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Impact of TSC on Terminal Voltage Parameter Control of a 3 Phase SEIG

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ABSTRACT

In this article, performance analysis of Thyristor Switched Capacitor (TSC) based regulator in voltage parameter of 3 phase Self Excited -Induction Generator (SEIG) with squirrel cage type rotor supplying R-L (Resistive- Inductive) load was described. The mathematical models of the SEIG with and without voltage regulator were analyzed. The main shortcoming of SEIG is not inherently self exciting. Voltage parameter highly correlated with reactive power. Hence for better voltage regulation, dynamic reactive power source during variations in load conditions should be provided. An analysis had been made to study the outcomes using TSC in SEIG. The complete proposed system is modeled in MATLAB/SIMULINK tool box. Experimentation also carried out with and without voltage regulator TSC. The simulated and experimentation results of a detailed study were done in open loop control on a 2.2KW induction motor. The given motor was operated in generator mode as a SEIG. The performance of SEIG were presented and discussed here.

Key words : FACTS, Reactive power, SEIG, TSC, Voltage parameter

1. INTRODUCTION

Recent years, especially in rural area for low and medium applications, more attention has paid on induction generator for renewable resources (specifically wind energy). It has proven as a substitute of synchronous generator due to many reasons. Induction generators are very simple, more reliable, rugged in construction, brushless, less weight, long life (more than 40 years), ease of maintenance, absence of separate dc source, self short circuit protection etc [1]-[3]. It is well acknowledged that, a 3 phase induction motor employed as induction generator only when its slip becomes negative.

The excitation of the induction generator is contributed by either by gird or by connecting a suitable size of three phase ac capacitor bank at its stator terminal are called self excited induction generator[4].The voltage parameter of three-phase SEIG highly depends on the following factors.1. External shunt capacitance 2. Prime mover swiftness. 3. Nature of the electric loads. [5],[6].

Adjustment in prime mover speed is not always a feasible solution for getting desirable voltage. However, controllable capacitive reactance value can be achieved by applying FACTS technology [7],[8].

At the same time it is observed that, system may have surplus excitation current with either system is loaded with capacitive loads (or) system is lightly loaded. Hence, reactive power management places a crucial role to normalize load voltage of the given system. Different approaches had been proposed in the literature [9]-[12] with an objective of regulating load voltage of the SEIG. This paper describes how terminal voltage profile of the system will be improved using Thyristor Switched Capacitor (TSC). In [16], order to the voltage control system of SEIG, a TRIAC based approach had been described.. The main intention of the article was to define the system voltage up to a permissible terminal voltage level by using Fixed Capacitor Thyristor Controlled Reactor [17].

This paper describes how terminal voltage profile of the system will be improved using Thyristor Switched Capacitor (TSC). The simulation had been done using MATLAB software.[13]

2. MATHEMATICAL MODELING OF 3 PHASE SEIG

Figure 1 illustrates three phase SEIG in absence of TSC.

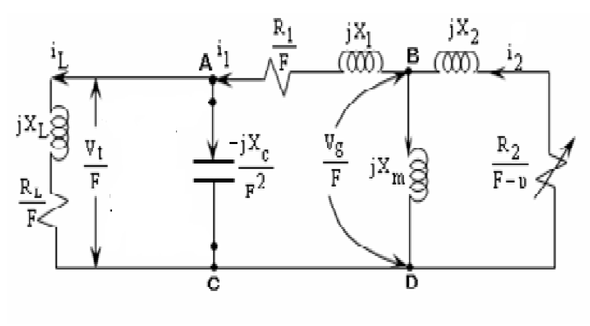

Figure 1: Equivalent circuit of one phase of 3 phase induction generator without voltage regulator

(All quantities are per-phase values referred to stator, and related to base frequency. Per unit quantities are to the base of respective rated values)
Self excitation of an induction machine had cropped up, as soon as, the rotor is driven by an external prime mover and a

suitable capacitors were connected across its stator terminals. The frequency parameter and magnetizing reactance of the SEIG shows a discrepancy with load even when the rotor speed is maintained constant.

