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Voltage Control of Single-Phase Two Winding Self Excited Induction Generator Using SVC-MERS for Isolated System

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ABSTRACT

Single-phase induction generator is very suitable to be used in the typical loads which only need a single-phase power supply with small power capacity requirement, such as diesel engine, picohydro or small wind plant. It has some advantages such as rugged, effective cost, maintenance free and require no external excitation. However, it has inductive characteristic which makes poor voltage regulation. This paper proposed a shunt reactive compensator called SVC-MERS which can provide a variable reactive power to maintain the generator voltage despite of load variations. The experiment was conducted on single-phase two winding induction generator coupled by a three-phase induction motor which serves as the prime mover. SVC-MERS and the load are connected in shunt to the main winding, while the excitation capacitor was connected to the auxiliary winding. The experimental results showed that SVC-MERS can improve voltage regulation and substantially enhanced steady state loading limit.

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1. INTRODUCTION

In the last decade, locally renewable energy sources with a small or medium size potential capacity, such as mini/pico hydro, wind or biofuel diesel, has been increasingly developed because the government policy to use clean energy and to increase electrification in rural area becomes important requirement. In isolated areas located far away from the grid, a single-phase power supply systems is effective to supply lighting equipment or other residential appliances. Single-phase squirrel cage induction generator, in this regard, are found to be extremely useful machine due to cost effective, compactness, ruggedness, high reliability, maintenance free, and ease to find in the local market [1]. This generator is usually has a small capacity that is only able to supply a load less than 10 kW [2].

In-spite of numerous advantages offered by single-phase induction generators, they have poor voltage regulation due to their inability to supply reactive power. In case the induction generator was connected to the grid, its reactive power was supplied from the grid. However, in isolated or stand-alone condition a reactive power source is required [3,4,5,6]. This system is called self-excited induction generator (SEIG). TF Chan [7] mentioned that range value of shunt capacitor can be calculated mathematically to maintain voltage despite of any changes on load and speed.

Some research works related to the improvement of voltage regulation on a single-phase induction generator using fixed capacitor connected in series or shunt are conducted in reference [3]-[5]. Rapid development of power electronics technology has successfully delivered the idea to make variable reactive power supply based on power semiconductor switches, e.g. SCR, TRIAC, MOSFET or IGBT. Some reactive power supplies were developed with using static reactive power such as SVC or STATCOM. However, the control system is very complex and requires large dc capacitors as well to store energy [1, 9]. Related to single-phase induction generator, B. Singh et al. [6] used an electronic load controller (ELC) which consists of a single-phase rectifier and connected in series with dc-chopper and dummy load to maintain the generator output voltage at constant. T. Ahmed et al. [7] used combination of fixed capacitor, TSC and TCR connected to the main winding of a single-phase induction generator. It has discrete variable reactive power. Other work was conducted in [8] by using AC-DC and DC-AC converters to suplly induction motor load. These topologies have complex control in order to carry out DC voltage of SIEG and AC voltage output.

This paper proposed continuously variable reactive power using SVC MERS (magnetic energy recovery sources) which has implemented to control voltage of an isolated small-scale generating system of double winding single-phase induction generator. SVC-MERS has some advantages such as simple control, low loss switching due to zero switching control and small dc capacitor.

2. MERS OPERATION PRINCIPLE

MERS consists of full-bridge switches and dc capacitor. The switches are switched in pairs (UV and XY) to control the capacitor charging process by turning them on and off at a certain firing angle. Figure 1 a) shows the basic configuration of MERS. It means that the capacitor charging time can be set by adjusting the firing angle. Capacitor charging time will determine the amount of reactive power generated [10]. The configuration of MERS is similar to common full-wave converters, but there are two important differences. First, MERS can be connected either in series or shunt with the system. Second, the value of dc voltage on the MERS capacitor can be changed dynamically even to zero.

