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Utilization of a low power wind turbine with the self-excited induction generator for heating in rural areas

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Abstract
Recent studies have shown that Turkey has great amount of wind potential as energy prices unpredictably increase in the world today. This wind potential can be used to generate electricity through low and high power wind turbines. Several environmentally-conscious public and private companies have carried out few works to partially meet their needs of electrical power by means of wind turbines. Unlike the high power wind turbines, low power wind turbines are usually designed to partially meet energy demands for lighting and heating needs in rural areas isolated from power grids during the winter. It is widely accepted that electrically heating is independent of voltage and frequency and that makes the system under design simple and easy. Therefore the self-excited induction generator is highly appropriate machine to generate electricity despite its poor voltage-frequency regulation as well as many advantages over other types of generators. In this paper, the partially developed 5kW wind turbine is designed to heat up small houses in poor areas in Northwest Black Sea cost where wind potential is available during winter. The designed wind turbine which is isolated from the interconnected power grid starts to generate electricity at initial speed of 3ms-1 and the generated ac power is routed to feed electrical heaters. The results indicated that the developed system works well as long as the wind speed is over initial speed. However, if the wind speed is under the threshold speed the system is automatically connected to the national power grid. During the whole year, the produced electricity significantly contributes to the budget of a house in terms of energy saving.

Keywords: Wind power; Induction generators; Power conversion; Genetic algorithms;

1. Introduction

The recent survey has shown that Turkey has great amount of wind potential in particular, wind speed reaches 8.5ms-1 at some location near Aegean Sea. According to Turkey’s Wind Energy Atlas published in 2007, onshore and offshore wind power potentials are estimated to be 131756.4MW and 17393.2MW [1]. In other words, wind power density varies from 300 to 800Wm-2 in Turkey and Marmara and Aegean coasts have the highest wind potential as shown in Fig. 1. Few private and public companies have attempted to utilize this wind potential through some project investments. Besides, a number of researchers designed suitable wind turbines to generate electricity in small scale using this wind potential [2-7]. Sánchez et al built a 350W horizontal axis wind turbine operating in a range from 3.5 to 9 ms-1 for powering communications devices in rural areas through the computer aided design [8]. Similarly, Messineo et al developed a low power wind turbine to feed a base station located in Palermo, Sicily Island [9]. Another investigation by G. Notton et al was about effects of load profiles energized by a wind turbine in terms of input-output powers and power losses [10]. Fernández et al designed and constructed a horizontal axis wind turbine connected to a car alternator and requiring no mechanical control system to meet electricity needs of small shops in the third world countries [11]. In fact, there are widely used methods and approaches to design and build low power wind turbines but, unfortunately they are not all mentioned here due to the restricted page number. However, it is well-known that the main objective of these works is to utilize wind energy economically and efficiently as much as possible in wide-range applications.

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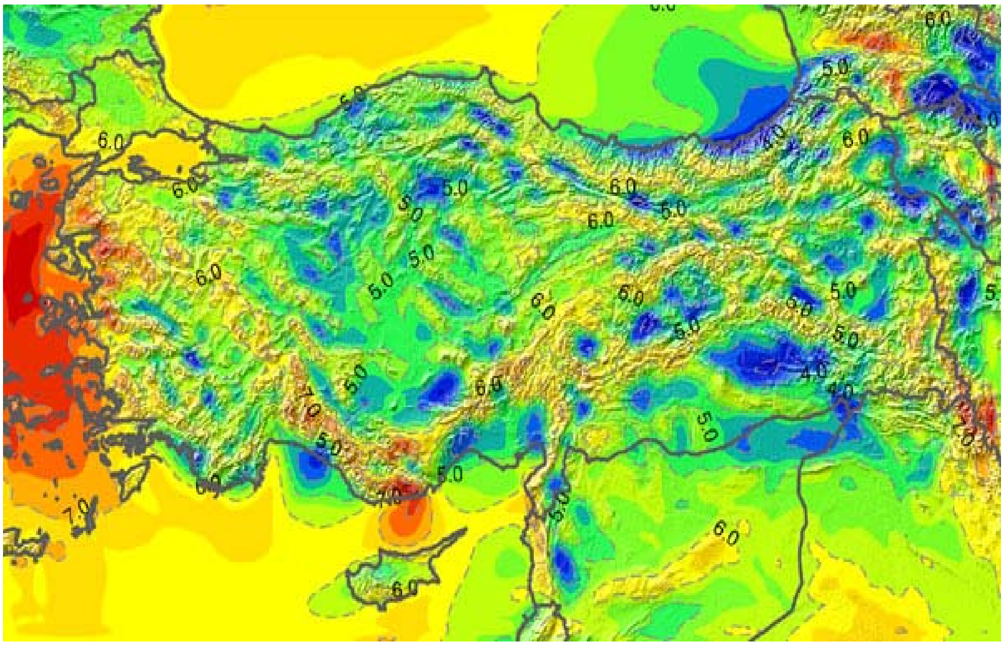

Figure 1. Turkey's wind atlas published in 2007 [1].

