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Study of the Efficiency of A Doubly Fed Induction Generator (Delta-Stator) Connected On Grid by Manual Synchronisation: A Case Study at Kampala International University, Western Campus

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ABSTRACT

The report presents the efficiency of a Doubly Fed Induction Generator (DFIG) driven by a wind turbine. DC prime mover is used instead of a wind turbine because it produces a constant speed. In the DFIG the stator is connected direct to the grid while the rotor is connected to a back to back converter and also coupled with the DC prime mover. This structure requires some care during grid synchronization to avoid undesired overloads. The main goal of synchronization is to minimize the electrical transients and mechanical stress components during synchronization. Different panels are interlinked for the functionality of the machine I.e. dimmer panel for increasing and decreasing the resistance, LC filter panel for filtering the PWM to a sinusoidal signal, Multifunction converter 3 phase measurement panel for metering and they display frequency, power factor, voltage, current, energy, Digital Oscilloscope for displaying the signal waveform, a DC prime mover is coupled to a generator to generate electricity, variable DC voltmeter and DC ammeter for measuring voltage and current respectively ,Direct On Line motor starter panel is used for protection against overload, fault and external fault and supply 3 phase power, Insulated Gate Bipolar Transistor (IGBT) acts as the back to back converter and the FPGA displays the frequency The efficiency is also determined of the DFIG by using the shaft power i.e. used to couple with the rotor, the inverter power for the back to back converter, and the powers exported to the grid in watt and are all expressed in percentage.

Keywords: Efficiency, Induction, Generator and Grid

INTRODUCTION

The use of wind energy to generate electricity first appeared in the late 19th century but did not gain ground owing to the then dominance of steam turbines in electricity generation. The interest in wind energy was renewed in the mid-1970s following the oil crises and increased concerns over resource conservation. Initially, wind energy started to gain popularity in electricity generation to charge batteries in remote power systems, residential scale power systems, isolated or island power systems, and utility networks. These wind turbines themselves are generally small but could be made up to a large wind farm. It was until the early 1990s [1] when wind projects really took off the ground, primarily driven by the governmental and industrial initiatives. It was also in 1990s there seemed a shift of focus from onshore to offshore development in major wind development countries, especially in Europe. Offshore wind turbines were first proposed in Germany in 1930s and first installed in Sweden in 1991 and in Denmark in 1992 [1]. Offshore wind energy has some appealing attributes such as higher wind speeds, availability of larger sites for development, lower wind shear and lower intrinsic turbulence intensity. But the drawbacks are associated with harsh working conditions, high installation and maintenance costs. For offshore operation, major components should be Mimi zed with additional anti-corrosion measures and de-humidification capacity. In order to avoid unscheduled maintenance, they should also be equipped with fault-ride-through capacity to improve their reliability. Due to environmental changes caused by excessive exploitation of the national resources. Here most of the focus has been put on the non-renewable resources i.e. solar and wind energy. Wind energy is clean and environmentally friendly. Nowadays the amount of wind energy generated by wind turbine has been increased to a considerable grid level because of the use of a DFIG during generation. As a result, utilities typically disconnect the WTs immediately from the grid when such a contingency occurs. With the tripping of certain WTs in a large wind farm, the overall power system stability becomes poor. Due to above mentioned problems with traditional set up there was need of new system which could incorporate previous drawbacks. Therefore, concept of variable speed wind turbine (VSWT) came in existence [2].The drawback of the Kramer drive is that the machines need to be over dimensioned in order to cope with the extra circulating power. This drawback was corrected in the Scherbius drive where the slip power is fed back to the AC grid by motor generator sets [3].

