International Journal of Electrical and Electronics Engineering Studies
Vol.9, No.1, pp. 47-65, 2023
ISSN 2056-581X (Print),
ISSN 2056-5828(Online)
Website: https://www.eajournals.org/
Publication of the European Centre for Research Training and Development -UK

Direct Reduction Plant Alternator Synchronization Using DC Motor and Synchronous Generator with Complete Reduced Machines Transient

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doi: https://doi.org/10.37745/ijeees.13/vol9n14765 Published June 6, 2023

Citation: Esobinenwu C.S. and Owuda L.S. (2023) Direct Reduction Plant Alternator Synchronization Using DC Motor and Synchronous Generator with Complete Reduced Machines Transient, *International Journal of Electrical and Electronics Engineering Studies*, Vol.9, No.1, pp. 47-65

ABSTRACT*:* *Direct Reduction Plant alternator synchronization using D.C. motor and synchronous generator with complete reduced machines transient is presented. This is very significance in the industrial world. Direct Reduction plant is an iron making process plant for the new era which utilizes natural gas to reduce iron ore to produce Direct Reduced Iron used in steel industry. An alternator is an electrical generator that converts mechanical energy into AC electrical energy. Synchronization is connection of an alternator into the grid in parallel with many other alternators that is live of constant voltage and frequency. Transient stability is one of the major factors for proper operation of the Direct Reduction plant production systems that lead to major system collapses. The stress on Direct Reduction plant machines systems is increasing day by day, due to faults, economic and environmental pressures, sudden load change, deviation of active power and frequency. This phenomenon constitutes negative threat to Direct Reduction plant stability. The study was carried out to examine the capacity and transient stability on the Direct Reduction plant machines to withstand disturbance while quality of service is maintained. The effect of improper phase condition upon the synchronizing process, phase sequence of three phase power line, direct current excitation effect upon the power deliver by alternator, power delivered by an alternator upon the torque delivered by the prime mover. The challenges were solved and analyzed using individual machine with the help of accurate step by step integration and Electrical Transient Analyzer Program MatLab software. Swing equation was solved using advanced Runge-Kutta's method. An experiment was conducted in Electrical Engineering laboratory and machines transient stability of the plant was improved by 64 percent averagely. The results were depicted graphically for machines dynamic behavior studies and recommended for Technician and Engineers in steel and related industries*

KEY WORD: synchronization, flicking, hybrid, excitation, tooth-tooth, beat-frequency, iron ore.

INTRODUCTION

Direct Reduction plant is an iron making process plant that utilizes natural gas to reduce iron ore to produce Direct Reduced Iron in steel industry. This is incorporated with iron-electric arc furnace for producing steel from iron ore using a mixture of hydrogen and carbon monoxide as a reducing agent [1]. It uses electrical equipment for its operation. One of such is an alternator that converts mechanical energy to AC electrical energy. A generator is a mechanical device which converts mechanical energy to either AC or DC electrical energy. A generator generates either alternating or direct current while an alternator is an electrical generator that converts mechanical energy to electrical energy and induces an alternating current. Synchronization of an alternator is connection of an alternator to the grid in parallel with many other alternators that are live of constant voltage and frequency [3, 2].

Transient in Production Plant

Transient stability is one of the major factors for proper operation of the Direct Reduction plant production systems that lead to major system collapses. The stress on Direct Reduction plant machines systems is increasing day by day, due to faults, economic and environmental pressures, sudden load change, deviation of active power and frequency. This phenomenon constitutes negative threat to Direct Reduction plant stability. The study was carried out to examine the capacity and transient stability on the Direct Reduction plant machines to withstand disturbance while quality of service is maintained. Such as alternator synchronization, the effect of improper phase condition upon the synchronizing process, phase sequence of three phase power line. Direct current excitation effect upon the power deliver by alternator, power delivered by an alternator upon the torque delivered by the prime mover in direct reduction plant.

The challenges were solved and analyzed using individual machine with the help of accurate step by step integration and Electrical Transient Analyzer Program MatLab software. Swing equation was solved using advanced Runge-Kutta's method. The electromagnetic torque developed a maximum peak torque of about 230Nm at 5.3ms. The graph of q-d axis voltage against time and the q-axis voltage is seen in mirror that the d-axis voltage albeit with slight deviation. The machines attained a maximum rotor speed of 300rad/s in 5.3ms and at about 40ms the machines attained a steady-state speed of 180rad/s. The copper loss of machines under test was high at 8.2ms and it dropped steadily to its steady-state value (≈1.7W) 30ms after start up. [5, 8, 9] .An experiment was conducted in UNIPORT Electrical Engineering Research laboratory plant. Figure 1

