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Aluminium Smelting Plant Direct Current Machines Transient Control Using Silicon Control Rectifier Speed Control

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ABSTRACT
Aluminum Smelting Plant Direct Current machine transient control using silicon control rectifier speed control is presented. Stress on Aluminum Smelting plant systems is increasing day by day, due to faults and sudden load change that constitutes negative threat to Aluminum Smelting plant stability. Study was carried out to examine the capacity and transient stability of the Aluminum Smelting plant so as to maintained quality services. Aluminum is a silver white, lightweight metal, soft and is increasingly used in a huge variety for making products in aluminums smelting plant which includes: ships, cars, spacecraft construction, electronics, power lines, kitchen utensils, window frames because of its peculiar properties. It can be casted, melted, formed, machined and fabricated. Smelting is the process by which a metal is extracted from an ore and forced beyond its temperature of melting point. Direct current (DC) machines are electro-mechanical energy converters in which the electrical energy is exchanged with their supply load in the form of direct voltages and currents. Silicon Controlled Rectifier (SCR) used is a high-power control and has 3 terminal and 4 solid state layer semiconductor current controlling device. SCR dc controller allows electricity to flow in one direction but with the added ability to be able to turn it on and off. The laboratory experiment conducted shows that as the rheostat 'R' was varied until armature voltage'E_A' = 180Vdc. The effect upon the dc machine speed and the armature voltage'E_A' shows that at low dc machine speed, the armature conducts late. The highest speed obtained was 3560 rev/min before the dc machine turned 'OFF'. Silicon Control Rectifier (SCR) reactance '$'X_L$'' filter choke was incorporated and connected to terminal 3 and 10 of the SCR to provide filtration for the smooth operation of the dc machine in the Aluminum smelting plant to prevent heavy armature transient surge current. Silicon Control Rectifier Capacitor '$'C_2$'' the electrolytic filtering capacitor was connected across the dc machine and the armature winding was connected to terminal 8 and 1. Since the capacitor have to discharge through armature winding when the SCR is not conducting and for the smooth running of the dc machine then terminal 8 and 11 was used for the smooth operation of the dc machine instead of terminal 8 and 1. The dc machine was observed to vibrate cooler than before because, the capacitor absorbs the current peak during each cycle rather than the armature. The experiment on the drives performances and the dc machine run-up characteristics using silicon control rectifier speed control for various results was presented graphically for dynamic study and recommendation for machines designers, engineers and operators of Aluminum Smelting plants industries.
Keywords: Rectifier, Smelting, Ore, Semiconductor, Transient, Filtration, Capacitor, Rheostat, Reactance.

1.0 INTRODUCTION
Aluminum Smelting Direct Current machine transient control using silicon control rectifier speed control is presented. Stress on Aluminum Smelting plant systems is increasing day by day, due to faults and sudden load change that constitutes negative threat to Aluminum smelting plant stability. Study was

carried out to examine the capacity and transient stability of the Aluminum smelting plant so as to maintained quality services. Aluminum is a silver white, lightweight metal and soft that is increasingly used in a huge variety of aluminums smelting industries for products making, such as ships, cars, spacecraft construction, electronics, power lines, kitchen utensils, window frames because of its peculiar properties [2, 5, 7]. It can be casted, melted, formed, machined and fabricated. Smelting is the process by which a metal is extracted from an ore and forced beyond its temperature of melting point.

Figure 1a: Direct Current Machine (UNIPORT)

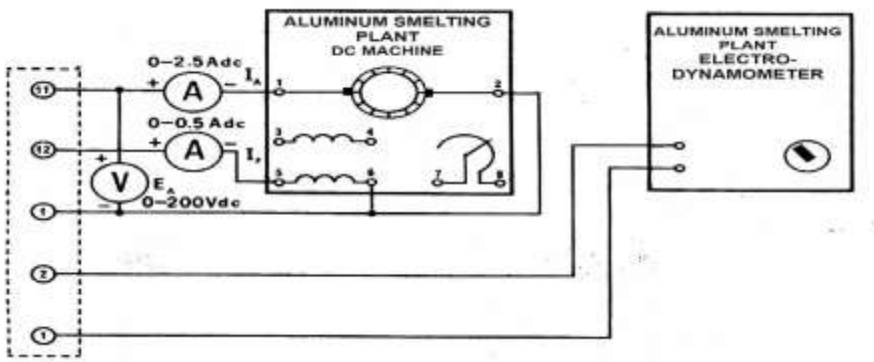

Figure 1b: Direct Current Machine Circuit Diagram for Aluminum Smelting plant

2.0: ALUMINUM SMELTING DIRECT CURRENT MACHINE

Aluminum Smelting Direct Current machine is electro - mechanical energy converter by which the electrical energy is exchanged with supply load in the form of direct voltages and currents Aluminum smelting plant direct current (DC) machine and circuit diagram is as shown in figures 1a and 1b. The direct current machine of aluminum smelting plant electronically controls variable magnitude of dc component of voltage through controlled rectification of a sinusoidal alternating current (AC) supply. [3,6, 7] There are three types of DC machines used; Series machine, Shunt machine, and Compound machine. The series dc machine was used for high starting torque and speed variation such as vacuum cleaner, air Compressor, cranes, and traction system. [5,8, 9]

Aluminum smelting silicon-controlled rectifier (SRC) used for high power control 3 terminal and 4 solid state layer semiconductor current controlling device. SCR dc machine controller allows electricity to flow in one direction to turn the dc machine 'ON' and 'OFF'.