METHODOLOGY

The rotor is coupled to the DC prime mover and rotor terminals connected to the meter. The starter is in delta connection and the output also taken to the meter to display the produced voltage, current power factor, energy frequency and if at all the produced voltage is lower than the required one a synchronization panel helps in importing from the grid power as shown in panel

An experiment to calculate the efficiency of DFIG (delta stator) setup connected on grid by manual synchronization of DFIG with a grid supply

Below is the procedure and for the connection and its block diagram

NO	FROM	TO	NO	FROM	TO
1	EMT8 (14)	EMT23/3(1)	2	EMT8 (15)	EMT23/3(2)
3	EMT23/3(3)	EMT9 (7)	4	EMT23/3(4)	EMT9 (8)
5	EMT8 (6)	EMT9 (14)	6	EMT8 (7)	EMT9 (4)
7	EMT8 (8)	EMT9 (16)	8	EMT8 (9)	EMT9 (19)
9	EMT8 (12)	EMT23/2(1)	1O	EMT8 (13)	EMT23/2(2)
11	EMT8 (10)	EMT23/1(1)	12	EMT8 (11)	EMT23/1(2)
13	EMT9 (14)	EMT9 (28)	14	EMT9 (9)	EMT6B/3(1)
15	EMT9 (13)	EMT6B/3(3)	16	EMT6B/3(2)	EMT6B/3(5)
17	EMT6B/3(6)	DC M/C (5)	18	EMT6B/3(4)	DC M/C (3)
19	EMT23/2(3)	EMT23/2(5)	20	EMT23/2(4)	EMT23/2(6)
21	EMT23/2(7)	EMT6B/2(1)	22	EMT23/2(8)	EMT6B/2(3)
23	EMT6B/2(2)	EMT6B/2(5)	24	EMT6B/2(6)	DC M/C (7)
25	EMT6B/2(4)	DC M/C (5)	26	EMT23/1(3)	EMT23/1(5)
27	EMT23/1(4)	EMT23/1(6)	28	EMT23/1(7)	EMT6B/1(1)
29	EMT23/1(8)	EMT6B/1(3)	30	EMT6B/1(2)	EMT6B/1(5)
31	EMT6B/1(6)	PE7A/L (8)	32	EMT6B/1(4)	PE7A/L (12)
33	PE7A/L (9)	PE7A/L (14)	34	PE7A/L (15)	PE7A/L (20)
35	PE7A/L (21)	PE7A/L (26)	36	PE7A/L (11)	PE7A/L (16)
37	PE7A/L (23)	PE7A/L (28)	38	PE7A/L (13)	PE7A/L (18)
39	PE7A/L (19)	PE7A/L (24)	40	PE7A/L (25)	PE7A/L (30)
41	PE7A/L (27)	PE7A/R (8)	42	PE7A/L (31)	PE7A/R (12)
43	PE7A/R (9)	PE7A/R (14)	44	PE7A/R (11)	PE7A/R (16)
45	PE7A/R (13)	PE7A/R (18)	46	PE7A/L (17)	EMT74 (I)
47	PE7A/L (29)	EMT74 (2)	48	PE7A/R (10)	EMT74 (3)

49	PE7A/R (19)	EMT74 (7)	50	EMT74 (4)	EMT34/3(1)
51	EMT74 (5)	EMT34/3(2)	52	EMT74 (6)	EMT34/3(3)
53	EMT34/3(5)	3ϕAC M/C (1)	54	EMT34/3(6)	3ϕAC M/C (3)
55	EMT34/3(7)	3ϕAC M/C(5)	56	3ϕAC M/C (8)	3ϕAC M/C (18)
57	3ϕAC M/C (10)	3ϕAC M/C (12)	58	3ϕAC M/C (14)	3ϕ AC M/C (16)
59	3ϕAC M/C (7)	EMT34/2(1)	60	3ϕACM/C (11)	EMT34/2(2)
61	3ϕAC M/C (15)	EMT34/2(3)	62	EMT34/2(5)	EMT26B (10)
63	EMT34/2(6)	EMT26B (11)	64	EMT34/2(7)	EMT26B (12)
65	EMT1 (5)	EMT1 (6)	66	EMT1 (1)	EMT34/1(1)
67	EMT1 (2)	EMT34/1(2)	68	EMT1 (3)	EMT34/1(3)
69	EMT34/1(5)	EMT26B (1)	70	EMT34/1(6)	EMT26B (2)
71	EMT34/1(7)	EMT26B (3)	72	EMT26B (4)	EMT26A (32)
73	EMT26B (5)	EMT26A (49)	74	EMT26B (6)	EMT26A (51)
75	EMT26B (7)	EMT26A (31)	76	EMT26B (8)	EMT26A (33)
77	EMT26B (9)	EMT26A (50)	78		