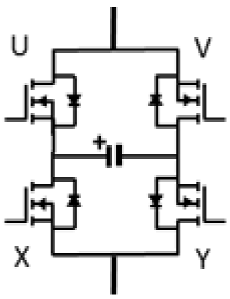
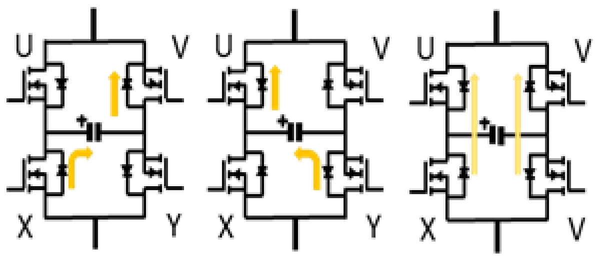


Figure 1. (a) Configuration of MERS



(a) (b) (c)

Figure 2. MERS operating states. (a) Capacitor charging (b) Capacitor discharging (c) Capacitor is bypassed

Compared to the conventional single-phase full-bridge circuit, the capacitance of dc capacitor can be several times smaller due to the allowance of capacitor voltage to vary and even becomes zero at every fundamental cycle (50 Hz or 60 Hz). In the other hand, full-bridge configuration is trying to maintain a large voltage, so that the capacitance value of the capacitors becomes large. MERS configuration also utilizes the line frequency as its switching frequency, which means that each switch is only turned on and off at the fundamental cycle. In one cycle, MERS has three operating states, which are charging dc capacitor by switching XY, discharging dc capacitor by switching UV and by passing when dc capacitor voltage is zero or there is no energy stored in dc capacitor. The operating states are illustrated in Figure 2.

In order to compensate the reactive power, a MERS variable reactance, X_{MERS}, is obtained by shifting the phase of gate signals to the phase of line voltage. By using this method, there are three modes of operation that can be obtained, i.e. balance, dc-offset, and discontinuous mode [10] as shown in Figure 3. Each operation mode can be determined by observing the capacitor voltage waveform (V_c).

The first one is discontinuous mode. This mode occurs when the time of capacitor charging and discharging is shorter than the switching period or fundamental half-wave period. In the discontinuous mode capacitor is not charged for a moment, so that the energy in the form of the voltage stored by the capacitor is reduced from the maximum limit that can be accommodated by the capacitor. Figure 3(c) shows the capacitor and MERS voltage waveform in discontinuous mode. The discontinuous mode will occur if X_{MERS} is less than Xc.

The second one is balance mode. This mode occurs when the capacitor charging and discharging time equal to the switching period or fundamental half-wave period. In this mode, the energy stored by the capacitor in the form of voltage will be discharged entirely in accordance to the maximum limit based on its capacitance value. Figure 3(a) shows the capacitor and MERS voltage waveform in balance mode. The balance mode will occur if X_{MERS} equals to Xc.