Aluminum Smelting DC machine Silicon control rectifier (SCR) circuit diagram as shown in figure 2 and was arranged so as to provide only unidirectional flow of current to the dc machine from the alternating current (AC) supply. The half-wave, full-wave, single phase was used in the system. The AC point was control through the uses of SCR where the dc machine was fired to maintain the SCR from firing during the initial period. The maximum dc voltage was equal to that provided by the basic diode circuit and may be reduced from maximum to zero. [1, 4, 6] Aluminum Smelting plant Direct Current (DC) machine transient control from zero to maximum varying the armature voltage while keeping the field voltage control constant. [5, 8, 12] The control element varies the power applied to the dc machine through the uses of SCR. [1, 12] The SCR is a solid-state device whose function is analogous to that of the grid-controlled thyratron tube. It passes current in one direction only and rectifies. It turns and passed current upon the receipt of a trigger signal on the control electrode known as gate. As it turns 'ON' SCR continues to conduct until the polarity of voltage across reversed. [3, 11] The point during the positive half-cycle of the input current which the rectification turned 'ON' was adjusted by the timing of the applied trigger signal to the gate. The SCR turned off at the end of the positive half-cycle as the polarity of the applied voltage reversed.

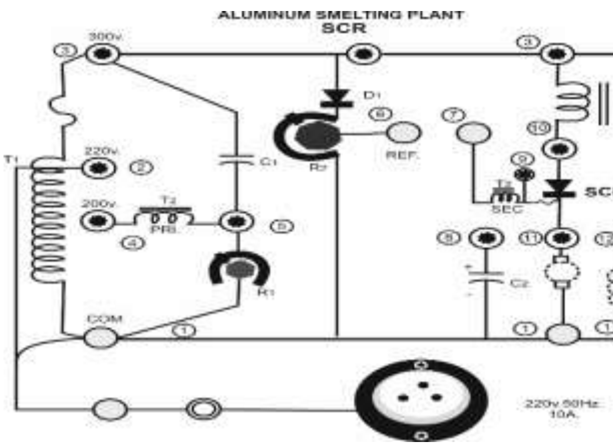

Figure 2: **Aluminum Smelting Plant SCR Speed Control Circuit Diagram**

The phase control the amount of power transmitted through the SCR was reversed by controlling the phase relationship of the triggered signal to zero axis crossing the positive half-cycle of alternating current. Form factor which is the measured of the departure of pulsating, unfiltered and unidirectional current of this nature from a steady direction current. The form factor is one and the unidirectional current is determined by the root means square (r m s) value of the current divided by the average value of the current. Full-wave=1.11 and half-wave =1.57. DC machines operating half-wave of form factor of 1.57 have rectification of 2.5times the heat rise of the same machine operating on unity form factor in addition to 1^2R losses. Commutator and brushes wear are accelerating when operating at a high form factor. High form factor affected the machines operation at low speed.

3.0: Component of SCR Speed Control for Aluminum Smelting Plant DC Machine

Aluminum Smelting SCR speed control has the following feature: It operate at 220Vac, Rectifies alternating current, varies DC machines by retarding the firing angle of SCR and allows firing angle to change. The major component that form Aluminum Smelting DC machine SCR speed control is as shown in figure 2 and 3 circuit diagram.

SCR Transformer'T_1' is autotransformer which changes the 220Vac terminal 2 and 1 to 300Vac terminal 3 and 1. The transformer is center tapped terminal 4 giving 200Vac between terminal4 and 1 or terminal 4 and 3.

SCR Capacitor ''C_1'' and **Rheostat'R_1'** Varying'R_1' the phase angle voltage between terminal 4 and 5 change from zero to150 degree lag.

SCR Transformer''T_1''Primary winding voltage between terminal 4 and 5 step down the secondary voltage of terminal 7 and 9 of the transformer T_2' varying rheostat R_1' The change from zero to 150degree with respect to the zero unit the 300volts output 1 and 3 of the transformer 'T_1'

SCR Diode '$'D_1$'' and the potentiometer '$'R_2$'' are the dc reference voltage terminal 6 and 1, this was vary from 0 to 140Vdc. (Closed loop control system).
SCR Reactance '$'X_L$'' is the part of the SCR that provide filtration for the smooth operation of the dc machine in the Aluminum smelting plant and prevent heavy armature transient surge current terminal 3 and 10.
SCR Silicon Control Rectifier (SCR) The SCR anode, cathode and gate are the terminal 10, 11 and 9. The AC voltage across the transformer '$'T_2$'' at the terminal 7 and 9 cause the gate at the terminal 9 of the SCR to trigger the SCR on earlier and later in the cycle as setted on the rheostat '$'R_1$'' control terminal 7 and is connected to terminal 11 of the SCR. for Closed loop system.
SCR Armature 'A' Terminal 1 and 11 was connected to the armature of the dc machine terminal 11 and is positive with respect to terminal1 at ground potential.
SCR Capacitor '$'C_2$'' The electrolytic filtering capacitor was connected across the dc machine and armature winding connected to terminal 8 and 1. Since the capacitor have to discharge through armature winding when the SCR is not conducting and for the smooth running of the dc machine then terminal 8 and 11 was used for the smooth operation of the dc machine. The dc machine was observed to vibrate cooler than before because the capacitor absorbs the current peak during each cycle rather than the armature.