Fig. 1: shows the procedure for the connection

Panel name	Length	Panel number	Quantity
Instrumentation power supply cum multichannel DPM panel	Single	EMT 8	1
8 IGBT power sensing panel	Double	PE7A/L and PE7A/R	1
FPGA base controller panel	Single	XPO-EST (FPGA-11)	1
Variable AC and DC supply panel (dimmer)	Single	EMT23	3
DC voltmeter and ammeter panel	Single	EMT 6B	3
SCR actuator cum sensor signal conditioning panel	Single	EMT9	1
Multifunctional 3 phase measurement panel	Single	EMT 34	3
3 phase alternator synchronizing panel	Double	EMT 26A/B	1

Input 3 phase DOL starter panel	Single	EMT 1	1
LC filter panel	Double	EMT 74A/B	1

Fig. 2: Shows panel names, length, panel number and quantity

PROCEDURE

1. Connect main cords to the EMT8 panel. Connect the 3 pin main cords from EMT8, FPGA kit and each EMT34 panels to extension board to, apply 230Vac.
2. Connections are made as per the below block diagram.
3. Connections are also made as per wiring sequence by using patch cords.
4. Connect the 6 pin M-M cable from the torque output of DC motor to the J10 of EMT9 panel to measure torque of DC motor o display on EMT8 panel.
5. Connect the 6 pin M-M cable from speed sensor of DC motor to J6 of EMT9 panel to measure the speed of DC motor on display OF emt8 panel.
6. Keep the 10T pot (SP) on EMT9 at fully CCW direction. Keep switch SW2 t left side (feedback) and switchSW4 at down side for PI controller mode.
7. Keep the SW5 at right side on EMT9 panel to select right side load to measure torque of DC motor.
8. Keep sensor selection switch at 1st position on EMT8 to measure speed of DC motor.
9. Keep the knob on the table top EMT23/3 panel at fully clockwise so that 270Vac will apply to SCR actuator panel EMT9.
10. Previously keep the dimmer of EMT23/1 panel such that 10% voltage (10-20Vdc) will apply to dc bus of inverter (PE7 panel). If DC bus voltage is kept at zero, inverter output voltage which is connected to rotor excitation also zero. Means I cannot observe generator output (stator)/frequency on EMT34/2 panel.
11. Press the switches SW1, SW2 AND SW3 on the EMT8 panel to apply 230Vacto SCR actuator (EMT9) and bothEMT23/1 and EMT23/2 panels simultaneously and (+ and -) 12Vdc and +5Vdc to EMT9 and PE7 panels through 20 pin FRC cable.
12. Set the dimmer on EMT23/2 panel such that to set 200Vdc voltage on EMT6B/2 panel, shunt field voltage of DC motor.
13. Connect the DSO CHI to the TP2 and GND to the inverter panel (PE7) to measure the frequency of the inverter (PE7).At power ON the inverter frequency is +50Hz.
14. Connect the 5 pin male power connector from the EMT1 panel to the grid.
15. Keep the synchronizing switch on EMT26A panel at OFF position.
16. Set the +15Hz frequency of inverter by pressing the decrement switch (PB1) on PE7 panel and verify that frequency at TP2 w.r.t. GND on DSO.
17. Slowly increase 10T pot on EMT9 panel to increase the speed of DC motor. Set the speed of DC motor at 1050RPM (frequency=35Hz) and measure the RPM of DC motor on the 7 segment display on EMT8 panel.
18. Press the key **sys** on both EMT34/1 and EMT34/2 panels so that you can observe the line to neutral voltage and frequency of grid and generator on the display of both EMT34/1 panels.

