TRIAC-DIAC Based DC Series Motor Speed Controller for Mud Pumps of Drill-Rig Equipment

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***Abstract*—The present investigations relate to the development of TRIAC-DIAC based DC series motor speed controller for mud pumps of industrial drill-rig equipment. This paper deals with mud pumps on drilling rigs provide the means for supplying flow and pressure of the chemical mud fluid through the drill pipe, drill bit and return to the surface via the annulus of drill pipe. In this process, the mud maintains down-hole pressure, cools the drill bit and removes the cuttings from the well bore. Since flow is proportional to motor speed and pressure is proportional to motor current, flow and pressure signals can be obtained from the speed calculator card and from the field current of the DC series motor. The speed control of a dc series motor using a TRIAC together with a bridge rectifier is developed. The TRIACs of today are well suited to the requirements of switching inductive loads. TRIAC control circuits must be particularly well tuned to be both economical and applicable to inductive loads.**

***Keywords*—Mud Pumps, DC Series Motor, TRIAC, DIAC, Speed Calculator**

I. INTRODUCTION

The speed control of dc series motors using thyristor switching elements is now very widely used for drill rig equipment, particularly in mud pumps applications. A variety of schemes have been evolved incorporating these elements for such purpose. Half-controlled converters and full-controlled ones are examples for such schemes. The steady-state and the transient behaviour of converter controlled dc series motors, assuming linear and nonlinear models, were the subjects for many authors [1, 2, 3, 4]. Doradla has also used a single thyristor switch together with a bridge rectifier to regulate the speed of dc series motors [5]. In all the above mentioned control schemes phase angle method of thyristor triggering is used. The motor speed is controlled by advancing or retarding the triggering angle of the thyristor.

There was only one published attempt to use the other method of thyristor triggering, namely the integral-cycle method of triggering to control the speed of dc series motors [6]. However theoretical analysis was not given and only experimental results was presented.

In this paper the method of controlling the speed of a dc series motor using an integral-cycle controlled single TRIAC and a bridge rectifier is investigated. Magnetic saturation, iron losses, mechanical losses and the dependence of motor self inductance [7] on armature current are considered. The suggested analysis is useful for the proper choice of the TRIAC rating and the proper design of the protective schemes.

II. MUD PUMPS

Mud pumps on drilling rigs provide the means for supplying flow and pressure of the chemical mud fluid through the drill pipe, drill bit and return to the surface via the annulus of drill pipe. In this process, the mud maintains down-hole pressure, cools the drill bit and removes the cuttings from the well bore [8].

The motor(s) driving the mud pump through a chain and sprocket must have the ability for variable speed since flow from the positive displacement simplex, duplex or triplex pump is directly proportional to speed. Since down hole conditions require a variable flow rate, the ability to vary the motor speed is essential. Output mud pump pressure is determined by the hole

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depth, natural down hole pressures, drill bit nozzle sizes, pipe size and restrictions of the mud flow path. Under surface drilling conditions, the pressure requirements are at their minimum. As the hole progresses to deeper conditions, the pressure requirement is increased which is met by the increased motor torque [9].

Since flow is proportional to motor speed and pressure is proportional to motor current, the voltmeter and ammeter recording the activity of a shunt type motor accurately depicts the flow and pressure conditions of a mud pump. Through proper calibration, the voltmeter can display flow in gallons / minute while the ammeter displays mud pump pressure in pounds / square inch for a given liner size. In the event a series type motor is used, flow and pressure signals can be obtained from the speed calculator card and from the field current. Accuracy of this information to correlate flow and pressure to speed and current is not as precise as with a shunt type motor but will provide a general indication of conditions. Mud pump applications typically require a continuous rating on the part of the motor.

III. DC SERIES MOTOR FOR MUD PUMP

When supplied power from a DC generator, the series type DC motor was avoided in drilling applications because of the possibility of over speed conditions when its mechanical load was suddenly decreased or lost.ˉ However, with the introduction of the TRIAC –DIAC based regulator, the ability to control the over speed condition of the series motor was solved.

The basic equation for speed (N) of a series type DC motor is:

$$\mathrm{N} = \frac{V_a - I_a R_a}{K_1 I_a} \tag{1}$$

where, N = motor speed in RPM,
K_1 = a proportional motor constant,
V_a = motor armature voltage,
I_a = motor armature current = I_f = motor field current.

