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Energy Procedia 34 (2013) 382 – 389

Energy Procedia

10th Eco-Energy and Materials Science and Engineering (EMSES2012)

Study of Generator Mode on Permanent Magnet Synchronous Motor (PMSM) for Application on Elevator Energy Regenerative Unit (EERU)

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Abstract

This article presents the operating principle of transformation from permanent magnet synchronous motor (PMSM) to function as Generator in Energy regenerative mode. From experiment it is observed that when voltage is fed into permanent magnet motor, the electric input energy is converted to mechanical energy. On the other way, when motor is rotated without supplying input power while no load or light load, it generated electric output energy. This situation is call "Regenerative". Therefore this electric output energy can be fed back to the system for replacement of the energy that has been used. The study is done by simulation using Matlab/simulink program. The simulation used closed loop control, PMSM is running at 1000 RPM, controlled by PI controller through an inverter with PWM controller switching waveform from insulated gate bipolar transistor: (IGBT). The characteristic of motor is observed while feeding both positive and negative load. When it is fed with positive load it behaves as motor and with negative load it suddenly behaves as generator. This experiment will lead to a proper design of Elevator Energy Regenerative Unit (EERU) applications.

Selection and peer-review under responsibility of COE of Sustainalble Energy System, Rajamangala University of Technology Thanyaburi (RMUTT)

Keywords: Regenerative; Transformation of motor to generator; Permanent magnet synchronous motor

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Selection and peer-review under responsibility of COE of Sustainalble Energy System, Rajamangala University of Technology Thanyaburi (RMUTT)
doi:10.1016/j.egypro.2013.06.766

1. Introduction

Motor is an electrical device which converts electrical energy into mechanical energy. Motor is an appliance with widely daily life use such as fans, air conditioners, machine tool technology, education, and many other types of motors used in industrial machines [1].

Permanent Magnet Synchronous Motors (PMSM) are also widely used in industries applications because the ratio torque to weight is high effectively respond to the speed control, low moment of inertia, small size with light weight compared to the same size of electric motors, and good heat dissipation. The low loss motor can be used in dangerous industries such as oil and gas or flammable without causing environmental problems [2].

Thus this paper will study the Synchronous permanent magnet motor that transform into generator. The 4 Quadrants will be described for the characteristic of PMSM. By the content of this article will discuss the 4 Quadrant in section 2, the simulation of the system with Matlab/Simulink in section 3, the results in section 4 and conclusions in section 5.

2. Theory and Implementation

2.1. Principles of Four-Quadrant Operation

Figure 1 shows a graph of the speed and torque control in both the positive and negative directions.

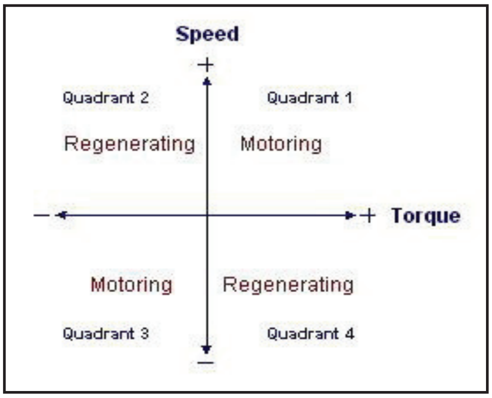

Fig. 1. the comparison between the various state motor speed and torque

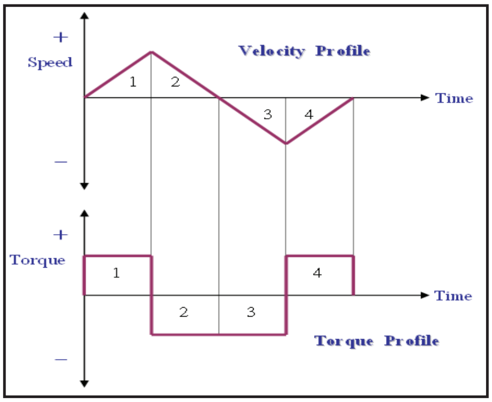

Fig. 2. A graph of the speed and torque of the motor during each time period

From figure 1, progress in Quadrant 1 and 3 are defined as motor mode which means that the speed and torque is in the same direction. The progress in Quadrant 2 and 4 are assigned to be a generator, sometimes called regenerative mode. This means that the speed and torque is in the opposite direction. The torque of the motor's and motor speed is in different direction of rotation. This will cause the motor to produce power. This energy is able to be fed back into the electrical system.

