Study on Voltage Controller of Self-Excited Induction Generator Using Controlled Shunt Capacitor, SVC Magnetic Energy Recovery Switch

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Abstract

Reactive compensation is required to maintain terminal voltage of induction generator under varying load and speed operation. A new variable shunt capacitor, which is called SVC magnetic energy recovery switch (SVC MERS), is proposed. The operation principle, characteristics of injected current, operating range of reactive compensation of SVC MERS in star and delta configuration were investigated. Application for induction generator voltage controller, which is required leading reactive compensator, is suitable for SVC MERS. Small scale experiments were conducted to verify the proposed system performance to control induction generator voltage in variable load and speed conditions. The advantage of this device is simple control with low switching frequency. Moreover in delta configuration, the SVC MERS current is low means downsizing of heatsink can be achieved.

Keywords : Voltage controller, induction generator, reactive compensation, SVC MERS

1 Introduction

The global warming issue as well as the fossil fuel limitation has made human kind to do more research in the area of renewable energy sources. One of the promising research area is application of self-excited induction generator (SEIG) in micro-hydro power, wind power and diesel engine with bio-fuel. For example, in Indonesia as energy supply became a problem, the government projected 500 MW of micro-hydro to be installed, especially in rural areas to develop a green source power system [1]. Such a system would normally be operated as an isolated system supplying electricity to local un-electrified areas because it can save transmission and distribution capital investment cost. Some advantages can be achieved such as CO2 reduction and environmental awareness.

SEIG consists of an ordinary three phase induction machine excited by a bank of capacitors and driven by a prime mover, such as hydro turbine, wind turbine, flywheel system or diesel engine [2]. Low cost, robustness and low maintenance need are some of the reasons to use this machine.

However, there is a problem in the operation of SEIG, with poor voltage regulation in varying load conditions. Various approaches have been proposed for overcoming these problems. Availability of low cost controllable power devices, such as IGBTs, have made the application of power electronic based VAR compensation possible. Various controllable reactive power supplies exist such as TSC (Thyristor Switched Capacitor), TSC-TCR (Thyristor Controlled Reactor), STATCOM, and other variable shunt compensators [3][4][5][6]. TSC can only give a variation of capacitance in discrete steps. In transients conditions, charging and discharging of the capacitor will stress the thyristor. To avoid these problems, a combination of TCR and TSC is developed. It has a large reactor in the TCR, in order to have a large continuous control range. The latest technology is STATCOM, which uses PWM inverter as voltage source with high frequency switching to reduce harmonic and more complex control is required [4][5].

In this paper, SVC MERS is proposed to control the voltage of induction generator with low switching and simple control using voltage feedback with PI controller.

2 Induction Generator Characteristics

To generate rated voltage of induction generator, VAR compensation is required. If the induction generator is connected to the grid, VAR can be supplied from the grid by other reactive power sources, such as synchronous generator. In isolated or stand-alone condition, capacitor is usually used. This system is called SEIG.

Self excitation of the generator begins by the action of either a residual magnetism of the iron core and charge in the excitation capacitors. When the induction machine is driven by a prime mover, the residual magnetism of the iron core associated with an external capacitor that generates current by rotor movement inside of this magnetic field will produce induces voltages in the stator windings at a frequency proportional to the rotor speed. However, if there is no residual magnetism, induction generator voltage cannot be generated.

A variable capacitor is required in order to realize voltage regulation of SEIG in varying load conditions or for variable speeds. From theoretical calculations [7], a range of fixed shunt capacitor sizes can be calculated to maintain rated voltage under load varying conditions. Figure 1 shows load characteristic curve for a range of fixed capacitor sizes at synchronous speed and unity power factor load for a 200V 1.5 kW induction machine with magnetizing curve given in equation (1) and induction generator parameter shown in Table 1.

$$L_m = 0.6778 I_m^3 - 7.9931 I_m^2 + 16.231 I_m + 115.04 \quad (1)$$

The curve in Figure 1 shows that variable compensation is needed to maintain rated voltage. Higher capacitance is required if load has low power factor as shown in Figure 2.