Figure1a: Electrical Engineering Research Laboratory Plant

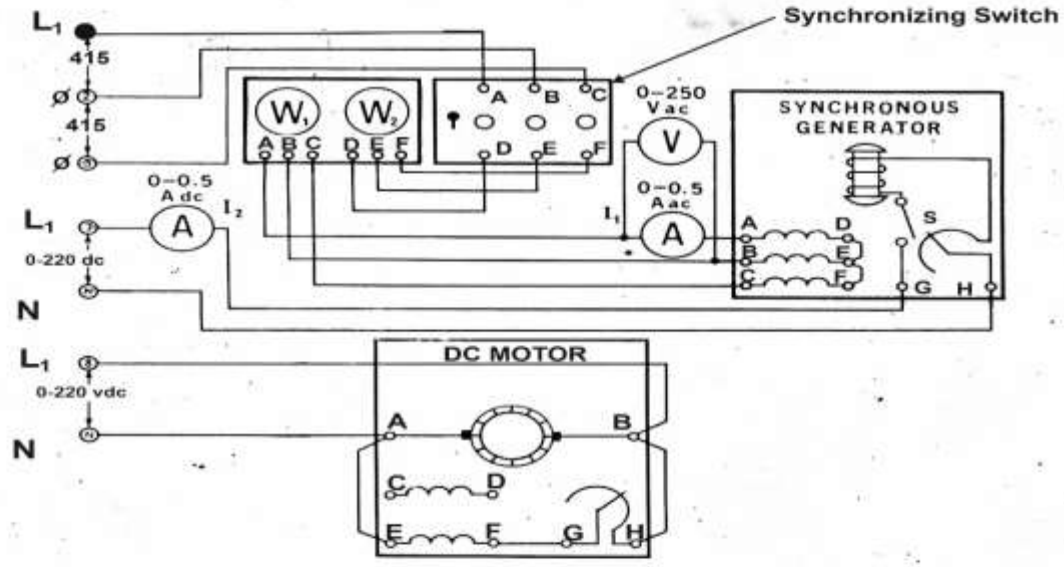


Figure1b: Alternator Synchronization using D.C. Motor and Synchronous Generator (Electrical Engineering Research Laboratory Plant)

Plant synchronization

Direct Reduction Plant alternator synchronization using D.C. motor and synchronous generator with complete reduced machines transient is the connection of two alternators and an infinite bus bar system in parallel with the other auxiliary plant power system and are parallel with many other alternators. Electrical load do not remain constant, thus the need to synchronized two or more alternator to power supply to the load cannot be overemphasized. Figure2.

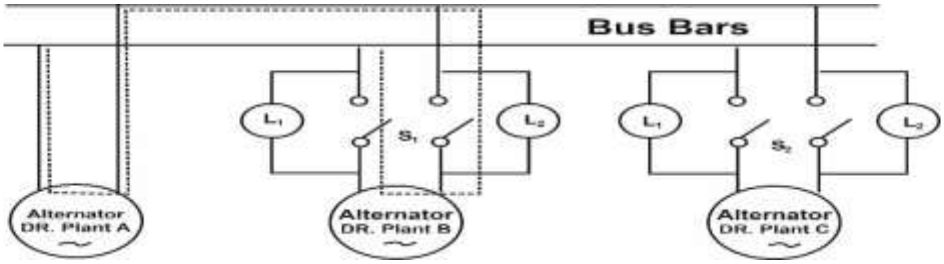


Figure2: Synchronization of an alternator

An alternator joined to an existing power supply with wrong phase sequence, the direction is immediately reversed and the motor run in opposite direction against the rotation of the driving plant machines system. The reason being that power line set up a rotating magnetic field in the alternator which tried to make the alternator run as synchronous motor in the reversed direction,[6, 7] which eventually caused large current in the stator and result to electrical overload and mechanical shock, caused damage to both the driving plant system and the alternator.[2, 5] Closing the synchronizing switch when the generated and the existing voltage are out of phase, a heavy surge current will flow in the stator and tried to force the rotor into proper position to bring the two voltage in phase with each other. This will develop a very sudden acceleration or deceleration of the rotor and the mechanical shock, damage the alternator and the driving plant system. [3, 9]

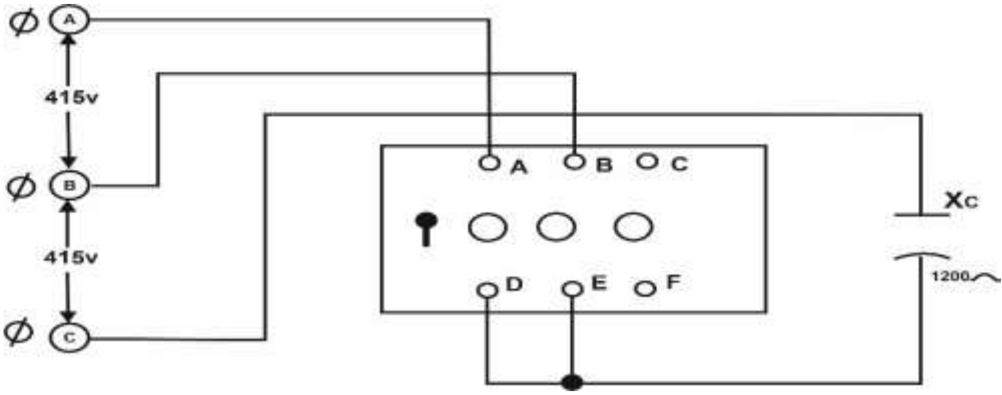
Direct Reduction Plant alternator synchronization using D.C. motor and synchronous generator with complete reduced transient, the frequency was established by the rotating speed of powerful alternator and all are connected by various tie-line into the total network. The collective inertia and power of this generator is so great that there is no single load or disturbance which would be large enough to change their speed of rotation. The frequency of an electrical system is therefore remarkable stable. [7, 8]

Alternator delivered power to an existing power system if it operates at the same frequency as the system. A system that 50,000Hz cannot receive power from an alternator that operates at 50,001Hz. They must both operates at the same frequency. This is not as difficult to realize as may first appear, because automatic force come into play when an alternator is connected into an existing system to keep its frequency constant [4, 6].

