COMPARISON STUDIES BETWEEN PRESSURE-CONTROLLED PUMP WITH CONVENTIONAL PUMP FOR DOMESTIC APPLICATION

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SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Master of Science.

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STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang Al-Sultan Abdullah or any other institutions.

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ABSTRAK

Sumber dan infrastruktur yang mengagihkan air ke kediaman dirujuk sebagai bekalan air domestik. Mengepam adalah cara penting untuk mendapatkan air daripada pelbagai sumber di mana graviti sahaja tidak mencukupi kerana geografi dan aras sampingan. Pam yang banyak terdapat di pasaran untuk kegunaan kediaman kebanyakannya adalah pam empar. Pam jenis ini mempunyai reka bentuk yang ringkas dan murah. Motor pam air empar domestik secara konvensional berfungsi pada kelajuan sekata dan memberikan hasil yang sekata. Walau bagaimanapun, pam berkelajuan sekata tidak mudah untuk menangani perubahan keperluan aliran air dan menyebabkan kehilangan tenaga dan kehilangan air yang berlebihan. Pelbagai kaedah penjimatan tenaga dalam aplikasi pengepaman telah diaplikasikan oleh beberapa kumpulan penyelidik, seperti talian pintasan, kawalan pendikit, pam selari dan kawalan pembolehubah kelajuan. Oleh itu, penyelidikan ini dimulakan untuk mengkaji pam kawalan tekanan pembolehubah kelajuan. Penyelidikan ini bertujuan untuk mengkaji dan membandingkan prestasi pam kelajuan tetap dan kelajuan berubah dari segi ciri prestasi seperti tekanan air, kadar alir dan kelajuan pam. Selain itu, kajian ini juga bertujuan untuk menganalisis penjimatan kos tenaga yang ditawarkan oleh pam air pembolehubah kelajuan. Dalam penyelidikan ini, satu teknik yang sesuai telah dicadangkan untuk menukar pam kelajuan tetap kepada pam pembolehubah kelajuan dengan menambah Pemacu Pembolehubah Frekuensi (VFD) pada motor pam konvensional untuk mengawal kelajuan pam agar sepadan dengan permintaan beban air. Sebuah pelantar ujian yang ringkas dan murah telah direka bentuk sebagai gambaran pengagihan air untuk kegunaan domestik seperti aplikasi untuk rumah satu tingkat. Kaedah ini kemudiannya disahkan secara eksperimen untuk mengesahkan prestasi pam dan penjimatan tenaga antara pam air konvensional dan pam air pembolehubah kelajuan. Bukaan injap yang separuh terbuka dan terbuka penuh juga telah diuji untuk melihat variasi kadar aliran isipadu dan perbezaan tekanan. Untuk pam pembolehubah kelajuan yang dikawal tekanan, untuk mengekalkan tekanan di dalam paip kepada 20.68 kPa, kelajuan dikawal dengan melaraskan frekuensi. Hasilnya menunjukkan bahawa pam pembolehubah kelajuan adalah pilihan yang sesuai untuk memadankan beban yang diperlukan dengan itu menjimatkan tenaga dan penggunaan kuasa dan juga meningkatkan ciri ekonomi motor elektrik. Jadi, kesimpulannya bahawa tenaga kurang digunakan apabila motor berjalan pada kelajuan yang lebih rendah. Pembukaan injap mempengaruhi kadar aliran isipadu pam, tekanan, dan tenaga pam. Semakin kecil pembukaan injap, semakin sedikit kadar aliran isipadu yang dicapai, yang menyebabkan pengurangan kegunaan tenaga. Manakala, hasil untuk tekanan paip adalah disebaliknya. Pada masa pembukaan injap berkurangan, tekanan pam akan meningkat. Untuk pam pembolehubah kelajuan kawalan tekanan, bukaan terkecil injap boleh menjimatkan tenaga kira-kira 92% berbanding pam air konvensional.