4.0: MACHINE MATHEMATICAL MODELLING

The sum of voltages of three phase balance system voltages are zero, as a result the zero sequence voltage will be zero. The voltage transformation in the stator reference frame for this type of source can be written as the stator of the machine windings as the wound rotor winding of synchronous machines are similar [8, 9]. Thus, d, q equations of the machine in the rotor reference frame are [4, 9]

$$V_q = R\, i_q + p\lambda_q + \omega_s \lambda_d \tag{1}$$

$$V_d = R\, i_d + p\lambda_d + \omega_s \lambda_q \tag{2}$$

Where

$$\lambda_q = L_q\, i_q \tag{3}$$

And

$$\lambda_d = L_d\, i_d + \lambda_{df} \tag{4}$$

V_d and V_q are the d, q, axis voltages, i_d and i_q are the d, q axis stator current, L_d and L_q are the d, q axis inductance, λ_d and λ_q are the d, q axis stator flux linkages. While R and ω_s are the stator resistance and inverter frequency, respectively. λ_{df} is the flux linkage due to the rotor magnet linking the stator. [9, 10, 11]

The electric torque is

$$T_e = 3\, p\, [\lambda_{df}\, i_q + (L_d - L_q)\, i_d\, i_q] / 2 \tag{5}$$

And the equation for the machine dynamic is

$$T_e = T_L + B\omega_r + J\, p\omega_r . \tag{6}$$

P is the number of pole pairs, T_L is the load torque, B is the coefficient, ω_r is the rotor speed, and J is the moment of the inertia. The inverter frequency is related to the rotor speed as follows:

$$\omega_s = p\omega_r . \tag{7}$$

The machines model is nonlinear as it contains product terms such as speed with i_d and i_q. Note that ω_r, i_q and i_d are state variables.

Machine equation is presented in (1)-(6) and express in state-space form shown in (8) - (10):

$$p\, i_d = (V_d - R\, i_d + \omega_s L_q\, i_q) / L_d \tag{8}$$

$$p\, i_q = (V_q - R\, i_q - \omega_s L_d\, i_d - \omega_s \lambda_{df}) / L_q \tag{9}$$

$$p\,\omega_r. = (T_r - T_L - B\,\omega_r) / J. \tag{10}$$

Machine results in a good number of simultaneous of non-linear equations that are algebraically in nature and their solution may be cumbersome. These mathematical transformations make complex system simple to analyze and solutions easy to find. [1, 9, 10, 11] the analysis is simplified by a change of variable for current, voltage and flux linkage. d, q variable are obtained from a, b, c variable through the park transform as define bellow:

$$\begin{bmatrix} v_q \\ v_d \\ v_o \end{bmatrix} = 2/3 \begin{bmatrix} \cos(\theta) & \cos(\theta - 2\pi/3) & \cos(\theta + 2\pi/3) \\ \sin(\theta) & \sin(\theta - 2\pi/3) & \sin(\theta + 2\pi/3) \\ 1/2 & 1/2 & 1/2 \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \tag{11}$$

These a, b, c, variables are obtained from the d, q variables through the inverse of the park transform defined below:

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \begin{bmatrix} \cos(\theta) & \sin(\theta) & 1 \\ \cos(\theta - 2\pi/3) & \sin(\theta - 2\pi/3) & 1 \\ \cos(\theta + 2\pi/3) & \sin(\theta + 2\pi/3) & 1 \end{bmatrix} \begin{bmatrix} v_q \\ v_d \\ v_o \end{bmatrix} \tag{12}$$

The transformation applicable to current and linkages, total input power to the machine in term of a, b, c variables Balance system. [9, 10]

$$\text{Power} = v_a\, i_a + v_b\, i_b + v_c\, i_c \tag{13}$$

Thus, in d, q variables,

$$\text{Power} = 3\,(v_d\, i_d = v_q\, i_q\,) / 2 \tag{14}$$

The experiment was carried out in the research laboratory [UNIPORT]. The materials and component used are SCR speed control, DC machine, Electro-dynamometer, DC metering, Hand tachometer, Connecting leads, Timing belt. Using these instruments, materials and component, the DC Machine, Silicon Control Rectifier Speed Control and the Circuit Diagram for Aluminum Smelting Plant SCR was connected as shown in figure 3.

The armature of the dc machine was connected in series with armature to terminal 11 and 1. The shunt field of the dc machine was connected in series with the milliammeter at terminal 12 and 1. The voltmeter (0-200Vdc) was connected across the armature power supply source to terminal 11 and 1 and terminal 7 and 11 was connected together to trigger the signal from the secondary of transformer ‘$'T_2$’ as applied to the gate of the SCR. The rheostat ‘$'R_1$’ was adjusted for full anticlockwise position for maximum

resistance. The reactance '$'X_L$' was short out by connecting a wire lead between terminal 3 and 10. The power supply of 220Vac was connected to the input of SCR. The power supply was switched 'ON'.
The effect upon the dc machine speed and the armature voltage'E_A' was noted as the rheostat 'R' was varied. The rheostat 'R' was adjusted until armature voltage'E_A' = 180Vdc. It was observed that at low dc machine speed, the armature conduct late. The highest speed obtained before the dc machine turned 'OFF' was 3560 rev/min.
The armature current, field current and motor speed was recorded as shown in the table1.

Table 1: Experimental result record of DC Machine Silicon Control Rectifier (SCR) Speed Control

S/N	E_A (volts)	I_A (amps)	I_f (amps)	Speed (rev/min)
1	180	0.35	0.450	1500
2	195	0,35	0.445	1620
3	210	0.35	0.440	1446
4	235	0.35	0.440	2000
5	250	0.35	0.440	2910
6	275	0.35	0.440	3560

The dc machine was coupled with the timing belt to electro-dynamometer as shown in figure 3. The electro-dynamometer control knob was fully adjusted anticlockwise for minimum loading and the rheostat was set at its full clockwise position for maximum resistance. The power was turn 'ON' and the speed rheostat control knob was adjusted and the electro-dynamometer control knob was also adjusted for the motor speed of 1500rev/min at a loading of 3Ib.in.ft. The armature voltage, armature current and field current was recorded as E_A = 200V dc, I_A = 2.55A dc, I_f = 300A dc. An Appreciable sparking at the brushes and appreciable machine vibration was noted and at the frequency of 50Hz