19. Set the dimmer bon EMT23/1 such that to achieve 230V line to neutral voltage at the o/p of generator on EMT34/2 panels.
20. Slowly adjust the 10T pot on EMT9 panel to achieve 50 Hz frequencies and slowly adjust the dimmer on EMT23/1 panel such that to achieve 230V line neutral voltage on EMT34/2 panel.
21. Now press start push button on EMT1 panel to apply grid voltage to the synchro scope (EMT26A/B)

BLOCK DIAGRAM SHOWING THE CONNECTION

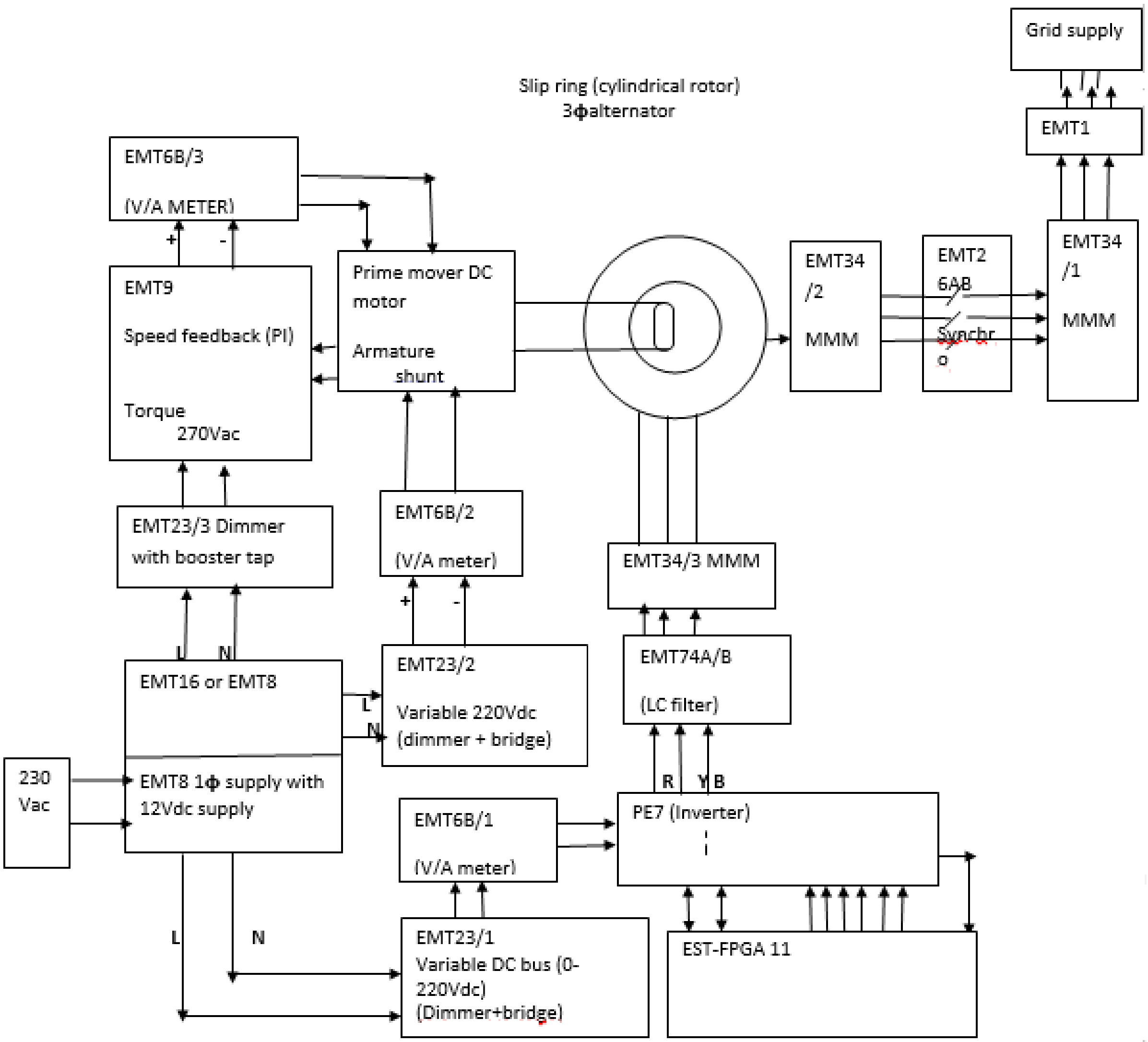


Fig. 3: shows the block diagram

Observations

If there is phase difference between grid RYB voltages and generator RYB voltages, then we can/t ON synchronizing switch on EMT26 panel but just interchange the Rand Y phases connected from EMT34/2 to EMT26 panel.

There is phase difference between grid RYB voltages and generator RYB voltages incase the 3 lamps on EMT26 glow continuous. If the generator voltage is higher or less than grid voltages, then adjust the voltages of generator by using a dimmer on EMT23/1 panel. If the generator frequency is higher or less than the grid voltage, then slowly adjust the frequency of the generator by using fine tuning 10T pot on EMT9 panel.