ABSTRACT

The source and infrastructure that distributes water to residences are referred to as the domestic water supply. Pumping is an important way for obtaining water from various resources where gravity alone is insufficient due to geography and side levels. Centrifugal pumps are the most common type of pumps used in residential applications. This kind of pump is affordable and simple in design. Domestic centrifugal water pumps motor conventionally works at constant speed and provide a constant output. However, constant speed pumps are not easily able to deal with changing demands in water flows which will yield excessive energy losses and water losses. Various methods of energy saving in pumping applications have been applied by several groups of researchers, such as bypass lines, throttle control, parallel pumps, and variable speed control. Therefore, this research was commenced to study pressure-controlled variable speed pumps. This research aimed to study and compare the performance of constant speed and variable speed pumps in terms of performance characteristics like water pressure, flow rate, and pump speed. Moreover, this research also aimed to analyze energy cost saving offered by the variable speed water pump. In this research, a suitable technique was proposed to change the constant speed pump to a variable speed pump by adding Variable Frequency Drive (VFD) to the conventional pump's motor to control the speed of the pump to match the water load demand. A simple and inexpensive test rig was designed and fabricated to represent water distribution for domestic use for example single-storey home application. The method is then experimentally validated to verify the pump performance and energy saving between conventional and variable speed water pumps. The valve opening which is half open and full open also was tested to see the variation of volume flowrate and pressure difference. For the pressure-controlled variable speed pump, to maintain the pressure inside the pipe to 20.68 kPa, the speed was controlled by adjusting the frequency. The results demonstrated that variable-speed pumps are the best option for matching the required loads, saving energy and water while also increasing the economic features of electrical motors. So, we conclude that less energy is applied when the motor runs at lower speeds. Pump energy, pressure, and volume flow rate are all influenced by the valve opening. A lower volume flow rate is achieved with a smaller valve opening, which reduces energy consumption where inversely correlated to pipe pressure. Pump pressure will rise by the time the valve opening is decreasing. The smallest opening of the valve for a pressure-controlled variable speed pump can reduce energy consumption by about 92% in comparison to a conventional water pump.

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REFERENCES

Abdel-Rahim, N., & Shaltout, A. (2002, 5-8 Nov. 2002). *Operation of single-phase induction motor as two-phase motor.* Paper presented at the IEEE 2002 28th Annual Conference of the Industrial Electronics Society. IECON 02.

Agamloh, E. B. (2017). Power and Efficiency Measurement of Motor-Variable-Frequency Drive Systems. *IEEE Transactions on Industry Applications, 53*(1), 766-773. doi:10.1109/TIA.2016.2602807

Ahmad Firdaus Ahmad & Azmi, S. K., Kamarulzaman & Norazli, Nurul Izyan Norazli. (2019). Design and Simulation of Fuzzy Logic Controller for Variable Frequency Drive of Three Phase AC Induction Motor. *Journal of Advanced Research in Dynamical and Control Systems., 11,* 834-842. doi:10.5373/JARDCS/V11SP12/20193283

Ahmad, H., & Atikol, U. (2018). Retracted: A simple algorithm for reducing the operation frequency of residential water pumps during peak hours of power consumption. *Energy Science & Engineering, 6*(4), 253-271. doi:https://doi.org/10.1002/ese3.204

Ahmadullah, R., & Dongshik, K. (2015, 28-30 Nov. 2015). *Construction of hydraulically balanced water distribution network.* Paper presented at the 2015 International Conference on Intelligent Informatics and Biomedical Sciences (ICIIBMS), Okinawa, Japan.

Al-Bahadly, I. (2007, 17-19, 2007). *Energy Saving with Variable Speed Drives in Industry Applications* Paper presented at the WSEAS Int. Conference on Circuits, Systems, Signal and Telecommunications, Gold Coast, Australia.

Al-Khalifah, M. H., & McMillan, G. K. (2012). *Control valve versus variable speed drive for flow control.* Paper presented at the International Society of Automation

Al-Naseem, O. A., & El-Sayed, M. A. (2013, 27-30 Aug. 2013). *Analysis of electrical and non-electrical causes of variable frequency drive failures.* Paper presented at the 2013 9th IEEE International Symposium on Diagnostics for Electric Machines, Power Electronics and Drives (SDEMPED), Valencia, Spain.