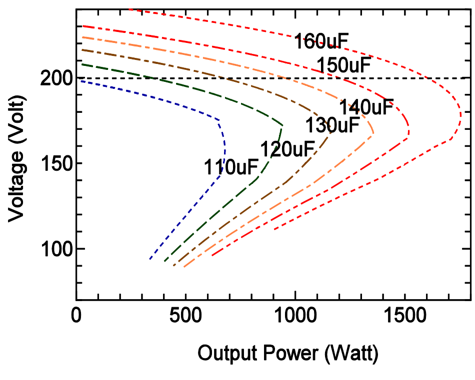

Figure 1 Effect of excitation capacitorof 1.5 kW 200 V induction generator

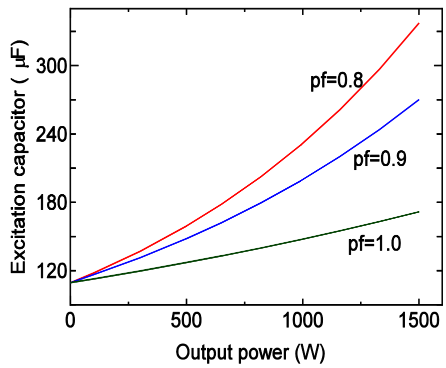

Figure 2 Required excitation capacitor of SEIG for inductive load at constant voltage and speed

Table 1 Parameters of induction generator

Induction generator	1.5 kW, 200V, 6.8 A, 50 Hz
- Stator resistance, R_s	1.337 Ω
- Rotor resistance, R_r	0.713 Ω
- Stator & rotor inductance, L_s, L_r	3.85 mH

3 SVC Magnetic Energy Recovery Switch

3.1 Star Configuration

The configuration of this device is based on 4 IGBTs and a dc capacitor per phase. It is called magnetic energy recovery switch (MERS), and typically inserted in series between AC source and load, as series reactive compensation applied for power factor correction and power flow control [7,8,9]. In this paper, this device is used as shunt reactive compensation as shown in Figure3. MERS is connected with an inductor in series as a filter to reduce the harmonic current flowing in the system and then it is called SVC MERS.

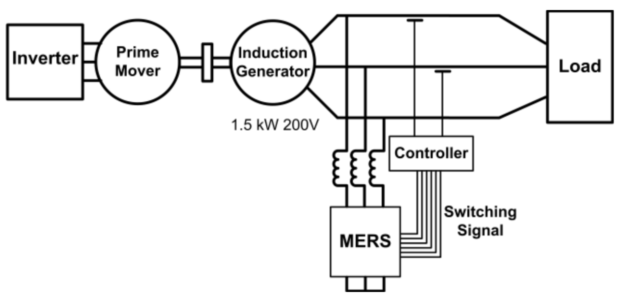

Figure 3 Configuration of SVC MERS in star connection

3.1.1 Operational Principle

Operational states to control the injected current are shown in Figure 4. Two IGBTs are turned on and off in pairs one time each cycle of the ac power source (50 Hz) and controlled synchronously. In a half cycle, two switches (S1 and S3) are turned on, the current flowing is charging and discharging the dc capacitor with the same polarity. When the dc capacitor voltage is equal to zero, the current is flowing in parallel. The other half cycle, the other pair (S2 and S4) is turned on, with similar conditions, but with the opposite current flow direction The waveforms of phase voltage, shunt current, dc capacitor voltage, gate signal and IGBT current are shown in Figure 5. It can be seen that the IGBT always turn on at zero current and turn off at zero voltage, therefore the low switching losses can be achieved. By controlling the switches as describe above, three different control can be achieved, which are balance mode when $Xc = X_{mers}$, dc-offset mode when $X_{mers} > Xc$ and discontinuous mode when $X_{mers} < Xc$, where Xc is MERS capacitance and X_{mers} is variable capacitance. In the dc-offset mode, the IGBT will turn off at non zero voltage. This is because a small voltage still remain in the dc capacitor. For three phase systems there will be one SVC MERS per phase.