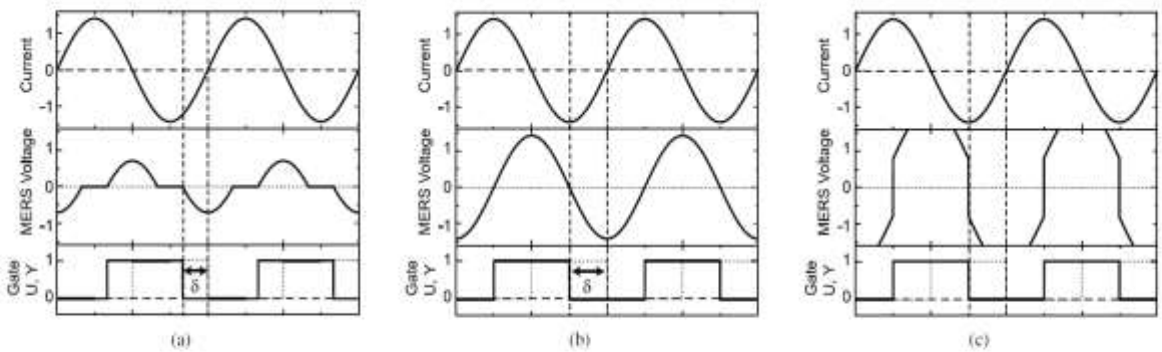


Figure 3. Schematic waveforms of the MERS in various equivalent reactance with the same current (current, MERS voltage and gate signal of UY with phase shift angle (δ): (a) discontinuous mode ($X_{MERS} < X_{C}$), (b) balance mode ($X_{MERS}=X_C$), (c) dc-offset mode ($X_{MERS} > X_{C}$) [10].

The last one is a dc-offset mode. In this mode, dc voltage between the tips of capacitor has an offset value. This is due to the time of capacitor charging and discharging is longer than the switching period or fundamental half-wave period, so that when the charge stored in capacitor is not fully empty, the capacitor has already started to be charged again. So the capacitor still stores energy in the form of dc-offset voltage. Figure 3(b) shows the capacitor and MERS voltage waveform in dc-offset mode. The dc-offset mode will occur if the value of reactance X_{MERS} is more than Xc. The three mode states can be achieved by controlling firing angle (δ) to gate signal of the pairs of the switches. The advantages of MERS are simple control and low switching switching losses.

3. SYSTEM DESIGN

Figure 4 shows the experiment setup that has been conducted. A three-phase wound rotor induction motor is coupled to a single-phase two winding induction generator and serves as the prime movers. This system was designed to represent the stand-alone conditions which often found in small-scale power plants that utilize renewable energy. Induction motor was controlled by an inverter to keep the speed constant or to produce varying speed. A run-capacitor type single-phase induction motor can serve as a single-phase two winding induction generator with a slight modification, i.e. by disconnecting the auxiliary winding which is previously connected to the main winding. The excitation capacitor was connected to the auxiliary winding, while the shunt capacitor was connected to the main winding and serves as a fixed compensator. Due to these two windings in the single-phase induction generator were used, then this configuration was referred as single phase two winding induction generator. In the experiment using SVC-MERS [11]-[13], the excitation capacitor was permanently connected to the auxiliary winding, whereas the shunt capacitor will be removed and replaced by SVC-MERS. The load used was resistive load that connected to the main winding together with SVC-MERS. Table I shows the parameters used in this experiment.

SVC-MERS is controlled through a closed loop system by using PI controller as shown in Figure 5. The output voltage of single-phase induction generator is kept constant (or approximately constant) in a certain reference value by implementing a variable reactive power control of SVC-MERS according to load conditions. Variable reactive power is obtained by setting the firing angle (α) whose value depends on the output of PI controller. A closed loop control system is operated by comparing between the output value of single-phase induction generator which has been lowered and rectified to a reference value. This error is the main input for PI controller to determine the firing angle value which will be fed to the gate driver circuit to generate signal for turning on the MOSFET. α-phase limiter is also applied to keep the firing angle bound in the safe operating area, either for stability of PI controller or equipment rating. The hardware implementation of SVC-MERS can be seen in Figure 6.