Almeida, A. T. d., Ferreira, F. J. T. E., & Both, D. (2005). Technical and economical considerations in the application of variable-speed drives with electric motor systems. *IEEE Transactions on Industry Applications, 41*(1), 188-199. doi:10.1109/TIA.2004.841022

Arribas, J. R., & Gonzalez, C. M. V. (2002). Optimal vector control of pumping and ventilation induction motor drives. *IEEE Transactions on Industrial Electronics, 49*(4), 889-895. doi:10.1109/TIE.2002.801240

Artal-Sevil, J. S., Dufo-López, R., Bernal-Agustín, J. L., & Domínguez-Navarro, J. A. (2015, 8-10 Sept. 2015). *Asymmetrical multilevel inverter with staircase modulation for variable frequency drives in fractional horsepower applications.* Paper presented at the 2015 17th European Conference on Power Electronics and Applications (EPE'15 ECCE-Europe).

ASHRAE. (2016). Energy Standard for Buildings Except Low-Rise Residential Buildings *Chapter 6 – Heating, Ventilation, and Air Conditioning*. ASHRAE Standard 90.1.

B, M., & M.S.Aspalli. (2014). Speed Control of Three Phase Induction Motor by Variable Frequency Drive. *International Journal of Ethics in Engineering & Management Education (IJEEE), 1*(4), 35-36.

Ba-thunya, A. S., Khopkar, R., Kexin, W., & Toliyat, H. A. (2001, 2001). *Single phase induction motor drives-a literature survey.* Paper presented at the IEMDC 2001. IEEE International Electric Machines and Drives Conference (Cat. No.01EX485).

Barnes, M. (2003). Practical Variable Speed Drives and Power Electronics. *Practical professional books from Elsevier.* Retrieved from http://www.loc.gov/catdir/enhancements/fy0627/2005299458-t.html

Bene József, G., Selek, I., & Hös, C. (2010). Neutral Search Technique for Short-Term Pump Schedule Optimization. *Journal of Water Resources Planning and Management, 136*(1), 133-137. doi:10.1061/(ASCE)0733-9496(2010)136:1(133)

Bhatt, P. J., & Hajari, A. R. (2014). Energy Conservation in Automatic Fluid Flow Control using Variable Frequency Drive. *International Journal of Advanced Technology in Engineering and Science (IJATES), 02*(12), 53-62.

Bhavana, M. B., & Hegde, V. (2015, 12-14 Aug. 2015). *Energy conservation using variable frequency drives of a humidification plant in a textile mill.* Paper presented at the 2015 International Conference on Power and Advanced Control Engineering (ICPACE).

Binder, A. (2008, 11-13 June 2008). *Potentials for energy saving with modern drive technology - a survey.* Paper presented at the 2008 International Symposium on Power Electronics, Electrical Drives, Automation and Motion, Ischia, Italy.

Bose, B. K. (2009). Power Electronics and Motor Drives Recent Progress and Perspective. *IEEE Transactions on Industrial Electronics, 56*(2), 581-588. doi:10.1109/TIE.2008.2002726

Bucci, G., Ciancetta, F., Fiorucci, E., & Ometto, A. (2016). Uncertainty Issues in Direct and Indirect Efficiency Determination for Three-Phase Induction Motors: Remarks About the IEC 60034-2-1 Standard. *IEEE Transactions on Instrumentation and Measurement, 65*(12), 2701-2716. doi:10.1109/TIM.2016.2599459

Chaurette, J. (2005). Tutorial Centrifugal Pump Systems. Retrieved from www.fluidedesign.com

Coelho, B., & Andrade-Campos, A. (2014). Efficiency achievement in water supply systems—A review. *Renewable and Sustainable Energy Reviews, 30*, 59-84. doi:https://doi.org/10.1016/j.rser.2013.09.010

Dai, P. D., & Vie, N. H. (2021). Optimization of Variable Speed Pump Scheduling for Minimization of Energy and Water Leakage Costs in Water Distribution Systems with Storages. *13th International Conference on Electronics, Computers and Artificial Intelligence (ECAI)*, 1-6. doi:10.1109/ECAI52376.2021.9515135

Dave, P., Mokariya, K., & Patel, V. (2013). Energy Conservation in centrifugal pump with variable frequency drive including SCADA, PLC and HMI. *International Journal of Innovative Research in Science, Engineering and Technology (IJIRSET), 02*(05), 1461-1468.

Dhaimat, O., & Al-Helou, B. (2004). The Role of Centrifugal Pumps in Water Supply. *Journal of Applied Sciences, 4*, 406-410. doi:10.3923/jas.2004.406.410

Dharkar, A., & Daigavane, P. M. (2016). Control of Variable Frequency Drives with PLC: A Review. *International Journal of Electrical Engineering & Technology (IJEET), 08*(01), pp. 45–51.