Table 1: A Various parameters of induction generators

Parameters	Notation
R_1	Stator resistance per phase in ohm
R_2	Rotor resistance per phase in ohm
X_1	Stator reactance per phase in ohm
X_2	Rotor reactance per phase in ohm
X_m	Magnetizing reactance in ohm
X_c	Per phase capacitive reactance of static capacitor in ohm
R_L and X_L	Load resistance and reactance per phase in ohm
Z_L	Load impedance per phase in ohm
F and Y	Frequency and speed in per unit
I_1, I_2 and I_L	Stator, rotor and load current
V_g and V	Airgap and terminal voltage

3. DESCRIPTION OF TSC BASED VOLTAGE REGULATION FOR SEIG SYSTEM

The schematic arrangement of the proposed SEIG with TSC based voltage regulator was revealed in Figure 2. A set of static 3 phase capacitor bank (C_E) permanently associated with stator terminal. A four pole 415 Volts, 2.2 Kilowatts squirrel cage rotor, star connected 3 phase SEIG was considered to deliver a balanced 3 phase resistive – inductive (RL) load. TSC is connected across a 3 phase external capacitor bank. The capacitor bank supplies the reactive power offered by the induction generator. Whereas, TSC is associated the RL load.

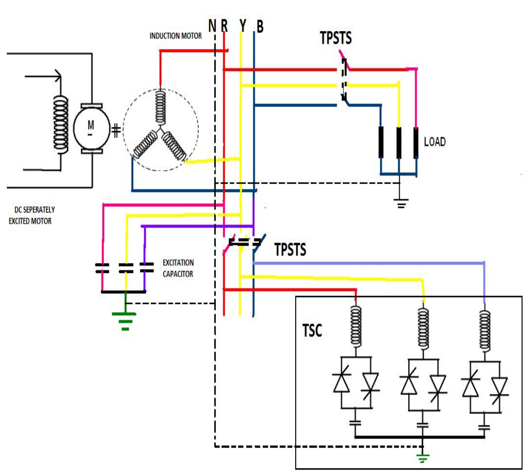

Figure 2: Proposed system configuration (Using TSC Voltage regulator)

4. FACTS – THYRISTOR SWITCHED CAPACITORS (TSC)

Figure 3 shown below is the basic configuration of the TSC, established by ASEA in the year1971. It belongs to shunt connected FACTS family and is utilized for reactive power compensation. [14],[15]

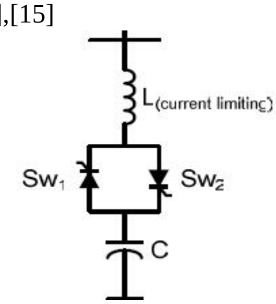

Figure 3: Thyristor Switched Capacitor configuration

5. SIMULATION OF THE PROPOSED SYSTEM

The simulation had been performed through MATLAB / SIMULINK software [13] as shown in Figure 4. A three phase, 2200 Watts, 415Volts, 4.7A, star connected induction machine is used as induction generator [18]. A 3 phase capacitor (16µfd / phase) was linked across its stator terminals.

Mechanical torque (T_m) of -13.6Nm was taken for the simulation study.

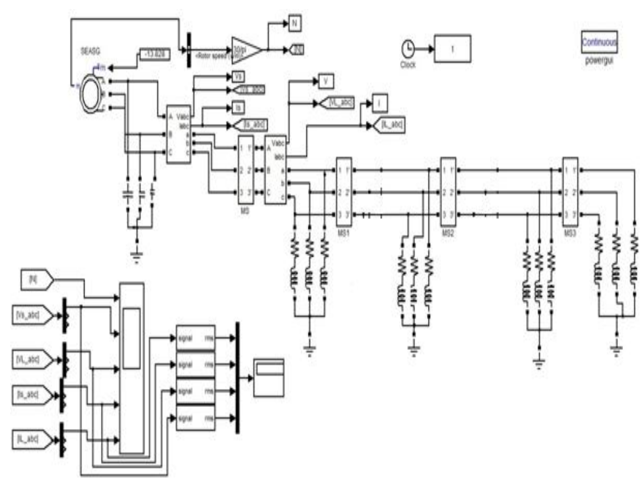

Figure 4: Simulation of the proposed system with various load conditions without voltage regulator

