FACULTY OF ENGINEERING

DEPARTMENT OF WATER RESOURCES ENGINEERING

FINAL YEAR PROJECT

DECISION SUPPORT TOOLS FOR THE OPTIMAL DESIGN AND OPERATION OF PUMPED-STORAGE HYDROPOWER PLANTS

By

NAME	REGISTRATION NUMBER
NUWAGUMYA GRANIA	BU/UP/2019/1870
ADEKE GLADYS	BU/UP/2019/1852

A final year project implementation submitted to the Department of Water Resources Engineering in fulfilment of the requirement for the award of the Bachelor of Science in Water Resources Engineering of Busitema University.

SEPTEMBER 2023.

ABSTRACT

Energy Storage systems in power plants are critical to achieving global renewable energy target, and pump storage systems are one of them. This final year project introduces decision support tools that were designed to enhance the efficiency, profitability and sustainability. The study aimed at addressing system operators, decision making in optimal sizing and operation. The decision support tools developed were for optimization of the design of pumped storage hydropower plants, a tool for real time demand forecasting and a tool for optimizing the pump storage hydropower plant's operation. Through research and development, this project achieved the optimal design out puts enabling precise sizing and configuration of pump storage hydropower plant components. It also provided real time demand forecasting allowing operators to anticipate fluctuations with remarkable accuracy. Additionally, the decision support tools provided both pumping and generation schedules for PSH. The tools were developed using MATLAB software and the genetic algorithm which was embedded in the software for optimization.

Key words: MATLAB, Genetic Algorithm, Pump Storage Systems, Optimization, Energy Storage.

DECLARATION

The undersigned, declare that this implementation report is our original work expect where due acknowledgements have been made. We declare that this work has never been submitted to this university or any other institution.

NAME: ADEKE GLADYS Signature Adeke

NAME: NUWAGUMYA GRANIA Signature Grania

Date 22nd / NOV / 2023

APPROVAL

This final report has been submitted to the faculty of engineering for examination with approval of our supervisor.

SUPERVISOR: MR. MUYINGO EMMANUEL

SIGNATURE: ....

DATE: 22 / 11 / 2023

DECLARATION

The undersigned, declare that this implementation report is our original work expect where due acknowledgements have been made. We declare that this work has never been submitted to this university or any other institution.

NAME: ………………………………………… Signature …………………………………

NAME: ………………………………………… Signature …………………………………

Date………/………/……….

APPROVAL

This final report has been submitted to the faculty of engineering for examination with approval of our supervisor.

SUPERVISOR: MR. MUYINGO EMMANUEL

SIGNATURE: ………………………………….

DATE: ……...../………. /……..

ACKNOWLEDGEMENT

We take this opportunity to thank the Almighty God for the gift of life and good health and for enabling us to gather the information in this report. We are truly grateful.

We extend our sincere gratitude to our dear supervisor: Mr. MUYINGO EMMANUEL for his time and guidance. We extend our sincere gratitude to Mr. MASERUKA BENEDICTO for his time and guidance. We are truly grateful and may the Almighty God bless you abundantly.

DEDICATION

This report is dedicated to our families and our supervisor MR**. MUYINGO EMMANUEL and MR Maseruka Bendicto** who endured all the hard work put upon them. we are very grateful especially to our beloved parents and our supervisors May the almighty God bless you all and repay you in abundance and excel in your various activities.

LIST OF ACRONYMS

ARMA: Autoregressive Moving Average

MAE: Mean Absolute Error

RMSE: Root Mean Absolute Error

R^2: Coefficient of Determination.

LSMT: Long Short-Term Memory

RNN: Recurrent Neutral Network

GRU: Gated Recurrent Units

SPA: Sequent Peak Algorithm

PACF: Partial Autocorrelation Functions

ACF: Autocorrelation Functions

GA: Genetic Algorithm

NLP: Non-Linear Programming

RMSLE: Root Mean Square Log Error

TABLE OF CONTENTS

LIST OF FIGURES

1 CHAPTER ONE

1.1 BACK GROUND

Energy systems provide an integrated solution to the world’s critical energy needs that is the electric grid modernization, reliability and resilience, sustainable mobility, flexibility for a diverse and secure, all -of – the electricity generation portfolio (Hodder *et al*., 2020). Storage technologies strengthen and stabilize the world’s grid by providing backup power , leveling loads ,and offering a range of other energy management services (Xu *et al*., 2020). Recognizing that specific storage technologies best serve in certain applications though with different limitations ,the US .Department of Energy (DOE) pursues a diverse portfolio of energy storage research and development to assure a continuous affordable and sustainable electricity supply (Zufelt, 2017).

