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CONTROL STRATEGY FOR A VARIABLE-SPEED WIND ENERGRY CONVERSION SYSTEM

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CONTROL STRATEGY FOR A VARIABLE-SPEED WIND ENERGY CONVERSION SYSTEM

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Introduction

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Wind energy is one of the renewable energy sources which we are exploring while we are trying to develop different economic generation schemes for the return of produced electric energy to a 60 Hz system. There are two main types of generation systems: fixed entrainment speed and constant frequency at 60 Hz (VEFFC); and variable entrainment speed and constant frequency (VEVFC).

The system we are going to utilize belongs to the second category (VEVFC). Accepting as a given the fact that wind velocity is variable, we plan to employ variable speed mechanical energy, produced by a wind-motor, to drive a variable speed electric generator. In the first phases of our work, we have chosen four different schemes incorporating asynchronous wound rotor machines or a variable speed synchronous machine. (1) For the second phase of our study, we have chosen an assembly employing an asynchonous squirrel-cage induction machine. (2) Within the framework of the present study, we are looking for a control strategy for the wind energy conversion system incorporating a cage asynchronous machine with a static thyristor converter system. The objective of the study is, first of all, to develop mathematical models for:

- the thyristor converter system - autonomous and non-autonomous - serving to supply energy to the asynchronous cage machine and to return the electrical energy to the system;
- the asynchronous cage, tension and variable speed machine.

We are searching for a simple model control strategy for the asynchronous machine and the converters which takes into account control restaints such as amplifier saturation. We will also give the calculation algorhythms for a digital indicator.

Generation Scheme

Description of Functional Power Scheme

A three-phase auxiliary commutation autonomous thyratron inverter represents the main apparatus of the static converters. A rectifier and a thyratron inverter regulated through the system will be added to the above-mentioned. The three-phase rectifier which supplies with continuous tension the autonomous inverter operates at constant start-up angle ($\alpha = 0^{\circ}$). The inverter regulated through the system and operating at constant start-up angle ($\alpha = 150^{\circ}$) returns to the 60 Hz system the energy available in the continuous current connection. The autonomous thyratron inverter is supplied with fixed continuous tension energy and the output supplies a three-phase variable frequency and tension system. Output tension varies linearly in relation to the frequency. This tension variation is obtained by means of a pulse frequency modulation procedure. (3) The employed electromechanic apparatus is an asynchronous cage machine the structure of which is strong and popular. Generally, the rated sideslip for such an apparatus is on the order of from 3 to 5% (generator or motor mode). To obtain with the generator operation within a wide range of speed, we have supplied energy to the asynchronous cage induction generator by means of the autonomous variable frequency and tension inverter, maintaining the flux of the machine constant.

Models of Machine and Electronic Converters

Asynchronous Cage Machines

Based on the usual hypothesis on the sinusoidal distribution of the magnetomotor force in the stator area and the negligible saturation effect, we can set forth a very detailed model of an asynchronous machine according to the well-known d-q transformations (4, 5). According to this method, linearized equations can be developed around an operating point and tranfer functions can be developed between the different input and output. Based on the fact that we are interested in studying the system with a non-linear model and taking into account the different converter groups, we shall use, for the asynchronous machine, a simple and realistic model based on the works described in the article (6): we shall employ the following relation between slips and electromagnetic torque:

$$\Delta C_e = k_t \cdot \Delta f_{sl} \quad (1)$$

where ΔC_e = change in electromagnetic torque

k_t = torque coefficient, constant

Δf_{sl} = change in slip frequency

The transfer function between slip and speed can be established /529 based on the following functional diagram:

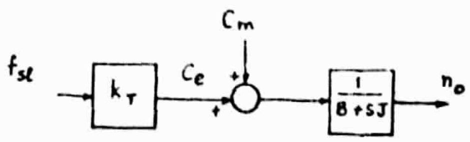


Fig. 1. Transfer function of an asynchronous machine.

For example, the transfer function between speed and slip frequency, when $C_m = 0$, is:

$$\frac{\Delta n_o}{\Delta f_{se}} = \frac{k_t}{B + SJ} \quad \ldots\ldots\ldots\ldots\ldots \quad (2)$$

Static Thyristor Converters

Three-Phase Rectifier

The three-phase rectifier operates at constant start-up angle. Tension at the rectifier's output is, therefore, constant since the energy supply tension of the three-phase source is constant. We must also note that the rectifier supplies active power only when starting up the asynchronous motor and that it is at rest when the operative mode is hypersynchronous.

Non-Autonomous Inverter, Controlled by the System

The non-autonomous inverter, when operating, returns to the system the energy available in the continuous current connection. The start-up angle has been maintained constant at about 150^{o}. Since no change in start-up angle has been provided for, we can consider the inverter input tension as continuous constant tension.

Autonomous Inverter with Auxiliary Commutation

A detailed simulation study is possible with the ATOSEC I computer. (7) However, this simulation will not be carried out in relation to the concept of the control circuit for the generation system. It is well known that, despite the nonsinusoidal tensions at the inverter's output, the electromechanic operation of the machine can be calculated based only on the fundamental tension figures. This approach is popular and is verified by several authors. (8, 9) The diode return bridge operating parallel to the assembly inverter supplies the continuous rectified tension at the autonomous and non-autonomous inverter input. We must note that this diode bridge receives its energy from three-phase tension generated by the asynchronous machine and operating at variable frequency.

The forced switchover in the autonomous inverter circuit is carried out by an auxiliary switchover circuit. The short switchover intervals as well as their related phenomena will not be taken into consideration in the study, since they do not alter the electromagnetic operation of the system.