The external circuits were associated through 3 main switches called S_1, S_2 & S_3, measuring units called M_1, M_2 & M_3 and load. Figure 4 and 5 described about the simulation of the proposed system without and with various load conditions with voltage regulator. Figure 6 revealed the Voltage regulator – (TSC) subsystem. Table 1 illustrates the specification of the simulated Machine.

Table 2: Specification of the simulated Machine

Rating, Voltage and Cycles/S	2.2KW,415 and 50Hz
Poles and Connection	4 and Delta
Stator and rotor resistance	11 and 8 ohms
Stator and mutual inductance	60mH and 1.06H
Inertia and speed	0.02 and 1520 rpm
Load (R,L)	100 ohm, 0.0314H

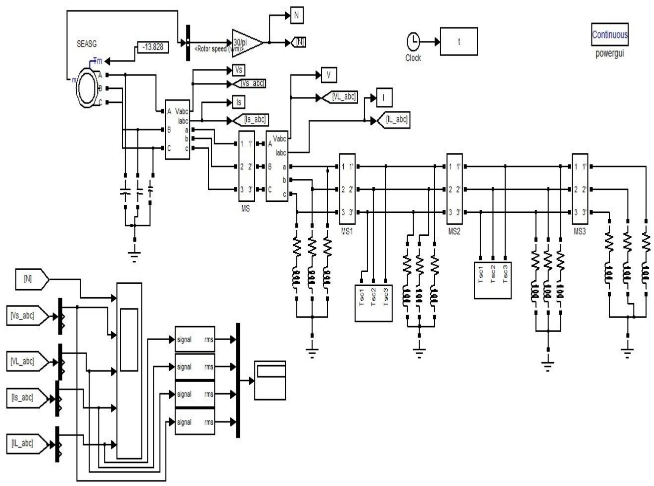

Figure 5: Simulation of the proposed system with various load conditions with voltage regulator

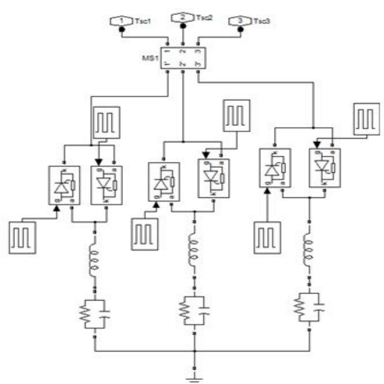

Figure 6: Voltage regulator – (TSC) subsystem

5. EXPERIMENTAL WORK OF THE PROPOSED SYSTEM

The induction machine (specification given in Table 1) was tied with a separately excited D.C. drive motor. Figure 7 (a) & 7(b) were the snapshots of experimental setup of the proposed system.

5.1 Minimum excitation capacitances requirement of a 3 Phase SEIG - Using Synchronous impedance test

The asynchronous machine was driven at synchronous speed using DC motor; the input voltages and the corresponding currents were measured. The speed has to be maintained constant at the synchronous speed of the machine. From the test, various readings of line voltage and current are tabulated in Table 2 and a graph is drawn between lines Voltage verses current. From the graph obtained between the terminal voltage and current a load line is drawn such that it intersects the curve at the rated terminal voltage. The slope of the graph is equal to X_m which is equated to X_c to obtain the minimum capacitance value. The resultant value is the minimum value of capacitance required to run the induction motor as a generator.

