RECENT TRENDS IN CONTROL OF ELECTRIC MACHINES

(Inivited Paper)

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ABSTRACT

Two major developments were noticed in the recent years in the topic of control of electric machines. The first was the extensive use of thyristors. Control of cage motors, sl-ipring motors, synchronous machines and d.c. motors are among many applications of thyis-tors. Future trend shall continue to show further applications of thyristors in control of machines.

The second development was in the computer applications. Microprecessors and programmable controllers are showing the begining of a dramatic change in means and methods of control of electric machine whether as a seperate unit or as a part of a plant or a process.

Aditional to the above two major developments, the recent years have shown some progress in investigations and developments of new machines and progress in increasing sizes of existing machines. New control components have seen a progess too.

1. INTRODUCTION

More than a century has passed since the starting of motion of the first rotating electric machine. Imporvments and slow developments of rotating machines continued all through those years. Cage induction motor for instance is still the prime mover providing motive power and absorbing around 30% of electricity in some countries.

Improvment of the performance of many machines is progressing. Generally attention is directed towards increasing efficiencies, reliabilities, and power factors. In other words the target is optimisation of performance in general. This is additional to some progress in developments of some new machines.

It would be impossible to survey all aspects of recent trends in machine control. Hence only main aspects are going to be discussed in this paper.

Thyristor control is definitely one of the major developments in machines control. Its application to various types of machines is going to discussed.(1-23) Microprocessors and programmable controllers are the second major developments (24-28) . Some aspects of their applications are going to be discussed.

The paper shall contain some other aspects of control of machines also (25-33).

2. THYRISTOR CONTROL OF MACHINES

Since the sixties, thyristors have shown increasing number of applications in power engineering, in general, and in controlof electric machines in specific. Larger and larger sizes of thristors are being constructed. Now elements withstanding 3000A and 4000V are in use (14). The general use of thyristor in motor controllers is for speed adjustment, although other uses are also available.

The topic of thyristor control of motors is known as "Adjustable or Variable speed Drives". Since the method of speed adjustment depends on the motor type, drives for different types of motors are going to be discussed. The discussion below shall be explained by some examples which are just for clerifications and by no means the only available methods.

2.1. Drives for slip ring motors.(1,4,5,6,34)

Wound rotor motor's speed is regulated by controlling the rotor current through changing the external rotor impedance. This impedance usually is a rheostat or a set of resistor banks with switches for their removal step by step. At low speeds, efficiencywill be low and a large amount of power is lost in the external resistance. Low speeds are not only encountered at starting conditions but also when the motor is run at a speed which is a small fraction of the working speed. Using the thyristor slip recovery system shown in figure (1), it is possible to rectify the rotor current at slip frequency, regulating the d.c. output and then inverting it to a.c. using an inverter. When the resulted frequency is the same as the supply frequency it may be fed back to the main supply directly. Such circuit usually suffer from low power factor . Hence the use of p.f. correcting network becomes necessary. Compensation network may be as simple as a single capacitive bank or some more complicated circuit. Tiggering of the thyristor gates may be performed through external signals or through signals fed from tachometer along the motor shaft or (and) from a signal proportional to the torque. It may be noticed here that the d.c. current between the rectifier inverter circuit is proportional to the torque.

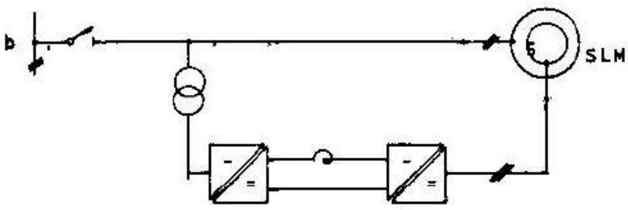


FIG 1 SLIP RECOVARY SYSTEM

Motors of more than 1I W are now driven using such drives.
A second type of slip ring recovery system that has been introduced is called the " Double Range Scherbius" and involves the use of a cycloconverter in the secondary circuit instead of the seperate rectifier inverter circuit.