Figure 2 illustrates the two engaged in a work which is being accelerated by the motor speed and torque in the positive direction. During the second phase, the speed still is a positive and a negative torque which the motor is stopped, but it turns out to be generator. The work of the third phase will work similar to the first phase, but the direction is opposite to the negative, which is still a function of the motor, phase 4 is similar to the second phase but with the opposite direction [3].

2.2. Characteristics of PMSM

The characteristics of the PMSM according to equations (1) - (4), which is applied to test the program in MATLAB/SIMULINK

$$\frac{di_d}{dt} = \frac{1}{L_d} v_d - \frac{R}{L_d} i_d + \frac{L_q}{L_d} p\omega_r i_q \tag{1}$$

$$\frac{di_q}{dt} = \frac{1}{Lq} vq - \frac{R}{Lq} iq - \frac{L_d}{L_q} p\omega_r i_d - \frac{\lambda p \omega_r}{L_q} \tag{2}$$

$$T_e = 1.5p\left[\lambda i_q + (L_d - L_q) i_d i_q\right] \tag{3}$$

$$\frac{d\omega_r}{dt} = \frac{1}{J}(T_e - F\omega_r - T_m) \tag{4}$$

Where:

Ld, Lq be Inductance of the d and q
R be Resistance of Stator
id, iq be current of d and q
Vd,Vq be voltage of d and q
ω_r be velocity of anle Rotor
λ be magnetics flux of motor
p be number of pole
T_e be torque produce by motor

2.3. Principle of Speed Control Using a PI Controller

The system will measure the speed of the motor that is compared with speed Reference, the response of the system is controlled by a PI controller as shown in figure 3. Therefore, the design of PI controller system is very important part. The PI controller is designed and to find the parameters Kp and Ki for this simulation, both the Software Tool GUI, a tool called SISOTOOL in Matlab / Simulink is used to help in the transfer function as follows.

$$PI(s) = \frac{Kp\left[Ki(s) + 1\right]}{Ki(s)} \tag{5}$$

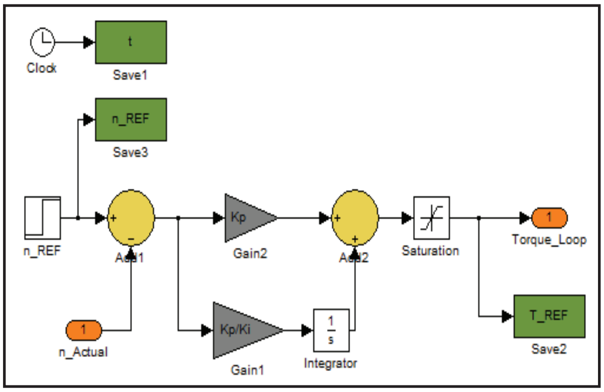

Fig. 3. Speed control circuit with PI controller

3. Simulation of the System

As mentioned, in this paper, system simulation of permanent magnet synchronous motors is done by Matlab/Simulink as shown in figure 4.