RESULTS

Testing and results

During the testing of the DFIG machine, at synchronization the grid and generator voltages are the same, the 3 lamps go off and green lights on the sychro scope panel turn. The speed of the DC prime mover is increased and decreased using the dimmer EMT 23/3. Synchronization helps to reduce mechanical stress on the machine. The when the frequency is low, speed is also low and when the frequency is high, the speed is low. The dimmer is used to set the voltage to be applied to the meters. The frequency is set and the corresponding speed and torque recorded from the display at EMT 8.

Calculation of the Efficiency

Efficiency= (power out/power in) ×100%

Power out=Export power in watts

Power in = (P1+P2)

P1 = $(2\pi NT)/60$ shaft power

Where N =speed in RPM

T =torque =L×9.81×0.07(N-M)

L = load in Kg

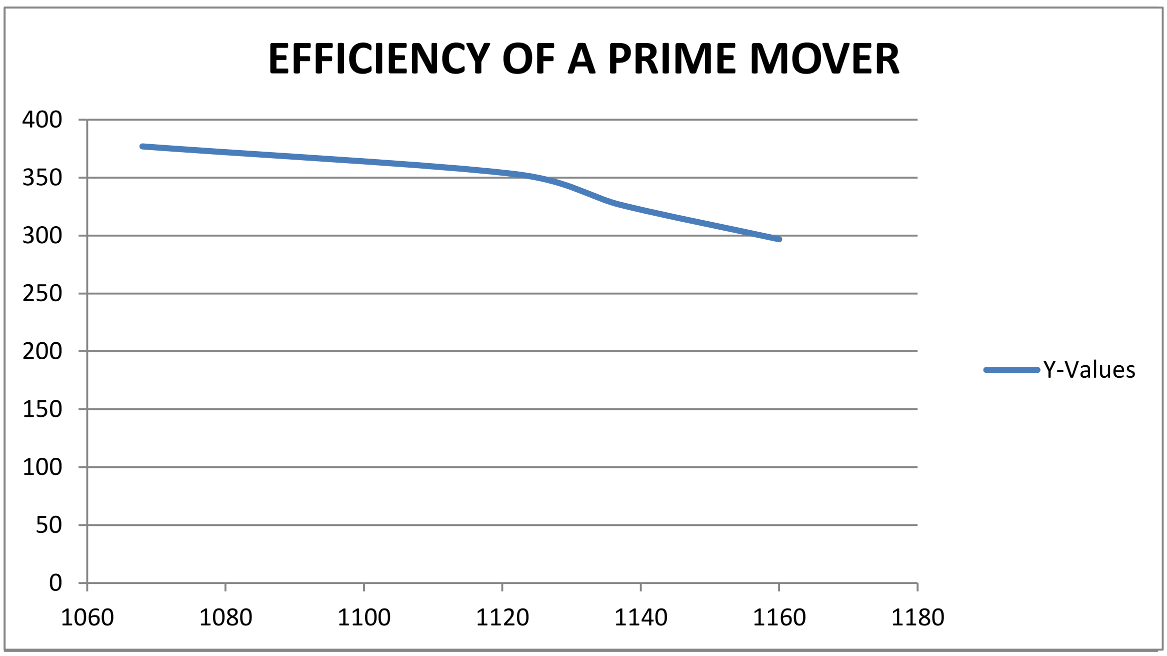
P2 =Vr×Ir (inverter power)