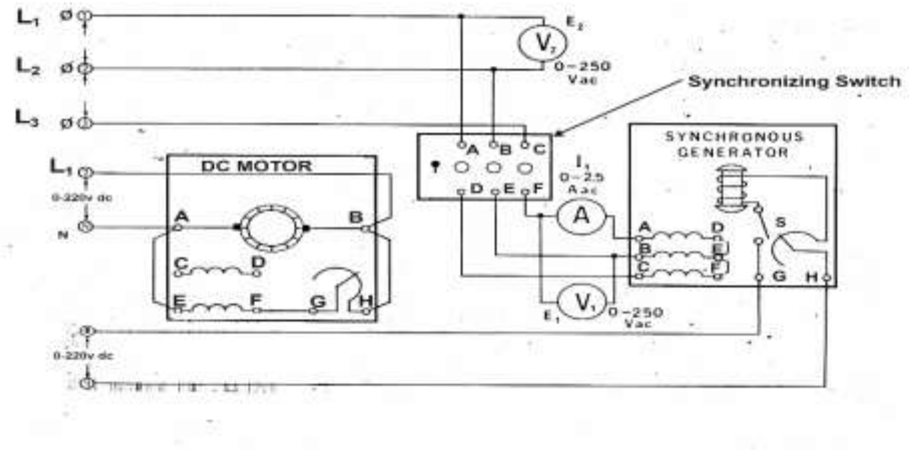
Direct Reduction Plant alternator synchronization using D.C. motor and synchronous generator with complete reduced transient means first that its frequency must be equal to that of the system supply. The phase sequence must be the same; the voltage of an alternator must be in phase with the voltage of the supply. Voltage amplitude of the generator should be equal to the supply of the voltage amplitude, as all this condition are met, the Direct Reduction Plant alternator synchronization using D.C. motor and synchronous generator with complete reduced transient is perfectly synchronized with the network and the switch between the system closed.

Direct Reduction Plant alternator synchronization using D.C. motor and synchronous generator with complete reduced transient was investigated using the circuit diagram figure1. Direct Reduction Plant alternator synchronization using D.C. motor and synchronous generator with complete reduced transient was investigated with the following tools and equipment: Synchronous Generator, D.C. Motor, Synchronizing Switch, Power Supply, AC Voltmeter, AC ammeter, Hand Tachometer, Connection Leads and Timing Belt. The circuit was connected as shown in figure 2
Using the tools and the equipment, the circuit was connected as shown in the figure 2 and 3. The output of an alternator was connected through the synchronizing switch to a three-phase fixed power supply 415Vac and the rotor was also connected to a fixed power supply 220Vdc output. The DC motor was connected to a variable power supply 220V dc.

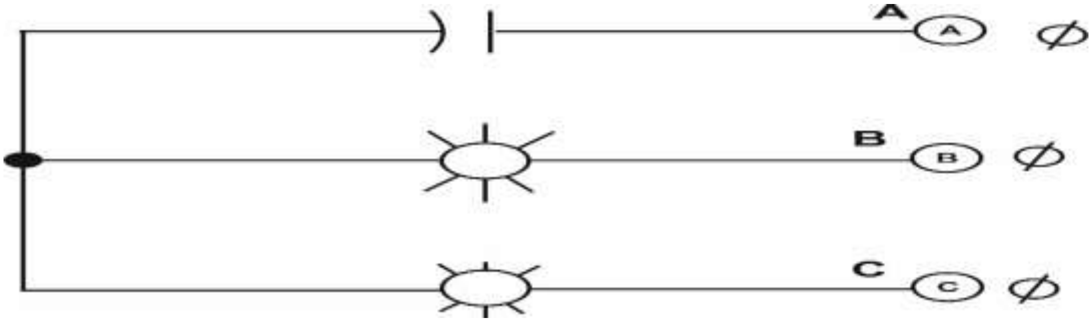
Alternator and the DC motor was couple together with timing belt. The fixed rheostat of the DC motor was adjusted to full clockwise position for minimum resistance while the synchronous switch was setted for full anticlockwise for maximum resistance.



(a)



(b)



(c)

Figure 3(a): Alternator Synchronization Switch Figure (b): Alternator Synchronization circuit
(c) Synchronizing light flicking

The synchronizing switch was tuned OFF and the power supply was turned ON. The motor speed was adjusted to 1800rev/min. The power supply was measured and recorded as E_2 = 415v and the switch were closed at this time. The dc excitation of the alternator was adjusted until the alternator output voltage E_1 corresponded to E_2.the three synchronizing light started flicking ON and OFF. Figure3c. The beat frequency was fine tuned to become quite low by adjusting dc motor speed. The three synchronizing lights did not initially bright at the same time but this was made to bright at the same time by interchanging two of the supply leads from the machine's stator. The motor speed was adjusted until the three lights show darken and slowly brighten which means that alternator frequency is nearly to the supply power. Immediately the entire light is completely darkened, it means that alternator and supply voltage are in phase, while brightening mean that the alternator and supply voltage are 180 degree out of phase. The synchronizing switch was not closed this time because this Tooth –Tooth condition.

The dc excitation of an alternator was adjusted to ensure that E_1andE_2 is equal. The synchronizing switch was finally closed and the current I_1 was recorded as 0.3 ampere. Closing the synchronizing switch when all the lights are dark, the stator current jumps quickly to 0.3ampere and return to zero at the moment the of closure because the two-line voltage are not equal in phase with each other. When all the three lights are dim as the synchronizing switch was closed, the stator current jump quickly to 1.2ampere and return to zero. This is because there is a small phase difference between the voltage which creates a greater voltage difference than when the lights are dark and the current surge to a higher value. When all the three lights are partially bright, the stator current jumped quickly to 2.0ampere and returned to zero.as the synchronizing switch closed, there is a relatively large phase difference between the two voltages that produced large voltage difference and current. The alternator jerk as the rotor was forced into the correction position by the large stator surge current, after the surge, the current again dropped back to zero. The dc excitation to the alternator was adjusted until the output voltage $E_2 = 450v.$ the motor speed was adjusted until the three lamps are synchronized see figure3.