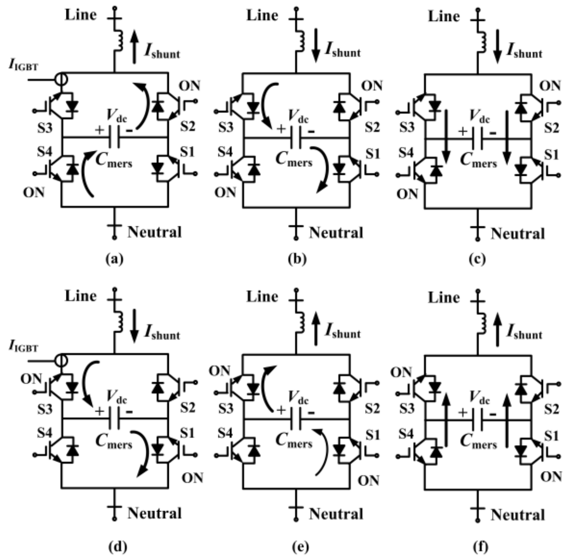

Figure 4 The operational state condition of SVC MERS

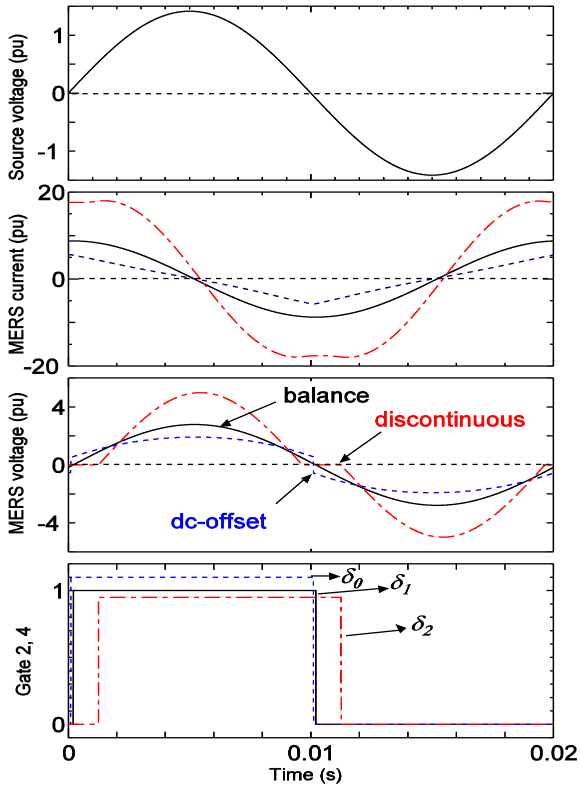

Figure 5 Typical waveforms of SVC MERS balance mode, discontinuous mode and dc-offset mode

Variable reactive compensation can be achieved by controlling the current flowing to the dc capacitor by applying appropriate gate signals. The control is based on performing a phase shift of the gate signals. The control variable called δ phase, which is the phase difference between phase voltage (V_{In}) and the time of switching. The value of δ phase depends on how much reactive power must be supplied to the induction generator and the load.

From other point of view, as illustrated in Figure 6, SVC MERS is a capacitor controlled by semiconductor devices. The reactive/shunt current $I_{svc\ mers}$ and the reactive power $Q_{svc\ mers}$, can be represented as follows:

$$I_{svc\ mers} = \left(\frac{V_{in}}{X_{svc\ mers}} \right) \quad (2)$$

$$Q_{svc\ mers} = \left(\frac{{V_{in}}^2}{X_{svc\ mers}} \right) \quad (3)$$

$$X_{svc\ mers} = \left(X_{mers}(\delta) - X_L \right) \quad (4)$$

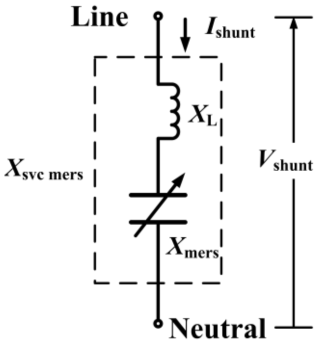

Figure 6 Equivalent circuit of SVC MERS

3.1.2 Control System

In order to control the terminal voltage, voltage feedback with PI control is proposed as shown in Figure 7. The control part starts with sensing the line to line voltage. Only two voltage sensors are used, which are fed to the control board. Phase lock loop (PLL) technique is applied to synchronize the gate switching time to the phase of the line voltage. However, zero detection can also be used to make this synchronization. However zero crossing detection of voltage can also be used for synchronization.