Diksha, S., Pratiksha, R., & Mangal, S. (2017). Variable Frequency Drive for Single Phase Induction Motor. *International Engineering Research Journal (IERJ), 2*(8), 2832-2834.

Dorjee, R. G. (2014). Monitoring and Control of a Variable Frequency Drive Using PLC and SCADA. *International Journal on Recent and Innovation Trends in Computing and Communication (IJRITCC), 02*(10), 3092-3098.

Emiliawati, A. (2014). *A research domestic water pump efficiency.* Universitas Gadjah Mada Yogyakarta.

Emiliawati, A. (2017). A study of water pump efficiency for household water demand at Lubuklinggau. *AIP Conference Proceedings 1903*. doi:https://doi.org/10.1063/1.5011613

Ferreira, F. J. T. E., Fong, J. A. C., & Almeida, A. T. d. (2011). Ecoanalysis of Variable-Speed Drives for Flow Regulation in Pumping Systems. *IEEE Transactions on Industrial Electronics, 58*(6), 2117-2125. doi:10.1109/TIE.2010.2057232

Gandhi, K., K.L.Mokariya, & Karvat, D. (2014). Simulation of PWM inverter for VFD application Using MATLAB. *International Journal of Engineering Research and Development (IJERD), 10*(04), 94-103.

Gandhi, K., K.L.Mokariya, karvat, D., & raval, M. (2014). Effect of PWM Inverter Used In VFD on Induction Motor Performance and Comparison with Direct On line Start. *International Journal of Engineering Research and Technology (IJERT), 03*(01), 2128-2134.

Georgescu, A. M., Cosoiu, C. I., Perju, S., Georgescu, S. C., Hasegan, L., & Anton, A. (2014). Estimation of the Efficiency for Variable Speed Pumps in EPANET Compared with Experimental Data. *Procedia Engineering, 89*, 1404-1411. doi:https://doi.org/10.1016/j.proeng.2014.11.466

Gevorkov, L., Bakman, I., & Vodovozov, V. (2014, 11-13 June 2014). *Hardware-in-the-loop simulation of motor drives for pumping applications.* Paper presented at the 2014 Electric Power Quality and Supply Reliability Conference (PQ).

Gevorkov, L., & Vodovozov, V. (2017, 4-6 April 2017). *Mixed pressure control system for a centrifugal pump.* Paper presented at the 2017 11th IEEE International Conference on Compatibility, Power Electronics and Power Engineering (CPE-POWERENG).

Gevorkov, L., Vodovozov, V., Lehtla, T., & Bakman, I. (2015, 14-14 Oct. 2015). *PLC-based flow rate control system for centrifugal pumps.* Paper presented at the 2015 56th International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON).

Giannoutsos, S. V., & Manias, S. N. (2013, 6-11 Oct. 2013). *Development of an integrated energy efficiency control system for ship power balance and diesel generator fuel consumption optimization.* Paper presented at the 2013 IEEE Industry Applications Society Annual Meeting.

Giannoutsos, S. V., & Manias, S. N. (2015). A Data-Driven Process Controller for Energy-Efficient Variable-Speed Pump Operation in the Central Cooling Water System of Marine Vessels. *IEEE Transactions on Industrial Electronics, 62*(1), 587-598. doi:10.1109/TIE.2014.2317456

Grundfos. (2020). How to select the right pump for boosting water from a roof tank. Retrieved from https://www.grundfos.com/my/learn/ecademy/all-courses/the-domestic-water-pressure-boosting-course/how-to-select-the-right-pump-for-boosting-water-from-a-roof-tank

Hasan, A., Hussain, B. K., Alzubaidi, L., & El-Gizawy, A. (2017, 7-9 March 2017). *Developing semiautonomous system for robust performance of centrifugal pumping system.* Paper presented at the 2017 Annual Conference on New Trends in Information & Communications Technology Applications (NTICT).

Hassan, S. U., & Akram, H. B. (2015). *Speed and Frequency Control of AC Induction Motor Using Variable Frequency Drive*. Paper presented at the Student Research Paper Conference.