The synchronizing switch was closed as the three lights dimmed. The moment of closure, the stator current jump from zero to a peak of 0.5 to 1.0apere and after closure the stator current fall back to as low as 0. 4ampere.The synchronizing switch was open and the voltage returned to zero and the power supply was turned off. The rotation of the dc motor was reversed by interchanging the shunt field to synchronize the alternator as before. The lights flashed in sequence instead of all at the same time. This indicated that the phase sequence of the power supply and the alternator are difference. This was remedied by without again reversing the dc motor by interchanging any of the two of the lead from the stator of the alternator.

Machines Modeling and Simulation

Modeling and Simulation of machines is very important in industrial world. The mathematical characteristics representation with in-built up MATLAB/SIMULINK software help to modeling the machines by setting its component transients to zero and sufficiently obtained the complete reduced system transients. We derived the mathematical equations that show the relationships of the machines from the equivalent diagram of machines is shown in Figure 1. [5, 8, 9].

Electrical Modeling

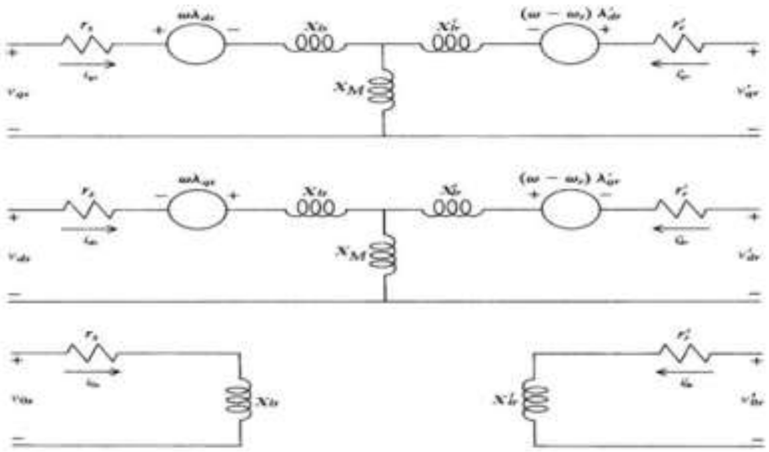


Figure4: Equivalent circuit diagram of machines.

$$V_{qs} = r_s i_{qs} + \frac{w_s}{w_b}\psi_{ds} + \frac{p}{w_b}\psi_{qs} \quad (1)$$

$$V_{ds} = r_s i_{ds} - \frac{w_s}{w_b}\psi_{qs} + \frac{p}{w_b}\psi_{ds} \quad (2)$$

$$V_{0s} = r_s i_{0s} + \frac{p}{w_b}\psi_{0s} \quad (3)$$

$$V_{qr} = r_r i_{qr} + \frac{w_s - w_r}{w_b}\psi_{dr} + \frac{p}{w_b}\psi_{qr} \quad (4)$$

$$V_{dr} = r_r i_{dr} - \frac{w_s - w_r}{w_b}\psi_{qr} + \frac{p}{w_b}\psi_{dr} \quad (5)$$

$$V_{0r} = r_r i_{0r} + \frac{p}{w_b}\psi_{0r} \quad (6)$$

The equation of the flux

$$\psi_{qs} = X_{ls}\ i_{qs} + X_m\left(i_{qs} + i_{qr}\right) \quad (7)$$

$$\psi_{ds} = X_{ls} i_{ds} + X_m\left(i_{ds} + i_{dr}\right) \quad (8)$$

$$\psi_{0s} = X_{ls} i_{0s} \quad (9)$$

$$\psi_{qr} = X_{lr} i_{qr} + X_m \left(i_{qs} + i_{qr}\right) \tag{10}$$

$$\psi_{dr} = X_{lr} i_{dr} + X_m \left(i_{ds} + i_{dr}\right) \tag{11}$$

$$\psi_{0r} = X_{lr} i_{0r} \tag{12}$$

The set of equation becomes:

$$X_{ss} = X_{ls} + X_m \tag{13}$$

$$X_{ss} = X_{ls} + X_m \tag{14}$$

The equations are express in matrices form:

$$\begin{bmatrix} V_{qs} \\ V_{ds} \\ V_{0s} \\ V_{qr} \\ V_{dr} \\ V_{0r} \end{bmatrix} = \begin{bmatrix} r_s + \frac{p}{w_b} X_{ss} & \frac{w_s}{w_b} X_{ss} & 0 & \frac{p}{w_b} X_m & \frac{w_s}{w_b} X_m & 0 \\ -\frac{w_s}{w_b} X_{ss} & r_s + \frac{p}{w_b} X_{ss} & 0 & -\frac{w_s}{w_b} X_m & \frac{p}{w_b} X_m & 0 \\ 0 & 0 & r_s + \frac{p}{w_b} X_{ls} & 0 & 0 & 0 \\ \frac{p}{w_b} X_m & \frac{w_s - w_r}{w_b} X_m & 0 & r_r + \frac{p}{w_b} X_{rr} & \frac{w_s - w_r}{w_b} X_{rr} & 0 \\ -\frac{w_s - w_r}{w_b} X_m & \frac{p}{w_b} X_m & 0 & -\frac{w_s - w_r}{w_b} X_{rr} & r_r + \frac{p}{w_b} X_{rr} & 0 \\ 0 & 0 & 0 & 0 & 0 & r_r + \frac{p}{w_b} X_{lr} \end{bmatrix} \begin{bmatrix} i_{qs} \\ i_{ds} \\ i_{0s} \\ i_{qr} \\ i_{dr} \\ i_{0r} \end{bmatrix} \tag{15}$$

$$\begin{bmatrix} \psi_{qs} \\ \psi_{ds} \\ \psi_{0s} \\ \psi_{qr} \\ \psi_{dr} \\ \psi_{0r} \end{bmatrix} = \begin{bmatrix} X_{ss} & 0 & 0 & X_m & 0 & 0 \\ 0 & X_{ss} & 0 & 0 & X_m & 0 \\ 0 & 0 & X_{ls} & 0 & 0 & 0 \\ X_m & 0 & 0 & X_{rr} & 0 & 0 \\ 0 & X_m & 0 & 0 & X_{rr} & 0 \\ 0 & 0 & 0 & 0 & 0 & X_{lr} \end{bmatrix} \begin{bmatrix} i_{qs} \\ i_{ds} \\ i_{0s} \\ i_{qr} \\ i_{dr} \\ i_{0r} \end{bmatrix} \tag{16}$$

