

DEVELOPMENT OF IRONLESS CORELESS AXIAL
FLUX PERMANENT MAGNET GENERATOR

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DEVELOPMENT OF IRONLESS CORELESS AXIAL FLUX PERMANENT
MAGNET GENERATOR

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for the award of the
degree of Master of Engineering

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LIST OF SYMBOLS

| | |
|------------|---|
| η | Efficiency |
| P_{out} | Power output |
| P_{in} | Power input |
| P_{loss} | Power losses |
| W_h | Hysteresis loss |
| K_h | Hysteresis constant |
| f | Frequency |
| B_m | Magnetic flux density |
| W_e | Eddy current loss |
| K_e | Eddy current constant |
| v | Velocity of the wire |
| ω | Rotating speed of rotor in rad/s |
| R | Turning radius |
| e | Generated voltage/Counter electromotive force |
| B | Magnetic flux |
| u | Velocity of moving charge |
| f | Force magnitude |
| ϕ | Magnetic flux |
| τ | Pole pitch |
| r | Radius |
| g | Thickness of magnet |
| μ_0 | Air permeability |
| B_r | Remanence |
| H_c | Coercivity of magnet |

| | |
|----------|-----------------------------------|
| δ | Air gap length |
| H_c | External magnetic field strength |
| m | Magnetic moment |
| t_1 | Desired end time |
| t_0 | Start time |
| I | Current |
| V | Voltage |
| R | Resistance |
| P | Power |
| V_L | Line voltage |
| V_ϕ | Phase voltage |
| I_L | Line current |
| I_ϕ | Phase current |
| p | Number of poles |
| N | Rotational speed of rotors in RPM |
| τ | Torque |

LIST OF ABBREVIATIONS

| | |
|--------|---|
| AC | Alternating Current |
| AFPM | Axial-flux permanent-magnet |
| CAD | Computer Aided Design |
| CEMF | Counter Electromotive Force |
| CNC | Computer Numerical Control |
| DC | Direct Current |
| DDPMG | Direct-drive permanent magnet generator |
| DDSG | Direct-drive synchronous generator with electrical excitation |
| DFIG | Double fed induction generator |
| DFIG3G | Double-fed induction generator with three-stage gearbox |
| EESG | Electrically Excited Synchronous Generator |
| emf | Electromotive Force |
| ESTRN | Equivalent strain |
| FE | Finite Element |
| FEM | Finite Element Method |
| IG | Induction generator |
| NdFeB | Neodymium Iron Boron |
| RFPM | Radial-flux permanent-magnet |
| RMS | Root Mean Square |
| URES | Displacement resultant |
| VFD | Variable frequency drive |

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ABSTRACT

Axial flux permanent magnet generator is well known on application of wind turbine electricity generation. The elimination of some iron core usage in the axial flux permanent magnet generator had significantly improve the generator's efficiency compare to the conventional generator. However, the presence of cog cause by the ferrite material within the generator is seen somehow restricting the application of the generator where low rotational torque is required. Cogging creates an attraction force between magnets and ferrite material in a generator. More power is required to overcome cogging before the generator can be spun continuously. With the increase of power output, the problem of cogging is also increased. Therefore, more power is required to overcome the increased torque. The research sought to fundamentally study the possibility of removing ferrite material in an electric generator. The generator was designed, fabricated and experimentally validated to qualify its no-load and loaded characteristics. The research began with fundamental studies on electric generator and eventually followed by the design concept. The concept was later analyzed in simulation mode by using finite element software to study its characteristics in order to determine its optimum arrangements. Based on the optimum design obtained in the finite element simulations, the generator was then developed and tested in experimental mode to qualify and quantify its qualitative and quantitative characteristics. Since the generator was made coreless and ironless, the cogging torque was therefore reduce to minimum. Results in both simulation and experimental modes showed good agreement between the two. The generator managed to generate a few hundred watts of power and the efficiency was rated to be approximately 78%. Based on the quantitative experiments, pure sinusoidal 3-phase voltage wave was captured on a scope. Cog-free motion was found to have demonstrated low starting torque spin. Hence, it can be concluded that it would be suitable for use in low torque application. Many applications can benefit from this generator such as in electric generation itself, wind turbine as well as applications in the automotive industry.

ABSTRAK

Penjana elektrik fluks paksi magnet kekal adalah terkenal dalam aplikasi penjanaan elektrik turbin angin. Oleh kerana penghapusan penggunaan teras besi dalam penjana elektrik fluks paksi magnet kekal, kecekapan penjana elektrik telah meningkat berbanding dengan penjana elektrik konvensional. Kewujudan gigi roda atau tugal disebabkan oleh bahan ferit kelihatan menghadkan aplikasi penjana elektrik dalam keadaan yang memerlukan putaran kilas atau tork yang rendah. Penugalan menghasilkan satu daya tarikan di antara magnet-magnet dengan teras besi berlamina di dalam penjana elektrik. Kuasa yang lebih diperlukan untuk mengatasi masalah gigi roda sebelum penjana elektrik boleh diputar secara berterusan. Dengan meningkatnya output kuasa, masalah penugalan juga meningkat. Oleh itu, lebih kuasa diperlukan untuk mengatasi peningkatan kilasan. Penyelidikan ini bertujuan mengkaji asas-asas kemungkinan penggunaan penjana elektrik tanpa bahan ferit. Penjana elektrik direka, dibina dan diuji untuk disahkan ciri-ciri penjana elektrik tanpa beban dan dengan beban secara uji kaji. Penyelidikan ini bermula dengan kajian asas terhadap penjana elektrik dan seterusnya konsep reka bentuk. Konsep ini kemudiannya dianalisis secara simulasi dengan menggunakan perisian “finite element” untuk mengkaji ciri-cirinya dan menentukan perkiraan optimumnya. Berdasarkan reka bentuk optimum yang diperolehi secara simulasi menggunakan finite elemen, penjana elektrik ini kemudian dibina dan diuji secara ujikaji untuk mengukur ciri-ciri kualitatif dan kuantitatif. Oleh kerana penjana ini dibuat dengan tanpa teras dan juga tanpa menggunakan besi, penugalan kilas dapat mengurangkan ke tahap minima. Keputusan dalam kedua-dua simulasi dan eksperimen telah menunjukkan keserasian antara kedua-duanya. Penjana elektrik ini berjaya menjana beberapa ratus watt kuasa dan dengan anggaran keberkesanan 78%. Berdasarkan eksperimen kuantitatif, gelombang bentuk sinus tulen bervoltan 3 fasa telah dikesan pada skop. Gerakan tanpa gigi roda didapati menghasilkan putaran kilas permulaan yang rendah. Oleh itu, dapatlah disimpulkan bahawa ia sesuai untuk kegunaan dalam aplikasi yang memerlukan kilas yang rendah. Banyak aplikasi dapat memanfaatkan penjana ini seperti dalam penjana elektrik sendiri, turbin angin dan juga dalam aplikasi lain dalam industri automotif.

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