

# Control strategies of a double stator permanent magnet generator applied in tidal current energy extracting

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**ABSTRACT** – This paper investigates the efficiency difference of a double stator permanent magnet generator controlled by three vector current control strategies (maximum torque per ampere control, unity power factor control and constant flux control) in a direct drive tidal energy system. The work will focus on the tidal speed below its rated value. The rotational speed of turbine is proportional with tidal speed to maximize the power coefficient. For the same rotational speed, the generator power loss (including converter loss) is different when it is controlled by different control strategy. Through calculating the generator efficiency under the three control condition, an optimal control strategy can be chosen for special turbine rotational speed or tidal current speed.

**KEY-WORDS** – Vector current control, double stator permanent magnet generator, converter power loss, tidal energy

## 1 Introduction

The most important characteristics for resource used for generating electricity are sustainability and predictability. An assessment of exploitable sites in Europe with strong tidal currents yielded a total energy potential of about 105 TWh/year. This potential is mainly in the United Kingdom (50 TWh/year) and France (44 TWh/year). The global tidal energy potential is about 5~10 times the European potential [1]. The tidal current energy resource has a major advantage over other renewable energy resources, as it is predictable over long time scales. Further more, tidal current turbine farms have little visual impact since tidal current turbines and the auxiliary facilities have their main parts submerged underwater. The method to harness tidal current power is based on the technologies of wind turbine and ship propellers which are relatively mature [2].

Direct drive permanent magnet generator with fully rated power electronics interface system has been proven as a better selection in the long run in terms of low maintenance cost and power output quality enhancement. Moreover, fully variable speed operation has benefit of increasing tidal farm efficiency [3]. Permanent magnet generator losses and fully rated converter losses calculation methods are explained in [5] and [6] respectively.

This paper will mainly research the efficiency of a double stator permanent magnet generator (1MW) including the losses of the AC/DC PWM rectifier when the tidal speed is under the rated value (0.6m/s~2.7m/s). Comparison of generator efficiency under three control strategies is fulfilled. The results confirm that by only changing the control strategy of rectifier we can improve the system efficiency.

## 2 Double Stator Surface Mounted Permanent Magnet Generator

Double stator surface mounted permanent magnet generator (DSSMPMG) has been designed to serve as the integrated starter generator for HEVs and wind energy application, which is claimed to offer much higher power density than traditional PMSG. Actually, DSSMPMG has much more merits such as smaller cogging torque, smaller rotor inertia and higher redundancy comparing with traditional PMSG [4]. Based on those advantages, DSSMPMG can be well suited for

tidal current energy extracting. Fig. 1 shows one possible system topology of DSSMPMG. The two stators are connected to two back-to-back converters and are controlled in parallel. The total torque of the generator is the superposition of the torque of inner and outer stator. DSSMPMG also can be controlled in series using one back-to-back converter with the two stators phase winding connected in series.

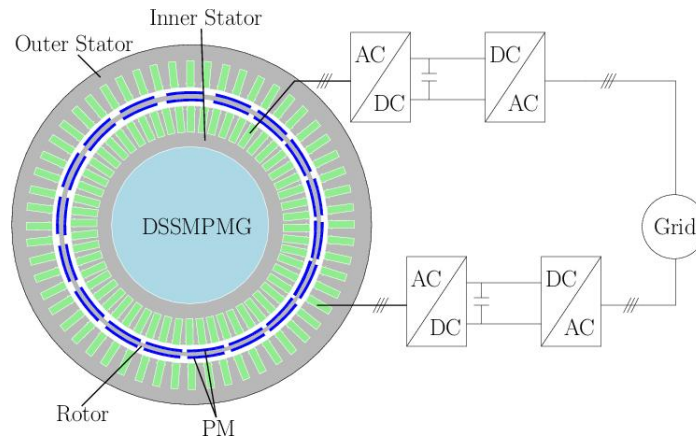


Figure 1: Two stators controlled in parallel

The permanent magnet can be surface mounted on the cup rotor or interior buried in the rotor. In [7], the authors quantitatively compared both steady and dynamic performances among the double stator surface mounted PM generator, double stator interior PM generator and traditional single stator PM generator. The comparison results confirms that double stator surface mounted PM generator has better performance. In the mechanical point of view, interior PM generator is suitable for high rotational speed application. However, in the tidal current turbine application which normally rotated in low speed, surface mounted PM generator is robust enough.