According (Nagbe *et al*., 2018). , the amount of surplus energy produced during off-peak hours varies depending on the operation of the plant, the level of demand for electricity and the availability of water which varies from region to region. A report by the U.S. Department of Energy found that some hydropower plants in the Pacific Northwest region of the United States were generating up to 50% more electricity than was needed during off-peak hours (Muljadi *et al*., 2021).According to (Cazzaniga *et al*., 2017) , due to varying demands from consumers which has resulted into intermittent output that often does not match the energy demands has made storage a necessity(Panel *et al*., 2020).

Different energy systems have been put in place to store excess energy to manage the variability of hydropower generation which include, compressed air energy storage (CAES), underground pumped hydroelectric storage (UPHS), flow battery storage and pumped hydroelectric storage (PHES) (Khadem *et al*., 2018).

CAES store energy by compressing air into an underground storage area. This method achieves efficiency rates of up to 70%, and a cost per kilo watt of $1750/KW but it requires appropriate geology and may be limited by the availability of suitable sites. On the other hand, Lithium batteries, which store energy in the form of electrolyte solutions, have efficiency rates of up to 75% with a cost per kilo wat of $2000/KW. However, these batteries depreciate with time and may have a shorter lifespan compared to(Cazzaniga *et al*., 2017) .

Pump storage reservoirs, which is the most commonly used method for storing surplus hydropower achieves efficiency rates of up to 80%. These include the underground pumped

5 REREFENCES

Alvarez, G. E. (2020). Operation of pumped storage hydropower plants through optimization for power systems. *Energy*, *202*, 117797. https://doi.org/10.1016/j.energy.2020.117797

Azad, A. S., Md, M. S., Watada, J., Vasant, P., & Vintaned, J. A. G. (2020). Optimization of the hydropower energy generation using Meta-Heuristic approaches: A review. *Energy Reports*, *6*, 2230–2248. https://doi.org/10.1016/j.egyr.2020.08.009

Benidis, K., Rangapuram, S. S., Flunkert, V., Wang, Y., Maddix, D., Turkmen, C., Gasthaus, J., Bohlke-Schneider, M., Salinas, D., Stella, L., Aubet, F. X., Callot, L., & Januschowski, T. (2022). Deep Learning for Time Series Forecasting: Tutorial and Literature Survey. *ACM Computing Surveys*, *55*(6). https://doi.org/10.1145/3533382

Bozorg Haddad, O., Ashofteh, P.-S., Rasoulzadeh-Gharibdousti, S., & Mariño, M. A. (2014). Optimization Model for Design-Operation of Pumped-Storage and Hydropower Systems. *Journal of Energy Engineering*, *140*(2), 1–11. https://doi.org/10.1061/(asce)ey.1943-7897.0000169

Cazzaniga, R., Cicu, M., Marrana, T., Rosa-clot, M., Rosa-clot, P., & Tina, G. M. (2017). DOGES : Deep ocean gravitational energy storage. *Journal of Energy Storage*. https://doi.org/10.1016/j.est.2017.06.008

Chan, Z. M. (2019). *Design Calculation of Penstock and Nozzle for 5kW Pelton Turbine Micro Hydropower Plant*. *3*(5), 1245–1247.

Correlation, O., & Pearson, T. (2006). *), the Pearson product- moment correlation coefficient is a measure of association given by*. 73–74.

Costa, C. M., Barbosa, J. C., Gonçalves, R., Castro, H., Campo, F. J. D., & Lanceros-Méndez, S. (2021). Recycling and environmental issues of lithium-ion batteries: Advances, challenges and opportunities. *Energy Storage Materials*, *37*(February), 433–465. https://doi.org/10.1016/j.ensm.2021.02.032

Dingli, A., & Fournier, K. S. (2017). Financial time series forecasting - a deep learning approach. *International Journal of Machine Learning and Computing*, *7*(5), 118–122. https://doi.org/10.18178/ijmlc.2017.7.5.632

Dudek, G., Piotrowski, P., & Baczyński, D. (2023). Intelligent Forecasting and Optimization in Electrical Power Systems: Advances in Models and Applications. *Energies*, *16*(7), 1–11. https://doi.org/10.3390/en16073024

Ela, P., & Glas, M. Van Der. (2002). *Introduction to Matlab*. *January*.