There has been many other developments in the speed contral of slip ring through the use of thyristors in the rotor circuits. One example is the bang-bang control with three thyristors connected in delta and controlled by triggering signal from tachometers (34).

2.2 Cage induction motor variable speed drives.

Cage induction motors are rigid in structure, efficient in operation (usually 70-90 %), realiable and cheap in general. Its main weakness lies in the difficulty in adjusting its speed, In general, cage motors were used in the past at nearly constant speeds. The change of speed (when necessary) used to be done on the account of substantial reduction of efficiency. There has been many attempts in the early years of the use of thyristors to control cage motors by thyristors in simple ways. However the most common speed control of cage motors now is the variable speed method using the converter-fed drives. This drive had been developed by the late sixties. Recently there has been decisive improvements particularly in increasing power ranges, frequency and speed as well as design optimisation. The effect of curent harmonices on the power system and on the motor temperature at high power was substantially reduced by means of the so called " high-pulse converter circuits". By using high-power thyristors and by simplifying the electronic control system, it was possible to considerably reduce the number of components, and consquently the size and price of the equipment also. The reliability of the components was also increased to a very high level, thus opening the door to more intensive employment of this equipment. The main advantages of the variable speed three-phase drives are their high efficiency, reduced gearing. exact speed control, high operating security, reduced stress on power system, rugged design of motor, minimum maintenance of motor nd some other adwantages. Figure (2) shows an a.c. motor drive producing quasisquare wave output voltage.

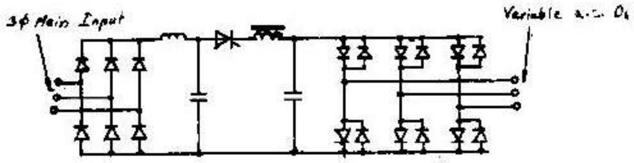


FIG 2 CAGE_MOTOR DRIVE

Voltage control of the output is achieved by inverting the direct voltage into the inverter section and the output frequency is determined by controlling the switching rate of the thyristors in the inverter switching units. By controlling the voltage and fuequency in the electronic circuity, a great deal of flexibility can be obtained because full voltage can be obtained at any frequency .

The lower frequency limit at which a quasisquare drive can operate satisfactorily is about 5HZ when driving a standard 4-pole, 50 HZ motor. This is because 6th-harmonic torque pulsations are produced causing speed varitions at the motor shaft. The upper frequency limit is governed by the inverter design and can be up to 200HZ. This implies a shaft speed of 120 000 r/min for a 2-pole machine (9).

The optimum performance of the a.c. variable speed drive is obtained by continuousely operating the motor close to its synchronous speed. Application of a simple current limiting device to the drive obtains a constant torque performance with minimum drive costs.

The a.c. adjustable drive is similor to the circuit used as an unintterupted power supply (UPS) with a standby battery set connected at the d.c. link and with the output frequency as the required one (may be the same as the input).

Induction motors may be fed also from a d.c. supply via a self-commutating thyristor inverter with an exciting capacitor. Speed and frequency can be varied by varying the copacitor, d.c. voltage and inverter control angle. This type suffers from the ability to start itself, ince it needs a driving starter; but later it is possible to vary the speed while it is on load. Self starting methodsare under study (10).

Another type of static variable frequency drive for induction motors is the system involving pluse width modulation (PWM) section. Such system are characterised by the ability to provide continuous variable frequency and variable voltage control in a single power stage. It has a constant commutating ability irrespective of frequency setting. Control strategy can be programmed to eliminate the significant harmonics in voltage output. However more complex control and circuit configuration is needed. There are different circuits for implementation of this technique; all of them are high frequency constant amplitude pulse train (carrier). Pulse duration of which are then modulated to specific modulation law (trapizoidal or sinusoidal) (15)

It has been reported recently that triangulation schemes employing synchronous modulation are known to be capable of excellent low speed performance (13).