### 3 Vector current control strategies

Vector current control is commonly used in direct drive permanent magnet generator system [8]. The quadrature axis current reference is obtain by speed controller output, but the direct axis current reference can be modified in different manners so the generator has different characteristics.

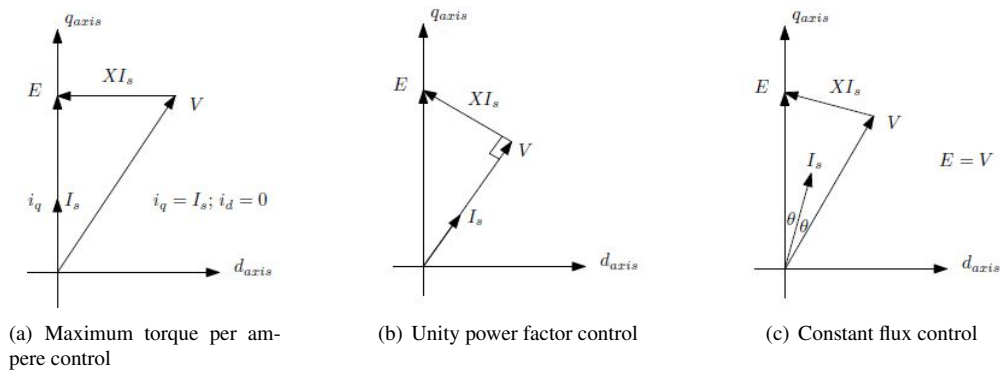


Figure 2: Vector current control strategies

There are three vector current control strategies which are usually chosen for controlling the permanent magnet generator as Fig. 2 shown. Each strategy has advantages and disadvantages due to generator working condition and delivered power. The first strategy is maximum torque per ampere control shown in Fig. 2(a). The phase current in this control strategy is the lowest current produced compared with the other strategies, which gives minimum copper loss at stator windings. But, the terminal voltage is always higher than the EMF which leads to higher core loss. The second strategy is unity power factor control. In this strategy we maximize the power factor to one that will give us the highest current among these three strategies which will affect generator's copper loss. At the same time, from vector analysis, this strategy will always has lower terminal voltage than EMF that will give us the lowest core losses among other strategies. The third

strategy is constant flux control, which is a compromise of the other two strategies. The terminal voltage is at the same value with EMF and the phase current is controlled at the middle between them.

## 4 Results

Our results will mainly focus on the low tidal speed region. For the speed above the rated value, flux weakening control is a solution to keep the generator operated at nominal power for a fixed pitch control turbine.