The Mechanical Modeling

The mechanical model of the machines torque equation is express as:

$$T_e = \left(\frac{3}{2}\right)\left(\frac{P}{2}\right)L_m\left(i_{qs}i_{dr} - i_{ds}i_{qr}\right) \tag{17}$$

The set of equation becomes:

$$L_m = \frac{X_m}{w_b} \tag{18}$$

$$D = X_{ss}X_{rr} - X_m^2 \tag{19}$$

The mechanical torque equation becomes

$$T_e = \left(\frac{3}{2}\right)\left(\frac{P}{2}\right)\frac{X_m}{Dw_b}\left(\psi_{qs}\psi_{dr} - \psi_{ds}\psi_{qr}\right) \tag{20}$$

The Complete Machines Model

The completely reduce machines component transient modeled simulation;
Machines component transients are set to zero, Thus,

$$\frac{d\psi_{ds}}{dt} = \frac{d\psi_{qs}}{dt} = 0 \tag{21}$$

The equation 1-3 now becomes:

$$V_{qs} = r_s i_{qs} + \frac{w_s}{w_b}\psi_{ds} \tag{22}$$

$$V_{ds} = r_s i_{ds} - \frac{w_s}{w_b}\psi_{qs} \tag{23}$$

$$V_{0s} = r_s i_{0s} \tag{24}$$

The completely reduced machines modeled component simulation in Matlab/Simulink block. figure 5

