on the AGC will be study to verify its effectiveness to overcome that problem. With the fully developed and suitable AGC, the RES can be perfectly implemented and fully optimize.

1.2 Problem Statement

Today, the renewable energy sources (RES) are largely being introduced in power system due to the declining conventional energy sources and its negative effects on the environment. Out of all RESs, solar energy resources are more prevalent in power system studies. However, solar energy resources suffer from high level of power variability, low-capacity utilization factor combined with unpredictable nature. As a result of these factors, firm power cannot be guaranteed for the autonomous system[2]. For example, solar energy power source might be varying based on the sunlight gathered by the solar panels (clouds/night/rain). The same with for example wind energy, the wind rate or speed might not always constant. With the changes in real power, the system frequency will also be affected. Hence in this project, an analysis and observation will be made in order to study the effect of RES in AGC that has been designed varying the output of individual generators to match the power with that of the load demand[3]. To maintain the power balance between power generation and the load, an efficient AGC systems is needed due to the unpredictability of the RES.

1.4 Objectives

i. To investigate on Automatic Generation Control Systems in power network.

ii. To develop an AGC system with solar energy resources integration.

iii. To verify the effectiveness of AGC system with solar resources in multi-area interconnected power system.

1.5 Scope

i. This project mainly focuses on the power generation part and a solar source with existing synchronous generators as the power sources.

ii. This project will focus on AGC30 model of Japanese Power System controlling the real power through maintaining system frequency within ± 0.5Hz.

iii. This project will use simulation only for the whole system mainly using MATLAB Simulink.

iv. Scenario one the simulation during low load demand without the presences of photovoltaic (PV) and with PV.

v. Scenario two the simulation during high load demand without the presences of photovoltaic (PV) and with PV.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This chapter focusses on the review of literature from journals, articles, books and other resources as well as previous studies regarded to this project. A little understanding on power system control, wind and solar power generation system, load frequency control system and automatic generation control system have been included in this chapter. These literature reviews are all important recent studies that have been done previously by other research works. The related works have been closely reviewed and referred since most of the knowledge and suggestions from the previous works can be used to successfully understand and executing this project. Literature review have been done throughout the whole time during the completion of this project as it was essential to refer a variety of sources to collect the knowledge and views of previous researchers to complete this project successfully.

2.2 Power system control

The power system control is the main part in the power system. The power control device detects the frequency of the power system, modifies its accordingly, schedules its movements and offers protection from unpredictable fault [4]. Today, a modern power grid is a dynamic system, distributed over a wide range of region. It rose too much as a result of increased demand and industrial expansion. Therefore, numerous new technical, methods and planning developments have arisen today in the power grid. The task of the power control system is to maintain system frequency and restore the balance when a sudden fault occurs, no matter how automated processing or human processing takes place. In summary power system control means the optimal output and system reliability to be maintained during disruptions including short circuits and lack of power or load [5].