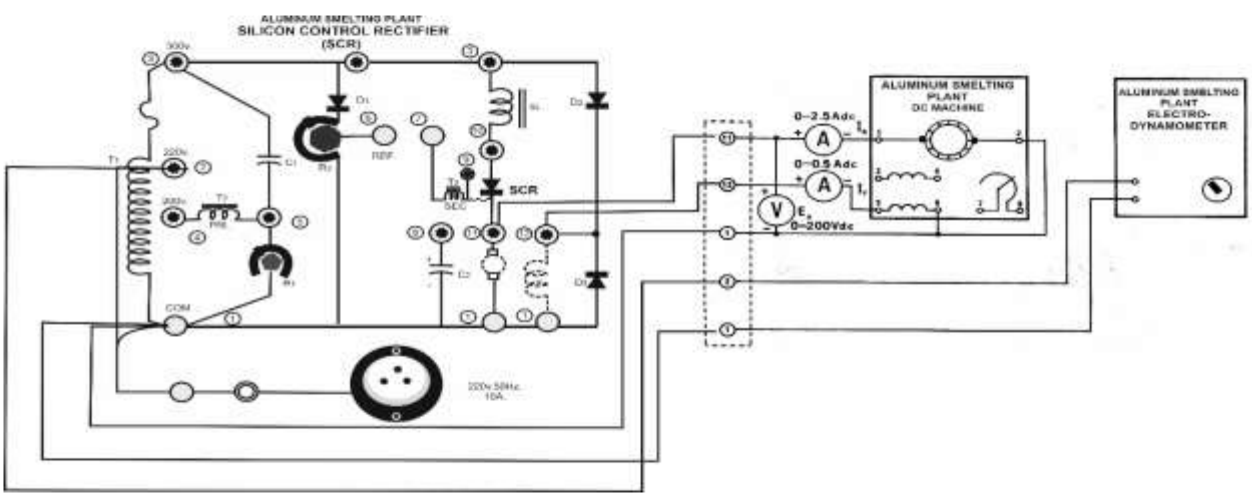

Figure 3: DC Machine Silicon Control Rectifier (SCR) Speed Control Circuit Diagram for Aluminum Smelting Plant

Table 1: DC Machine Silicon Control Rectifier (SCR) Speed Control for Aluminum Smelting Plant parameters in simulation model with SCR Speed control.

Stator leakage inductance	2.59Mh
q-axis rotor leakage inductance	40.61Mh
d-axis rotor resistance	0.8113Ω
q-axis rotor resistance	1.6226Ω
q-axis magnetizing inductance	40.69Mh
d-axis magnetizing inductance	19.05mH
d-axis rotor leakage inductance	18.97mH
Load torque	7.63Nm
Motor inertial	0.01986Kgm^2
Rated voltage	230V(208V, 255V)

Source:[9].

Table 2: DC Machine Silicon Control Rectifier (SCR) Speed Control for Aluminum Smelting Plant parameters in simulation model Parameters in simulation model without SCR Speed control.

d-axis inductance,L_d	1.4Mh
q-axis inductance, L_q	2.8mH (1.4mH)
Stator windings R_s	0.6 Ω (1.2 Ω)
Induced flux by magnet	0.12Wb
Number of pole, P	2
Rated Voltage, V	250 V
Rated frequency, f	50Hz
Combined rotor and load inertia, J_m	0.83Kgm^2
Shaft mechanical torque, T_l	3.2Nm

Source: [8].

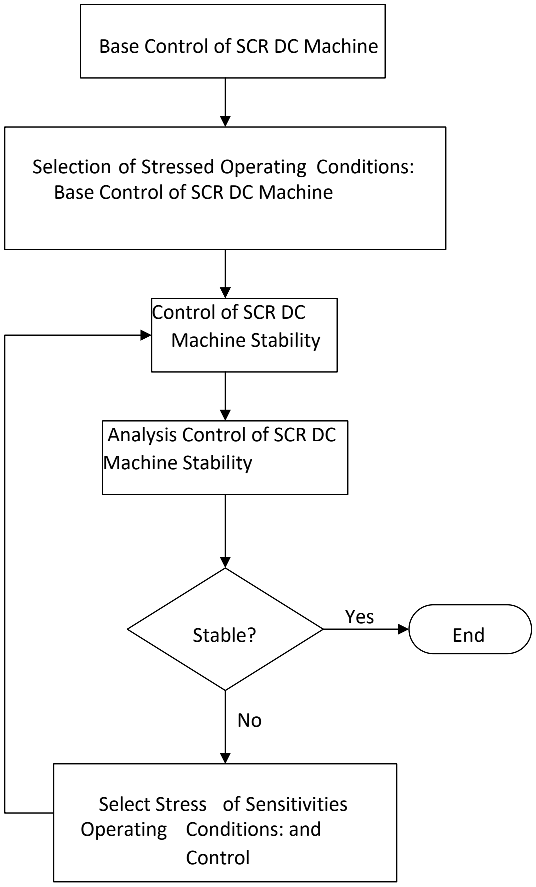

Figure 4: Flow Chart of DC Machine Silicon Control Rectifier (SCR) Speed Control for Aluminum Smelting Plant.