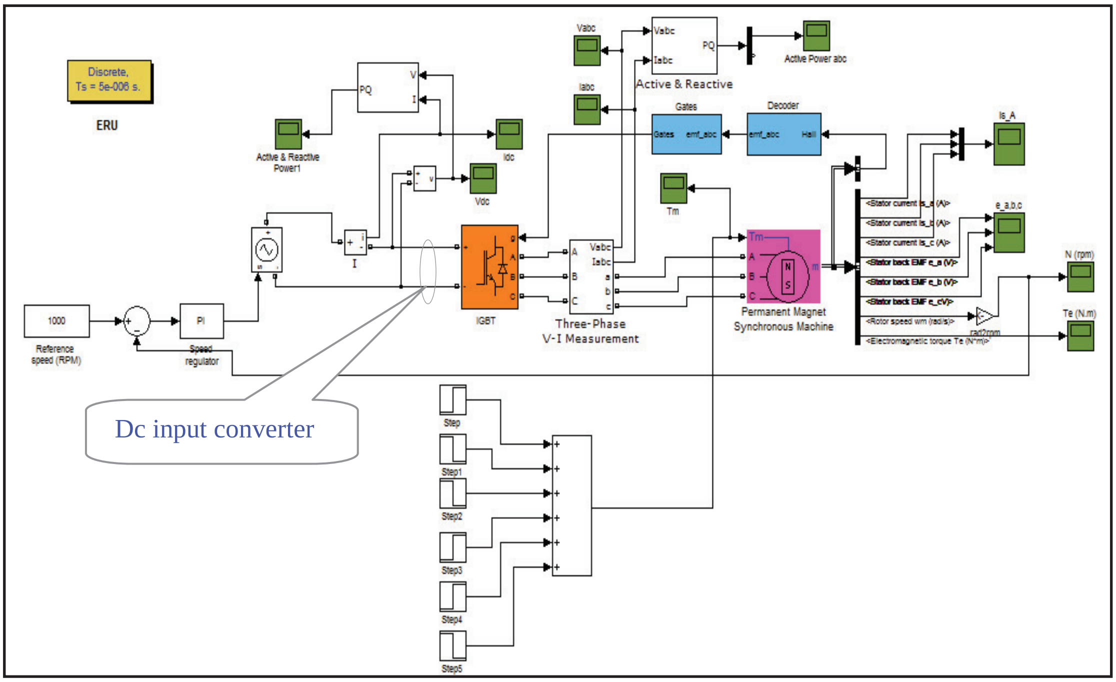

Fig. 4. Circuit simulation in Matlab/Simulink

From figure 4, it simulates the motor speed to maintain constant speed at 1000 RPM, and to simulate, the example values are selected from a typical PM motor which 625 Nm, 0 Nm, -625 Nm are entered. The configuration parameters used in the simulation are shown in Table 1 [5].

Table 1. parameters for the simulation

Parameters	Value
R	0.5 Ohm
Ld, Lq	9 mH
Pole	20 pairs
Magnetic Flux	1.1 Vs
Torque	+/- 625 Nm
J	0.1 kg.m^2

Before the simulation as in figure 4, it must evaluate the Kp and Ki, so that the response of the system design.Kp and Ki is as figure 5, after obtaining the Kp, Ki then the data from table 1 are entered into the simulation program.

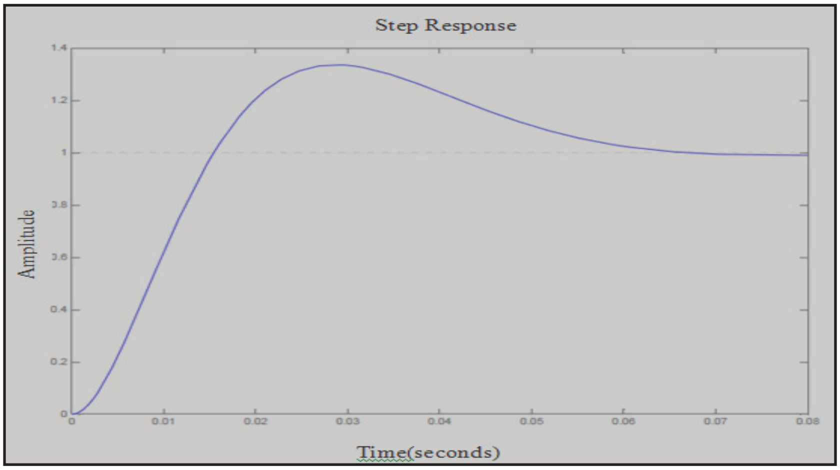

Fig. 5. The response of the system design.Kp and Ki compared with amplitude and time

Figure 5 shows the response to find Kp, Ki. The response of the system is controlled by a PI controller and it is designing on the appropriate Kp and Ki. The result from figure 5, the curve is over steady line not more than 20% and slowly came back to normal (Steady State). The motor torque and current at DC input converter are positive. With a constant speed continues at 1000 RPM, the DC input converter current is still positive. This means the motor is working as the motor mode. But when the motor torque is negative, with a constant speed of 1000 RPM, the DC input converter current is negative. That means the motor become a generator. Power will change if the load of motor has change. The power can become a positive and negative power depending on load. If the power is negative, the power supply is restored back to the system grid, (as generator), the simulation results showed in figure 6 - figure 10.