A 2:1 speed - range was developed using a 3-phase modulated supply in which quite accurate prediction of torque/speed performance was realised with symmetrical component techniques (14).

In order to design a proper variable frequency static drive, detailed consideration of the machine performance and waveform distortion levels must be excersised if the most expenditous choice for carrier frequency is to be made (13).

2.3 A.C. Drives for synchronous motors

The unique characteristic of synchronous machine is its constant speed at the synchronous speed. The machine can operate as a motor and a generator. Its construction is more complicated than a cage motor. It shares the necessity of brushes with slip ring motors. By the use of thyristor on the rotating part (exciter), it is possible to operate the machine as a brushless machine. By feeding the stator through an inverter, it would be possible to induce an alterating voltage in an auxiliary winding in the rotor. When this a.c. voltage is rectified, it produce the necessary excitation on the rotor.
Figure (3) shows a simple diagram of this arrangement (1, 17, 18, 19).

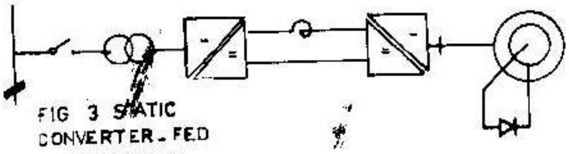


FIG 3 STATIC CONVERTER-FED SYNCHRONOUS MOTOR

The commutation from one phase to another phase of the inverter takes place with the aid of the terminal voltage of the synchronous machine, whichis operated with overexcitation. The forced commutation often required for static frequency converter can be used. The circuit is suitable for operation and braking in either directions, and is employed for maximum power and for frequency up to approximately 120HZ. The main application of this arrangement is in pumps compressors with precision control. Some modified arrangements are often found with two diodes in the rotor side (on two phases). Thid arrangement proved to have a combined effective saliency and very good synchronous performance (19). Rotor position may often be fed back to trigger the inverter thyristors (18). The good performance of the motor at low speed and very high satuation has provided a basis for their design for use traction motors.

Cycloconverters are often used to drive synchronous motors for high ratings with high starting torque and frequencies up to approximately 25HZ. Power up to 10MW for gearless cement mill drives can be met with such drives. It is mostly suited to application of large d.c. drives where d.c. motor can be no longer be used because prevailing ambient conditions, cost or power limitations.

As shown in figure (4), each motor phase is connected to the feeding power system via two static converters arrangement in an antiparallel 3-phase bridge network. A low frequency output voltage is delivered by the converters using phase angle control. With this arrangement, Four quadrant operation, i.e. reversal of the direction of rotation and regenerative braking is possible without addition to the power section of the static frequency converter or to the machine. Thus the system corresponds in full to a four-quadrant d.c. drive

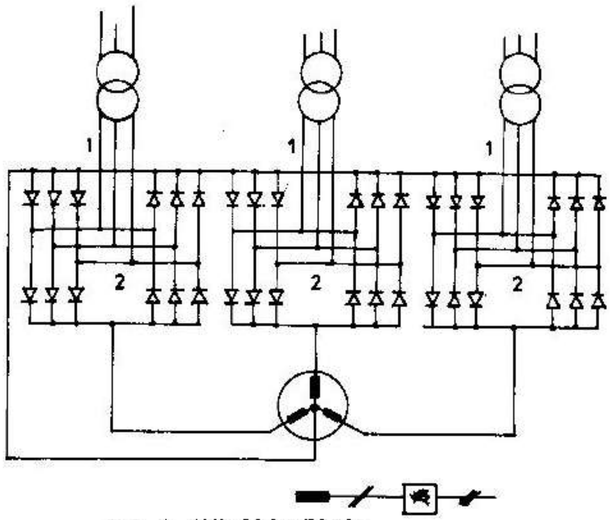


FIG 4 CYCLOCONVERTOR

There are other types to be used with synchronous motors, such as the synchrosil drive (8) shown in figure (5). It is a speed control system for synchronous motors. The converter section is a standard one. To generate maximum torque from the sychronous motor this current is switched into the motor stator windings at the correct phase position with respect to rotor anglular position sensor, by an inverter bridge. When running above about 5% of full speed, the back emf generated by the synchronous motor is sufficient to commutate the current into the next arm of the inverter.