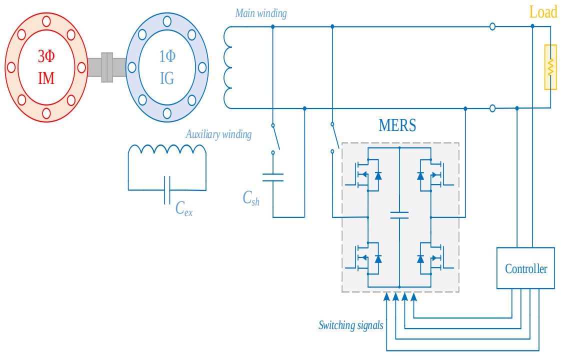


Figure 4. Configuration of SEIG experimental setup

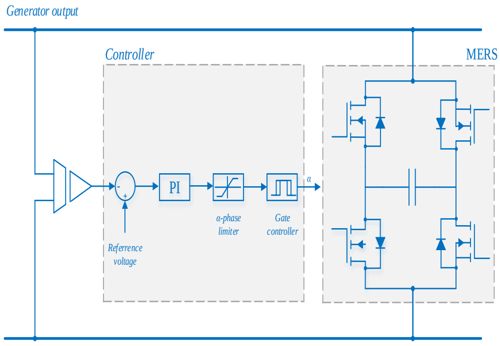


Figure 5. Voltage feedback control for SVC MERS using PI control

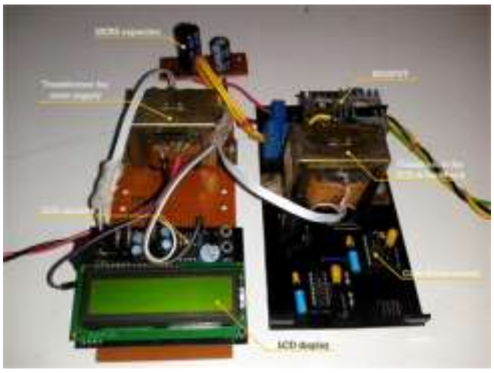


Figure 6. SVC MERS hardware with MOSFET and small dc capacitor

Table 1. The parameters used in the experiment.

Single-Phase Induction Motor (*capacitor-run*) (serves as the generator)		
Rated voltage	*V*	220 V
Rated current	*I*	6.3 A
Rated power	*P*	0.75 kW
Rated frequency	*F*	50 Hz
Power factor	*Pf*	0.85
Three-Phase Induction Motor (serves as the prime mover)		
Rated voltage	*P*	220/380 V
Rated current	*V*	6.3/3.6 A
Rated power	*P*	1.5 kW
Rated frequency	*F*	50 Hz
Power factor	*Pf*	0.82
Reactive Power Supply		
Excitation capacitor	C_{ex}	50 µF
Shunt capacitor	C_{sh}	7.87 µF
SVC-MERS	C_{MERS}	7.84 µF

The experiments of voltage control of single phase two winding SEIG with SVC-MERS were divided into two categories. The first one was experiment to find the steady state characteristic of SEIG with three different reactive power supplies i.e. 1) excitation capacitor at auxiliary winding; 2) shunt capacitor at main winding and 3) SVC-MERS at main winding. The second one was experiment to observe dynamic characteristic of the SEIG when SVC MERS was controlled by feedback PI controller. The proportional and integral gains (K_p=2.7 and K_i=16.2) were determined by running computer program calculation.

4. RESULTS AND ANALYSIS

Terminal output voltage of single phase two wingsing SEIG at the main winding was maintained at 110 V due to safety current operation in the auxialiary winding. In order to observe the loading characteristics, a resistive load was applied to the main winding of SEIG. Figure 7 shows the comparison on how loading affects the generator voltage when reactive power was supplied by 1) excitation capacitor at auxiliary winding; 2) shunt capacitor at main winding and 3) SVC-MERS at main winding. Excitation capacitor was selected at 50 µF and shunt capacitor at 7.78 µF in order to generate 110 V at the main winding. It is shown that these two fixed capacitors have a poor voltage regulation, while SVC MERS can improve the voltage regulation of the single phase two windings SEIG. The loading capacity can be enhanced up to 250 W.