For feedback control, the rms value of the line voltage is compared to the reference voltage. The error is given to the PI controller to determine the δphase, and then it is fed to the gate controller to generate the gate signals. A δphase limiter is to keep δphase in the operating area.

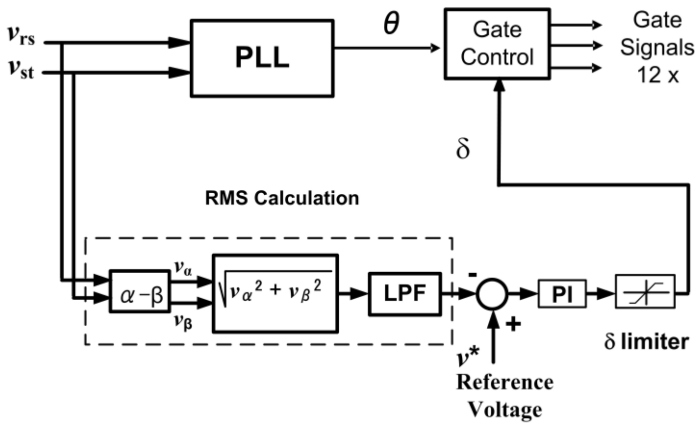

Figure 7 Control system of SVC MERS

3.1.3 Characteristics of Injected Current

The characteristic of the injected current to the system is determined by the size of the capacitor and inductor. The selection of the operating range can be based on Figure 1. The minimum injected current should be equal to the magnetizing current of the induction generator to generate rated voltage at no load condition.

Figure8 shows the relationship of the injected current to δ phase and the relative reactance. The relative reactance is the ratio of the equivalent reactance $X_{svc\ mers}$ to actual reactance X_C-X_L .

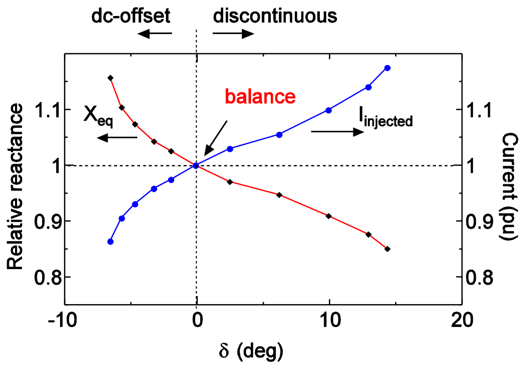

Figure 8 Characteristics of the injected current with 110uF and 10Mh

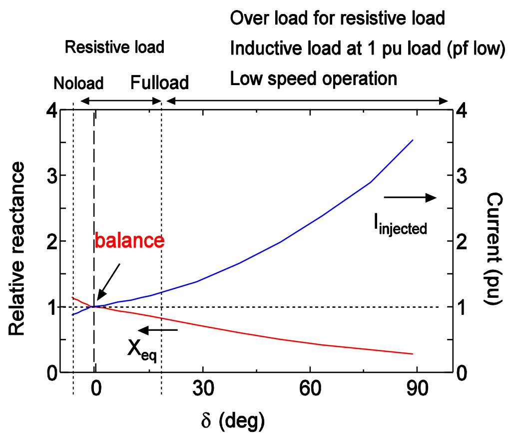

Figure 9 Operating range area of SVC MERS for SEIG at rated voltage

The operating range availability of SVC MERS to compensate reactive power of induction generator is shown in Figure9. In the induction generation operation point, more reactive power is required to supply in inductive load or low speed operation

The injected current contains some harmonics; therefore inductor must be inserted as a filter. The relationship between the inductance and the harmonic of the injected current for various operating points is shown in Figure 10. Three combinations of capacitor and inductor were simulated. It can be seen that higher inductance will reduce the harmonic of the injected current; on the other hand the capacitance can be reduced.

