AIN SHAMS UNIVERSITY
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DIGITAL CONTROL OF LARGE SYNCHRONOUS MACHINES CONNECTED TO ELECTRICAL POWER SYSTEMS

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ABSTRACT

The thesis presents a theoritical and experimental study of the performance of a synchronous generator, when it is equipped with a digital automatic voltage regulator (DAVR). The DAVR is of the proportional-pulse-integral-plus-derivative (PID) type which is well recommended in many industrial processes. The thesis presents a study of the two types of PID DAVR's. The first one is a digital equivalent of the analog PID regulators with constant preselected gains, while the second is a self-tuning PID regulator. The DAVR is designed, built and tested in the laboratory for a micro-alternator set, which is a scale model of a large turbo-alternator.

In the thesis a study of the steady-state, transient and dynamic performance of a synchronous generator, connected to a power system via transmission lines has been carried out. The generator is equipped with DAVR. The thesis includes a theoritical study of this problem. It presents a method of writting a combined mathematical model of the power system and digital regulator. This method unifies the equations of the analog and digital parts of the system into one set. The combined mathematical model is then solved by the use of a digital computer to investigate the performance characteristics of the synchronous generator under different load and transient conditions. The simulation results have been presented and commented upon.

The thesis gives an extensive experimental study of the machine performance when equipped with the DAVR. The self-tuning as well as the constant-parameter PID DAVR's have been designed, built and interfaced with the machine one at a time. The details of the interfacing circuits, sensors and transducers which were designed and built for use in tests are presented. The synchronous machine is tested to investigate the effect of the self-tuning and constant-gain PID DAVRs on its dynamic and transient stability.

A new method for experimental simulation of disturbances in power systems has been developed. It uses the techniques of ROM-based sequential circuits in applying faults to the system with prescribed durations, sequences and types.

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Experimental results and tests are reported in the thesis and compared to results obtained from computations.

The conclusions and recommendations achieved from the research are given.

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CHAPTER (I)

INTRODUCTION

1.1 AUTOMATIC VOLTAGE REGULATOR'S IN POWER SYSTEMS

Maintaing the terminal voltage in a power system is one of the basic ways of assuring proper performance. It is recommended by many standard specifications of electrical engineering that the maximum permitted voltage variation at the load terminals should not exceed ± 5 per cent of the rated value [1]. A voltage drop beyond the specified limits may result in excessive slippage of asynchronous motors with resultant reactive current overload of the feeding elements. Also decreased luminous effeciency of incandescent lamps takes place where lighting fittings employing such lamps are installed. Flcrescent lamps may even go out if the voltage drops slightly beyond the specified value. An excessive rise in voltage may cause damage to many incandescent lamps and radio equipment. More than that, an excessive increase in voltage causes premature deterioration of equipment insultaion (increase the leakage current) and may result in its failure. Voltage drop at power system node points reduce the capacity of power transmission lines and affects the stability of generators operating in parallel.

The voltage at the different points of a power system is maintained at the rated value by effeciently operating the system in conjunction with automatic excitation controllers, synchronous capacitors, automatic power transformer tap-changers, automatic switching equipment of load compensating capacitors etc......

Automatic voltage regulators (AVRs) are used to maintain, the voltage in compliance with the specified characteristics and distribute the reactive load between the power sources under normal operating conditions of power systems.

Excitation systems supply the exciting current to the field winding of a synchronous machine. They are the part of the system on which AVRs directly

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operate. In general, there are two types of excitation systems, namely, "the separate excitation systems" and "the self excitation systems". To improve the reliability of excitation systems, the tendency is now to replace d.c. commutator machines by semiconductor devices. Rapid-rate excitation systems with high excitation ceilings when employed with AVRs are found to raise the stability of generators working in parallel. The ceiling excitation voltage is determined by the excitation current multiplicity factor with respect to the magnitude of excitation current at normal operation of the generator. The multiplicity factor of rotor current with respect to the rated current allowed for a definite time is specified by the manufacturer for each type of exciters. If the forced excitation duration exceeds the permissible time, the AVR must reduce the excitation current (must perform de-excitation) and if the result is other than a droop in the rotor current to the specified value, they should disconnect the generator and discharge its field. In many standard specifications, the excitation systems must ensure an excitation forcing multiplicity factor of not less than 2 for generators and synchronous capacitors, while the rate of excitation rise should be not less than 2 units of excitation per second.

AVRs recieve input signal from the error in terminal voltage of the synchronous generator as measured from its specified reference value. It is the aim of the designers of AVRs to elimenate this error successfully in the shortest possible time with smallest overshoot response. The usual way to do this is to get the error signal of the terminal voltage amplified, then to use it to change the excitation voltage of the exciter, thus controlling the output terminal voltage in response. This type of voltage regulators is known as the proportional type with only one delay and one gain factor. Steady state stability of power systems equipped with this type of voltage regulation were studied in many references such as [2,3,4,5].

Derivative regulators, actuated either by voltage or power angle were given in [6,7]. The derivative regulators acquire their strong regulating action from being actuated not only by the error in terminal voltage but also by

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the first derivative, second derivative, third derivative,..... of the terminal voltage with respect to time. These derivative actions give the regulator anticipatory action on the error in terminal voltage. Regulators actuated from a signal derived from derivative of rotor angle has direct effect on the processes of forcing of excitation [8].