In this paper, the design and analysis of a 5kW horizontal axis wind turbine with the self-excited induction generator (SEIG) feeding an electrical heating system in a house situated in western Black Sea coastal area in Turkey. The results have shown that designed wind turbine system produces encouraging outcomes for utilization of wind potential and providing less energy bill to the house-holders.

2. Steady-state analysis of the SEIG

In order to carry out the performance analysis of the SEIG, the equivalent circuit is simplified by neglecting core losses assuming all the parameters to be constant but X_M. Besides, space harmonics of the magnetomotive force and the time harmonics in the induced voltage and the current waveforms are neglected as well as magnetic core losses in the machine. The steady-state performance analysis of the SEIG based on the impedance model given in per unit system was achieved. Using the impedance model for the circuit illustrated in Fig. 2, total impedance Z_T can be written as

$$Z_T = \left(\left(\frac{R_R}{F-\upsilon} + jX_R\right) || jX_M\right) + \frac{R_s}{F} + jX_s + \left(\frac{-jX_c}{F^2} || \left(\frac{R_L}{F} + jX_L\right)\right) \quad (2.1)$$

where R_R, R_S, and R_L, are rotor, stator and load resistances; X_R, X_S, X_L and X_C are rotor, stator, load, and capacitive reactances in per unit respectively.

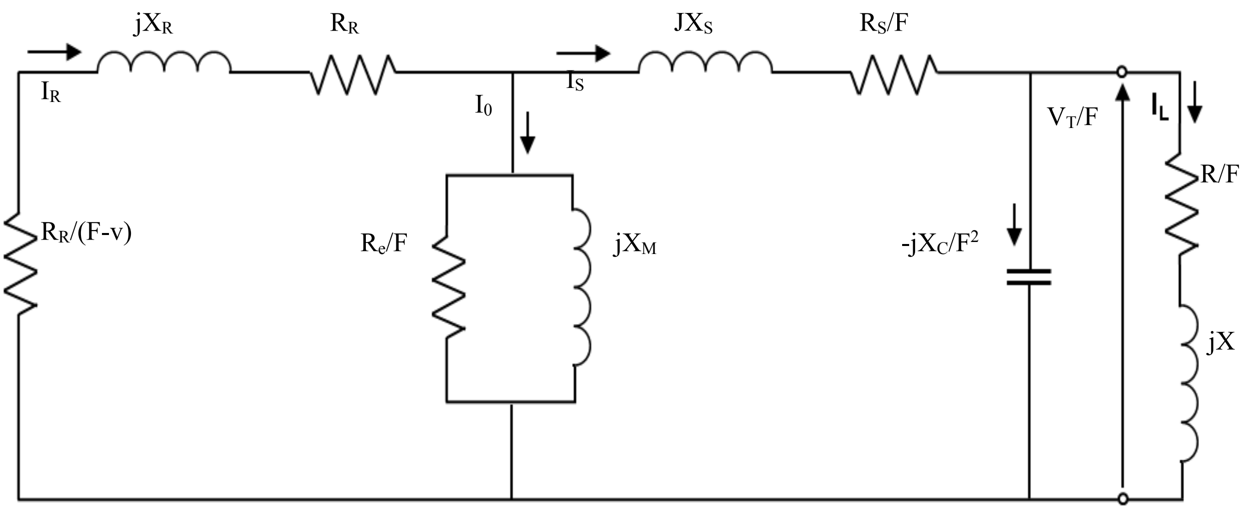

Figure. 2. The steady-state approximate equivalent circuit of the SEIG.

X_C, X_M, F and ν are unknown but, there are only two equations constructed after separating (2.1) into the real and imaginary parts.