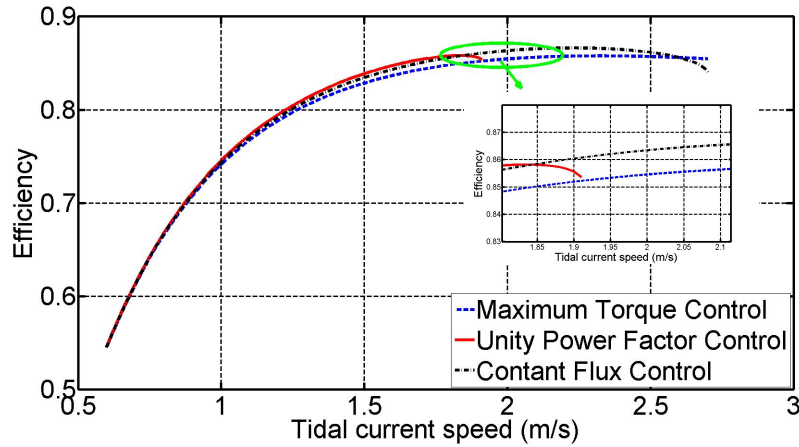


Figure 3: Three control method efficiency

Fig. 3 shows the efficiency curves of generator which operates under three different vector current control strategies respectively. We can see that in the speed region 0.6m/s~1.84m/s, unity power factor control method can obtain maximum efficiency. Then, constant flux control is the best method in the speed interval of 1.84m/s~2.6m/s. However, the most commonly used and simple control strategy  $i_d = 0$  or maximum torque per ampere control has the best performance only in a small interval near the rated tidal speed (2.7m/s). From the enlarged figure we can see that if we select the control method of generator appropriately, we can improve the system efficiency almost 1% in a wide tidal speed range.

Tidal current speed (m/s)	0.6~1.84	1.84~2.6	2.6~2.7
Optimal control strategy	Unity power factor control	Constant flux control	Maximum torque control

Table 1: Optimal control strategy for different tidal speed region

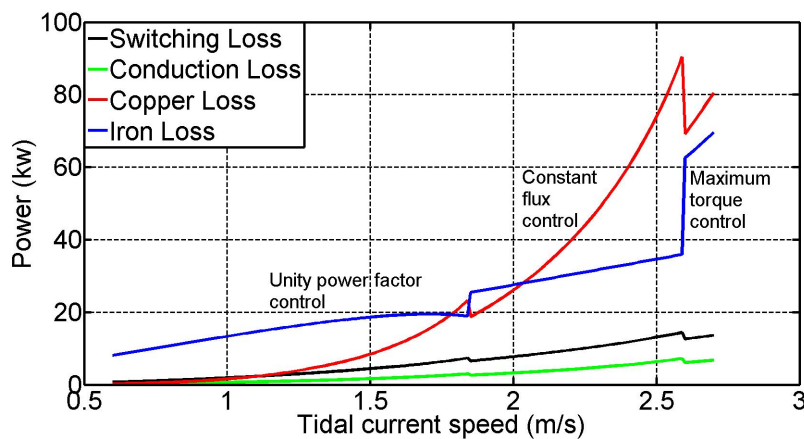


Figure 4: Power losses variation

Table.1 states that there is a optimal control strategy to achieve a better system efficiency for a special tidal current speed range. The details of power losses information for each control strategy region are given in Fig. 4. When the speed is

between 0.6m/s~1.84m/s, iron loss is the main part of power losses. The unity power factor control strategy which can decrease the iron loss will improve the efficiency of the generator. On the contrary, in high speed region 2.6m/s~2.7m/s, copper loss is the main part of power losses. Maximum torque per ampere control is priority compared with other two strategies even it increases the iron loss because of that it reduces the copper loss sharply. The choice of constant flux control in speed range 1.84m/s~2.6m/s is a compromised result of iron loss and copper loss. Switching loss and conduction loss of converter has a little impact on the selection of control strategy.

## 5 Conclusion

This paper presents the efficiency difference of a DSSMPMG with two stators controlled in parallel under three vector current control strategies condition. For the same turbine delivered power and rotational speed, there is an optimal control strategy to obtain a better system efficiency. The generator side converter power loss has been taken into account. The results show that unity power factor control and constant flux control are the best choice for tidal speed region 0.6m/s~1.84m/s and 1.84m/s~2.6m/s respectively in our case. However, the most simple and frequently used control method in laboratory  $i_d = 0$  or maximum torque per ampere control has the best performance only in a small speed interval 2.6m/s~2.7m/s. Through only changing the control strategy of the generator based on the tidal speed, the system can deliver more power to the grid.

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