García, I. F., Novara, D., & Nabola, A. M. (2019). A model for selecting the most cost-effective pressure control device for more sustainable water supply networks. *Water (Switzerland)*, *11*(6). https://doi.org/10.3390/w11061297

Garrett, K., McManamay, R. A., & Wang, J. (2021). Global hydropower expansion without building new dams. *Environmental Research Letters*, *16*(11). https://doi.org/10.1088/1748-9326/ac2f18

Gorla, R. S. R., & Khan, A. A. (n.d.). *Turbomachinery*.

Hodder, B. G., Meredith, J. D. C., & Sager, M. A. (2013). *Storage (ORES) System : Analysis of an Undersea Energy Storage Concept*. *101*(4).

Khadem, M., Rougé, C., Harou, J. J., Hansen, K. M., Medellin-Azuara, J., & Lund, J. R. (2018). Estimating the Economic Value of Interannual Reservoir Storage in Water Resource Systems. *Water Resources Research*, *54*(11), 8890–8908. https://doi.org/10.1029/2017WR022336

Lara-Benítez, P., Carranza-García, M., & Riquelme, J. C. (2021). An Experimental Review on Deep Learning Architectures for Time Series Forecasting. *International Journal of Neural Systems*, *31*(3). https://doi.org/10.1142/S0129065721300011

Ma, T., Yang, H., Lu, L., & Peng, J. (2015). Optimal design of an autonomous solar-wind-pumped storage power supply system. *Applied Energy*, *160*, 728–736. https://doi.org/10.1016/j.apenergy.2014.11.026

Maroua Haddad. (2019). *Sizing and management of a hybrid renewable energy system for data center supply*.

Mousavi, N., Kothapalli, G., Habibi, D., Khiadani, M., & Das, C. K. (2019). An improved mathematical model for a pumped hydro storage system considering electrical, mechanical, and hydraulic losses. *Applied Energy*, *247*(April), 228–236. https://doi.org/10.1016/j.apenergy.2019.03.015

Muljadi, E., Nelms, R. M., Chartan, E., Robichaud, R., George, L., & Obermeyer, H. (2021). *Electrical Systems of Pumped Storage Hydropower Plants: Electrical Generation, Machines, Power Electronics, and Power Systems*. *June*.

Nagbe, K., Cugliari, J., & Jacques, J. (2018). Short-term electricity demand forecasting using a functional state space model. *Energies*, *11*(5). https://doi.org/10.3390/en11051120

Özyön, S. (2020). Optimal short-term operation of pumped-storage power plants with differential evolution algorithm. *Energy*, *194*. https://doi.org/10.1016/j.energy.2019.116866

Panel, W., Secretariat, E. C., Secretariat, E. C., & Parties, C. (2020). *Energy Storage – Background Briefing*. *May*, 1–6.

Shaik, S. A. L. I. (2020). *Forecasting The Electricity Demand Using Machine Learning Algorithms*. *August*.

Sharma, T. C., & Panu, U. S. (2021). A drought magnitude-based method for reservoir sizing: A case of annual and monthly flows from Canadian rivers. *Journal of Hydrology: Regional Studies*, *36*(April), 100829. https://doi.org/10.1016/j.ejrh.2021.100829

Shi, F., Hu, Y., & Dong, F. (2017). *The Power Supplies Demand Conditions of the Big Data Technology Optimization Model*. *134*(Caai), 156–159. https://doi.org/10.2991/caai-17.2017.33

UMEME. (2022). *Electricity Retail Tariffs for Quarter One 2022*. *March*, 2022.

Wu, H., Chen, J., Xu, J., Zeng, G., Sang, L., Liu, Q., Yin, Z., Dai, J., Yin, D., Liang, J., & Ye, S. (2019). Effects of dam construction on biodiversity: A review. *Journal of Cleaner Production*, *221*, 480–489. https://doi.org/10.1016/j.jclepro.2019.03.001

www.it-ebooks.info. (n.d.).

Xu, X., Hu, W., Cao, D., Huang, Q., Chen, C., & Chen, Z. (2020). Optimized sizing of a standalone PV-wind-hydropower station with pumped-storage installation hybrid energy system. *Renewable Energy*, *147*, 1418–1431. https://doi.org/10.1016/j.renene.2019.09.099

Zeroual, A., Harrou, F., Dairi, A., & Sun, Y. (2020). Deep learning methods for forecasting COVID-19 time-Series data: A Comparative study. *Chaos, Solitons and Fractals*, *140*, 110121. https://doi.org/10.1016/j.chaos.2020.110121