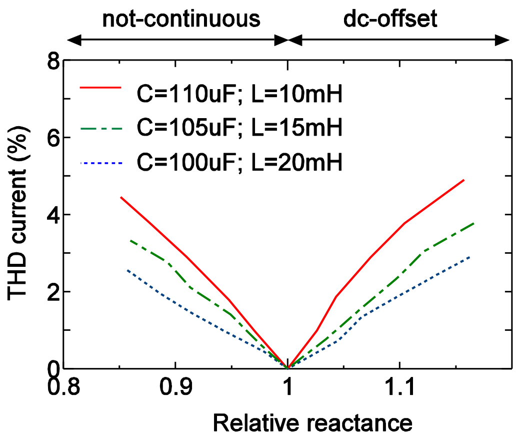

Figure 10 Harmonic of the injected current

3.1.4 Steady state and transient characteristics

The experimental data results in presented in pu which base voltage is 200 V, base current 6.8 A and base speed is 1500 rpm. Figure 11 and 12 show steady state voltage and current characteristics of the system.At no load condition, SVC MERS is supplied reactive current at about 0.56 pu in order to generate rated voltage. The reactive current represented by shunt current increased as load increased and terminal voltage always maintaned constant in load varying conditions.

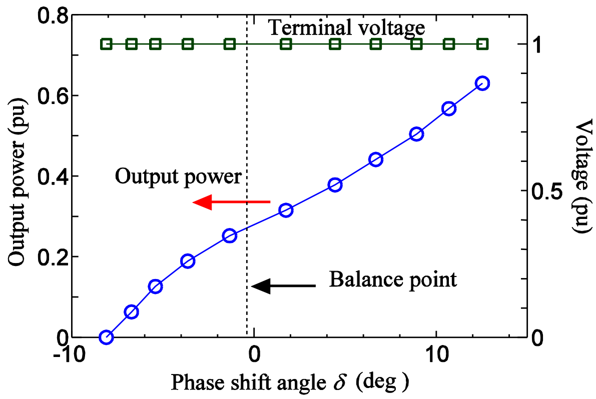

Figure 11 Steady state voltage characteristics at load varying conditions

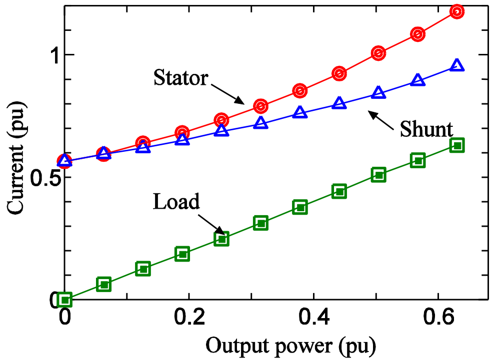

Figure 12 Steady state current characteristics

Figure 13 shows the experimental transient response of the voltage, load current, shunt current, and dc capacitor voltage with a step change from no load to full resistive load condition. The voltage is recovered within two cycles. Operation changed from dc-offset mode to discontinuous mode in order to supply required reactive power.

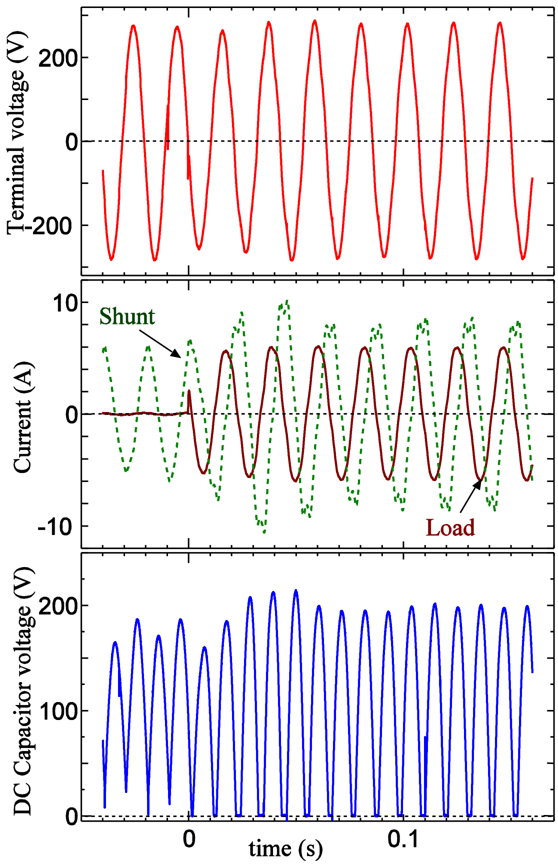

Figure 13 Transient characteristics of the system

Variable speed condition was also experimented. The results is shown in Figure 14. In this experiment, the rotor speed is changed from 0.8 pu to 1.3 pu, while the induction generator output power was setting at half of its rated power (750 W). It can be found that SVC MERS can control the voltage to its rated voltage keeping the induction generator to generate output power.