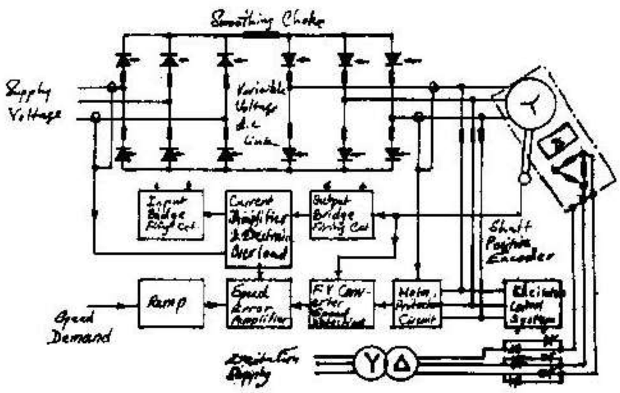


Fig 5 SYNCHROSIL DRIVE

2.4 Thyristor chopper for D.C. Motors

There has been extensive research efforts for development of chopper circuits. Many of these circuits were designed for feeding series wound d.c. traction motors. Figure (6) shows a basic circuit for resonant power controller. Power here is converted from constant d.c. voltage to a variable d.c. voltage. These controllers consist of thyristor and reasonant LC circuit. Resonance is initiated by the thyristor which is subsequently turned off by the voltage developed in the resonant circuit. The energy stored on the capacitor is then allowed to discharge in the circuit.

The power flow is determind by the repetition rate of the tr ggering of the thyristor. Many developments on this circuit and others have been reported in published litratures (20).

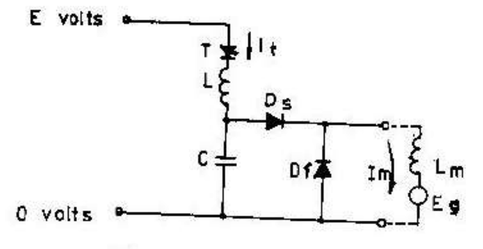


Fig 6 CHOPPER CIRCUIT

The major difficulty with chopper circuits used in d.c. traction drives is their interference with communication systems.
A lot of effort had been concentrated on the reduction of such interference to minimum (21, 33).

2.5 Further thyristor control of machines

Thyristor control had entered the machines applications other than those mentioned above too.
Transformers control by thyristor is performed according to the regulating transformer booster. A voltage regulator selects part of the supply voltage waveform by means of phase controlled switches and thus provides fast and phase controlled regulating booster (23).

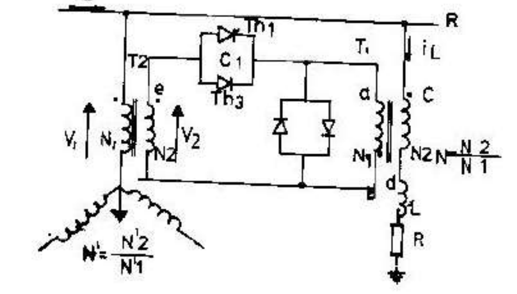


Fig 7 TRANSFORMER BOOSTER

The d.c. link mentioned above for cage motor control and other applications, finds its use for control of induction generator also. Self - excited induction generator controlled rectifier units eliminates the problems of voltage and frequency variations inherent in self excited induction machines.
The induction generator can be operated in the liner region of the magnetisation curve while feeding a variable d.c. load at constant voltage. The unit can be used to feed controllable power into existing a.c. network through a d.c. link (16). See figure (8).