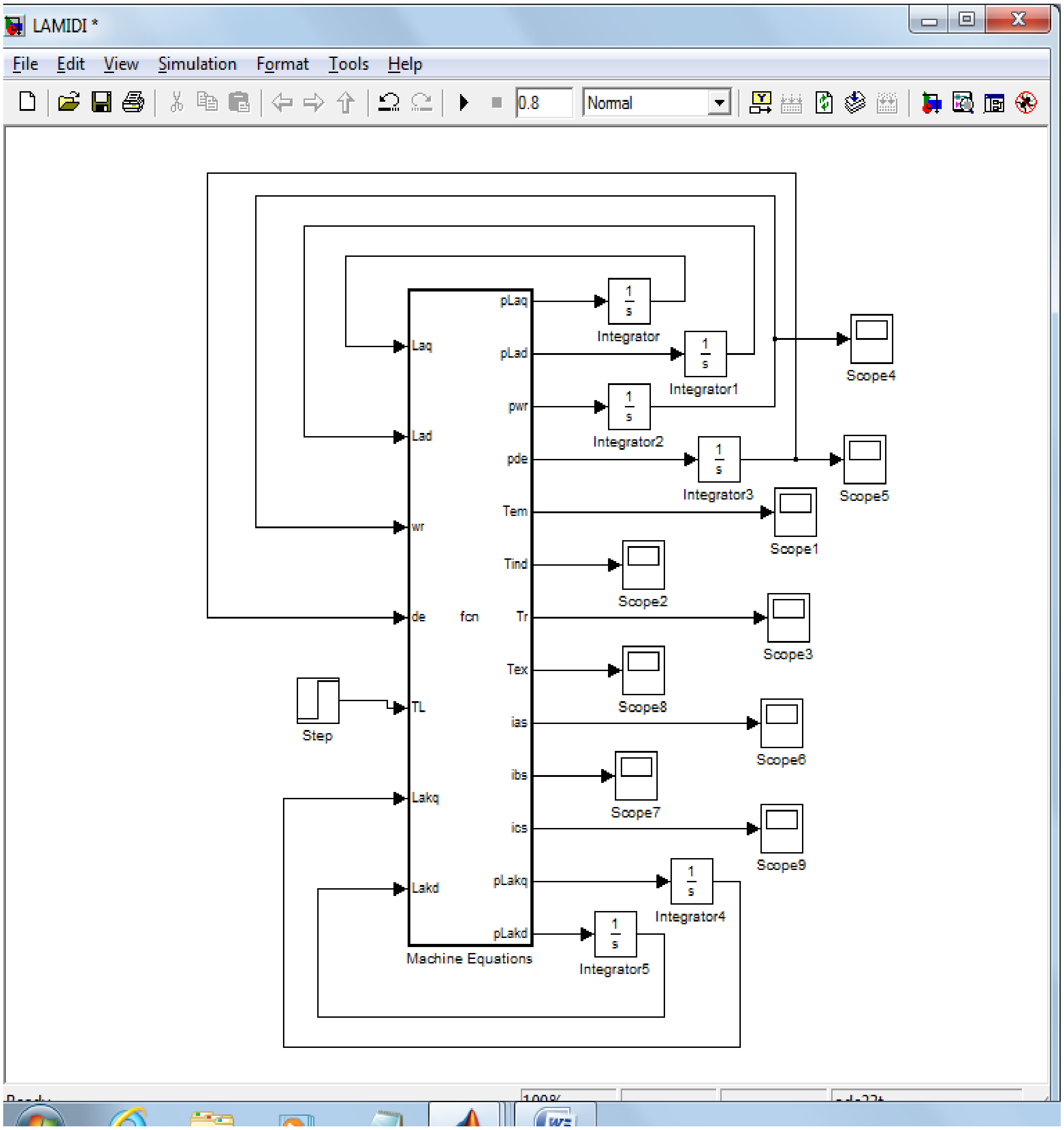


Figure5: Matlab/Simulink Used for Simulation of Machines Component Modeled

Table 1: Machines Parameters used for simulation

DC MOTOR		**Synchronous Generator**
Ra	0.0130Ω	0.0130Ω
La	0.010H	0.010H
R_f	1.430Ω	0.0260Ω
L_f	0.1670H	0.1670H
J	0.210Kg-m^2	0.210Kg-m^2
B	1.074e-6Nms^2	1.074e-6Nms^2
T_L	2.4930Nm	2.4930Nm
K_b	0.004N-m/A^2	0.004N-m/A^2
Va	24V	24V
V_f	12V	24V

Source: [1]

Table 2: Experimental Result

I_2(AMPS)	E_1 VOLTS)	I_1(Amp)	POWER (VA)	W_1	W_2	POWER(Watts)	PF
0	415	0.85	295	-57	124	67	0.23

0.1	415	0.66	245	-47	103	68	0.38
0.2	415	0.52	176	-27	80	68	0.47
0.3	415	0.45	96.4	20	50	65	0.68
0.4	415	0.36	60.4	35	35	65	0.98
0.5	415	0.45	82.0	50	20	65	0.85
0.6	415	0.36	136	96	-22	69	0.58

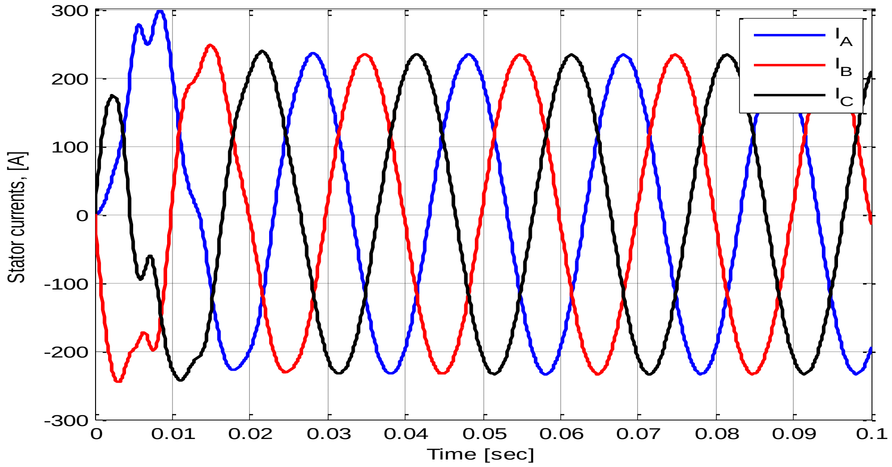


Figure 6: Graph of Stator Currents Against Time

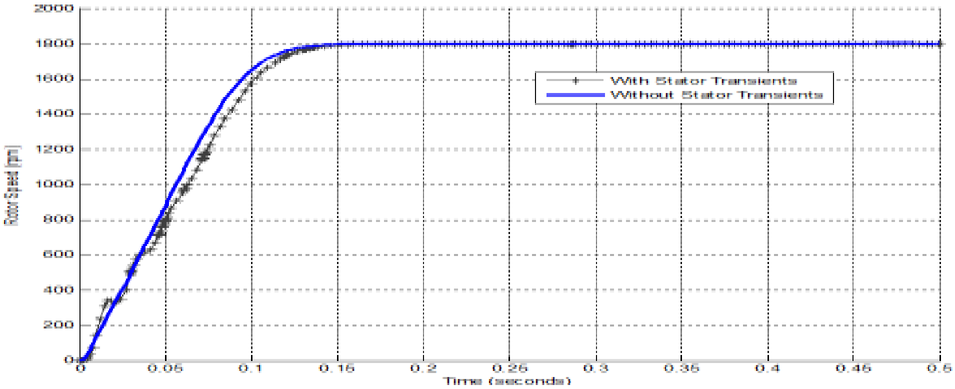


Figure-7: Graph of machines speed (rpm) against time (s)