Zhang, S., Zhang, N., Zhang, Z., & Chen, Y. (2022). Electric Power Load Forecasting Method Based on a Support Vector Machine Optimized by the Improved Seagull Optimization Algorithm. *Energies*, *15*(23). https://doi.org/10.3390/en15239197

Zheng, Y., & Sahraei-Ardakani, M. (2021). Leveraging existing water and wastewater infrastructure to develop distributed pumped storage hydropower in California. *Journal of Energy Storage*, *34*(July 2020), 102204. https://doi.org/10.1016/j.est.2020.102204

Zimmerman, D. C. (2000). Model validation and verification of large and complex space structures. *Inverse Problems in Engineering*, *8*(2), 93–118. https://doi.org/10.1080/174159700088027722

Zufelt, J. E. (2017). *Congress on Technical Advancement 2017 Infrastructure Resilience and Energy*. 65–76.

Alvarez, G. E. (2020). Operation of pumped storage hydropower plants through optimization for power systems. *Energy*, *202*, 117797. https://doi.org/10.1016/j.energy.2020.117797

Azad, A. S., Md, M. S., Watada, J., Vasant, P., & Vintaned, J. A. G. (2020). Optimization of the hydropower energy generation using Meta-Heuristic approaches: A review. *Energy Reports*, *6*, 2230–2248. https://doi.org/10.1016/j.egyr.2020.08.009

Benidis, K., Rangapuram, S. S., Flunkert, V., Wang, Y., Maddix, D., Turkmen, C., Gasthaus, J., Bohlke-Schneider, M., Salinas, D., Stella, L., Aubet, F. X., Callot, L., & Januschowski, T. (2022). Deep Learning for Time Series Forecasting: Tutorial and Literature Survey. *ACM Computing Surveys*, *55*(6). https://doi.org/10.1145/3533382

Bozorg Haddad, O., Ashofteh, P.-S., Rasoulzadeh-Gharibdousti, S., & Mariño, M. A. (2014). Optimization Model for Design-Operation of Pumped-Storage and Hydropower Systems. *Journal of Energy Engineering*, *140*(2), 1–11. https://doi.org/10.1061/(asce)ey.1943-7897.0000169

Cazzaniga, R., Cicu, M., Marrana, T., Rosa-clot, M., Rosa-clot, P., & Tina, G. M. (2017). DOGES : Deep ocean gravitational energy storage. *Journal of Energy Storage*. https://doi.org/10.1016/j.est.2017.06.008

Chan, Z. M. (2019). *Design Calculation of Penstock and Nozzle for 5kW Pelton Turbine Micro Hydropower Plant*. *3*(5), 1245–1247.

Correlation, O., & Pearson, T. (2006). *), the Pearson product- moment correlation coefficient is a measure of association given by*. 73–74.

Costa, C. M., Barbosa, J. C., Gonçalves, R., Castro, H., Campo, F. J. D., & Lanceros-Méndez, S. (2021). Recycling and environmental issues of lithium-ion batteries: Advances, challenges and opportunities. *Energy Storage Materials*, *37*(February), 433–465. https://doi.org/10.1016/j.ensm.2021.02.032

Dingli, A., & Fournier, K. S. (2017). Financial time series forecasting - a deep learning approach. *International Journal of Machine Learning and Computing*, *7*(5), 118–122. https://doi.org/10.18178/ijmlc.2017.7.5.632

Dudek, G., Piotrowski, P., & Baczyński, D. (2023). Intelligent Forecasting and Optimization in Electrical Power Systems: Advances in Models and Applications. *Energies*, *16*(7), 1–11. https://doi.org/10.3390/en16073024

Ela, P., & Glas, M. Van Der. (2002). *Introduction to Matlab*. *January*.

García, I. F., Novara, D., & Nabola, A. M. (2019). A model for selecting the most cost-effective pressure control device for more sustainable water supply networks. *Water (Switzerland)*, *11*(6). https://doi.org/10.3390/w11061297

Garrett, K., McManamay, R. A., & Wang, J. (2021). Global hydropower expansion without building new dams. *Environmental Research Letters*, *16*(11). https://doi.org/10.1088/1748-9326/ac2f18

Gorla, R. S. R., & Khan, A. A. (n.d.). *Turbomachinery*.

Hodder, B. G., Meredith, J. D. C., & Sager, M. A. (2013). *Storage (ORES) System : Analysis of an Undersea Energy Storage Concept*. *101*(4).