Proportional-plus-integral-plus-derivative 'actions regulators "PID" are widely used in industry and well recommended by many sources [9,10]. The integral action added to the PID regulator has the effect of eliminating the steady state error. But in doing this some oscillations in response may take place. The anticipatory action provided by derivative control add the necessary damping to these oscillations, thus obtaining a well damped response.

1.2 DIGITAL AVRs IN POWER SYSTEMS

It has been found by some investigators that digital control of power systems at the generating level is very effective in maintaining stable and proper operation of those systems [11]. A digital AVR (DAVR) must be capable of performing the functions of the conventional analog AVR and also of assuming special control duties not easily implemented into a completely analog device.

Functions basic to the operation of conventional analog AVRs may be summarized as follows:

- terminal voltage regulation;
- application of stabilizing signal(s) to improve machine performance in steady-state and during transient operation;
- automatic suspension of normal AVR action in order to initiate special excitation controls to limit rotor angle and to protect the generator from excessive overheating;
- bumpless transfer of controls so that transition between automatic and manual states of control can be achieved with no disturbance to the system.

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The DAVR would be required to perform the functions listed above and would also be capable of the following:

1) Direct interaction with higher levels of control and/or with an operator through a man-machine interface.

2) Modification of control parameters: A change of system control parameters is very difficult and time consuming for an analog AVR. As a result, most parameters remain fixed at values chosen and adjusted during the design and commissioning of the device. The DAVR would be capable of modifying the control parameters without any disturbance to the control action by using built-in logic switches or software tuning programs. In addition, control setting may be changed through action initiated by either the local operator or a computer on higher level of control hierarchy.

3) Mixing stabilizing signals as dictated by system operating conditions or configuration: If flexibility is built into a common design, stabilizers may be switched in and out depending on need and at no loss or interruption of service.

4) Application of advanced control actions.

1.3 SELF-TUNING VOLTAGE REGULATORS

Most of control methods are based on the knowledge of the process and its environment. However, this aperiori knowledge is often not available because of the complexity of systems under study [12]. This leads to an adaptive control problem. One way to solve this problem is to apply an identification method to obtain a model for the process and its environment by making use of a set of observations at the outputs and inputs of the plant. The control is then computed from the resulting model. An alternative way is to tune the control model parameters. These two approaches are usually implemented by the utilization of Model Reference Adaptive Systems (MARS) and Self-Tuning Regulators (STR). In this thesis, the self-tuning approach is applied. Self-tuning regulators have been developed by Aström and others e.g. [13,14];

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for the control of systems with constant but unknown parameters. The method is also applicable on systems with slowly varying parameters. The regulator is based on recursive least-squares estimator of the parameters of the system. The procedure to obtain a STR can be summarized as follows:

First step: Estimation of process parameters.
Second step: Calculation of controller parameters by using the estimated process parameters.
Third step: Computation of control law.

Such algorithms are called in literature explicit or indirect algorithms [15]. In certain cases it is possible to implement algorithms where the second step is avoided. Such algorithms are called implicit or direct algorithms because the controller parameters are updated directly via a modified model of the process [15].

Self-tuning automatic voltage regulators for synchronous generators are widely investigated and presented in many literature sources like [15,16,17]. Some investigators [16] use the Minimum-Variance technique in designing these regulators. They have yielded good results in many applications. Others, [15] applied different techniques like pole-placement method in tuning the parameters of the controllor and this method proved to be equally successful. The method of tuning the parameters of the regulator used in this thesis is based on the pole-placement design technique. The method is simple and not time consuming. A PID algorithm is chosen to implement the control. The gains of the PID algorithm is no-longer fixed but they are made to vary in accordance with the identified system parameters to achieve a desired closed-loop performance of the power system. The zeros of the PID control algorithm are made to cancel the undesired poles of the controlled synchronous machine. The result of this cancellation technique leads to the computation of the three gain factors of the PID algorithm at every loading condition.

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1.4 MAIN OUTLINES

The present research work aims to develop an efficient self-tuning PID DAVR for a large synchronous generator. The following chapters of the thesis describe this work.

In chapter 2 the mathematical model of the power system under consideration is discussed. The mathematical representation of the digital part of the system is also given in details. A combined mathematical method of representation of the whole system with its continuous and descrete parts is developed, and described. The second part of this chapter is devoted to the application of the least-squares identification method to the present problem. This identification is performed by the determination of a low-order model of the system. The parameters of this model are found from data directly collected from the system inputs and outputs while it is actually controlled. Some results which show the success of this procedure in tracing an experimental process are presented at the end of this chapter.

Chapter 3 is devoted to theoretical investigation of the theory, design and performance of the self-tuning PID DAVR.

This study has been performed by the use of a digital computer. A program which simulates the operation of the power system (continuous part) and the DAVR (Digital part) is developed and used to investigate the system performance under dynamic and transient conditions. The results of transient and dynamic performance of the system as obtained from the computer study are presented and commented upon.

Chapter 4 contains the description of the experimental set-up, special devices, and monitoring circuitry which were built for the experimental study of the DAVR. The experimental set-up contains the power equipment and the special devices. These are the time-constant regulator, the power-angle measurement device of the micro-alternator and the buffers of the D/A and A/D converters of the micro-processor which were designed, built and tested

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