Figure 5: Research Laboratory with DC machine SCR [UNIPORT]

Table 3: Experimental result record of DC Machine Silicon Control Rectifier (SCR) Speed Control of Aluminum smelting plant Shunt dc machine

E_A (volts)	I_A (amps)	Speed (rev/min)	Torque (Ibft.in)
220	0.35	1500	0
220	1.05	1425	3
220	1.75	1265	6
220	2.35	1220	9
220	2.95	1385	12
220	3.15	1415	15

Table 4: Experimental result record of DC Machine Silicon Control Rectifier (SCR) Speed Control of Aluminum smelting plant Series dc machine

E_A (volts)	I_A (amps)	Speed (rev/min)	Torque (Ibft.in)
220	0.65	5260	0
220	1.50	2553	3
220	2.0	2010	6
220	2.5	1735	9
220	2.80	1515	12
220	3.20	1435	15

Table 5: Experimental result record of DC Machine Silicon Control Rectifier (SCR) Speed Control of Aluminum smelting plant Compound dc machine

E_A (volts)	I_A (amps)	Speed (rev/min)	Torque (Ibft.in)
220	0.25	1500	0
220	0.85	1310	3
220	1.30	1250	6
220	2.70	1125	9
220	2.10	1100	12
220	2.00	1115	15

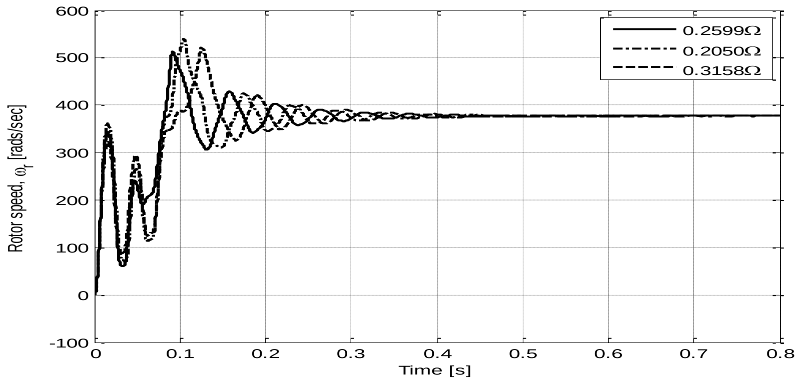

Figure 6: Graph of rotor speed versus time at varying DC machines resistance by retarding firing angle of SCR.

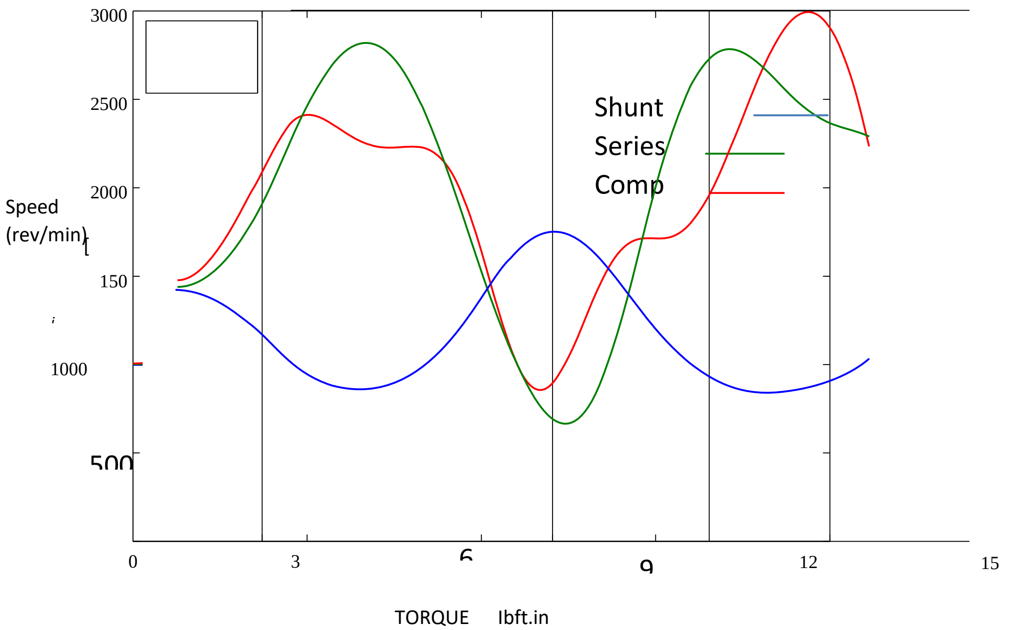

Figure 7: Graph of Speed/Torque of Aluminum Smelting Plant DC Machine without Silicon Control Rectifier (SCR) Speed Control

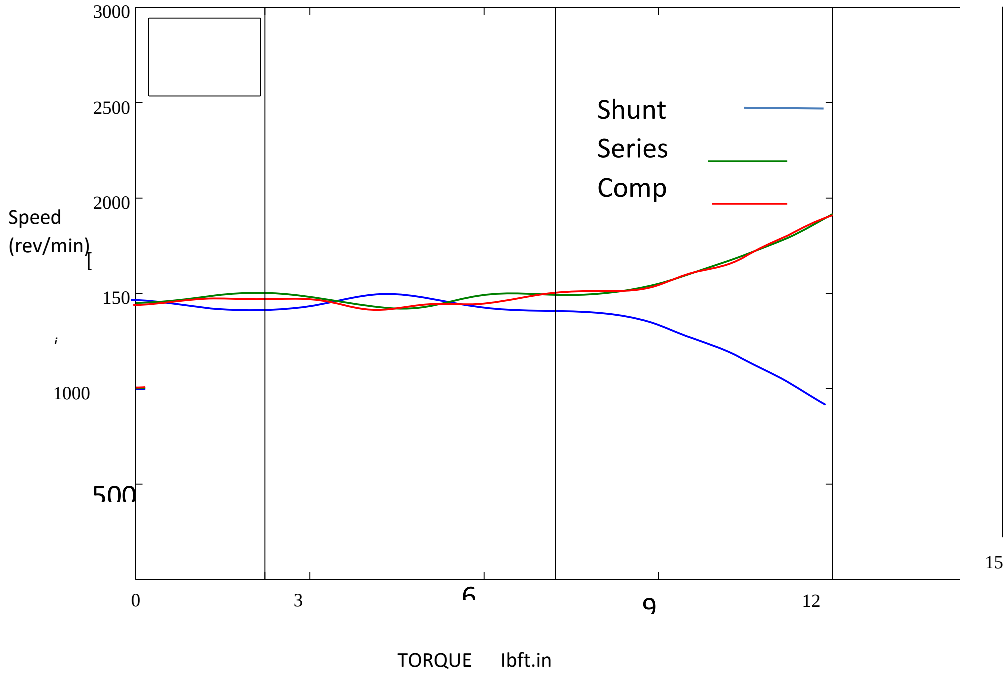

Figure 8: Graph of Speed/Torque of Aluminum Smelting Plant DC Machine With Silicon Control Rectifier (SCR) Speed Control