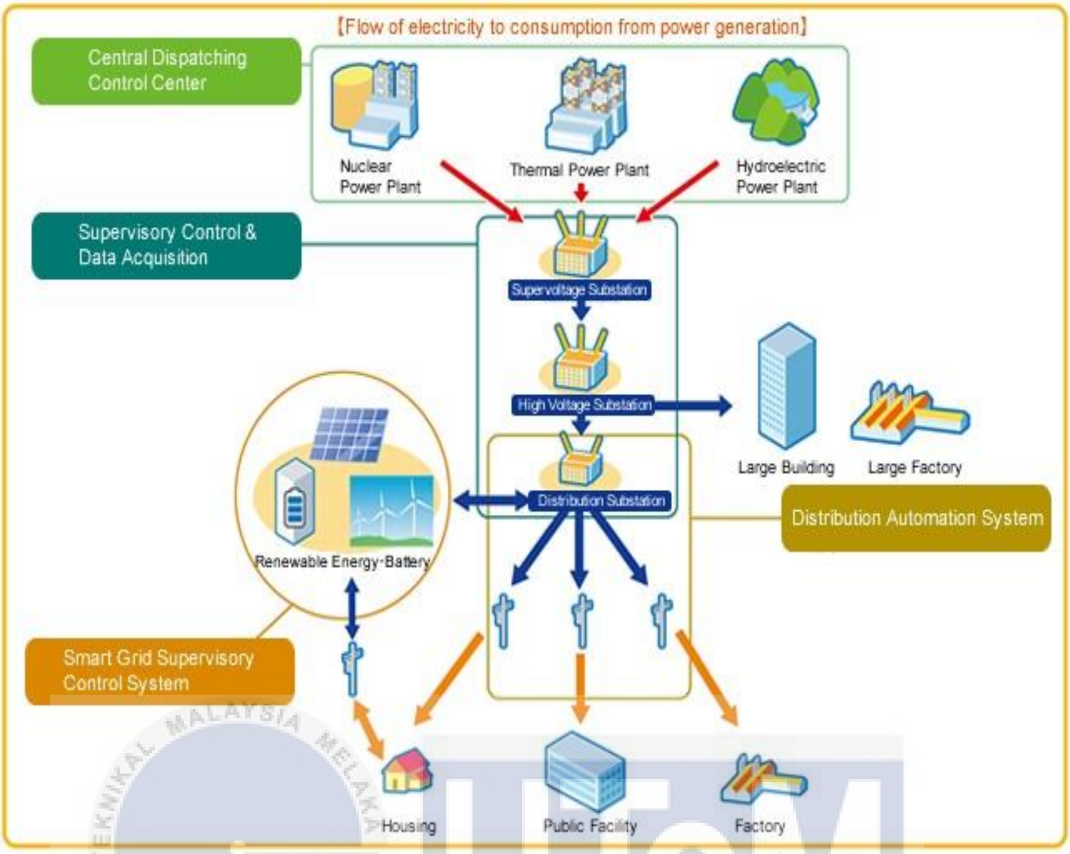

Figure 2.1: Power System Control [6]

The power control system tracks and gathers data all over the power grid. The essential framework of a grid or power system are generators, transmissions, storage and loads. Significant tasks for power control system are such concerns as reactive power and adaptive power control, angular stabilisation and voltage stability, inter-area transmission, power efficiency, automatic generation and frequency regulation for multi-machine systems, reliability assessment in a competitive environment.

The changes in actual power influence the frequency of the system, while reactive power is less susceptible to changes in the frequency of the system but mostly affect the voltage shift [6]. Due to this real power and reactive power are independently regulated. The load frequency controller (LFC) controller controls the true power while the AVR controller controls the voltage and reactive power. LFC is of significant importance for the production and function of the interconnected network. Today, it remains the basis or base of many advanced concepts to control system frequency [6].

The methods developed in modern energy control systems (ECC) from the control of a single generator to the control system of broad interconnections are extremely significant. ECC is typically fitted for all signal processing online computers via remote acquisition systems referred to as tracking control and acquisition of data through (SCADA) systems. The control centre also provides a way to easily verify stability and safety constraints on the capability of computer components [4].

2.2.1 Load frequency control (LFC)

The principal purpose of LFC is to maintain a very constant frequency such that loads can be separated between generators and the interchange schedules are regulated [6]. By monitoring system frequency, LFC control the true power balance in the system. When the actual power changes, the frequency changes. The frequency error is typically amplified, combined and changed to a command signal that is alerted or sent to the controller. By varying the turbine power or generator output, the governor acts to maintain a balance between input and output. This approach is also known as megawatt frequency or (P-f) control [7],[6].

2.2.1.1 Generator model and Load model

A variety of electrical devices or appliances will usually be loaded on a power grid. The resistive frequency of lighting or heating loads excluding engine load is independent. Engine loads are vulnerable to frequency changes. The sensitivity of the frequency depends on how load speed all operated equipment is composed. The composite load's speed characteristic is approximated.

$$\Delta P_{E} = \Delta P_{L} + D\Delta\omega \qquad (1)$$

Where the ΔP_L is the no frequency-sensitive load change, and $D\Delta\omega$ is the frequency sensitive load change D is expressed as percent change in load divided by percent change in frequency.