For higher speed, the value of phase shift angle δ is small, meaning low reactive power is generated by SVC MERS. While for lower speed, phase shift angle δ is larger, meaning higher reactive power is required to maintain its rated voltage.

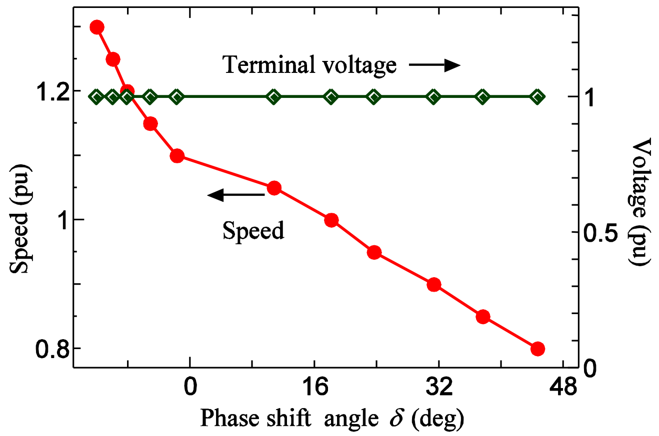

Figure 14 Variable speed characteristic using SVC MERS

3.2 Delta Configuration

In order to reduce the current rating of the switch, delta connection is configured for this application, however capacity rating will similar. By doing this, the capacitance can be reduced to 37 μF (1/3 of star). The control of the switch for MERS is the same as star configuration. Figure 15 shows the waveforms of terminal voltage, shunt current, MERS current, stator current, IGBT and gate signal of this configuration at 0.7 pu load. In half cycle capacitor will charge (a), dis-charge (b) and have parallel path (c). It can be found that MERS current is smaller than shunt current. As a result IGBT losses will be lower, therefore downsizing of heat sink can be achieved.

4 Conclusion

The operation principle, characteristics of injected current, operating range of reactive compensation of SVC MERS in star and delta configuration was investigated. Application for induction generator voltage control, which is required leading reactive compensator, is suitable for the proposed system. Experimental result confirmed that the proposed system can controlled induction generator in load and speed varying conditions. This proposed system has the following advantages:

1. simple control, where only two voltage sensors are required and voltage feedback control with PI controller gives a good response
2. low switching frequency, which zero current turn on and zero voltage turn off and resulting in low switching losses.

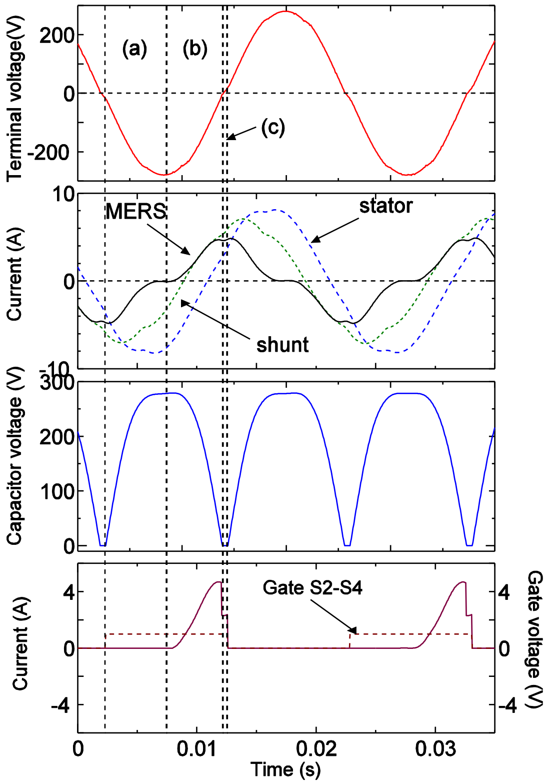

Figure 15 Waveforms of SVC MERS in delta configuration

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