Holmes, D. G., McGrath, B. P., & Parker, S. G. (2012). Current Regulation Strategies for Vector-Controlled Induction Motor Drives. *IEEE Transactions on Industrial Electronics, 59*(10), 3680-3689. doi:10.1109/TIE.2011.2165455

Hosamani, R., & Bagade, R. (2015). Arduino Based Water Billing System for Domestic Purpose *International Journal of Modern Trends in Engineering and Research (IJMTER), 02*(06), 424-431.

Ikonen, M., Laakkonen, O., & Kettunen, M. (2005). *Two-Level and Three-Level Converter Comparison in Wind Power Application*. Retrieved from

John, N., R, M., & Rajappan, S. C. (2013). Energy Saving Mechanism Using Variable Frequency Drives. *International Journal of Emerging Technology and Advanced Engineering, 03*(03), 784-790.

Jones, W. V. (2011, 19-23 June 2011). *Motor selection for centrifugal pump applications made easy.* Paper presented at the IEEE/IAS Pulp & Paper Industry Technical Paper Conference.

Kaya, D., Yagmur, E. A., Yigit, K. S., Kilic, F. C., Eren, A. S., & Celik, C. (2008). Energy efficiency in pumps. *Energy Conversion and Management, 49*(6), 1662-1673. doi:10.1016/j.enconman.2007.11.010

Khemchandani, R., Singh, A. N., & Khanna, H. (2014). Speed Control of Three Phase Induction Motor by Variable Frequency Drive. *International Journal of Research (IJR), 01*(11), 157-158.

Khushiev, S., & Ishnazarov, O. (2015). A Brief Review on Different Applications of Variable Speed Drive (VSD) in Electrical Motor Energy Savings and Energy Use. *International Journal of Engineering Innovation & Research (IJEIR), 04*(02), 294-299.

Kieferndorf, F. D., Forster, M., & Lipo, T. A. (2002, 13-18 Oct. 2002). *Reduction of DC bus capacitor ripple current with PAM/PWM converter*. Paper presented at the Conference Record of the 2002 IEEE Industry Applications Conference. 37th IAS Annual Meeting

Kim, J., Ha, K., & Krishnan, R. (2012). Single-Controllable-Switch-Based Switched Reluctance Motor Drive for Low Cost, Variable-Speed Applications. *IEEE Transactions on Power Electronics, 27*(1), 379-387. doi:10.1109/TPEL.2011.2158239

Liquidators, D. F. (2017). Optimizing Electrical Motor Efficiency: Get More Bang for Your Buck. Retrieved from http://www.dfliq.net/optimizing-electrical-motor-efficiency-get-more-bang-for-your-buck/

Lysenko, O. A. (2014, 11-13 Nov. 2014). *Pressure control system of the pumping units with frequency-controlled induction motor*. Paper presented at the 2014 Dynamics of Systems, Mechanisms and Machines (Dynamics).

M.Deepa. (2015). Design of VFD Drive for a 3-Phase Induction Motor. *International Journal of Innovative Research in Science, Engineering and Technology (IJIRSET), 4*(1), 18755-18762. doi:10.15680/IJIRSET.2015.0401056

Ma, Z., & Wang, S. (2009). Energy efficient control of variable speed pumps in complex building central air-conditioning systems. *Energy and Buildings, 41*(2), 197-205. doi:https://doi.org/10.1016/j.enbuild.2008.09.002

Malinowski, M., Kazmierkowski, M. P., & Trzynadlowski, A. M. (2003). A comparative study of control techniques for PWM rectifiers in AC adjustable speed drives. *IEEE Transactions on Power Electronics, 18*(6), 1390-1396. doi:10.1109/TPEL.2003.818871

Marchi, A., & Simpson Angus, R. (2013). Correction of the EPANET Inaccuracy in Computing the Efficiency of Variable Speed Pumps. *Journal of Water Resources Planning and Management, 139*(4), 456-459. doi:10.1061/(ASCE)WR.1943-5452.0000273

Mistry, J. N., Solanki, H. D., & Vala, T. M. (2012). Variable Frequency Drive. *Research Expo International Multidisciplinary Research Journal (REIMRJ), 2*(3), 252-256.