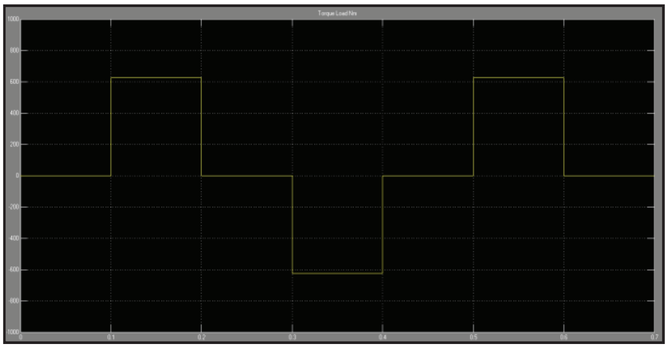

Fig. 6. The example values are selected from a typical PM motor which 625 Nm, 0 Nm, -625 Nm are entered

From figure 6, the system is fed torque to a motor and then considered the behavior of permanent magnet synchronous motors while keeping constant speed. The current and voltage results are showed as figure 7 and figure 8.

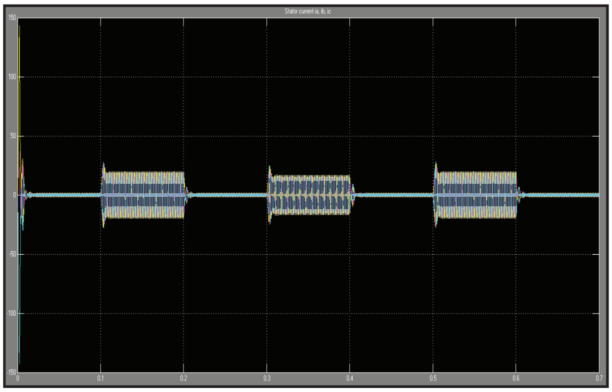

Fig. 7. The currents at stator of permanent synchronous magnet motor during each time period when torque has change

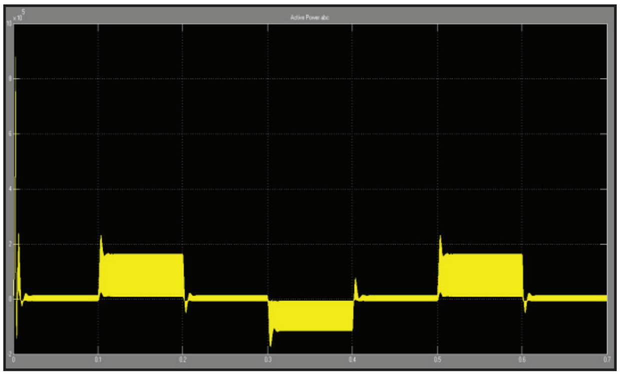

Fig. 8. The power of permanent synchronous magnet motor during each time period when torque has change

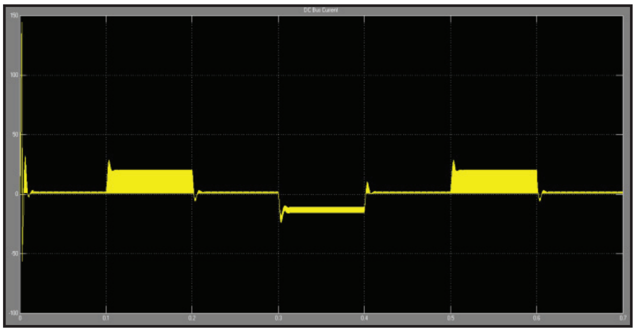

Fig. 9. The power at DC input converter of permanent synchronous magnet motor during each time period when torque has changed

