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# Binary Switched Capacitor Bank Controller for Voltage Regulation of Self Excited Induction Generator

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***Abstract:*** *The world is shifting gears towards green energy sources. However, a focus is still there on the minimization of the installation cost and maintenance overheads. The installation cost is huge for solar power while maintenance is nil. On the other hand, in small wind and hydro power generation, the installation cost is greatly affected by the alternators. The use of induction generators is becoming popular these days due to its characteristics like robustness, low cost, inherent overload/short circuit protection etc. The main drawback of induction generators is the requirement of reactive power and poor voltage regulation. This paper presents the voltage controller design for variable speed turbine based self excited induction generator using binary switched capacitor bank.*

***Keywords:*** capacitor, capacitor bank, self excitation, induction generator, binary weighted switching

## 1. INTRODUCTION

Induction generators are commonly used for small hydro and wind schemes due to advantages such as availability, low cost and robustness. The installation cost per KW of electricity produced of an alternator is much higher as compared to an induction generator. [1, 2] Hence it becomes economical to develop systems using a three phase induction generator. The typical excitation scheme Star – Delta (Y – Δ) is implemented where the stator windings of induction machine are configured in star whereas the capacitors are connected in delta. The capacitors provide the necessary reactive power i.e. self excitation to the induction machine [3, 4].

The terminal voltage is maintained fairly constant with the help of a binary weighted switched capacitor bank which is controlled such that the terminal voltage is maintained constant under variable speed (RPM) conditions [5]. In practical application, variable speed operation is triggered by wind mills.

## 2. SYSTEM DETAILS

### *Star Delta Configuration*

A three-phase self excited induction generator is configured such that the induction machine windings are connected in star configuration whereas the capacitor bank falls in delta configuration.

The advantage of this system is that the motor operates at lower voltage whereas the three phase connections operate at higher voltage. [6]

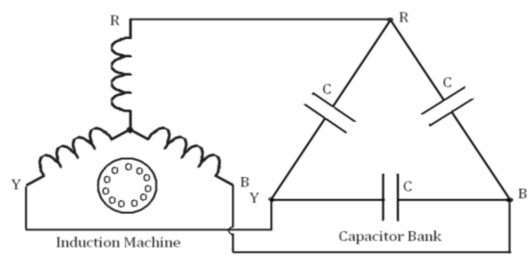


**Fig. 1:** Star Delta Configuration

### *Machine Ratings*

For experiment purpose an induction motor with following specifications was selected at laboratory usage.

1440 RPM, 4 pole, 2 HP, three phase, 220V, 4.5A, star connected induction motor.

To simulate the variable speed conditions as given by the wind turbine, the selected induction motor is coupled with a DC shunt motor with following specifications:

2.2KW, 220V, 10A, 1500RPM DC shunt motor

The overall arrangement is shown in fig 2

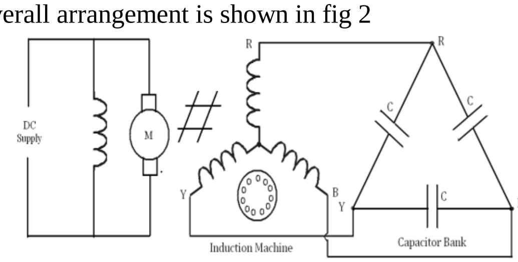


**Fig. 2:** DC shunt motor coupled with three phase induction machine

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## 3. HARDWARE DESIGN

### 3.1 *Self* Excitation Capacitor Calculations

The excitation capacitors for self excitation of the selected induction generator are calculated from simple power equations of a three phase circuit as: [5]

$$P = \sqrt{3}\, V\, I\, \cos\phi$$

$$\phi = \cos^{-1}\left(\frac{P}{\sqrt{3}\, V\, I}\right)$$

$$\text{Reactive Power} = \sqrt{3}\, V\, I\, \sin\phi$$

$$\text{Reactive Power per phase} = \frac{\sqrt{3}\, V\, I\, \sin\phi}{3}$$

$$\text{Capacitor Current} = \frac{\text{Per phase reactive power}}{V}$$

$$\text{Capacitive Reactance} = \frac{V}{\text{Capacitive Current}}$$

$$\text{Capacitor } (C) = \frac{1}{2\,\pi\, f\, X_C} = 18.21\mu F$$

Thus the capacitors are selected as
C = 20µf
The voltage rating of the capacitor is selected to be two times the voltage rating of induction machine hence, capacitor is selected for 440V
From the equation of capacitor, it is clearly seen that the value of capacitor is inversely proportional to the frequency of operation. The wind turbine gives variable speed operations. Hence this value of capacitor also should be variable i.e. controllable.
Thus a binary switched capacitor bank is used wherein the capacitors are designed ranging from 2.5µF to 40 µF