Therefore, the number of unknowns must be reduced to double by assigning certain values to X_C and ν. Thus, both equations can be solved simultaneously using a combination of the Newton-Raphson (NR) and the genetic algorithm (GA) methods. Once optimal solutions of X_M and F are computed, the relationship between V_G/F and X_M must be determined to calculate the performance parameters of the SEIG. The input and output powers P_i and P_o can be estimated by

$$P_i = I_R^2 \frac{R_R}{F-\upsilon} \quad (2.2)$$

$$P_o = I_L^2 \frac{R_L}{F} \quad (2.3)$$

where

$$I_R = \frac{V_G}{F\left(\frac{R_R}{F-\upsilon}+jX_R\right)} \quad \text{and} \quad I_L = \frac{jX_c I_s}{R_L F - jX_c}$$

3. Application Of The HGA

The hybrid GA (HGA) process initiated with a randomly generated initial population as shown in Fig. 3. The population consisted of 100 individuals with 12 bit two genotypes corresponding to F and the XM. The fitness values can be calculated by;

$$\Omega = \frac{1}{\sum_{i=1}^{2}|f_i\ (F, X_M)| + \varepsilon} \quad (3.4)$$

where ε is the error margin used to avoid making the denominator zero.

The roulette wheel selection criterion was used to select the individuals forming a temporary population. The uniform crossover was applied to the selected population with the crossover probability of 0.8 to generate dissimilar individuals. If individuals become similar in early generations, the better solutions may be trapped by local optima due to a lack of genetic diversity.

Since the crossover operator has no straight forward mechanism to avoid local optima, the mutation operation can be accomplished with mutation probability of 0.05. In addition, the elitist strategy was applied to the mutated population to retain the best individual in each generation and copy this to the next generation. This helped increase the performance of the HGA despite the risk of reducing diversity. The proposed HGA software was encoded in the MATLAB® environment available in the PC and run in order to determine the steady-state performance of the SEIG.