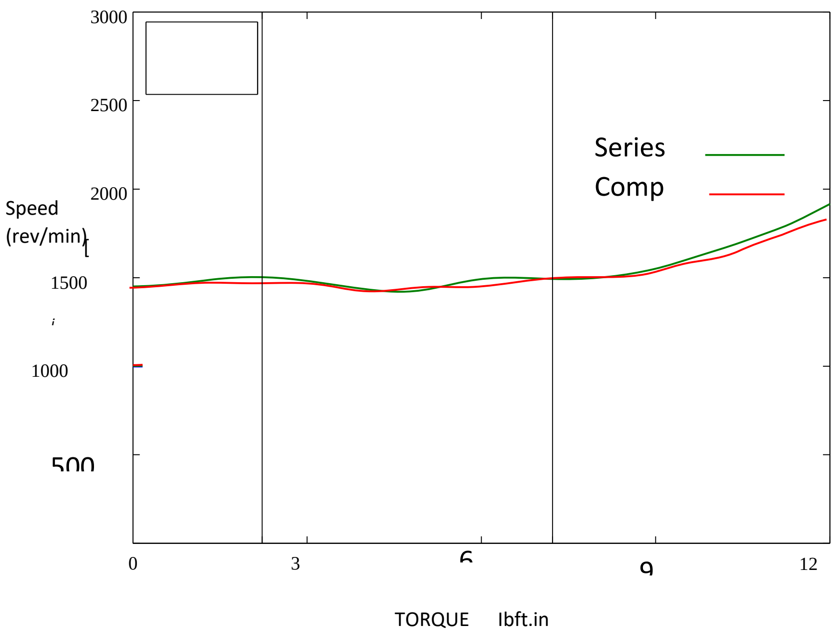

Figure 9: Graph of Speed/Torque of Aluminum Smelting Plant Series/Compound DC Machine with Silicon Control Rectifier (SCR) Speed Control

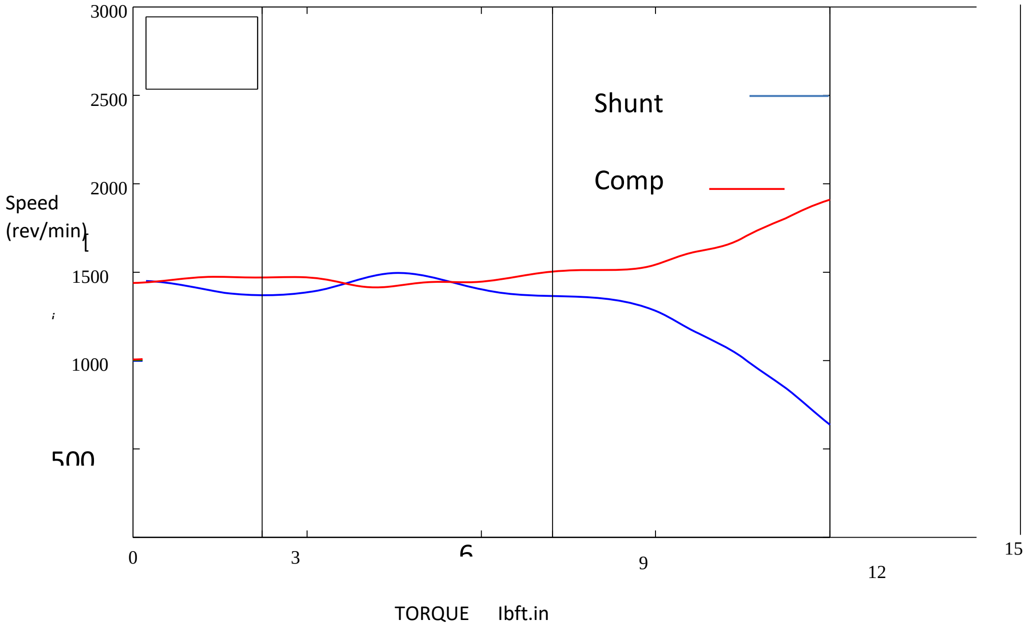

Figure 10: Graph of Speed/Torque of Aluminum Smelting Plant Shunt/Compound DC Machine with Silicon Control Rectifier (SCR) Speed Control