Table 3: Line voltage verses field current (Synchronous Impedance Test)

$I_L = I_{ph}$	Line Voltage V_{LL}	Phase voltage $V_{ph} = V_{LL}/\sqrt{3}$	Induced Emf $E_g = V_{ph} - I_a{*}R_a$
0	0	0	0
0.2	100	57.735	55.536
0.3	140	80.829	77.53
0.4	188	108.54	104.14
0.5	236	136.254	130.75
0.6	290	170.895	164.29
0.7	348	200.917	193.22
0.8	408	235.558	226.76
0.9	440	254.034	244.13
1	443	255.94	244.94
1.1	446	257.41	245.31

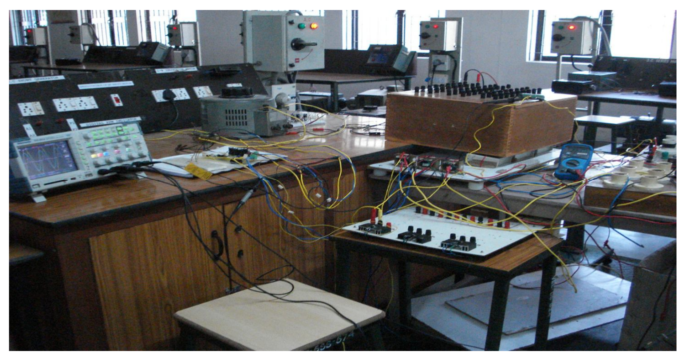

Figure 7(a)

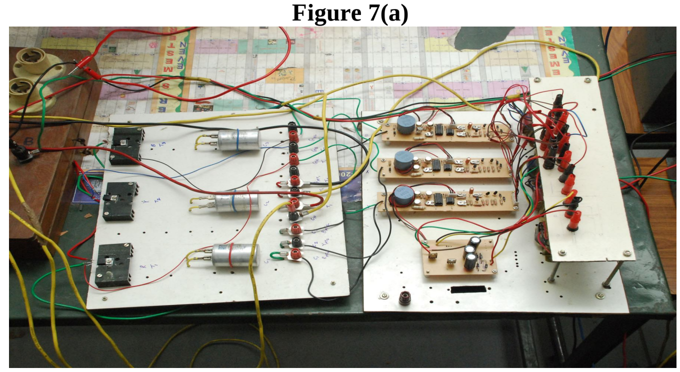

Figure 7(b)
Snapshot of an experimental setup

6. SIMULATION RESULTS & INFERENCES

The simulation studies of SEIG were analyzed with the following factors. (a)Without TSC (b)With voltage regulator

(TSC). In Figure 8(a), induced voltage shooted more than the rated value and then matured at 3000V as shown in Figure 8(b). The rise in induced voltage is owing to the surplus capacitance value of the capacitor (C_E).

Figure 8(c) illustrate extracted supply voltage waveform of SEIG and Figure 8(d) demonstrates simulated output waveforms with increase in load from the full load condition (without voltage controller) SEIG (when load current increases to 120% of full load value). The simulation result shows very clearly, as load increases, there is a drop in voltage at load side due the nature of SEIG load characteristic.
Figure 8(e) illustrates simulated output waveforms with increase in load from the full load condition (with voltage controller).Through the result, it is observed that, using TSC voltage regulator, when load current is increased to 120% of its full load, voltage is boosted hence the voltage regulation at load side is improved using TSC voltage regulator.

Figure 8(f) & 8(h) represents Load voltage waveform of SEIG without & with voltage regulator (TSC). Figure 8(g) & 8(i) shows the extracted load voltage waveform of SEIG without and with voltage regulator (TSC). Figure 8(j) & 8(k) illustrates the load current waveforms without and with voltage regulator.

The simulation has done with different load conditions without and with TSC voltage regulator and results are tabulated. Table 3 shows load voltage of the system is drooping when load current is gradually increases. Table 4 shows the comparison in variation of load with and without voltage regulator. It is observed that, using TSC voltage regulator, through reactive power injection, voltage profile at load side is improved.