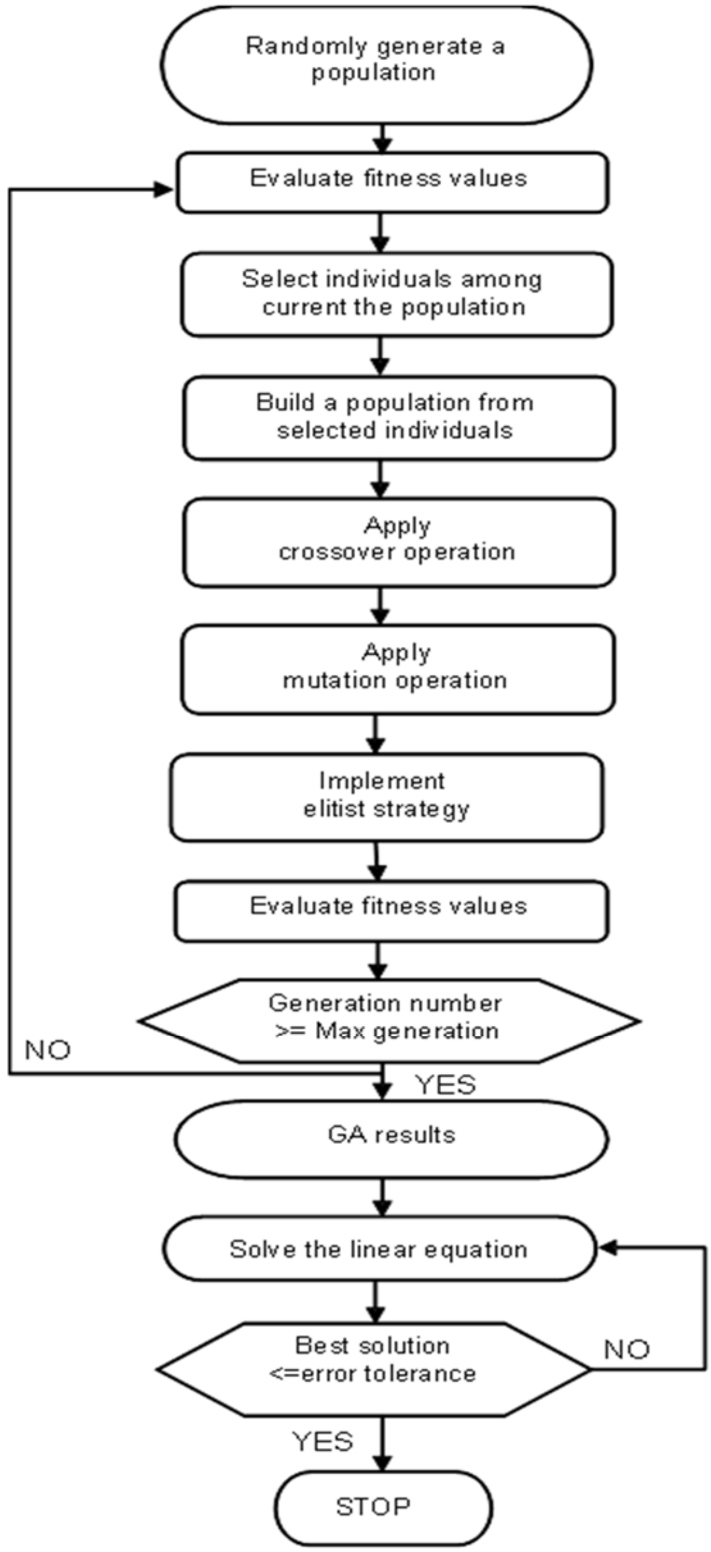

Figure 3. The flowchart of the hybrid genetic process.

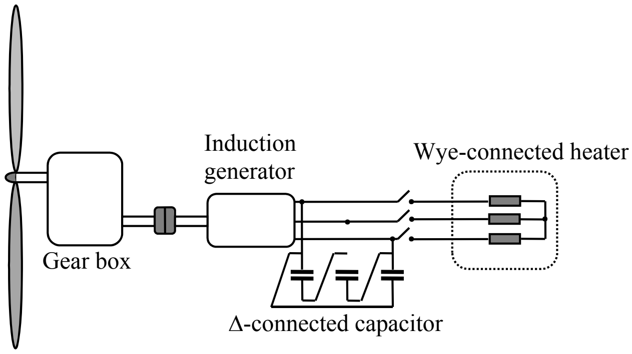

Figure 4. Simple wind power system powering wye-connected heater.

4. Results and Discussions

Several experiments were performed to see the effect of the capacitor used for the SEIG on the performance parameters under various load conditions at constant speed of 1 pu. X_M and F were estimated for a certain capacitance range and variation of X_M against the capacitance is illustrated in Fig 5.

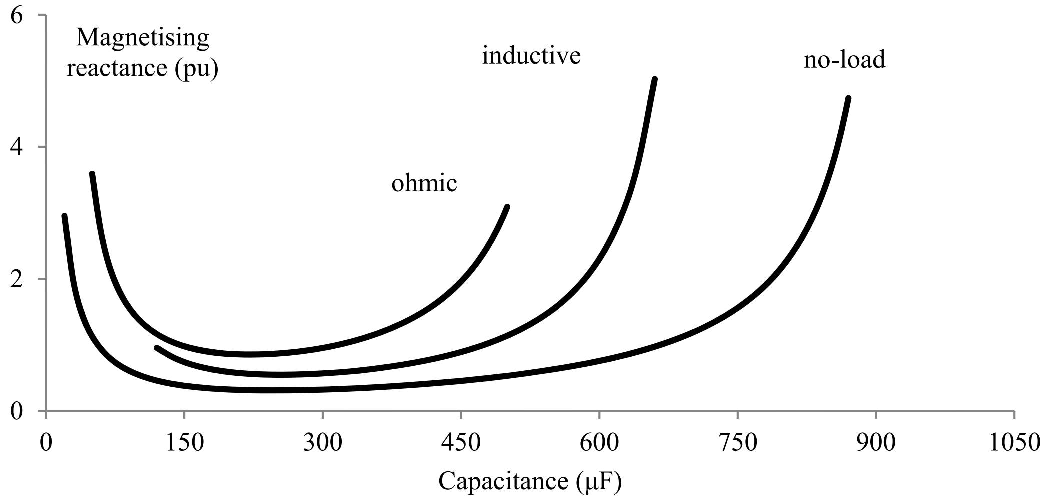

Figure 5. Variation of X_M with capacitance under various load conditions at speed of 1 pu.