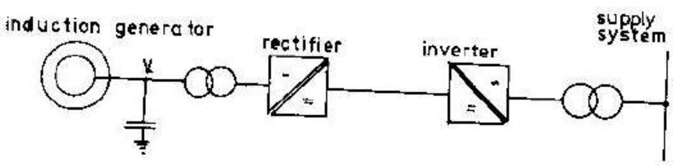


Fig 8 INDUCTION GENERATOR UNIT

Superconducting turbogenerators has seen the introduction of thyristor control also. Since the field winding of such machine has a negligible resistance, the field time constant is exceptionally large (300-800 sec). Hence obtaining voltage regulation will be difficult. The solution to this problem is by providing a thyristor controlled compensation to provide reactive power at the terminal of the super conducting generator (30).

3. COMPUTER CONTROL OF MACHINES

The use of computers to control industrial processes started in the early sixties. Recently many complete plants are operated by central computers with very little human interference. Nearly all industrial processes contain one kind of machine / or another. Hence in general, machines are controlled by computers as part of a plant rather than a stand - alone unit . Machine control by computer, in general, may consist of speed control, protection system, interlocks (sequence of events) with other units, connection with measuring and recording equipment etc.
Large industrial plants now are controlled by central computer (or computers) and some decentralised small computers(microprocessors or programmable controllers).

3.1 Programmable controllers

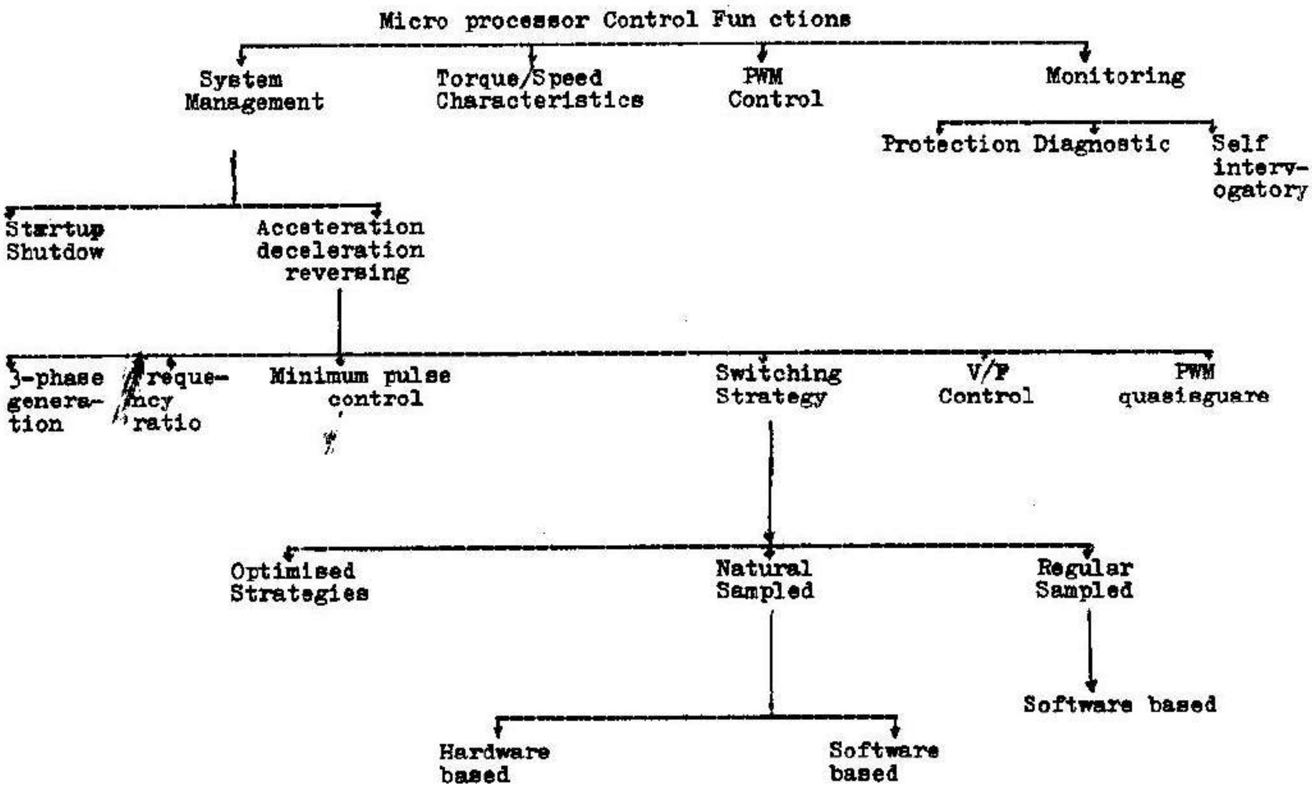
Programmable controllers has been recently a wide range of applications in power engineering and process control. They are replacing " hard wire " control systems. Installation cost are considerably less than hard wire systems. They are easy to program. And it is easy to modify their programs.
Input and output may consist both of analog or digital signals or both depending on the units to be operated upon. Such controllers may contain several handereds of input and output terminals. It can perform almost all mathematical operations needed in such systems usually with simple programming instructions and sometimes with ready made softwave, hence covering a wide range of assignments for the control of industrial processes.