Moreira, D. F., & Ramos, H. M. (2013). Energy Cost Optimization in a Water Supply System Case Study. *Journal of Energy, 2013*, 1-9. doi:10.1155/2013/620698

N.Gavande, S., D.Deshmukh, P., & S.Kulkarni, S. (2014). A Technique to Enhance the Discharge of a Multi Intake Centrifugal Pump. *International Journal of Advanced Engineering Research and Studies, 03*(03), 115-118.

Natarajan, S., Balaji, Anto, J., & Jenith. (2014). Raspberry Pi based liquid flow monitoring and control. *International Journal of Research in Engineering and Technology, 03*(07), 122-125. doi:10.15623/ijret.2014.0307020

Naveenkumar, M., Munjal, A., Srinivasan, S., & Prasad, D. (2015, 19-20 Dec. 2015). *Design and implementation of a variable frequency drive for single-phase induction motor*. Paper presented at the 2015 IEEE International WIE Conference on Electrical and Computer Engineering (WIECON-ECE).

Nogueira Vilanova, M. R., & Perrella Balestieri, J. A. (2014). Energy and hydraulic efficiency in conventional water supply systems. *Renewable and Sustainable Energy Reviews, 30*, 701-714. doi:https://doi.org/10.1016/j.rser.2013.11.024

Oliveira, A. C., Jacobina, C. B., & Lima, A. M. N. (2007). Improved Dead-Time Compensation for Sinusoidal PWM Inverters Operating at High Switching Frequencies. *IEEE Transactions on Industrial Electronics, 54*(4), 2295-2304. doi:10.1109/TIE.2007.894770

patel, M., Sen, P. K., & Sahu, G. (2015). To Review on Energy Consumption in Centrifugal Pump. *International Journal of Innovative Research in Technlogy (IJIRT), 2*(5), 12-15.

Patel, R., Sheth, N., & Patel, K. (2015). Energy Conservation Opportunity with a Variable Frequency Drive in Boiler Feed Pump. *International Journal of Application or Innovation in Engineering & Management (IJAIEM), 04*(02), 181-188.

Perai, J. B. M. B. S. (2017). Garis Panduan Pelan Setara Rumah Sesebuah Setingkat MBSP. Retrieved from https://www.mbsp.gov.my/brgonline/garispanduan/bangunan/pelan-rumah-setingkat.pdf

Priya.R, V., & Sithara.K. (2015). Adaptive Speed Control of Three phase Induction Machine using Variable Frequency Drive in Thermal Power Plant. *International Journal of Innovative Research in Science, Engineering and Technology (IJIRSET), 04*(06), 1210-1215.

Rahmat, R. F., Satria, I. S., Siregar, B., & Budiarto, R. (2017). Water Pipeline Monitoring and Leak Detection using Flow Liquid Meter Sensor. *IOP Conference Series: Materials Science and Engineering, 190*(1), 012036. doi:10.1088/1757-899X/190/1/012036

Ray, A. K., Prasad, K., & Kumar, N. (2013). The application of Variable Frequency Drive as an efficient control element in cement industry. *The International Journal Of Engineering And Science (IJES), 02*(08), 50-56.

Rekola, J. (2014). *Advantages of Variable Speed Drive in Pump Applications.* (Sähkötekniikan koulutusohjelma master thesis), Tampere University of Technology. Retrieved from http://URN.fi/URN:NBN:fi:tty-201510191644

Roba, A. Y. (2014). *Technical and Financial Analysis of Using Variable Frequency Drive for Water Pumps Compared with Fixed Frequency.* An-Najah National University, Nablus, Palestine. Retrieved from https://scholar.najah.edu/sites/default/files/Anwer%20Roba.pdf

Rooks, J. A., & Wallace, A. K. (2004). Energy efficiency of VSDs. *IEEE Industry Applications Magazine, 10*(3), 57-61. doi:10.1109/MIA.2004.1286616

Rothenhagen, K., & Fuchs, F. W. (2005, 11-14 Sept. 2005). *Performance of diagnosis methods for IGBT open circuit faults in three phase voltage source inverters for AC variable speed drives.* Paper presented at the 2005 European Conference on Power Electronics and Applications, Dresden, Germany.

S.Billade, P., & Chopade, S. S. (2015). 3 Phase Induction Motor Control Using Single Phase Input and GSM. *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering (IJAREEIE), 04*(06), 5006-5011.