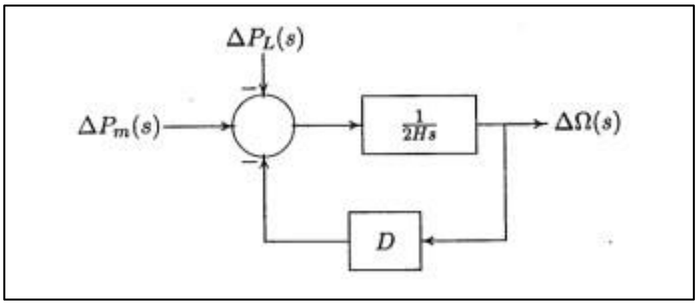

Figure 2.2: Generator and load block diagram [6]

2.2.1.2 Prime mover model

The mechanical power source under which the turbine is moved, it is called the main mover. It can be hydraulic engines, steam turbines, moved by fossil fuels. The turbine model relates to changes in mechanical output to the location of the steam valve. All turbines have their own properties and differ between themselves. A single time constant can be added to the simplest primary mover model for the non-reheated steam turbine, as in the transfer function below [6].

$$G_T = \frac{\Delta P_{M\,(S)}}{\Delta P_V\,(S)} = \frac{1}{1+T_{TS}} \qquad (2)$$

2.2.1.3 Governor model

When the power generator unexpectedly rises, electrical power will usually outweigh mechanical power input. The kinetic energy accumulated in the spinning mechanism induces this energy deficit. Modifications of kinetic energy influence the speed of the turbine and generator frequency. The turbine regulator will feel the changes in speed and will shift the turbine input valve in order to adapt the power output to a new steady state.

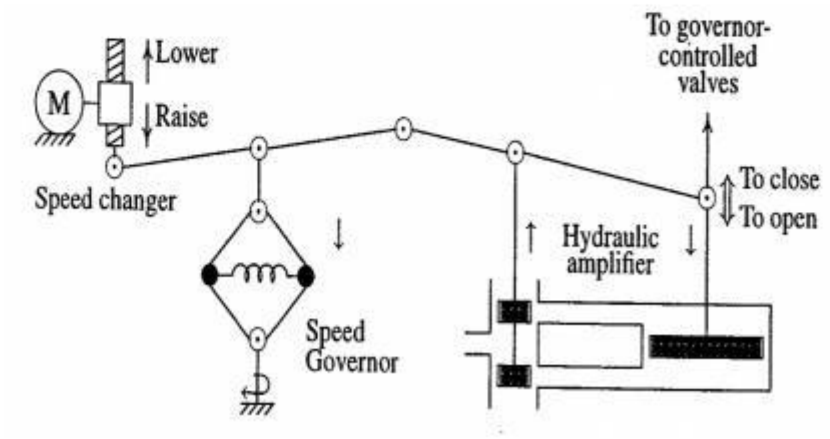

Figure 2.3: Speed governing system [6].

The most significant feature of this speed controller is the centrifugal flyballs powered directly or by turbine shaft transmission. The system gives up and down motion relative to changes in speed. Next are the connections to the turbine valve to turn the flyball movement. A hydraulic enhancer and input from the operation of the turbine valve. With some phases of the hydraulic amplifier, the regulator motions are converted into high intensity forces. Finally, the speed shift is a servomotor running at nominal frequency for producing a desired load.

2.2.1.4 Flat frequency control (FFC)

A FFC occurred in a power system is for example for a two-area network, only one station regulates a constant system frequency. If the constant frequency being regulate in station 1, there will be no regulation at station 2. Only the generation at 1 is adjusted to ensure an energy equilibrium between load and generation if the changes increases at 1 or 2 or at both. In this approach, however, a few shortcomings need to be adequate in order to absorb the load changes for whole systems. Next, the tie line 1-2 can absorb all variations in load at station 2. This is because generation 2 stays stable but varies in load. This could impose an immense pressure on Station1, and also waste resources economically. [8].

There is also another method that seems the same, that is flat tie-line control. The increasing generation will be at the region under flat tie line control with increased demand, while the other tends to be constant. This method suitable when a large power system interconnected with a small power system area.