For the converter and machine assembly we propose the following equivalent circuit:

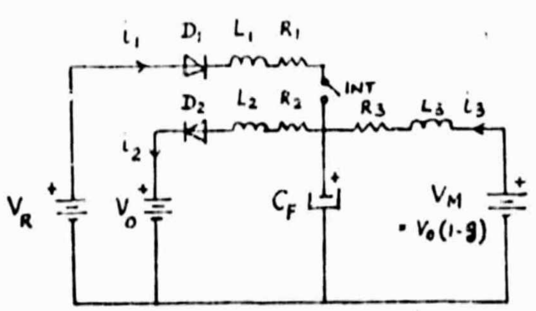


Fig. 2. Equivalent circuit of system.

V_R is the output tension of rectifier

V_0 is the non-autonomous inverter input tension

V_M is the autonomous inverter input tension

g is the slip value

L_1, L_2 represent filtering inductants

L_3 represents the inductants which

limit the value of $\frac{di}{dt}$ in the autonomous invertor thyristors.

C_F represents the filtering condenser

R_1, R_2, R_3 represent circuit resistances

D_1, D_2 represent two diodes which indicate current directions from the V_0 and V_R sources

INT remains open when the asynchronous machine operates in the auto-exited mode

i_1, i_2 represent unidirectional currents in the 1 and 2 branches

i_3 represents the autonomous inverter input current whose instantaneous value can be either positive or negative.

Fig. 3 shows the functional control diagram for the system:

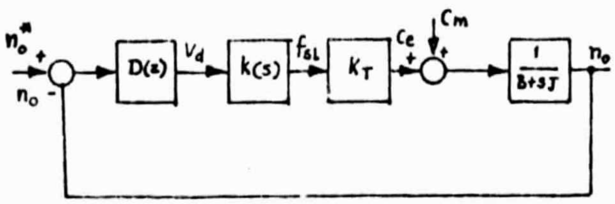


Fig. 3. Functional speed control scheme.

C_m is the engine entrainment torque, for example, a wind engine

C_e is the developed electromagnetic torque; this value is negative for machine operation with hypersynchronous generator

n_o* is the desired operating speed /530

n_o is the real speed of the motor-generator combination

D(z) is a digital speed indicator, to be calculated

K_T is the torque coefficient Nm/Hz

K(s) is the transport function between slip and input tension regulating the autonomous inverter frequency.

Design of an Optimal Digital Indicator

Let's consider the system whose functional control scheme is shown in Fig. 3. By comparing the transfer function between slip and control tension for the autonomous inverter as follows:

$$K(s) = e^{-T_A s} \quad \ldots\ldots\ldots\ldots\ (3)$$

we have an excellent system with a time constant (J/B) and a delay T_A. This delay, T_A, is introduced at the inverter's output, when there is a sudden change in the input signal of the oscillator which controls the operating frequency of the autonomous inverter. The delay T_A can normally vary between 0 and

T/6 where T represents the operating frequency of the autonomous inverter. A study of the system taking into account this variable delay could be quite complicated and we have tried to avoid this difficulty by introducing a sampler followed by a zero setting device. When developing a digital indicator , it is indispensable to introduce this kind of sampler. (10) The digital indicator we want to calculate is called optimal: this means that the regulated output stabilized itself without oscillation within a minimal time. We can demonstrate that this minimal time is expressed in a number of sampling periods equal to the system's order, if there are no ulterior restraints on the control system. In the case of the system under study, it is practical to limit the slip value of the asynchronous machine to the nominal value, this means that the torque is limited to the nominal value. Taking this restraint into account, we can draw a diagram of the system's state variables as shown in Fig. 4.

Having formulated the state equations for the system in Fig. 4, the design of the digital indicator is based on the well-known state transition method. (10) The indicator which has been calculated for the system is given by its transformation into Z:

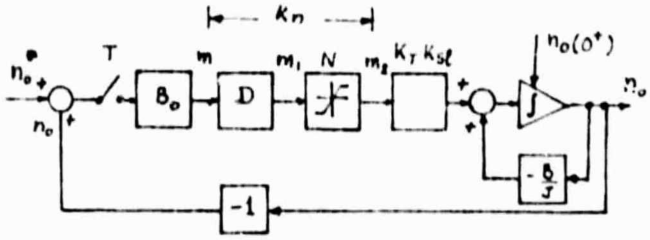
$$D_1(z) = 2.22 + 0.02z^{-1} + 0.02z^{-2} - \ldots$$

when $B = 0.1\text{Nm/rad/sec.}$

$$D_2(z) = \frac{5 + 5z^{-1} + 5z^{-2} + 5z^{-3} + 5z^{-4} + 0.002z^{-5} + 0.002z^{-6}}{1 + 0.75z^{-1} + 0.502z^{-2} + 0.256z^{-3} + 0.009z^{-4}}$$

when $B = 0.01\text{Nm/rad/sec}$

The algorhythm and calculation steps will be detailed in the appendix.



Notes: T sampling period

B_o zero setting device $= \frac{(1 - e^{-Ts})}{s}$

K_n variable digital indicator gain, for example, at t = nT, the gair is k_n

N non-linearity: ideal saturation characteristic

System Parameters	
$n_o^* = 2.5V/2000$ rpm	$J = 1$ Kg m^2
$M_1 = M_2 = \pm$ 5 volts	$K_T = 5$ Nm/Hz
$C_{emax} = 25$ Nm	$K_{s1} = 1$ Hz/volt
	$T = 1$ second

Stress on control variable:

$m_2max = M_2$.

Fig. 4. Diagram of system's state variables.

Conclusions

We have developed models for the elaboration of a variable speed generation system control strategy. The state transition method for the digital control design is very strong and seems well suited to the design obtained through the computer. We expect to develop this calculation method for the calculation of variable speed generation systems controlled by micro computers.

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