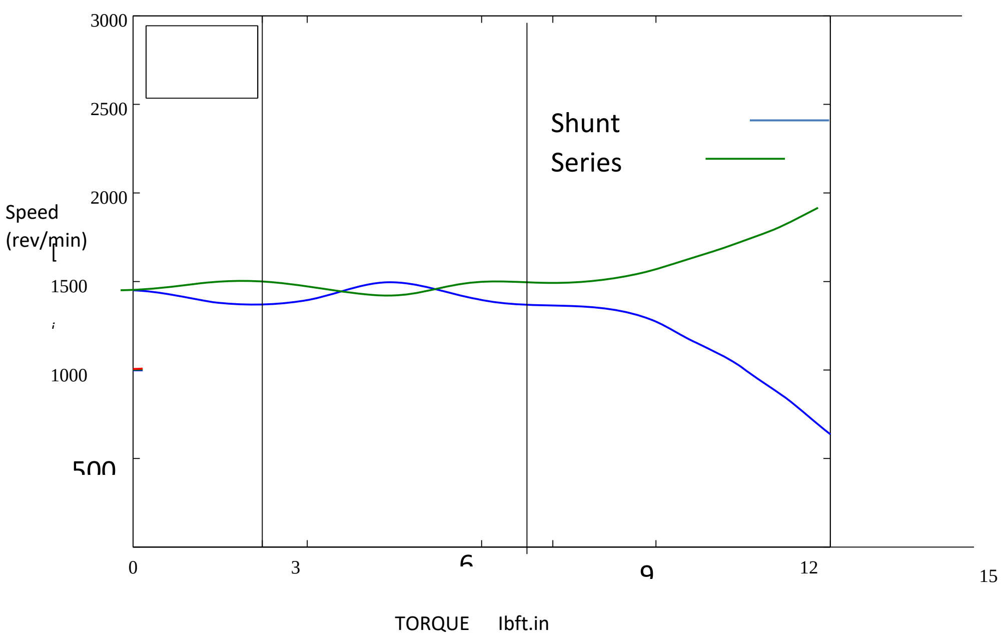

Figure 11: Graph of Speed/Torque of Aluminum Smelting Plant Series/shunt DC Machine with Silicon Control Rectifier (SCR) Speed Control

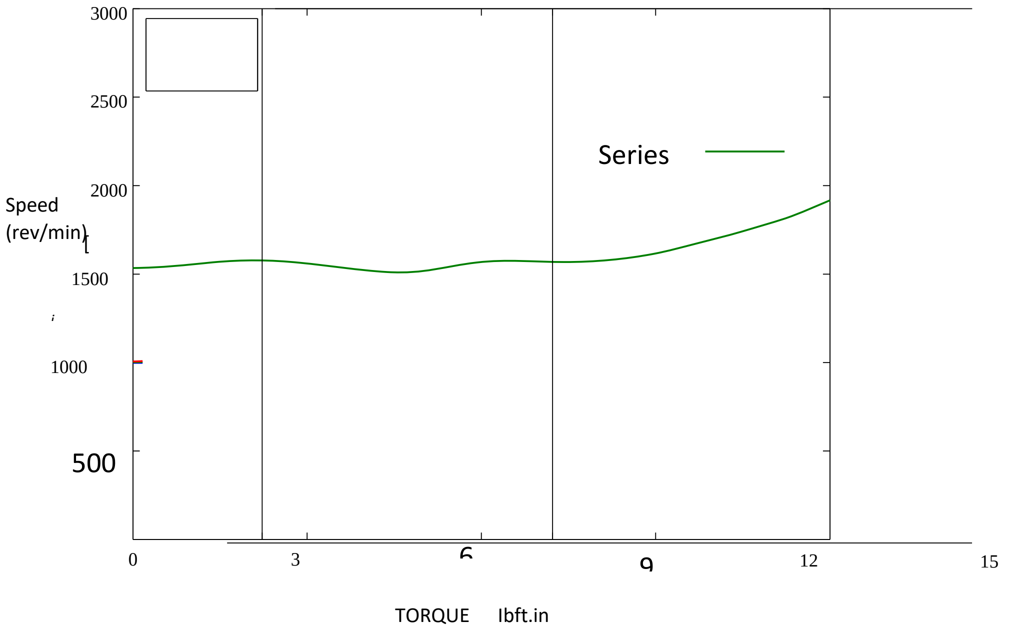

Figure 12: Graph of Speed/Torque of Aluminum Smelting Plant Series DC Machine with Silicon Control Rectifier (SCR) Speed Control

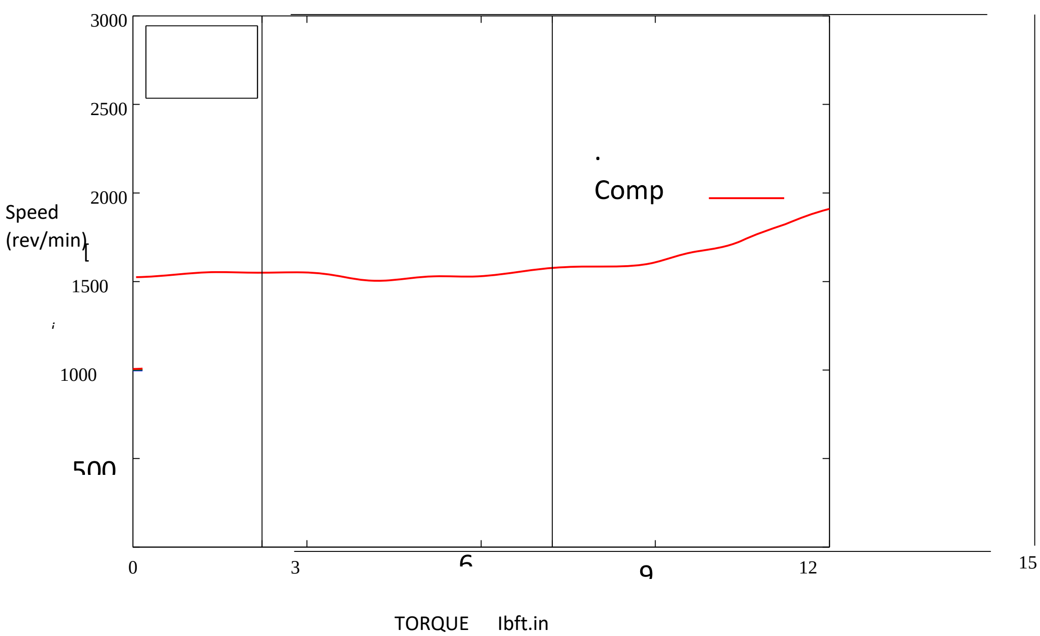

Figure 13: Graph of Speed/Torque of Aluminum Smelting Plant Compound DC Machine with Silicon Control Rectifier (SCR) Speed Control