This equation states that the motor speed is directly proportional to the ratio of voltage to current. With a fixed value of armature voltage, decrease in field (or armature) current will cause a corresponding increase in motor speed and vice-versa. The TRIAC-DIAC based electronic regulator has the ability to respond very rapidly when called upon in certain situations. For example, when a heavily loaded mud pump being driven by a series DC motor has its drive chain break, the series motor could over speed to destruction. With electronic detection of decreasing motor current when the chain breaks, the regulator can either be turned off completely or "phased back" to remove or reduce the armature voltage to prevent this runaway condition.

The series motor has several operating characteristics in drilling applications:

- No separate field supply is needed with a series type DC motor for normal operation. However, when regenerative or dynamic braking a series motor, some manufacturers provide a separate high current field supply to create this mode of operation for the drawworks motor. With the mud pump and rotary table, braking with the field supply is not required.
- When reversing is not required, such as with the mud pump motors, only two conductors are required to the motor.
- To prevent over speed and to regulate speed under normal operating conditions, an electronic "speed calculator" card is required in conjunction with the TRIAC-DIAC based electronic regulator.
- The DC series motor produces greater torque than the shunt motor at the upper end of the torque-current curve. This is a result of the mechanical construction of the field coils which take up less space than the multiple small shunt coil wires to get the same electrical flux / torque. A comparison between the shunt and series motor torque-current curves is shown in Figure 1.

The correlation of speed to voltage of a series motor is not as accurate as with a shunt type motor. This is because speed is a function of both field current and voltage. Consequently, a load change (torque / pressure in a mud pump) will result in a change in current. Since field current and armature current are the same in a series motor, this then results also in a speed change.

$$\mathrm{T} = K_2 \times I_a \times I_f = K_2 \times I_a \times I_a = K_2 \times I_a^2 \tag{2}$$

where, T = torque,
K_2 = motor design constant,
I_a = motor armature current = I_f = motor field current.

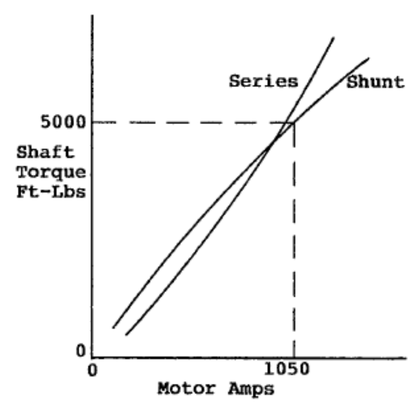

Figure 1. Torque current curves of shunt and series type DC motors

IV. SUGGESTED TRIAC-DIAC BASED MOTOR CONTROL SCHEME

The TRIACs of today are well suited to the requirements of switching inductive loads. TRIAC-DIAC control circuits must be particularly well tuned to be both economical and applicable to inductive loads. The TRIAC-DIAC based motor control scheme suggested for our study is shown in Figure 2. It consists mainly of a single TRIAC connected in series with the bridge rectifier and ac supply lines. The motor current is rectified using a bridge rectifier. The bridge provides also a relaxation path for the motor current during the extinction period of the TRIAC. The motor is controlled by applying a conduction period of a complete number of supply cycles followed by an extinction period of another number of supply cycles to the motor terminal. The necessary firing circuit for such method of TRIAC triggering was developed.

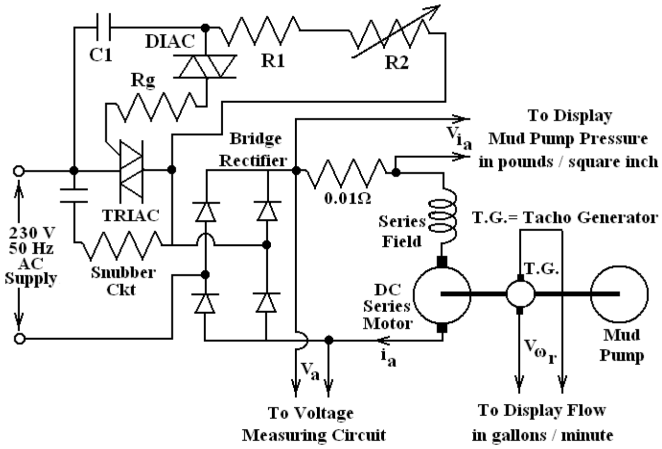

Figure 2. Suggested TRIAC-DIAC based motor control scheme

The TRIAC-DIAC based suggested motor control scheme can be simulated with the help of PSPICE software under the following assumptions:

