Investigation of a New Topology of Hybrid Excitation Doubly Salient Brushless DC Generator

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***Abstract*—This paper proposes and implements a new topology of hybrid excitation doubly salient brushless DC generator. Configuration and flux control principle of the generator are presented. Two-dimensional finite element methods are used to investigate the static field distribution characteristics of this new type of generator. Field-circuit coupled analysis is successfully performed, and the output characteristics of different windings are obtained. A prototype hybrid excitation doubly salient brushless DC generator is designed and developed, and the experimentation is also given to verify the validity of the proposed brushless DC generator with one and dual terminal outputs. The results confirm the excellent field-regulation capability of hybrid excitation doubly salient brushless DC generator, and the rectified output of permanent magnet part can serve as the independent power of the excitation winding when the hybrid excitation doubly salient brushless DC generator has two sets of output windings.**

***Index Terms*—Brushless machine, permanent magnet, doubly salient, finite element methods, hybrid excitation, magnetic flux, wind power generation.**

NOMENCLATURE

2D-FEA	Two-dimensional finite element analyses.
PM	Permanent magnet.
DSPM	Doubly salient permanent magnet.
SRM	Switched reluctance machine.
DSEM	Doubly salient electromagnet machine.
HEDSM	Hybrid excitation doubly salient machine.
FSPM	Flux-switching permanent magnet.
HEFSM	Hybrid excited flux-switching machine.
HEDS-BLDCG	Hybrid excitation doubly salient brushless DC generator.
MMF	Magnetomotive force.
If	Excitation current.

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I. INTRODUCTION

DOUBLY salient permanent magnet machine (DSPM) proposed in the early 1990s [1], which resembles the simple structure of a switched reluctance machine (SRM) [2-4], has received wide attention [5-9]. As a kind of stator-PM (magnets located in the stator) brushless machine, DSPM can offer higher efficiency and higher power density [10-14]. However, DSPM suffers from the problem of uncontrollable PM flux and high PM material cost, just as the other PM machines. With the replacement of the permanent magnets in DSPM by dc electrical excitation windings, the doubly salient electromagnetic machine (DSEM) is constructed. Thus, the voltage regulation and fault protection of DSEM is easy to be realized by regulating the air gap flux. Meanwhile, excitation power loss in DSEM may exert a negative impact on the efficiency and power density of the machine [15-20].

Recently, the concept of hybrid excitation doubly salient machine (HEDSM), which strives to combine the merits of DSPM and DSEM, is proposed. The HEDSM not only maintains the advantages of DSPM but also has the ability of controlling magnetic field flux by field windings. Dr. Chen presented a coordinate structure HEDSM composed of a DSPM and a DSEM [21]. The magnetic paths of the DSPM and DSEM are independent from each other, which means that the HEDSM machine can be equal to the addition of a DSPM machine and a DSEM machine. Dr. Zhu proposed a stator hybrid excited doubly salient machine with the PMs located in the stator back-iron [22]. The novelty of this machine is the addition of an extra flux path in shunt with each PM pole, hence amplifying the effect of flux weakening for constant power operation [23-24].

Moreover, by reducing the magnets in flux-switching PM (FSPM) machine to accommodate the excitation windings, novel hybrid excited flux-switching machines (HEFSM) are proposed. In [25], a new structure of (HEFSM) which may be used as a low speed gearless wind generator is proposed. The advantage of the structure is the possibility to modulate the excitation flux and its consequence on iron losses. In [26] and [27], another structure of HEFSM machine with iron flux bridges is introduced. By adding an iron bridge at outer radius of the machine, the field coil excitation can be effectively increased at the cost of slightly reduced torque density. A novel