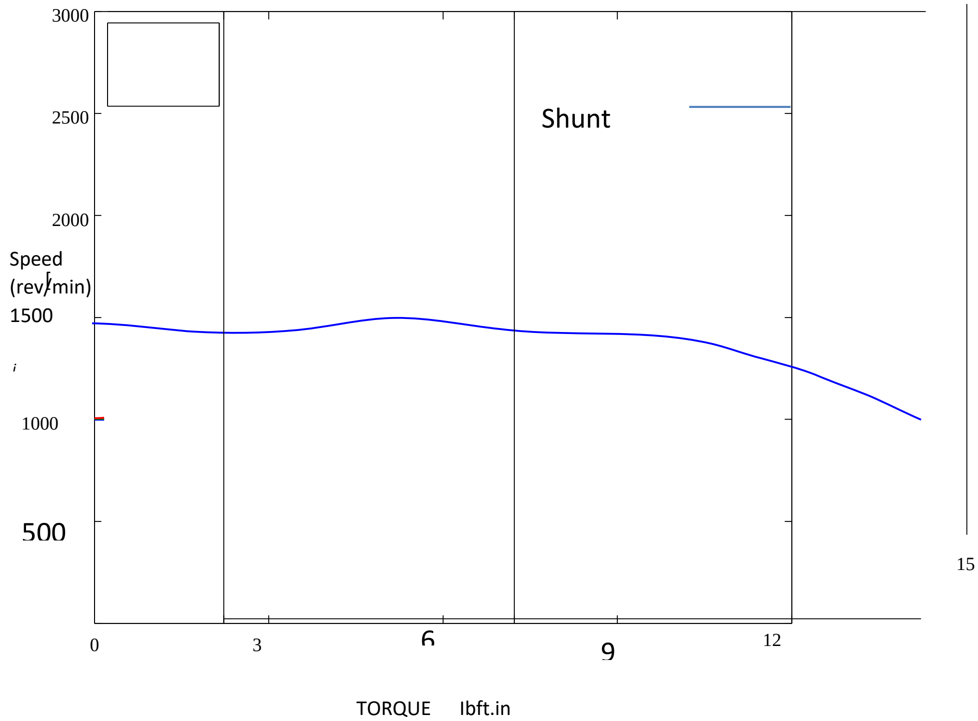

Figure 14: Graph of Speed/Torque of Aluminum Smelting Plant Shunt DC Machine with Silicon Control Rectifier (SCR) Speed Control

The torque of the dc machine depends upon the product of the armature current and magnetic field. The figure shows the graphs of Speed/Torque of Aluminum Smelting Plant DC Machine with and without Silicon Control Rectifier (SCR) Speed Control. The torque was very high for armature current for series dc machine as compare to shunt dc machine. The compound dc machine starting torque was higher than that of series dc machine due to the additional torque contributed by the shunt dc machine. The shunt dc machine was observed to have constant speed because its armature voltage and magnetic field.

The effect upon the dc machine speed and the armature voltage 'E_A'=180Vdc was observed that at low dc machine speed, the armature conduct late at the speed of 3560 rev/min before the dc machine turned 'OFF'. Varying DC machines resistance at 0.2599Ω, 0.2050Ω, and 0.3158Ω by retarding firing angle of SCR and allows firing angle to change and at 0.1 second, the rotor torque was 500rad/sec then stabilized at 0.4second

The magnetic field was produced by the current flows through the armature windings with weak magnetic field. When load was light, the magnetic field draws minimum current and when the magnetic field was strong when the load was heavy and armature winding draw maximum current. The speed of series dc machine was observed to depend on the load current. It was observed that when the load was light, the speed was high and when the load was heavy the speed was low. It was observed that at low dc machine speed, the armature conduct late. The highest speed that was obtained before the dc machine turned 'OFF was 3560 rev/min' An Appreciable sparking at the brushes and appreciable machine vibration was noted and at the frequency of 50Hz

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5.0: CONCLUSION

Aluminum Smelting Direct Current machine transient control using silicon control rectifier speed control has shunt, series and compound machines The torque of the dc machine depends upon the product of the armature current and magnetic field.

Experiment carried out shows that the shunt dc machine was observed to have constant speed because its armature voltage and magnetic field remain unchanged from no-load to full-load.

The torque was very high for armature current for series dc machine as compare to shunt dc machine. The compound dc machine starting torque was higher than that of series dc machine due to the additional torque contributed by the shunt dc machine. The armature voltage, armature current and field current was recorded as E_A = 200V dc, I_A = 2.55A dc, I_f = 300A dc. An Appreciable sparking at the brushes and appreciable machine vibration was noted and at the frequency of 50Hz.

Silicon Control Rectifier (SCR) reactance ‘‘$'X_L$’’ the filter choke was incorporated and connected to terminal 3 and 10 of the SCR to provide filtration for the smooth operation of the dc machine in the Aluminum smelting plant to prevent heavy armature transient surge current and Silicon Control Rectifier Capacitor ‘‘$'C_2$’’ the electrolytic filtering capacitor was connected across the dc machine and the armature winding was connected to terminal 8 and 1. Since the capacitor have to discharge through armature winding when the SCR is not conducting and instead of terminal 8 and 1, It was re-connected to terminal 8 and 11 for the stability and smooth operation of the smelting plant dc machine. The smelting plant dc machine was noted to vibrate cooler than before because, the capacitor absorbs the current peak during each cycle rather than the armature.

The effect upon the dc machine speed and the armature voltage$'\mathrm{E_A}$’=180Vdc was observed that at low dc machine speed, the armature conduct late at the speed of 3560 rev/min before the dc machine turned ‘OFF’. Series dc machine should be used when high starting torque is requires like electric bus, train, aluminum smelting plant dc machine and heavy duty traction-application. This is recommended for machines designers, engineers and Aluminum Smelting plants industries operators.

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