In Figure 5 the self-excitation occurs in a certain capacitance range depending on the type of the loads. As seen from the Figure 5 the largest X_M was found to be around 5 pu under inductive loads in which load angle was 45º. The smallest X_M was around 0.5 pu at capacitance of 200 μF under no-load condition. It should be noted that the capacitance range were greater under no-load condition with respect to others. Surprisingly, X_M arises as capacitance increases under inductive load compare to ohmic load for this specific machine. It is important to emphasize that X_M values are close to each other in a capacitance range from 150 to 300 μF under three load conditions. All these outcomes indicate that in proper operation of wind turbines with the SEIGs it is necessary to have a capacitance regulator for variable loads. The variation of F with the capacitance for various load resistances at the speed of 1pu is shown in Fig. 6. As the capacitance increases, the F almost linearly decreases under three load conditions.

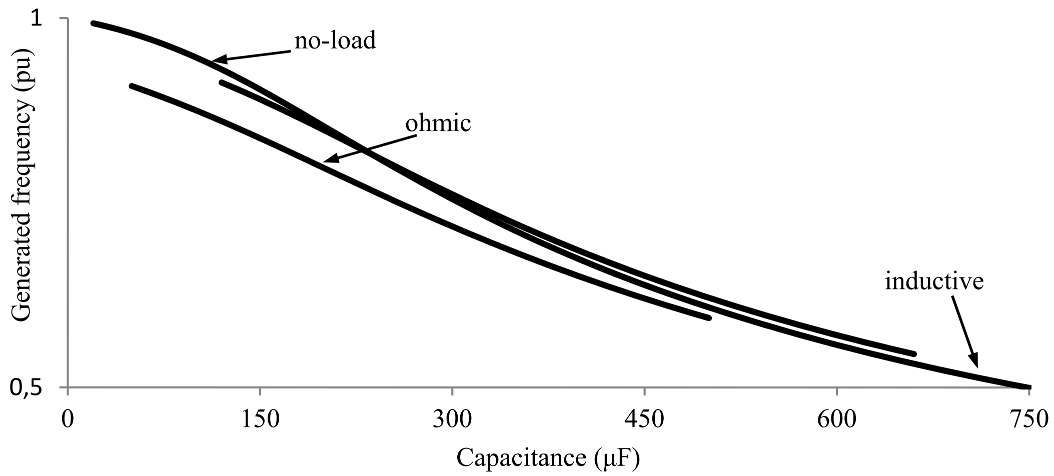

Figure 6. Variation of F with capacitance under 3 resistive loads.

It is also emphasized that the generated frequency exhibits slide differences at capacitance values less than 300 μF and under resistive load the F becomes smaller than that under load condition. Besides, to maintain F around at 1 pu the excitation capacitance of the SEIG should be held in its minimum. Variation of terminal voltage with capacitance is shown in Figure 7.

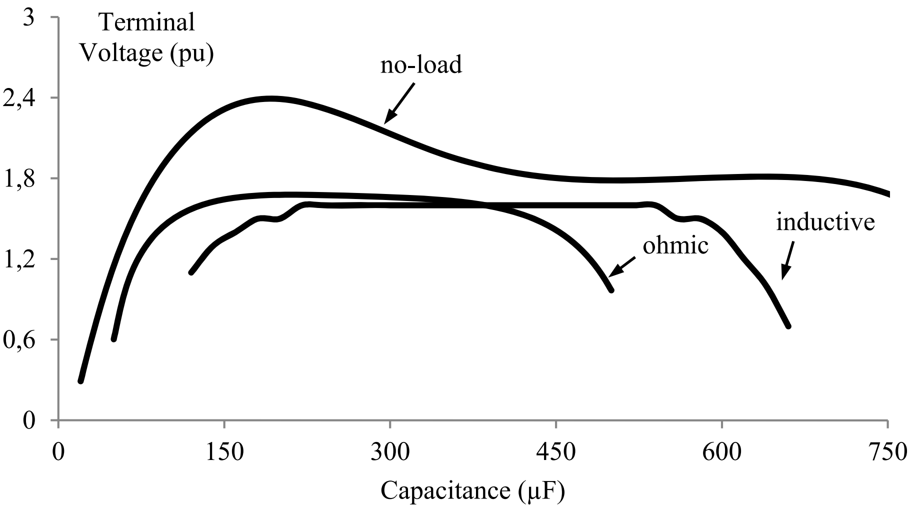

Figure 7. Variation of V_T with capacitance under various loads at ν=1pu.