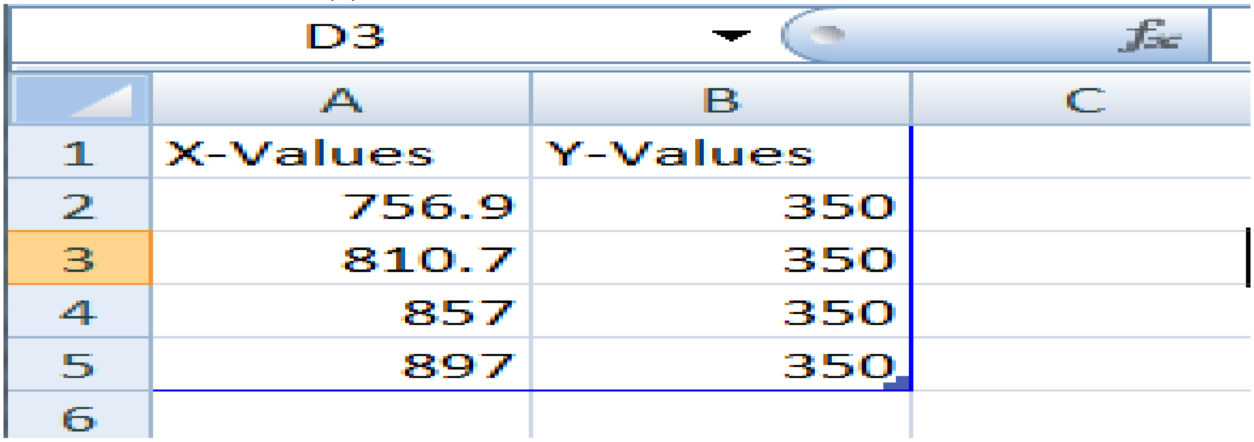
Prime mover (separately excited DC prime mover)												
									Electrical I/P		Mechanical O/P	DC machine
Speed (N) in RPM	F In Hz	Load L in (Kg)	Armature field			Shunt field			Pm=Pa+Pf In W	Torque T=L×9.81×0.07 In (N-M)	Shaft power(P1)= (2ΠNT)/60 In W	Efficiency= (P1/Pm)×100%
			Va	Ia	Power Pa= Va×Ia	Vf	If	Power Pf= Vf×If				
1050	35	4	200	3	600	200	2.8	560	1160	2.7	296.9	25.6
1200	40	3.8	210	2.9	609	220	2.4	528	1137	2.6	326.7	28.7
1350	45	3.7	220	2.8	616	230	2.2	506	1122	2.5	353	31.4
1500	50	3.6	230	2.6	598	235	2	470	1068	2.4	377	35.3

Frequency In HZ	DFIG inverter DC bus			DFIG Inverter O/P	Pjn=P1+P2	Slip ring 3ϕ generator O/P delta connected stator			DFIG efficiency= (Pout/Pin)×100%
	Vr	Ir	P2=Vr× Ir in W	Frequency Finv(F2)	Input power Pin =P1+P2 In W	Voltage Vout Line to line	Frequency (Fout)=F1± F2 in Hz	Export power (Pout) in W	
35	230	2	460	15	756.9	415	50	350	46.2
40	220	2.2	484	10	810.7	415	50	350	43.2
45	210	2.4	504	5	857	415	50	350	40.8
50	200	2.6	520	0	897	415	50	350	39

