Steady-State Time-Stepping Analysis of a Single-Phase PMSG with Capacitors for Voltage Regulation

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***Abstract*—A steady-state time-stepping analysis of a single-phase permanent magnet synchronous generator (PMSG) with different capacitor arrangements for voltage regulation is presented in this paper. The analyzed arrangements of the single-phase PMSG are the direct connection to the load (conventional), a parallel capacitor connection with the load and a proposed connection. The proposed uses a quadrature auxiliary winding with a serial capacitor; this circuit is parallel connected with the main winding. To carried out the steady-state time-stepping analysis, it was used a magnetodynamic two dimensional (2D) finite element (FE) single-phase PMSG model. The simulation results prove that the proposed configuration has advantages over the typical parallel capacitor configuration.**

***Index Terms*—Permanent magnet machines, generator, finite element method.**

I. Introduction

Nowadays, permanent magnet synchronous generator (PMSG) is being used widely due to its high efficiency, low volume and cost. The application of PMSGs in single-phase power plants is attractive because the advantages mentioned above. The single-phase PMSG power plants are used in domestic and rural applications. A known problem of PMSGs is the voltage regulation. The terminal voltage is decreasing when the load increases. The easiest and cheapest way to regulate the terminal voltage is adding a capacitor in parallel connection with the load [1], [2]. There are several ways to regulate the voltage in a PMSG including electronic power converters, hybrid generator (wound rotor, and permanent magnet rotor) and pole shape modifications. In small power plants is important to maintain a low cost in its construction, for this reason a single-phase PMSG combined with a capacitor bank is a good option. The steady-state analysis of this machine is important to understand its behavior and select the correct capacitor value [3]-[7].

In this paper a steady-state time-stepping analysis of a single-phase PMSG with a capacitor is carried out with a magnetodynamic two dimensional (2D) finite element (FE) model. Three different configuration of the single-phase PMSG feeding the load were analyzed. The first configuration is the conventional way to feed the load without capacitor, as presented in Fig. 1a. The second configuration uses a capacitor in parallel connection with the load as shown in Fig. 1b; it is the typical way to increase the voltage in electrical systems. The third is a proposed configuration; it consists in an auxiliary winding in quadrature with the main winding of the PMSG stator as in Fig 1c. Several steady-state time-stepping simulations of the single-phase PMSG model with different capacitor values were done to show the performance of the machine. The simulation results reveal that the proposed configuration has a better voltage regulation than the typical parallel capacitor configuration when they use the same capacitor values.

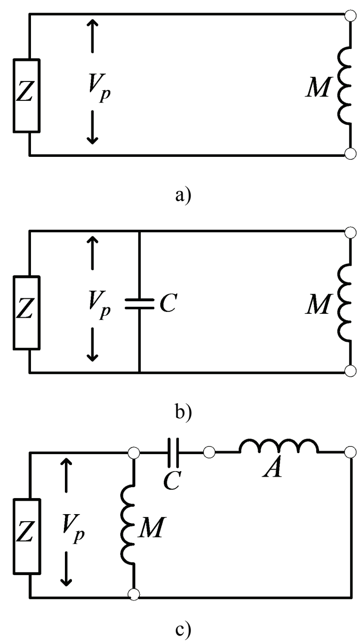


Fig. 1. Single-phase PMSG configurations. a) Conventional connection. b) Parallel capacitor connection. c) Proposed connection.

II. 2D-FE PMSG Model

A 2D-FE magnetodynamic model of a PMSG was built to analyze the configuration mentioned above. The analyzed machine is a 10 salient poles, ferrite permanent magnets single-phase PMSG. The generator was modeled in a commercial software Flux 2D. The mesh model was constructed only with one-pole of the PMSG by using periodicity conditions. The mesh contains 17160 nodes and 5720 second order 2D finite elements. The one pole geometry and its magnetic vector potential are shown is Fig. 2. In the proposed configuration (Fig. 1c) the auxiliary winding A is fourth times the turns of the main winding. The main winding M and the auxiliary winding A occupy 2/3 and 1/3 of the stator slots respectively.

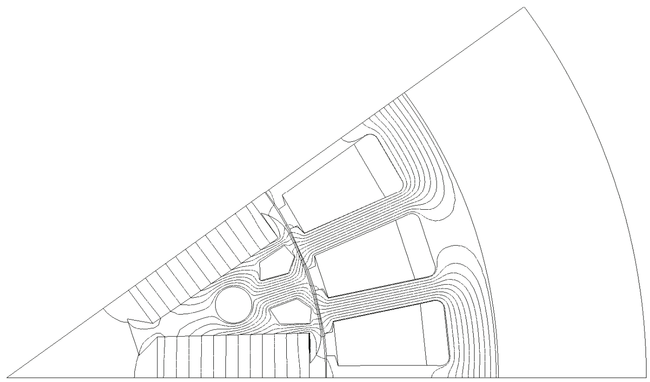


Fig. 2. One pole geometry and magnetic vector potential of the single-phase PMSG.