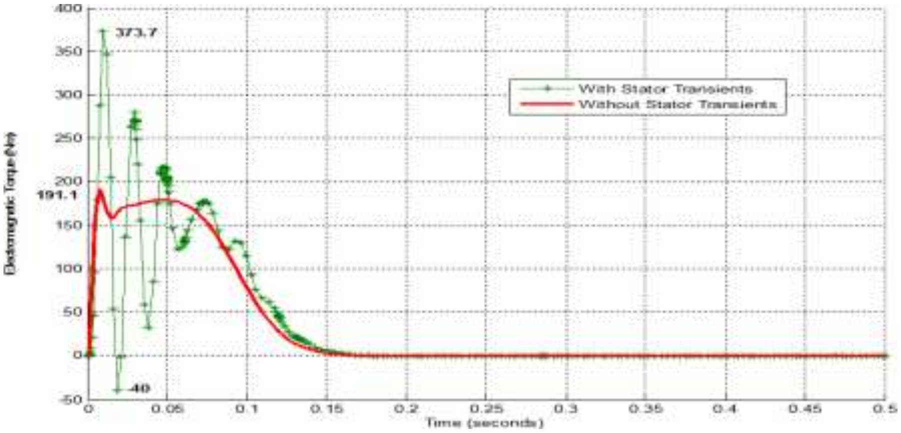


Figure 8: Graph of electromagnetic torque (Nm) against time (s) at start up

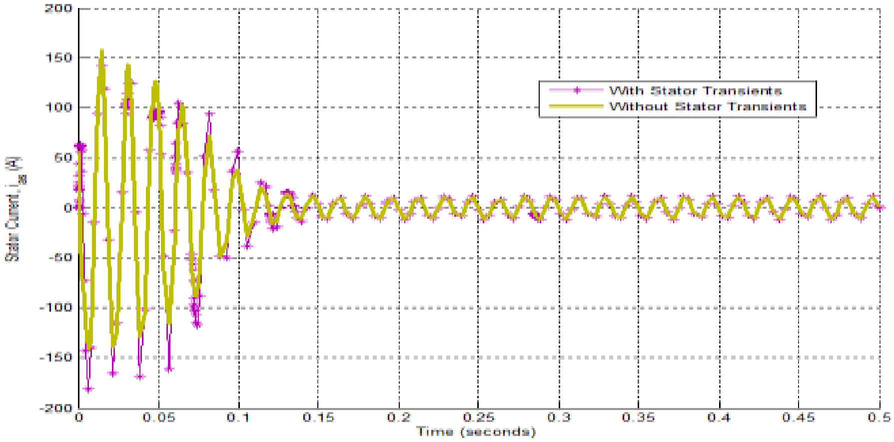


Figure 9: Graph of stator current, as (A) against time (s)

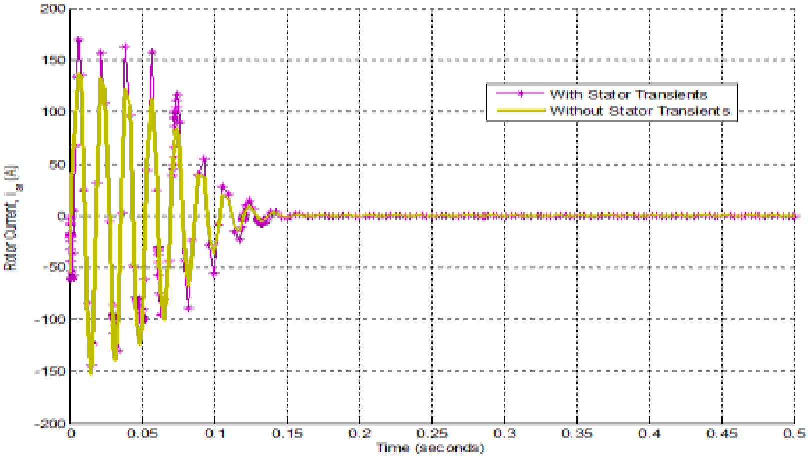


Figure 10: Graph of rotor current (A) against time (s)

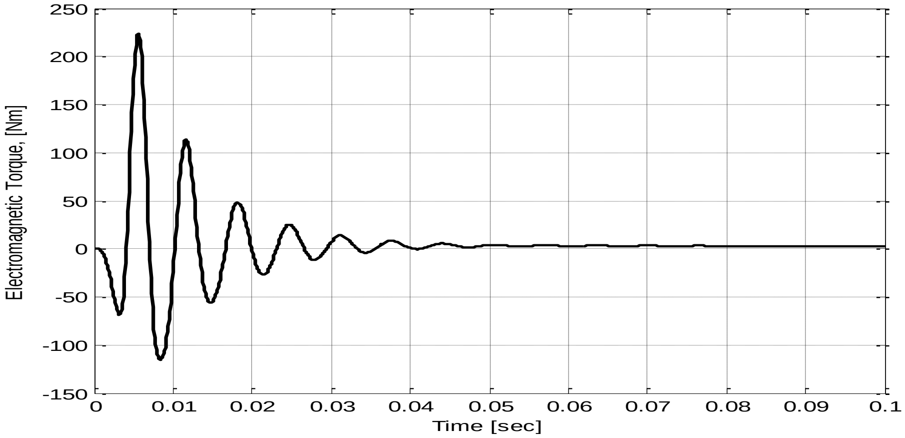


Figure 11: Graph of Electromagnetic Torque Against Time at run up condition

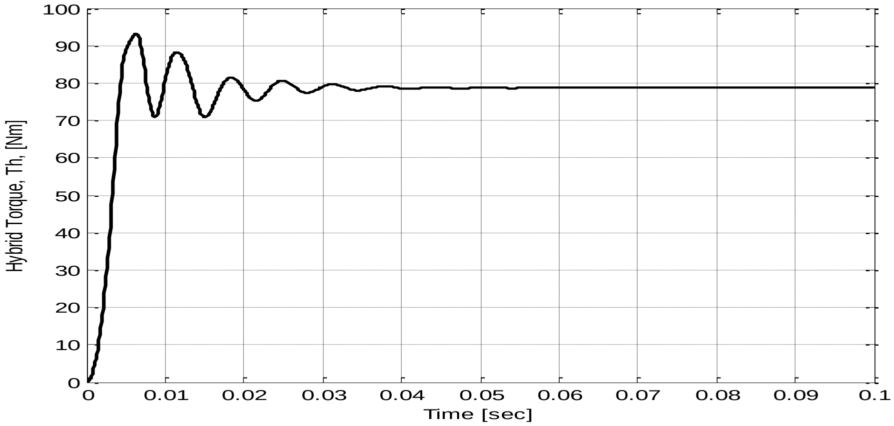


Figure 12: Graph of Hybrid Torque Against Time.