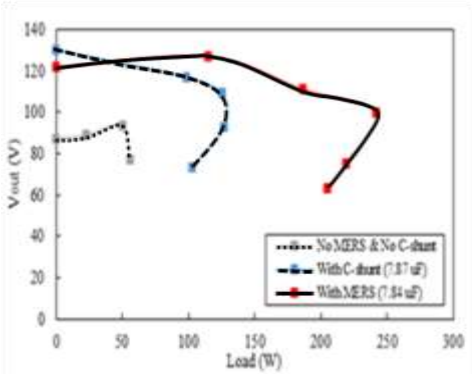


Figure 7. The comparison SEIG voltage during loading condition were supplied three different reactive power sources

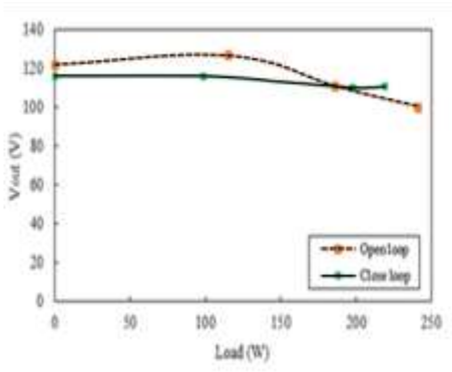


Figure 8. The comparison of the SEIG voltage using open-loop and close-loop system

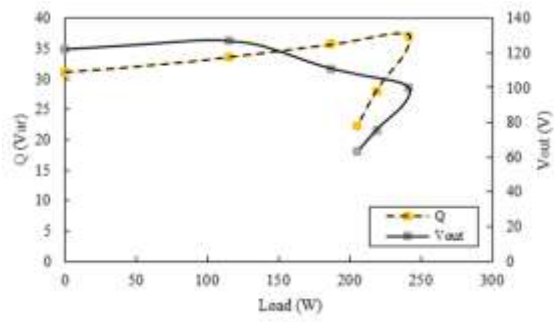


Figure 9. The influence of load variation to the reactive power generated by SVC-MERS and the generator output voltage

Comparison between the generator voltage when using the open-loop and closed-loop system in load varying condition is illustrated in Figure 8. The PI controller based-feedback control scheme using SVC MERS was employed for stable generated voltage regulation of the single phase two windings SEIG system. This was due to the possibility to adjust automatically the firing angle of the SVC MERS switches.

Figure 9 shows the characteristics of reactive power generated by SVC-MERS when operated on load condition. Reactive power increased in order to maintain SEIG voltage while resistive load was varying from no-load state until 250 W. The generator would not be able to supply the active power greater than that value although the reactive power of the SVC-MERS is increased due to induction generator magnetizing charactercs. At this critical condition any additional loads would make the generator experiences a demagnetization (the value of reactive power decreases) and finally cannot supply active power again or collapse.

The dynamic response of single phase SEIG voltage at step load (from no-load to full load and from full load to no load) is shown in Figure 10. The SVC-MERS with PI controller can maintain smooth voltage regulation of the SEIG system in dynamic loading condition.

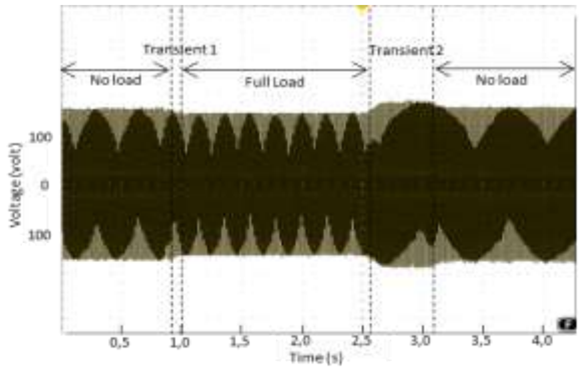


Figure 10. Dynamic response of single phase SEIG voltage when loading capacity was changing

5. CONCLUSION

This paper proposed an isolated small-scale power plant using a single-phase two winding induction self excited induction generator. Experimental result indicated that SVC-MERS can improve voltage regulation and enhance loading capacity of the single phase two winding SEIG system. Moreover in the dynamic conditions, SVC MERS with PI controller was able to make the system voltage remains stable. The prospective application of the proposed system would be as an automatic voltage controller in small generator capacity with diesel engine, pico hydro or wind plant.

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