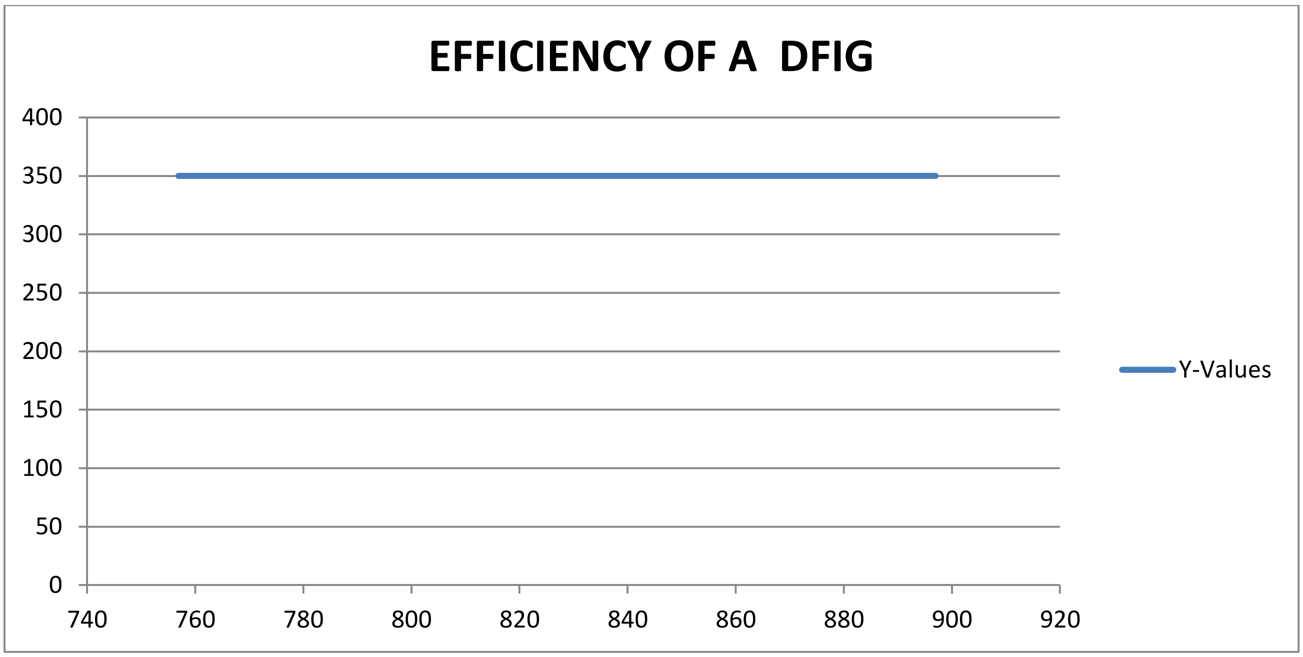
FIG 4. Shows the table of results

	A	B	C
1	X-Values	Y-Values	
2	1160	296.9	
3	1137	326.7	
4	1122	353	
5	1068	377	
6			





	A	B	C
1	X-Values	Y-Values	
2	756.9	350	
3	810.7	350	
4	857	350	
5	897	350	
6			



Explanation of the efficiency graphs

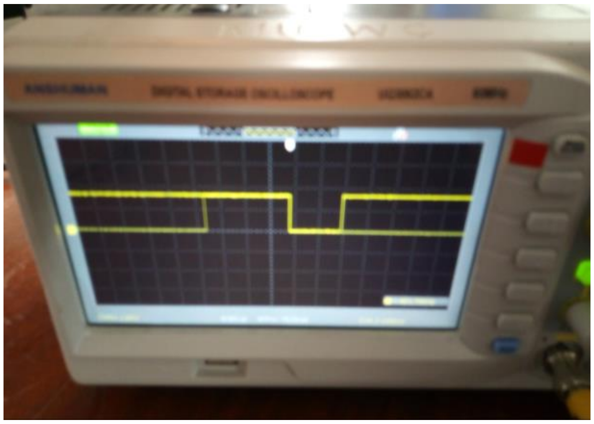
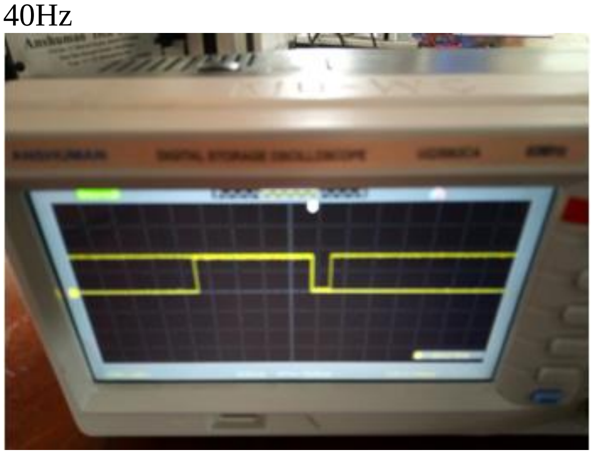
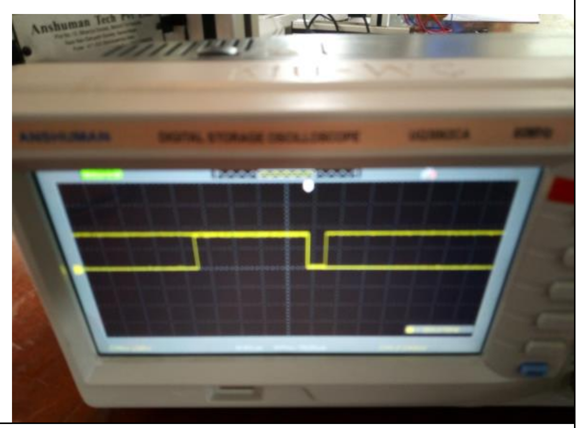
Dc prime mover

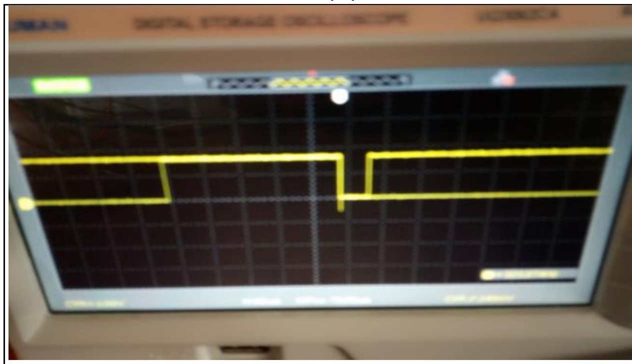
The higher the input power the lower the efficiency.The lower the input power the higher the efficiency.

DFIG inverter

The graph is a constant graph because there were no changes in the output power. The lower the input power the higher the efficiency and the higher the input power the lower the efficiency as seen above in the table of results.

The nature of the waveform displayed at the DSO at different frequencies

30Hz  35Hz	35Hz 
40Hz 	45Hz 
0 50Hz	



DISCUSSION

If there was a phase difference between grid RYB voltages and generator RYB voltages, then we can't "ON" synchronizing switch on EMT 26 panel. Interchange the R and Y phases connected from EMT 34/2 to EMT 26 panel. After synchronizing the generator imports power from the grid, negative sign on EMT 34/2 meter means generator is exporting power from the grid. Slowly increase the 10T pot on EMT 9 panel to export power to grid, DC motor armature current (on EMT 6B/3) and simultaneously export power (on EMT 34/2) also increases up to maximum export capacity of generator, then armature current falls and generator imports power from grid. The increase and decrease cycle repeats continuously. When armature current is falling down, slightly adjust the 10T pot on EMT 9 panel such that the armature current stop to fall and the generator will export stable power to the grid continuously and stops hunting. However, this stable point is below the maximum power point. At this stable condition, the generator continues to export power to grid without hunting but at lower value.

CONCLUSION

The lower the input power of the DC prime mover the higher the efficiency and the higher the input power the lower the efficiency. The lower the power input of a DFIG the bigger the efficiency and the bigger the input power the smaller the efficiency. Hence the machine is energy efficient and still gives a good efficiency.

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