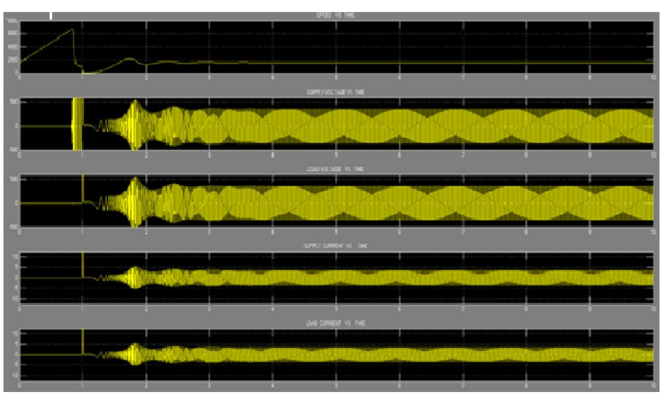

Figure 8(a) : Simulated output waveforms under full load condition without voltage regulator

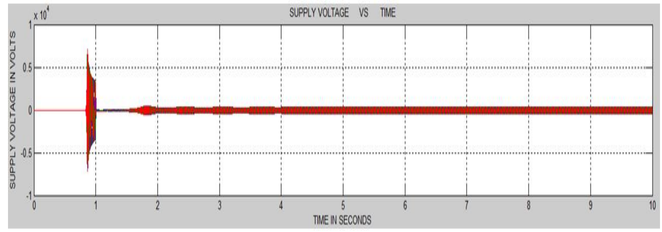

Figure 8(b): 3 phase voltage waveform of SEIG

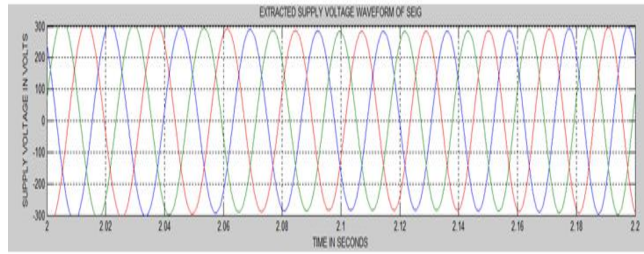

Figure 8(c): Supply voltage waveform (Extracted) of SEIG

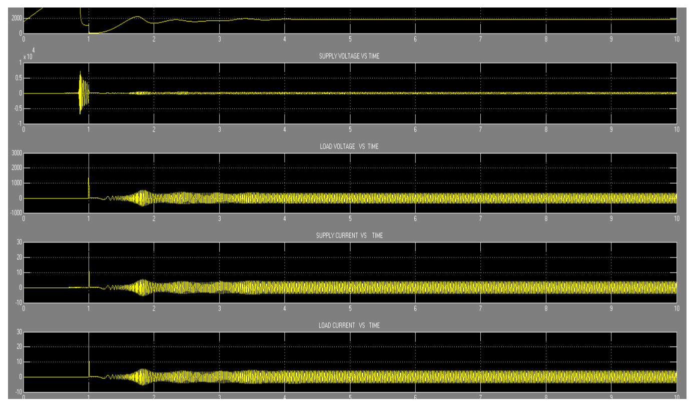

Figure 8(d): Simulated output waveforms with augment in load (absence of voltage controller)

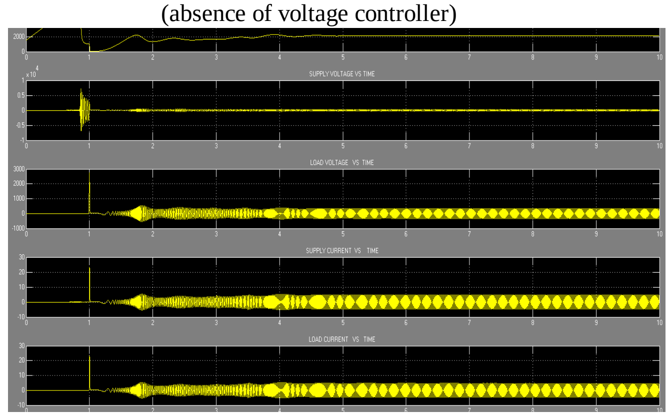

Figure 8(e): Simulated output waveforms with augment in load (In presence of voltage controller - TSC)