It should be noticed that there is an optimal capacitance which makes V_T higher than expected. It is widely accepted that this will be highly risky to the SEIG's insulation if the capacitance is set to an optimal value in any case. Therefore, the appropriate selection of the capacitance is highly significant for the proper operation of the SEIG. Surprisingly, magnitude of the V_T is 1.5 times more than that of V_G and the V_T is almost 1.5 times higher than the rated voltage for the machine under consideration. As seen from Fig 7, V_T is almost stable at 1.5 pu under inductive load condition. In order to find the capacitance variation with input power Figure 8 is plotted. As seen from the Figure 8 input power values is to be multiplied by 0.12. Input power is highest and lowest under no-load and ohmic load conditions respectively. phase angle a limited number of experiments was carried out by maintaining Input power under all the load conditions almost the same at the capacitance values between 120 and 250 μF. Surprisingly as the capacitance increases input power dramatically decreases even it becomes zero under no-load condition. For the specific machine output power reaches is maximum at around 400 μF under all the load conditions. Figure 9 shows variation of output power with capacitance under three load conditions at constant speed of 1 pu. As seen from Figure 9 output power shows complete difference from input power in the certain capacitance range. Output power stays unchanged in the range from 200 to 400 μF under ohmic and inductive loads conditions. In this case it can be said that capacitance is very influential for these loads conditions.

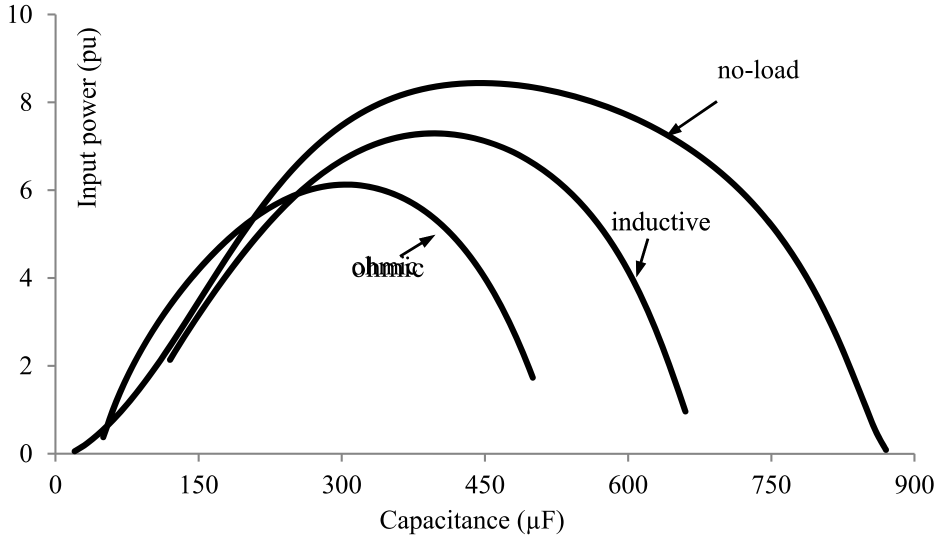

Figure 8. Variation of input power with capacitance under various loads conditions at ν=1pu.

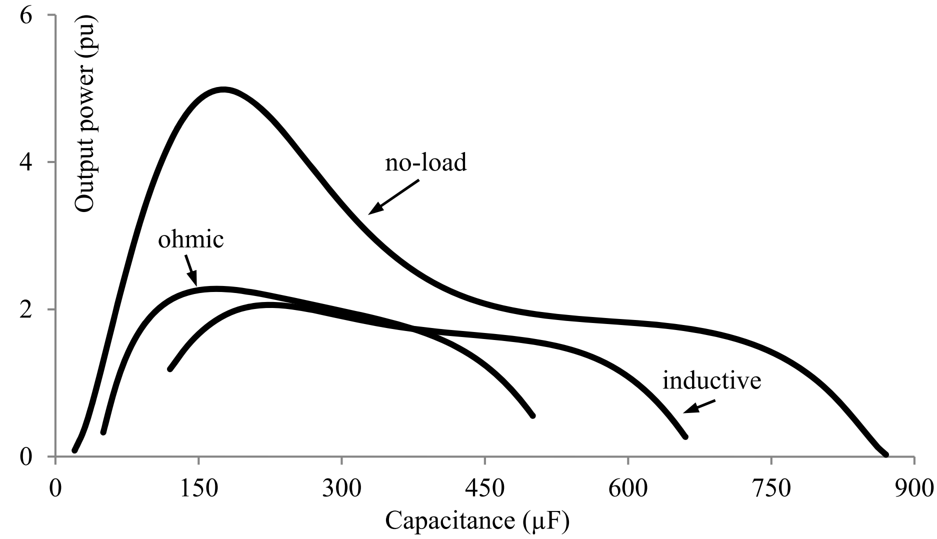

Figure 9. Variation of output power with capacitance under various loads conditions at ν=1pu.