3.2. Microprocessor control of speed and voltage

Microprocessors are now used for speed regulators and voltage control in power systems. Synchronous machine as part of large power systems has a complicated behaviour. On line simulation for systems and henee dedeuction of control options and modifications are carried by microprocessors. Multivariable controllers for turbogenerators are also operated by such units for optimisation of operation of such big unit (26). Many other applications are now in operation.

3.3 Microprocessor control of thyristor drives.

Microprocessor control of power electionic equipment offers the possibility of improvements in manufactures, reliability, maintenance and servicing, and increased control flexibility. Pulse with modulation technique used in thyristor drive meed a complicated triggering signalling. Control of such drives, Microprocessor makes life easier. Below is the hierarchy of the possibility of implementation of Microprocessor control of such system (3, 27).



4. FUTURE TRENDS IN POWER ELECTRONICS

Inspite of large expansion in the applications of thyristor, new semiconductor devices are under serious investigations, some of these are the Gate Turn off switches (GTO) as switching elements, D-MOS (power MOSFET), BIP-MOS (hybrid with MOS drive and pipolar output) etc. The fastest device and the one with the most rapid growth prospect is the power MOSFET. This comprises many small transistor cells connected in paralled as many as 100 000 per cm^2. Each cell becomes a restive path through the crystal when a bias is applied to its gate terminal. GTOS are now showing some use in motor-control applications and in switching circuits up to 35KHZ(31).

Power transistor of 400V and 350A now in use with "ON" and "off" time less than 10^{-8} controlled from a ba se current less than 0.1 A. They are now used for connecting AC supply source to the load without direct conection to solid state device. They offer limited harmonic generation and reflection on supply circuits. Time load control is not required.

Controllers using transistors now find a wide range of applications in slip/motor, control of reduced voltage starting of large motors distribution transformers, a.c. load switching, energy conservation system and the future will show some serious competition to thyristors.

5. FUTURE TRENDS IN MACHINES CONTROL

Future trends in machines construction will continue to show larger and larger sizes of machines. Solid state compoments development shall see an accelerated progress and shall be implemented in machines control with more complications in circuits. Energy saving controllers to improve efficiency and reliability are going to expand. Computer controlled (Central and distributed) machines are going to be/wide use. Futher joint combinations of machines and electronics in many application are going to be noticedin the future more frequently even to the extent of implanting electronic circuits inside the machines.

Investigations into new machines fields such as large trubo generators, superconduction machines magneto hydrodynamics, Wind generators and other types of machines shall need extensive research into their various aspects of operation and control.

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