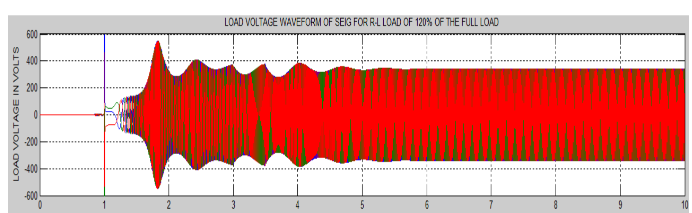

Figure 8(f): Load voltage waveform of SEIG without voltage regulator (TSC)

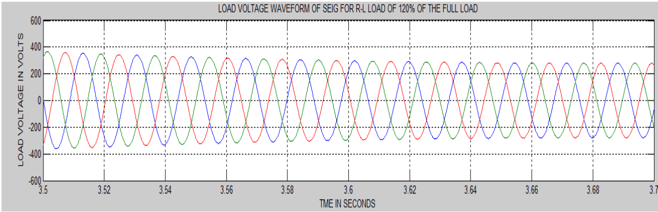

Figure 8(g): Extracted load voltage waveform of SEIG (without voltage regulator)

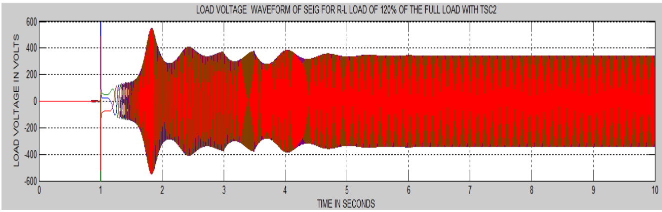

Figure 8(h): Load voltage waveform of SEIG with voltage regulator (TSC)

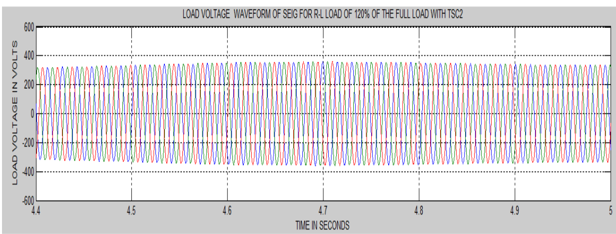

Figure 8(i): Extracted load voltage waveform of SEIG (with voltage regulator)

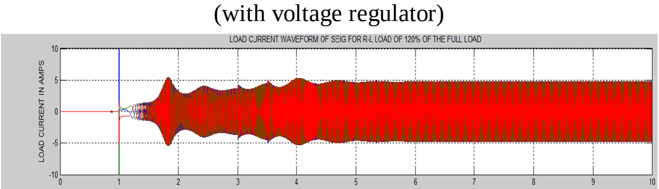

Figure 8(j): Load Current waveform of SEIG without voltage regulator(TSC)

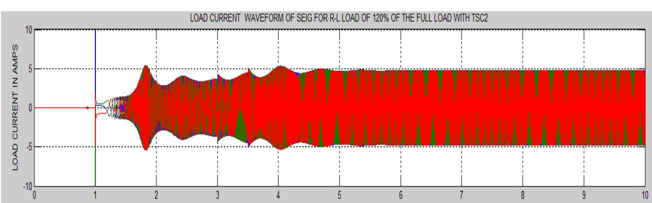

Figure 8(k): Load current waveform of SEIG with voltage regulator (TSC)

Table 3: Terminal voltage across the load under different load condition with voltage regulator

Load Voltage (in V)	Load current (in A)	Load Voltage (in V)	Load current (in A)
Without TSC		With TSC	
234.4	2.834	241.9	2.843
228.1	3.237	239.6	3.384
220.8	3.92	236.4	4.02
234.4	2.834	241.9	2.843

7. EXPERIMENTAL RESULTS & INFERENCES

From the Figure 9, the value of X_m was calculated which was equal to X_c. Table 4, 5 and 6 reveals the contribution of various capacitance while conducing load test on SEIG.