- The TRIAC and diodes are assumed to be ideal switches.
- Skin effect in armature conductors and field winding is neglected, so that the total motor series resistance can be assumed constant.
- Eddy current losses in armature conductors and in field winding are also neglected.
- The relation between the motor current and the induced e.m.f is described by the magnetization curve.
- Armature reaction and brush voltage drop are ignored.
- The mechanical losses for both motor and load generator are non linear functions of motor speed.
- The iron losses for both motor and load generator are also nonlinear functions of magnetic flux and speed.
- The motor se1f inductance varies with the variation of the motor armature current.
- The source inductance is neglected.

V. RESULTS AND DISCUSSION

The circuit is simulated by PSPICE software. The speed control of the dc series motor used in mud pump is obtained by armature voltage control method. And this variable voltage can be availed by changing the variable resistance R2. It has been observed from the PSPICE simulation that for higher value of R2, the area of voltage across TRIAC [shown in Figure 3] is more and as a result the area of voltage across motor terminal [shown in Figure 4] is less and vice versa. So, by changing the resistance R2, TRIAC firing angle is changed and variable voltage appeared across the motor terminal and different speed of motor as well as different speed of mud pump can be obtained.

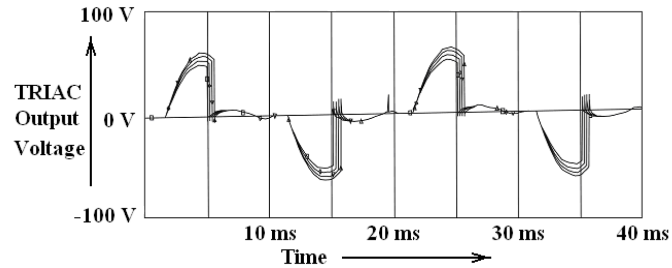

Figure 3. Wave form of voltage across TRIAC

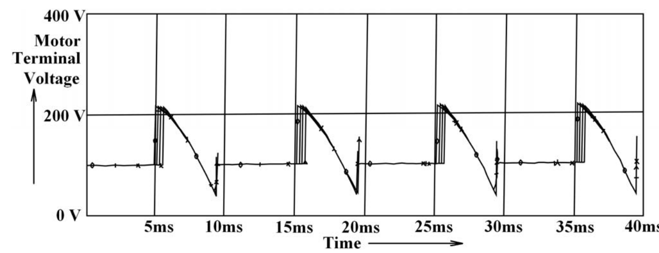

Figure 4. Wave form of voltage across motor terminals

VI. CONCLUSION

The performance characteristics of a dc series motor having an integral-cycle controlled single TRIAC connected in series with one of its ac supply lines is studied. The motor current is unified using a rectifier bridge. It shows that the average speed of a dc series motor can be controlled using the suggested scheme presented in this paper. However speed ripple, vibration and noise may probably make this form of control unsuitable for large motors. Speed ripple has to be reduced to improve motor dynamics. This will be investigated in a future study. This control strategy combines both the advantages of integral-cycle and phase controlled drives. The control scheme for our study which is shown in Figure 2 can be supplied from the output of a higher frequency power. The saturation in the magnetic circuit, the iron losses, the mechanical losses and the variation of the motor self inductance with the armature current will be considered in the digital simulation of the motor model for future work. The validity of the mathematical model can be checked experimentally. A microprocessor aided measuring circuit can be used to measure the motor performances. In this paper DC series motor is used with DIAC-TRIAC based speed controller. The operating circuit is simulated using P-SPICE software. The simulation results are found feasible for real implementation as per as mud pump operation is concerned.

ACKNOWLEDGMENT

For this work, PSPICE software was supported by UNIVERSITY GRANTS COMMISSION (UGC), Bahadurshah Zafar Marg, New Delhi, India, Govt. of India, project no. UGC (33)/2008-2009/221/EE

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