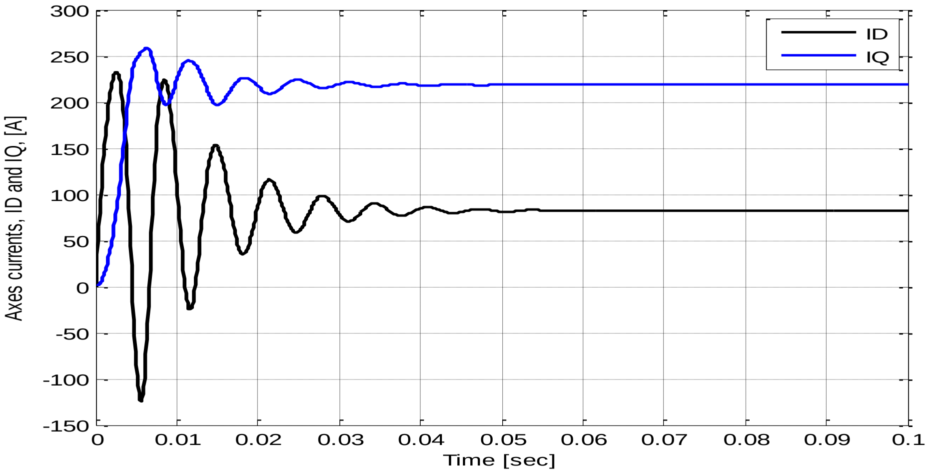


Figure 13: Graph of Axis Current ID and IQ against Time.

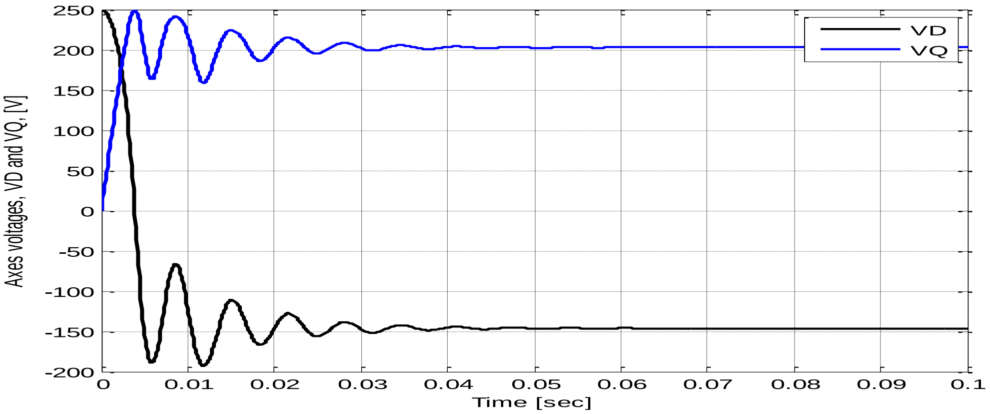


Figure 15: Graph of Axes Voltages VD and VQ against Time

The transient of the machines modeled equations in state variable form with flux linkages as state variables were used. MATLAB function program which make use of the Runge-Kutta fouth-order method was used to solve the set of equations both electrical and mechanical models. It was assumed that the rotor and the stator flux linkages are initially at zero. Synchronous machine transient responses at run-up conditions are simulated. The depicted graph shows that the transients of the simulated machine for the machines torque, machines stator current, machines speed, machines electromagnetic torque, machines hybrid torque and stator axis currents (ID and IQ), axis voltage (VD and VQ) as a function of time respectively. The challenges were solved and analyzed using individual machine with the help of accurate step by step integration and Electrical Transient Analyzer Program MatLab software. Swing equation was solved using advanced Runge-

Kutta's method. The electromagnetic torque developed a maximum peak torque of about 230Nm at 5.3ms. The graph of q-d axis voltage against time and the q-axis voltage is seen in mirror that the d-axis voltage albeit with slight deviation. The machines attained a maximum rotor speed of 300rad/s in 5.3ms and at about 40ms the machines attained a steady-state speed of 180rad/s. The copper loss of machines under test was high at 8.2ms and it dropped steadily to its steady-state value (≈1.7W) 30ms after start up.

Varying the plant machines stator resistance effect the transient performance of the machines as a result f sudden load change. At lower values of the stator resistance, the motor possesses initial peak magnitude of the rotor speed and motor torque. The maximum hybrid torque is attained at high value of the stator resistance. The effect of varying the equivalent field current above and below was investigated and shows that the equivalent field current increases, the machines speed and torque lead to mechanical shock and damaged. Forces the plant machines to drop considerably

CONCLUSION

Synchronizing an alternator to an existing three phase power line, the frequency, phase and phase sequence and the voltage amplitude must be the equal to each other. If the phase sequence is not the same and the voltage is out of phase, an alternator could be severely damaged mechanically in attempting to synchronized.it with power line. Both frequencies must be the same in other for the alternator to delivered power because an alternator generating different values of voltages may not be exactly in phase with power line.

Three-phase synchronous generator, DC motor and synchronizing switch was used to establish a three-phase power line phase sequence by observing the direction of rotation. The motor ran in clockwise as view from one end and the input terminal was labeled in accordance with the existing power sequence, it means motor terminal are identical. Assumed the phase sequence was difference when the motor was hook up, then, it could be labeled opposite sequence to that of motor terminal. Three line-neutral voltage are 120 degree out of phase with each other because the neutral point is not at zero potential when the phase load is unbalance while three phase-line-line voltage are 120 degree out phase with each other.

The reduced model of the synchronization of direct reduction plant alternator using D.C. motor and synchronous generator with complete reduced machines transient was modeled by setting the stator transients to zero. This paper presents the complete model and the reduced model of synchronization of direct reduction plant alternator using D.C. motor and synchronous generator which reduced machines transient and sufficiently represent the dynamic synchronization characteristics of the plant, transient of machines currents, rotor speed and the torque characteristics synchronization. The results were depicted graphically for plant machines dynamic behavior studies and recommended for Technician and Engineers in steel and related industries.

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