Saidur, R., Mekhilef, S., Ali, M. B., Safari, A., & Mohammed, H. A. (2011). Applications of variable speed drive (VSD) in electrical motors energy savings. *Renewable and Sustainable Energy*.

Salmasi, F., Abraham, J., & Salmasi, A. (2022). Evaluation of variable speed pumps in pressurized water distribution systems. *Applied Water Science 12*. doi:https://doi.org/10.1007/s13201-022-01577-8

Salomons, E., Goryashko, A., Shamir, U., Rao, Z., & Alvisi, S. (2007). Optimizing the operation of the Haifa-A water-distribution network. *Journal of Hydroinformatics, 9*(1), 51-64. doi:10.2166/hydro.2006.017

Salunkhe, A. B., Todkar, R. G., & Relekar, K. M. (2015). A Review on Improvement of Efficiency of Centrifugal Pump Through Modifications in Suction Manifold. *International Journal Of Innovations In Engineering Research And Technology [IJIERT], 2*(12), 1-6.

Sarbu, I. (2016). *A Study of Energy Optimisation of Urban Water Distribution Systems Using Potential Elements* (Vol. 8).

Sarbu, I., & Valea, E. (2015). *Energy Savings Potential for Pumping Water in District Heating Stations* (Vol. 7).

Shah, D. A., Sanas, P. G., Mahajan, A. O., Jamdade, M. A., & Gulame, M. B. (2015). Literature Review on Variable Frequency Drive. *International Journal for Scientific Research and Development (IJSRD), 03*(08), 690-691.

Sheng, X., & Duanmu, L. (2016). Electricity consumption and economic analyses of district heating system with distributed variable speed pumps. *Energy and Buildings, 118*, 291-300. doi:https://doi.org/10.1016/j.enbuild.2016.03.005

Sheng, X., & Lin, D. (2016). Energy saving analyses on the reconstruction project in district heating system with distributed variable speed pumps. *Applied Thermal Engineering, 101*, 432-445. doi:https://doi.org/10.1016/j.applthermaleng.2016.01.059

Shinde, P., Burungale, R., Kale, P., & Jain, P. (2014). Speed Control of Induction Motor by Using Variable Frequency Drive. *International Journal of Engineering Research and Applications (IJERA), 04*(04), 35-37.

Sike, H., Xuejing, J., & Huifen, G. (2012). Optimization of the Number of Multiple Pumps Running Simultaneously in Open Cycle Cooling Water System in Power Plant. *International Conference on Future Electrical Power and Energy Systems, 17*, 1161-1168. doi:https://doi.org/10.1016/j.egypro.2012.02.222

Simpson Angus, R., & Marchi, A. (2013). Evaluating the Approximation of the Affinity Laws and Improving the Efficiency Estimate for Variable Speed Pumps. *Journal of Hydraulic Engineering, 139*(12), 1314-1317. doi:10.1061/(ASCE)HY.1943-7900.0000776

Song, Y., & Zhao, J. (2017). Power characteristics of variable frequency speed control-based water pumps in open cooling water systems. *Building Services Engineering Research and Technology, 0*(0), 1-11. doi:10.1177/0143624417733364

Su, C. L., Chen, C. J., & Lee, C. C. (2013). Fast Evaluation Methods for Voltage Sags in Ship Electrical Power Systems. *IEEE Transactions on Industry Applications, 49*(1), 233-241. doi:10.1109/TIA.2012.2229255

Suhane, A. (2012). Experimental Study on Centrifugal Pump to Determine the Effect of Radial Clearance on Pressure Pulsations, Vibrations and Noise. *International Journal of Engineering Research and Application (IJERA), 2*(4), pp.1823-1829.

Susan-Resiga, R. F., Bosioc, A. I., & Stuparu, A. C. (2023). Enhanced affinity law for centrifugal pumps at variable speed. *IOP Conf. Series: Earth and Environmental Science, 1136*. doi:10.1088/1755-1315/1136/1/012056

Tamminen, J., Ahonen, T., Kosonen, A., Ahola, J., & Tolvanen, J. (2014, 26-28 Aug. 2014). *Variable speed drive-based pressure optimization of a pumping system comprising individual branch flow control elements.* Paper presented at the 2014 16th European Conference on Power Electronics and Applications.