5. Conclusion

The self-excitation only occurs in a range from the lower to the upper capacitance and this range becomes largest under no load steady-state condition. The resonance phenomenon takes place in the self-excitation at a specific capacitance depending on the load impedance and the equivalent circuit parameters. At this resonant condition, V_T, P_o and P_i take higher values than the rated values and this may lead to insulation breakdown. To maintain constant V_G/F at 1 pu is very influential on the self-excitation and to limit the magnitudes of the main parameters mentioned above. The variation of P_o with the load current is highly remarkable under ohmic load condition and it deserves a further investigation.

6. Appendix

The test machine used for this investigation was 3 phase delta connected, 220 V, 8.8 A, 50 Hz and 1420 rpm its parameters are R_S=0.0644 pu, R_R=0.08 pu, X_R=X_S=0.164 pu. The machine was driven by a typical DC motor at synchronous speed at 1500 rpm or ν=1 pu.

References

[1] S. S. Murthy, O. P. Malik, and A. K. Tandon, Analysis of self excited induction generator, in 1982 Proc. Inst. Elect. Eng. Conf., pp. 260–265.

[2] L. Quazene and G. McPherson Jr., “Analysis of an isolated induction generator,” in 1983 Proc. PAS-8, pp. 2793–2798.

[3] D. K. Jain, A. P. Mittal, and B. Singh, “An efficient iterative technique for the analysis of self excited induction generator,” J. Inst. Eng., vol. 79, pp. 172–177, 1999.

[4] T. F. Chan, “Analysis of self-excited induction generators using an iterative method,” IEEE Trans. Energy Convers., vol. 10, pp. 502–507, Sep. 1995.

[5] S. Rajakaruna and R. Bonert, “A technique for the steady state analysis of a induction generator with variable speed,” IEEE Trans. Energy Convers., vol. 8, pp. 757–761, Dec. 1993.

[6] S. P. Singh, B. Singh, and M. P. Jain, “Simplified approach for the analysis of self excited induction generator,” J. Inst. Eng., vol. 76, pp. 14–17, 1995.

[7] A. L. Alolah and M. A. Alkanthal, “Optimization based steady state analysis of three phase SEIG,” IEEE Trans. Energy Convers., vol. 15, pp. 61–65, Mar. 2000.

[8] T. F. Chan and L. L. Loi, “Capacitance requirements of a three-phase induction generator self-excited with a single capacitance and supplying a single-phase load,” IEEE Trans. Energy Convers., vol. 17, pp. 90–94, Mar. 2002.

[9] C. Chakraborty, et al, “Excitation requirements for stand-alone three-phase induction generator,” IEEE Trans. Energy Convers., vol. 13, pp. 358–365, Dec. 1998.

[10] N. H. Malik and A. A. Mazi, “Capacitive requirements for isolated self-excited induction generators,” IEEE Trans. Energy Convers., vol. EC-2, pp. 62–69, 1987.

[11] N. Hashemnia and H. Lesani, “A novel method for steady state analysis of the three-phase self excited induction generators,” in 2008 Proc. ICEM Conf., pp. 1-4.

[12] S. Vadhera and K. S. Sandhu, “Constant voltage operation of self excited induction generator using optimization tools,” Int. J. Energy and Environment, vol. 2, pp. 191–198, 2008.

[13] D. Joshi, K. S. Sandhu, M. K. Soni, “Voltage control of self-excited induction generator using genetic algorithm,” Turkish J. of Electrical Engineering, vol. 17, pp. 1-11, 2009.

[14] F. Arslan, “Kapasitör uyarmalı asenkron generatörün optimal kapasitesinin hibrit genetik algoritma ile belirlenmesi”, M.S. thesis, Dept. of Electrical & Electronics Engineering, Duzce University, Duzce, Turkey, 2010.

[15] N. Tutkun, F. Arslan, "Determination of capacitance range in the self-excited induction generator through the hybrid genetic algorithms," in Power Electronics Electrical Drives Automation and Motion (SPEEDAM), 2010 International Symposium on , vol., no., pp.1613-1617, 14-16 June 2010