### 3.2 The capacitor bank Controller

The system uses PIC 16F877 microcontroller. The controller is selected to provide the sensing of voltage through on chip ADC and controlling the ON & OFF state of excitation capacitor. The terminal voltage is sensed by microcontroller through ADC and proportionate signal is given as output for switching operation of excitation capacitor in binary weighted manner. The switching operation continues until the output voltage falls within the desired band

### 3.3 Voltage Sensing

The voltage sensing is done by converting the AC output of the induction generator into DC. The AC to DC conversion is achieved through rectifier. The sensing of voltage level is carried out through a 100:1 attenuator so that the ADC inside the microcontroller operated within the limits.

### 3.4 Main Theme

The main theme of the system is achieving the terminal voltage regulation by controlling the capacitance value in the capacitor bank by using a binary switched capacitor bank method. [7]
The block diagram of the overall control system is shown in fig. 3

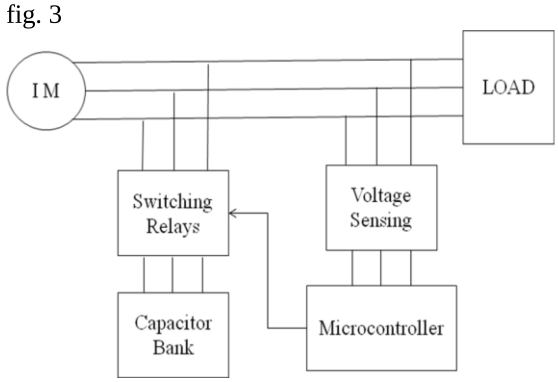


**Fig. 3:** Hardware block diagram

The overall hardware design of the system is presented in fig 3. Here, an induction generator is excited in self excitation with the help of switched capacitors.
For voltage buildup in an induction generator there must be a suitable value of residual magnetism present in the rotor. In the absence of a proper value of residual magnetism, the voltage will not build up. When an induction generator first starts to run, the residual magnetism in the rotor circuit produces a small voltage. This small voltage produces a reactive current flow, which increases the voltage and so forth until the voltage is fully built up. [8]
This voltage is proportional to the speed of rotation as well as the reactive power supplied by the capacitor. This voltage is sensed by microcontroller through the on-chip ADC. The microcontroller compares this input voltage with the set point and proportionately switches the capacitors in binary steps.[9, 10, 11]

## 4. SOFTWARE DESIGN

To find the exact programming requirement, the system is tested without controller. Initially, the system is run without controller with capacitance value ranging from one fifth of the rated value to twice the rated value. It has been observed that the induction machine starts generating power for highest value of capacitance at lower speed also. However as the speed increases the value of voltage built up increases and vice versa.
Hence it is clearly seen that for lower speed the value of excitation capacitance is more and as speed increases the excitation capacitance value should be decreased.
The software design for the voltage regulation is the most crucial part of the system where, in programming all these requirements are taken into account.

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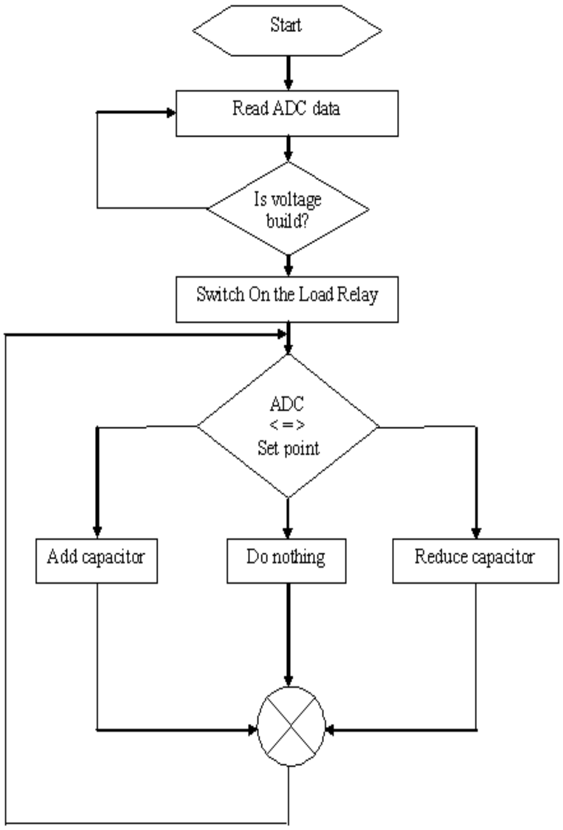