Tonapi, S., Chopade, P., Kadam, T., Julaha, J., & Tyagi, P. (2015). Speed Control of AC Motor Using VFD. *International Journal of Innovative and Emerging Research in Engineering, 2*(3), 161-164.

Umran, H. M. (2015). Parameters Identification of a 3-phase LC Filter used for Variable Frequency Drive Based on Practical Induction Motor Testing. *Kufa Journal of Engineering, 6*(2), 76-89.

Vandervort, D. (2018). Home Plumbing System. Retrieved from https://www.hometips.com/plumbing_fixtures.html

Vieira, R. P., Gastaldini, C. C., Azzolin, R. Z., & Gründling, H. A. (2014). Sensorless Sliding-Mode Rotor Speed Observer of Induction Machines Based on Magnetizing Current Estimation. *IEEE Transactions on Industrial Electronics, 61*(9), 4573-4582. doi:10.1109/TIE.2013.2290759

Viholainen, J., Tamminen, J., Ahonen, T., Ahola, J., Vakkilainen, E., & Soukka, R. (2013). Energy-efficient control strategy for variable speed-driven parallel pumping systems. *Springer Energy Efficiency Journal, 6*(3), 495-509. doi:10.1007/s12053-012-9188-0

Vinesh, T., & Lim Min, H. (2017). Fluids vertical transfer utilizing VFD based centrifugal pumps. *Journal of Physics: Conference Series*, *822*(1), 012062.

Vodovozov, V., Gevorkov, L., & Raud, Z. (2017, 4-6 April 2017). *Circulation centrifugal pump with variable speed drives and minimal electricity consumption.* Paper presented at the 2017 11th IEEE International Conference on Compatibility, Power Electronics and Power Engineering (CPE-POWERENG).

W.Mustafa, M.F.Humar, K.P.Zakaria, & Hamid, H. (2014). Solar Water Pumping Optimization for Domestic Use in Kota Bharu, East Coast of Peninsular Malaysia. *2014 4th International Conference on Engineering Technology and Technopreneuship (ICE2T)*, 116-120. doi:10.1109/ICE2T.2014.7006230

Wang, Y.-F., & Chen, Q. (2015). A direct optimal control strategy of variable speed pumps in heat exchanger networks and experimental validations. *Energy*, *85*, 609-619. doi:https://doi.org/10.1016/j.energy.2015.03.107

Wiechmann, E. P., Aqueveque, P., Burgos, R., & Rodriguez, J. (2008). On the Efficiency of Voltage Source and Current Source Inverters for High-Power Drives. *IEEE Transactions on Industrial Electronics*, *55*(4), 1771-1782. doi:10.1109/TIE.2008.918625

Wood, D. J., & Reddy, L. S. (1995). Using Variable Speed Pumps to Reduce Leakage and Improve PerformanceImproving Efficiency and Reliability in Water Distribution Systems (Vol. 14). Water Science and Technology Library: Springer, Dordrecht. doi:https://doi.org/10.1007/978-94-017-1841-7_6

Xiaodong, L., & Wilsun, X. (2013, 6-11 Oct. 2013). *Modeling variable frequency drive and motor systems in power systems dynamic studies.* Paper presented at the 2013 IEEE Industry Applications Society Annual Meeting.

Yang, Z., & Børsting, H. (2010, December 15-17, 2010). *Energy Efficient Control of a Boosting System with Multiple Variable-Speed Pumps in Parallel.* Paper presented at the 49th IEEE Conference on Decision and Control, Hilton Atlanta Hotel, Atlanta, GA, USA.

Yimchoy, S., & Supatti, U. (2021). An Energy-Savings Evaluation Method for Variable-Frequency-Drive Applications on Water Pump Systems. *24th International Conference on Electrical Machines and Systems (ICEMS)*, 603-608. doi:10.23919/ICEMS52562.2021.9634486

Yiping, S., & Jianing, Z. (2016). Operating characteristics of the variable frequency speed-regulating system for a single pump in a closed system. *Building Services Engineering Research and Technology*, *38*(3), 309-317. doi:10.1177/0143624416680690

Zhang, H., Xia, X., & Zhang, J. (2012). Optimal sizing and operation of pumping systems to achieve energy efficiency and load shifting. *Electric Power Systems Research*, *86*, 41-50. doi:https://doi.org/10.1016/j.epsr.2011.12.002