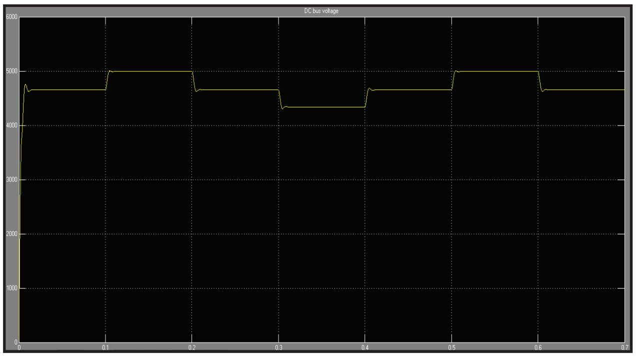

Fig. 10. The voltage on the DC input converter.

4. Results

Simulation results of permanent magnet synchronous motor are summarized in Table 2.

Table 2. results of when operating conditions at different loads.

Torque Load	Status				
	DC Input Converter		Motor		
	Current (A)	Voltage (V)	Current (A)	Voltage (V)	Power (kW)
625	19	5000	±19	±5000	160
0	1.5	4600	±1.5	±4600	+1.2 (max) -0.5 (min)
- 625	-16	4300	±16	±4300	-115

By simulation program at different load, using Matlab/ Simulink, the motor speed is kept constant, the load for motor is 625, 0 Nm, motor is working and having both a positive and negative power. The motor current at DC input converter is a positive current. It means that the motor is running and remains to work as a motor. When the system input load is -625 Nm, the power measured from the motor is negative and the DC input converter voltage is also negative. It means that the motor is operating as a temporary generator. It is happens practically at a time when the load is removed.

Normally for this regenerative energy, it can be controlled to feed back to the grid by a diode rectifier to flow the current direction. The paper proposes the new design conceptual model with regenerative drive in figure 11 which used IGBT to control the power flow in bi-directional. This means that one direction is feeding the power to motor and other direction is fed back to the system as a generator [4].

Therefore, this study can be able to support the idea and design to the Energy Regenerative Unit (ERU) as shown in Figure 11.

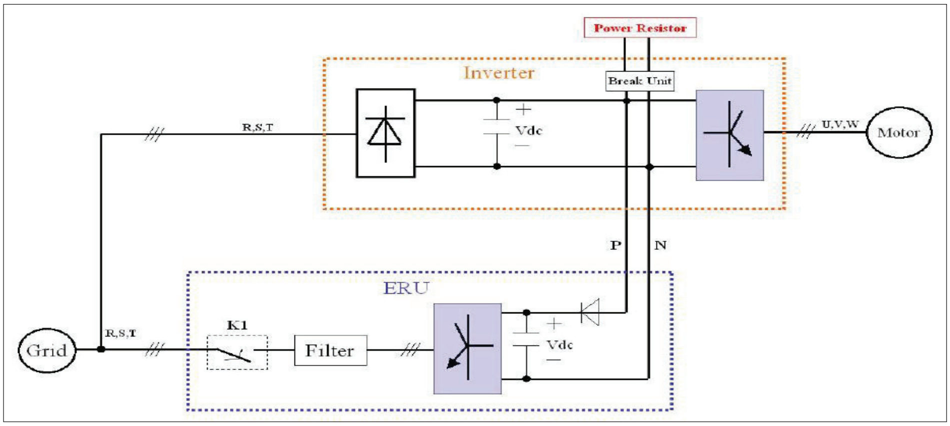

Fig. 11. proposed ERU integrated system

5. Conclusion

The study of synchronous permanent magnet motor (PMSM) is performed via simulation to study the behavior of the motor in a generator mode called regenerative mode. If the motor is run in different load, when the motor has a positive speed and torque load, it can function to be as a generator. In generator mode, it can feed back the power to the system. This is the so-called “generative phenomenon”. Normally nowadays, this power is wasted via dump load resistor in order to protect the elevator system. This study proposed the regenerative energy to be used as Energy Regenerative Unit (ERU) that is fed waste energy from the elevator to the grid when the elevator moves upward, downward, and break.

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