2.2.2 Automatic voltage regulator (AVR)

The AVR is responsible for controlling the device voltage by adjusting from limit to load-or output-based change of the generator arousal [6],[7]. The AVR is used for the regulation of the voltage in other words. The variation or the shifting in the voltage usually occur due to the load requirement itself as it is normally varied at the load of the power system. A voltage regulator collects and feels the difference between the voltage rectified from the voltage of the stator and the reference voltage. The error signal is amplified and sent to the excitor circuit. The shifts in excitation maintain the network's reactive power balance [7].

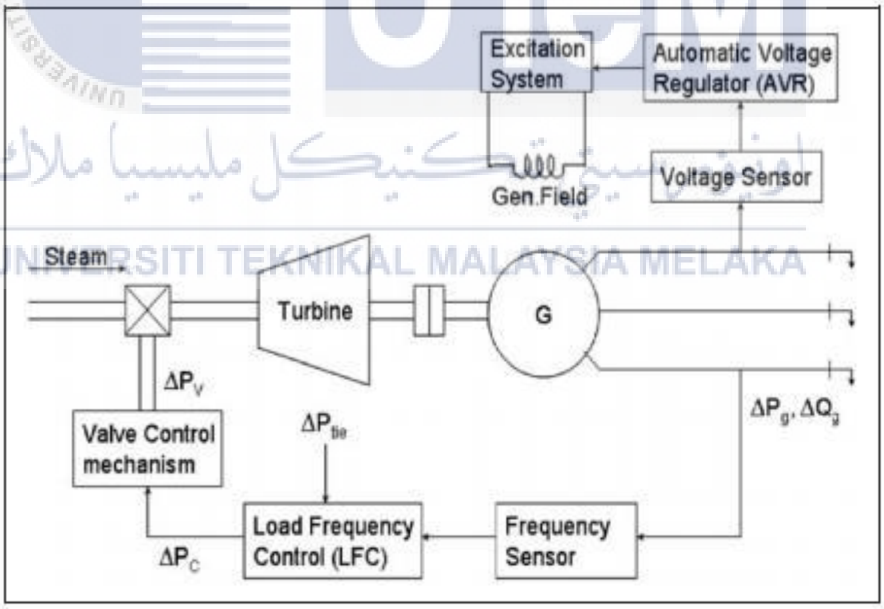

Figure 2.4: Figure of AVR and LFC of a synchronous generator [6].

2.2.2.1 Amplifier model

A magnet amplifier, a current electronic amplifier, or a rotating amplifier is the examples of amplifier model. The amplifier is represented by gain K_A and time constant T_A [6]. The model of the amplifier in the AVR system is represented in Eqn. 3. The gain and time constants are K_A and T_A, respectively.

$$\frac{V_t(s)}{V_u(s)} = \frac{K_A}{T_{A\,S+1}} \qquad (3)$$

2.2.2.2 Exciter model

Modern excitation systems nowadays is using sources from a solid-state rectifier. The exciter's output voltage is a nonlinear field voltage equation dependent on the magnetic circuit's saturation effects. There is no direct relation between the terminal voltage and the exciter's field voltage. [6]. Transfer function as shown below in equation 4.

$$\frac{V_{f\,(S)}}{V_{r\,(S)}} = \frac{K_E}{T_{E\,S+1}} \quad (4)$$

2.2.2.3 Generator model

The emf synchronous generator is a system magnetization curve feature which relies on the generator load of its terminal voltage. With the linearized model, KG gain and a TG time constant can be express the transmission function of the generator terminal voltage to its field voltage [6]. The transfer function of the AVR device generator is seen in equation 5 below where KG is gained and TG is time constant.

$$\frac{V_t\,(S)}{V_f\,(S)} = \frac{K_G}{T_{G\,S+1}} \qquad (5)$$

2.2.2.4 Sensor model

The voltage is sensed and rectified in a sensor model by a potential transformer by a bridge rectifier. The sensor is modelled in equation 6 below with a simple first order transfer function [6].

$$\frac{V_t\,(S)}{V_f\,(S)} = \frac{K_R}{1+T_{R\,S}} \quad (6)$$