**Fig. 4:** Software program flow for binary switched capacitor bank controller

## 5. RESULTS AND DISCUSSIONS

No Load test on capacitor bank controlled induction generator

| Speed (RPM) | Voltage (V) | Capacitance (µF) | Frequency (Hz) |
|---|---|---|---|
| 860 | 220 | 40 | 26.66 |
| 890 | 217 | 37.5 | 29.66 |
| 920 | 219 | 35 | 30.66 |
| 942 | 216 | 32.5 | 31.40 |
| 964 | 219 | 30 | 32.23 |

**Table 1:** No load test with controller

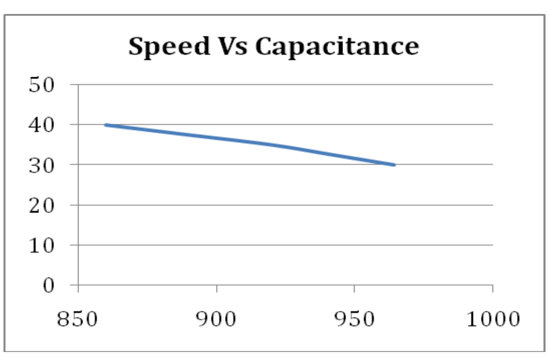


**Fig. 5:** Variation of capacitance with speed at no load

Load test on capacitor bank controlled induction generator (load 300W)

| Speed (RPM) | Voltage (V) | Capacitance (µF) | Frequency (Hz) |
|---|---|---|---|
| 900 | 214 | 40 | 30 |
| 930 | 216 | 37.5 | 31 |
| 966 | 215 | 35 | 32.2 |
| 1005 | 214 | 32.5 | 33.5 |
| 1042 | 214 | 30 | 34.7 |

**Table 2:** Load test with controller (300W)

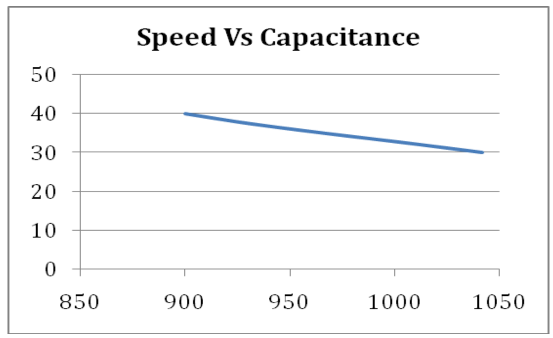


**Fig. 6:** Variation of capacitance with speed at load 300W

Load test on capacitor bank controlled induction generator (load 600W)

| Speed (RPM) | Voltage (V) | Capacitance (µF) | Frequency (Hz) |
|---|---|---|---|
| 967 | 213 | 40 | 32.3 |
| 994 | 214 | 37.5 | 33.1 |
| 1058 | 214 | 35 | 35.3 |
| 1096 | 215 | 32.5 | 36.5 |
| 1138 | 214 | 30 | 37.9 |

**Table 3:** Load test with controller (600W)

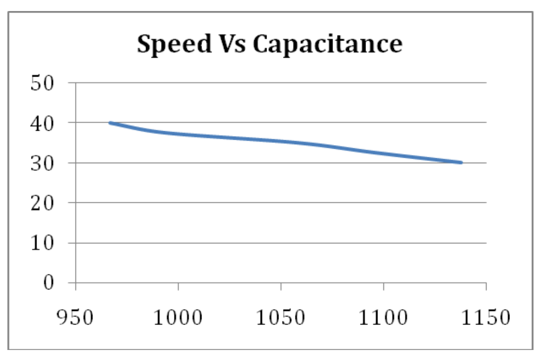


**Fig. 7:** Variation of capacitance with speed at load 600W

## 6. CONCLUSION

The operation of the three-phase induction generator under variable speed conditions is presented. In order to obtain terminal voltage of induction generator constant, reactive power supplied to it has to be controlled. The reactive power supplied to self excited induction generator is controlled by controlling the effective capacitor value. The results show that the terminal voltage falls within the band (2% – 3%) for various speeds. The use of AC – DC link shall be useful for battery charging in case of isolated wind power generations

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