III. Simulation Results

A terminal voltage steady-state time-stepping solution against rotor position of the PMSG conventional configuration (Fig. 1a) is presented in Fig. 3, where the PMSG is feeding a resistive load of 15 Ω. Several steady-state time-stepping simulations were done to compare the terminal voltage of the different configurations depicted in Fig. 1. The comparison was carried out by using two different capacitor values as shown in Fig. 4a and Fig. 4b, where the capacitor values are 4 and 8 μF respectively. The capacitor values were selected arbitrarily, because the aim is to see the terminal voltage behavior. Fig. 4 reveals that the proposed capacitor configuration has the bigger increase in terminal voltage than the parallel capacitor connection. The proposed connection has an auxiliary winding which is a fourth times the impedance of the main winding. The parallel capacitor connection shows a decreasing in terminal voltage in comparison with the conventional and proposed connection. In parallel capacitor connection, the PMSG does not improve the terminal voltage with the used capacitor values. The best improvement in the terminal voltage is reached with the proposed connection, because it is be able to increment the terminal voltage with lower capacitor values. The correct selection of the capacitor and the analysis of the single-phase PMSG efficiency will be presented in the full paper.

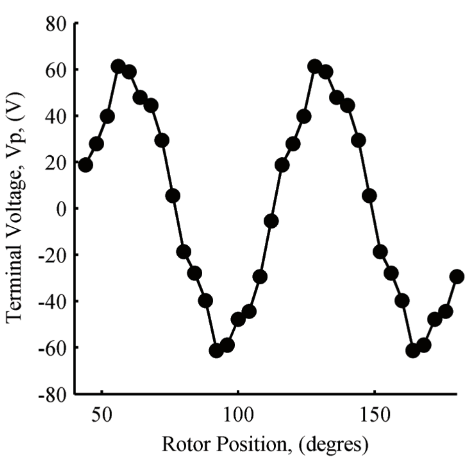
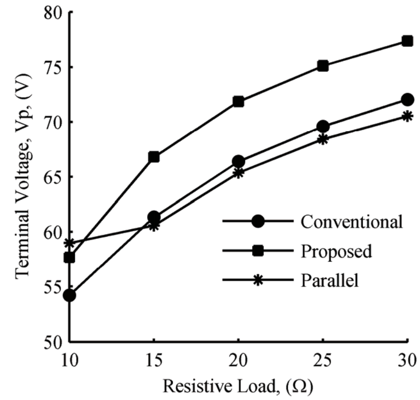
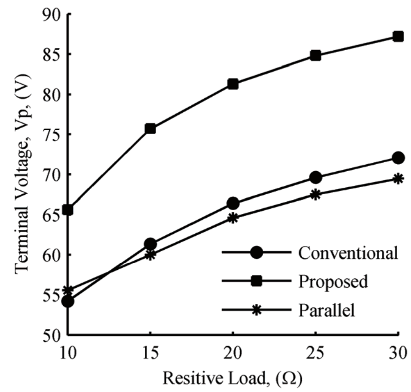


Fig. 3. Terminal voltage against rotor position of the conventional single-phase PMSG configuration with a resistive load of 15 Ω.



a)



b)

Fig. 4. Terminal voltage against resistive load of the conventional, parallel and proposed configuration. a) $C = 4$ μF. b) $C = 8$ μF.

IV. Conclusions

A steady-state time-stepping analysis of a single-phase PMSG of different capacitor arrangement configurations was presented in this paper. The novelty of this work is that the proposed capacitor configuration has a better improvement in the terminal voltage than the conventional and parallel capacitor configuration.

References

[1] N. Naoe, "Voltage compensation of permanent-magnet generator with capacitors," *IEEE Int. Electric Machines and Drive Conf. Rec., 1997*, pp. WB2/14.1-WB2/14.3.

[2] N. Naoe, "Fundamental characteristics of voltage compensation type permanent-magnet generator," *Int. Conf. on Energy Management and Power Delivery, 1995.* Vol. 2, pp. 624-627.

[3] H. X. Wu, D. H. Pan, B. Q. Kou, and L. Y. Li, "Research on closed-loop control of single-phase excited permanent magnet synchronous generator," *Power and Energy Engineering Conf., 2009*, pp. 1-4.

[4] T. F. Chan, W. Wang, and L. L. Lai, "Permanent-magnet synchronous generator supplying an isolated load," *IEEE Trans. Magn.*, vol. 46, no. 8, pp. 3353-3356, 2010.

[5] F. Xinghe, and Z. Jibin, "Numerical analysis on the magnetic field hybrid exciting synchronous generator," *IEEE Trans. Magn.,* vol. 45, no. 10, pp. 4590-4593, 2009.

[6] P. Pisek, B. Stumberger, T. Marcic, and P. Virtic, "Design analysis and experimental validation of a double synchronous PM machines used for HEV," *IEEE Trans. Magn.*, vol. 49, no. 1, pp. 152-155, 2013.

[7] J. A. Tapia, J. Pyrhonen, J. Puranen, P. Lindh, and S. Nyman, "Optimal design of large permanent synchronous generator," *IEEE Trans. Magn.*, vol. 49, no. 1, part 3, pp. 642-650, 2013.