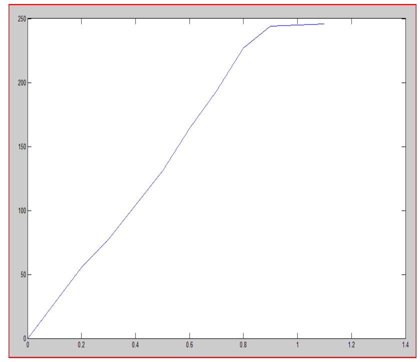

Figure 9 – Line voltage Verses Field current (Synchronous impedance test)

From the line voltage verses field current graph,

$Z = X_m = 240/0.86 = 279.069\ \Omega$

$X_m = X_c = 1/(2*\pi*f*c)$

$C_{min} = 11.412\mu f$

Table 4 : Load test on SEIG without voltage regulator (Frequency = 49.5Hz)

V_{dc}	I_{dc}	I_{ac}	V_{ac}	W_1	W_2
230	5.2	1.5	360	360	60
220	4	1.2	400	280	20
220	3.5	1.0	420	260	0
218	3.2	0.5	480	220	0
216	2.8	0	540	200	0

Table 5 : Load test on SEIG with voltage regulator – TSC (Chosen capacitor value =4µf)

V_{dc}	I_{dc}	I_{ac}	V_{ac}	W_1	W_2
220	4.2	1.5	370	440	0
220	4.5	1.2	420	500	0
218	4.9	1.0	440	520	70
216	5.5	0.5	490	600	60
216	5.9	0	540	670	80

Table 6 Load test on SEIG with voltage regulator – TSC (Chosen capacitor value =4µf)

V_{dc}	I_{dc}	I_{ac}	V_{ac}	W_1	W_2
220	5.2	1.5	384	660	0
220	6.5	1.2	430	700	0
218	8	1.0	450	760	60
216	7.6	0.5	500	720	200
218	7.4	0	540	0	0

From the above experiment results, a graph called load curve is plotted between load voltages (V_{ac}) Vs load current I_{ac} as shown in Figure 10. There are 3 categories of load curves plotted based on capacitance values (4µf and 8µf) chosen in

TSC and in case of 3rd load curve, the graph is plotted without considering voltage regulator TSC. These plots shown very clearly that, as load current increases, terminal voltage drops.

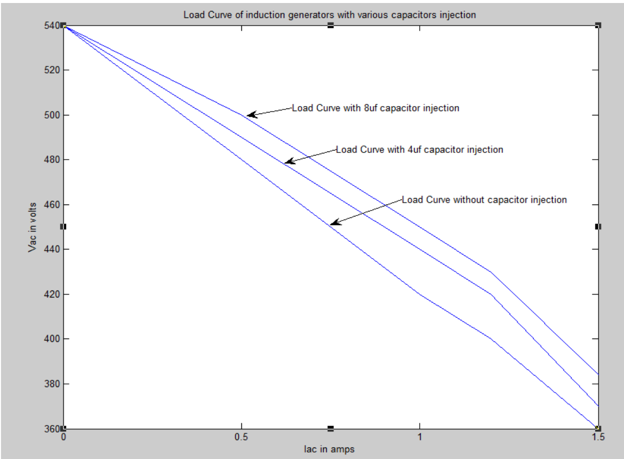

Figure 10: Load voltage verses load current without TSC & with TSC (having different capacitance value)

8. CONCLUSION

The negative aspect on SEIG is its drooping terminal voltage load characteristics. A simplest method had been proposed in this research article to progress load voltage parameter of a SEIG.

Since SEIG cannot produce any reactive power (Q) but at the same time it consumes Q. Therefore, there is a rapid decrease in the terminal voltage with the application of electric load. To get rid off, an external source of reactive power must be installed all times to maintain its stator magnetic field and also to control the terminal voltage profile.

A 3 phase passive resistive – inductive load variation were applied for examine the performance of the TSC based system to regulate the terminal voltage of SEIG. Simulation result shows there is an improvement in system voltage regulation. Various voltage regulating schemes of the SEIG to improve the system performance are discussed. It is concluded that, from the experimentation and observed simulation results, using TSC terminal voltage profile had been improved significantly.

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