Khadem, M., Rougé, C., Harou, J. J., Hansen, K. M., Medellin-Azuara, J., & Lund, J. R. (2018). Estimating the Economic Value of Interannual Reservoir Storage in Water Resource Systems. *Water Resources Research*, *54*(11), 8890–8908. https://doi.org/10.1029/2017WR022336

Lara-Benítez, P., Carranza-García, M., & Riquelme, J. C. (2021). An Experimental Review on Deep Learning Architectures for Time Series Forecasting. *International Journal of Neural Systems*, *31*(3). https://doi.org/10.1142/S0129065721300011

Ma, T., Yang, H., Lu, L., & Peng, J. (2015). Optimal design of an autonomous solar-wind-pumped storage power supply system. *Applied Energy*, *160*, 728–736. https://doi.org/10.1016/j.apenergy.2014.11.026

Maroua Haddad. (2019). *Sizing and management of a hybrid renewable energy system for data center supply*.

Mousavi, N., Kothapalli, G., Habibi, D., Khiadani, M., & Das, C. K. (2019). An improved mathematical model for a pumped hydro storage system considering electrical, mechanical, and hydraulic losses. *Applied Energy*, *247*(April), 228–236. https://doi.org/10.1016/j.apenergy.2019.03.015

Muljadi, E., Nelms, R. M., Chartan, E., Robichaud, R., George, L., & Obermeyer, H. (2021). *Electrical Systems of Pumped Storage Hydropower Plants: Electrical Generation, Machines, Power Electronics, and Power Systems*. *June*.

Nagbe, K., Cugliari, J., & Jacques, J. (2018). Short-term electricity demand forecasting using a functional state space model. *Energies*, *11*(5). https://doi.org/10.3390/en11051120

Özyön, S. (2020). Optimal short-term operation of pumped-storage power plants with differential evolution algorithm. *Energy*, *194*. https://doi.org/10.1016/j.energy.2019.116866

Panel, W., Secretariat, E. C., Secretariat, E. C., & Parties, C. (2020). *Energy Storage – Background Briefing*. *May*, 1–6.

Shaik, S. A. L. I. (2020). *Forecasting The Electricity Demand Using Machine Learning Algorithms*. *August*.

Sharma, T. C., & Panu, U. S. (2021). A drought magnitude-based method for reservoir sizing: A case of annual and monthly flows from Canadian rivers. *Journal of Hydrology: Regional Studies*, *36*(April), 100829. https://doi.org/10.1016/j.ejrh.2021.100829

Shi, F., Hu, Y., & Dong, F. (2017). *The Power Supplies Demand Conditions of the Big Data Technology Optimization Model*. *134*(Caai), 156–159. https://doi.org/10.2991/caai-17.2017.33

UMEME. (2022). *Electricity Retail Tariffs for Quarter One 2022*. *March*, 2022.

Wu, H., Chen, J., Xu, J., Zeng, G., Sang, L., Liu, Q., Yin, Z., Dai, J., Yin, D., Liang, J., & Ye, S. (2019). Effects of dam construction on biodiversity: A review. *Journal of Cleaner Production*, *221*, 480–489. https://doi.org/10.1016/j.jclepro.2019.03.001

www.it-ebooks.info. (n.d.).

Xu, X., Hu, W., Cao, D., Huang, Q., Chen, C., & Chen, Z. (2020). Optimized sizing of a standalone PV-wind-hydropower station with pumped-storage installation hybrid energy system. *Renewable Energy*, *147*, 1418–1431. https://doi.org/10.1016/j.renene.2019.09.099

Zeroual, A., Harrou, F., Dairi, A., & Sun, Y. (2020). Deep learning methods for forecasting COVID-19 time-Series data: A Comparative study. *Chaos, Solitons and Fractals*, *140*, 110121. https://doi.org/10.1016/j.chaos.2020.110121

Zhang, S., Zhang, N., Zhang, Z., & Chen, Y. (2022). Electric Power Load Forecasting Method Based on a Support Vector Machine Optimized by the Improved Seagull Optimization Algorithm. *Energies*, *15*(23). https://doi.org/10.3390/en15239197

Zheng, Y., & Sahraei-Ardakani, M. (2021). Leveraging existing water and wastewater infrastructure to develop distributed pumped storage hydropower in California. *Journal of Energy Storage*, *34*(July 2020), 102204. https://doi.org/10.1016/j.est.2020.102204

Zimmerman, D. C. (2000). Model validation and verification of large and complex space structures. *Inverse Problems in Engineering*, *8*(2), 93–118. https://doi.org/10.1080/174159700088027722

Zufelt, J. E. (2017). *Congress on Technical Advancement 2017 Infrastructure Resilience and Energy*. 65–76.